WATER CONSERVATION TECHNIQUES ON SMALL PLOTS IN SEMI-ARID AREAS TO ENHANCE RAINFALL USE EFFICIENCY, FOOD SECURITY, AND SUSTAINABLE CROP PRODUCTION

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EXECUTIVE SUMMARY

WATER CONSERVATION TECHNIQUES ON SMALL PLOTS IN SEMI-ARID AREAS TO ENHANCE RAINFALL USE EFFICIENCY, FOOD SECURITY, AND SUSTAINABLE CROP PRODUCTION

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The project had three main objectives: (a) to study quantitatively within the in-field rain water harvesting (IRWH) system, different combinations of mulching techniques aimed primarily at reducing evaporation from the soil surface, soil fertility aspects with the focus on nitrogen, and the sustainability of the system; (b) to develop the capacity of three previously disadvantaged technical assistants; and (c) to transfer the technology to the developing farmers and to the Department of Agriculture. The first and second objectives were achieved concurrently by means of field experiments at Glen and on farmers' fields near Thaba Nchu, the technical assistants gaining invaluable skills and experience by being intensively involved in all the relevant activities. The crops grown were maize, sunflower and beans. The third objective was achieved by means of the demonstration plots on farmers' fields, and by numerous information days, lectures and demonstrations in the villages, all held in close cooperation with officials of the Department of Agriculture.

In the executive summary of a preceding WRC report entitled "Optimizing precipitation use efficiency for developing farmers with limited access to irrigation water", further research on eight aspects was recommended. The current project has dealt with seven of these in an appropriate way. This demonstrates the foresight of the Water Research Commission in terms of efficient value adding, in this case to the benefit of developing farmers.

Each ecotope was characterized in detail to lay the foundation for efficient extrapolation of all experimental results to other ecotopes where field experiments have not been done.

Runoff measurements on the Glen/Bonheim ecotope, converted to long-term predictions by appropriate equations, indicated that where the 2 m runoff strip in the IRWH system was left bare, covered by stones (60 - 70 % cover), or organic mulch, the amount of water harvested annually in the basins was predicted to be 196, 130 and 62 mm, respectively, more than with the conventional (*CON*) treatment. It needs to be kept in mind that these results represent the respective systems without a crop. They represent conditions present during early spring rains and while the crop is small. With a mature crop much rain will be intercepted, tending to equalize runoff from the different treatments to some extent. This is only one of the factors which causes measured yield differences between treatments to be disproportional to the predicted amounts of water gained in the basins by harvesting from the runoff strip. The runoff/sedimentation studies revealed that basins could be expected to become silted up in approximately 12, 21 and 75 years with bare, stone covered and organic mulch covered runoff strips, respectively. This information is important in relation to the sustainability of the IRWH system. Of primary importance is the fact that with this system, since ex-field runoff is reduced to zero, ex-field soil loss is also zero. In contrast, topsoil losses of around 0.6 mm per year were measured on conventionally tilled plots on long-term runoff experiments at Glen and Pretoria. The advantage of IRWH with regard to sustainability is clear. Maintenance of the basins to ensure that their capacity does not fall below a critical value will

be necessary, whatever treatment is implemented, to prevent them from overflowing during heavy storms

Four different IRWH systems and *CON* tillage were compared in field experiments at Glen and on farmers' fields near Thaba Nchu. The four IRWH treatments were: organic mulch in the basins with a bare runoff area (*ObBr*); organic mulch in the basins with organic mulch on the runoff area (*ObOr*); organic mulch in the basins with stones on the runoff area (*ObSr*); stones in the basins with organic mulch on the runoff area (*SbOr*). The crops grown were maize, sunflower and dry beans. An empirical stress model termed "Crop Yield Prediction for Semi-Arid Areas" (CYP-SA) was developed to enable long-term yield predictions to be made. The composition of the model for each crop is described in detail, together with validation results. Measured yields over three seasons in the field experiments, and predicted long-term yields using the model, showed the following: For all the crops on all the ecotopes the *ObSr* treatment was the best IRWH treatment, but generally only statistically significantly better than *ObBr*. The clearly defined superiority of IRWH over *CON*, already shown in the 1996 – 1999 WRC project, was confirmed. These results are strongly supported and eloquently described by the long-term, yield cumulative probability functions (CPFs) obtained with CYP-SA. The yield advantage with early January planting of the crops, compared to mid-December and mid-October planting dates, is also well described by the CPFs.

Measurements on the experimental plots showed that water losses by deep drainage were negligible during the three growing seasons. Since runoff losses were also zero on all the IRWH plots, the only cause of water loss was evaporation from the soil surface (Es). This was shown on the maize plots to be highest on the *ObBr* treatment, and similar on the other three treatments, amounting to 79 % and 74 % of the annual rainfall, respectively. The equivalent value for the sunflower plots was approximately 70 % for all the treatments. It is clear that in order to further improve precipitation use efficiency (PUE) above the current best values of 7.4 and 4.8 kg ha^{-1} mm^{-1} for maize and sunflower respectively, it will be necessary to find ways of suppressing Es still further. An initial study in this connection was made by calculating infiltration ratios for the basins versus the runoff area. Data for all IRWH treatments on the maize and sunflower plots was pooled and the ratios plotted against relative yield. A parabolic curve fitted the data well (r^2 = 0.98) and the optimum infiltration ratio, associated with stones on the runoff area, was found to be between 1.6 and 1.9. This is a valuable result and more research with different kinds of mulch (e.g. gravels) could lead to further improvements in PUE.

The soil fertility study focused on nitrogen. Two levels were applied in the IRWH experiments: a recommended level (15 kg N ha^{-1}), and a "high" level (70 kg N ha^{-1} for maize and 90 kg N ha^{-1} for sunflower). Where the available water (rainfall plus profile available water) was > 470 mm, sunflower responded positively to the high N level (significant at P = 0.05). Maize did not respond to the high N level, probably due to: (i) the lower available water levels (376 – 404 mm), and (ii) the relatively high nitrogen supply capacity for the crop-soil system of 58 kg N ha^{-1}. Both crops responded to 15 kg N ha^{-1} compared to zero N. The study also revealed that the recommended N application of 15 kg N ha^{-1} needs to be slightly increased, depending on the mulch combinations and crop rotation systems, if agronomic and conservation sustainability is to be maintained in the long run.

Specific "indicators" used to monitor socio-acceptability of the IRWH technique included the following: community, mobilization, capacity building, empowerment, human well-being, self-reliance and community participation. These indicators showed that there is a strong movement towards building an active learning process in farmer groups and individual farmers lower down the hierarchy. When taking account of the large study area and huge number of end-users, much time and effort was invested in empowering the end-users, which is essential for long-term sustainability. The large number of farmer-managed trials (108 homesteads in 6 villages), and the 'training of trainers' programme, formed a solid basis from which further training and learning could be launched. The residents of villages who applied the IRWH technique at their homesteads during the 2002/03 season, varied between 1 and 46 families per community. From the first season (2001/2002) the homesteads in which IRWH were applied expanded from 6 in four villages to 108 homesteads in six villages. Four new communities implemented the IRWH technique at their own request. The residents of the different villages planted a variety of crops, some of which were never demonstrated to them, as part of their IRWH strategy to combat food insecurity. They planted maize, dry beans, watermelons, pumpkins, peas, carrots, beetroot, spinach, tomatoes and potatoes.

Short-term data indicate that the IRWH technique is far more sustainable than *CON* for this specific study area. Of all the IRWH techniques tested, *ObSr* has been shown to be the best, followed by *SbSr*, *ObOr*, *SbOr* and *ObBr*. In general, evaluation of the project in terms of the different sustainability criteria (agronomic productivity, risk - security, conservation techniques, economic viability and social acceptability) really needs to be done in the long-term. Only then could it be properly judged whether or not the project has succeeded in implementing sustainable land management practices (or best practice components thereof) among an acceptable percentage of the farmers. However, there are sufficient indications that they are moving towards the goals, objectives and outcomes of sustainable agriculture. If the ARC-ISCW perseveres with the approach of 'true participation' for a critical period of at least 5 to 10 years, there is no doubt that sustainability can be achieved.

Taking all the above mentioned results into consideration it can be concluded that IRWH will enhance PUE, promote food security and ensure sustainability. The *ObSr* treatment was overall the best treatment, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and a bare basin with a bare runoff area (*BbBr)*.

RECOMMENDATIONS, INCLUDING ADDITIONAL RESEARCH NEEDS

(a) Farmers

a. Firstly, apply the IRWH technique to obtain higher yields.
b. Secondly, apply any mulch that is available in the basins of the IRWH technique. If enough mulch is available, apply it in the basins and on the runoff area. If organic and stone mulches are available, apply the organic mulch in the basins and the stone mulch on the runoff area (*ObSr*).
c. Plant later in the season rather than early, on a profile with a soil water content that is more than half full whenever possible.

(b) Administrators and Policy makers

a. A very good foundation has been laid for people in rural villages around Thaba Nchu to become self-sufficient and produce more, and to earn a good income with the IRWH technique. It is a long-term process that should be continued in the future.

b. When a new crop production technique is to be introduced into rural villages, one should first start with the homesteads. These provide a simple environment for promoting a new technique through training. The starting point of a new technique should first focus on food security, and later be expanded to larger scale operations.
c. For a total improvement in rural villages in dry areas, IRWH and other water harvesting techniques should be applied. But the first step should be IRWH, since it is easy, simple and reproducable. Later, other rainwater harvesting techniques such as water collection from roads, roofs etc., can be implemented to complement the system.
d. Technology exchange and training concerning the results of this report should take place in future.
e. A future focus should be the development of the croplands of rural villagers into sustainable enterprises.
f. On-farm demonstration of IRWH techniques assessing the impact of investment in weeding.
g. On-farm demonstration of IRWH techniques assessing the impact of investment in fertilizer.
h. Development of formal education material for primary, secondary and tertiary institutions needs to be addressed urgently.

(c) Researchers

a. Investigate other ways to reduce Es. It is clear that in order to further improve PUE, it will be necessary to find ways of suppressing Es still further. Options could be to investigate the percentage cover, and also different types of mulches. Evaporation from the soil surface, especially with a crop present, is a complex process. It would be of great value if this process could be modelled.
b. Although the correlations between rainfall amounts and in-field runoff with different mulches are very useful as first approximations, they expose by default the important influence which rainfall intensity has on runoff and sediment load. A fruitful avenue for future research is revealed here – especially for model building purposes.
c. The parabolic curve of optimum infiltration ratio associated with the mulch type in the basins and on the runoff area is valuable, and more research with different kinds of mulch (e.g. gravels) could lead to further improvements in PUE.
d. Improvements in the CYP-SA model for maize, sunflower and dry beans, and other crops are necessary. An efficient IRWH adapted crop model would make a valuable contribution towards the "NEPAD" expressed aim of improving rainfed crop production in Africa by means of water harvesting. The model would make it possible to extrapolate results to a wide range of ecotopes in Africa.
e. Ways of combining crops and animals in an integrated IRWH system need to be investigated.
f. Future research is needed with regard to the introduction of a permanent crop into the IRWH system. The IRWH could also be used to improve rangeland conditions and the rehabilitation of old lands.
g. As a first approximation, nitrogen fertilizer application can be adjusted for mulch practices within the IRWH system. Preliminary results showed that the

N_{rec} should be adjusted to rates of 20, 30, 32 and 50 kg N ha^{-1} for *ObOr*, *ObSr*, *ObBr* and *SbOr* respectively.

h. One of the major constraints restricting the extrapolation and hence the application of the IRWH techniques, is the modeling of the water and soil nitrogen balance components.
i. In-depth study to determine the economic viability and socio-acceptability of the different treatments used in this study.

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α	=	slope of the relationship of ΣEs vs $t^{½}$ for phase 2 evaporation
AI	=	aridity index (rainfall/evaporation)
APSIM	=	Agricultural Production Systems sIMulator
ACIAR	=	Australian Centre for International Agricultural Research
ARC-ISCW	=	Agricultural Research Council - Institute for Soil, Climate and Water
BA	=	basin area
B-B-B	=	beans (1999/2000) - beans (2000/2001) - beans (2001/2002)
BbBr	=	IRWH with a bare basin and a bare runoff area
BD	=	bulk density (g cm^{-3})
B-M-B	=	beans (1999/2000) - maize (2000/2001) - beans (2001/2002
Bo	=	Glen/Bonhein-Onrus ecotope
B_{mon}	=	beans momoculture
B_{rm}	=	beans in rotation with maize
B_{rs}	=	beans in rotation with sunflower
C	=	carbon
C	=	cropland
CB:WHIG	=	Community-based Water Harvesting Interest Group
CDF	=	cumulative distribution function
CEC	=	cation exchange capacity ($cmol^+$ kg^{-1} soil)
CF	=	crop factor
CIMYT	=	International Maize and Wheat Improvement Centre
Cl	=	clay
ClLm	=	clay loam
CMUL	=	crop modified upper limit of available water (mm)
CNSC	=	cumulative nitrogen supply capacity
CON	=	conventional tillage
CPF	=	cumulative probability function
CPF-SP	=	Community Projects Fund – Support Programme
CYP-SA	=	Crop Yield Predictor for Semi-Arid areas
D	=	deep drainage (mm)
DAP	=	days after planting
D-index	=	index of agreement
DkBr	=	dark brown
DOY	=	day of the year
DSSAT	=	Decision Support System of Agrotechnology Transfer
DUL	=	drained upper limit of available water (mm)
EERD	=	estimated effective rooting depth
E_f	=	evaporation during the fallow period
Eo	=	potential evaporation (mm)
EoCF	=	crop water requirement
Es	=	evaporation from the soil surface (mm)
Esl	=	first phase evaporation
Es2	=	second phase evaporation

ESW_b	=	extractable soil water at the beginning of a day
ESW_e	=	extractable soil water at the end of a day
ET	=	evapotranspiration (mm)
ETo	=	reference crop evaporation (mm)
Ev	=	evaporation from the crop (transpiration) (mm)
FDR	=	frequency domain reflectometry
F_p	=	fallow period
fSat	=	field saturation
FSDA	=	Free State Department of Agriculture
FSRE	=	Free State Research and Extension unit
FTESW	=	fraction of total extractable soil water
$FTESW_{aa}$	=	adapted fraction of total extractable soil water
GI	=	galvanized iron
G_p	=	growing season
H	=	homestead
HI	=	harvest index
Hi	=	high level of fertilizer
I_{BA}	=	infiltration in the basin area
ICRISAT	=	International Crops Research Institute of the Semi-Arid Tropics
I_{RA}	=	infiltration in the runoff area
IR	=	in-field runoff
IR_b	=	water harvested from bare runoff surfaces (mm)
IR_s	=	water harvested from stone runoff surfaces (mm)
IR_o	=	water harvested from organic runoff surfaces (mm)
IWMI	=	International Water Management Institute
IRWH	=	in-field rainwater harvesting and micro-basin tillage
ISF	=	integrated stress factor
K	=	potassium
k	=	transpiration efficiency coefficient ($gm^{-2}mm^{-2}$)
Ks	=	Khumo/Swartland-Amandel ecotope
KS	=	Kolmogorov-Smirnov test
LAI	=	leaf area index
LL	=	lower limit of plant available water (mm)
Lo	=	low level of fertilizer
LT	=	long-term
M	=	organic mulch
M-B-M	=	maize (1999/2000) - beans (2000/2001) - maize (2001/2002)
ml	=	melanic diagnostic soil horizon
M-M-M	=	maize (1999/2000) - maize (2000/2001) - maize (2001/2002)
MSD	=	mean saturation deficit over the growing season
MSM	=	maize-sunflower-maize crop rotation
N	=	nitrogen

NAE	=	nitrogen agronomic efficiency (kg seed kg^{-1} N)
NEPAD	=	New Partnership for African Development
Nh	=	nitrogen high level
N_i	=	nitrogen application (kg N ha^{-1})
NDA	=	National Department of Agriculture
NR	=	nitrogen recovered (kg N ha^{-1})
NRE	=	nitrogen recovery efficiency (%)
Nrec	=	nitrogen recommended level
NSC	=	nitrogen supply capacity
NUE	=	nitrogen use efficiency
NWM	=	neutron water meter
ObBr	=	IRWH with organic mulch in basin and a bare runoff area
ObOr	=	IRWH with organic mulch in basin and organic mulch on the runoff area
ObSr	=	IRWH with organic mulch in basin and stone mulch on the runoff area
$\theta_{h(n-1)}$	=	root zone water content at harvesting of previous crop (mm)
θm	=	soil water content (mm) determined gravimetrically
θr	=	soil water content (mm) of the root zone determined by NWM
θr_a	=	water content of root zone, not adapted to cater for values above CMUL
θr_b	=	adapted water content of root zone, to cater for values not to exceed CMUL
θ_p	=	root zone water content at planting
$\theta_{p(n)}$	=	root zone water content at planting of current crop (mm)
θv	=	volumetric soil water content
OSWU	=	Optimizing Soil Water Use
ot	=	orthic diagnostic soil horizon
P	=	phosphate
P	=	precipitation (mm)
PAR	=	Participatory Action Research
PPWA	=	pre-plant water advantage
PAW	=	plant available water (mm)
PAW_p	=	plant available water at planting (mm)
WC_{pc}	=	plant available water at harvesting of previous crop (mm)
$PAW_{T/F}$	=	plant available water at tasseling/flowering (mm)
PAWSC	=	plant available water storage capacity
P_f	=	rainfall during the fallow season (mm)
P_p	=	production period
PPWA	=	pre plant water advantage
PRA	=	Participatory Rural Appraisal
PUE	=	precipitation use efficiency (kg ha^{-1} mm^{-1})
PUE_a	=	yield expressed in terms of the annual rainfall
PUE_g	=	precipitation use efficiency during the growing season (kg ha^{-1} mm^{-1})
PUE_{fg}	=	precipitation use efficiency over the preceding fallow period and the current growing season (kg ha^{-1} mm^{-1})
R	=	runoff (mm)
r^2	=	correlation coefficient

RA	=	runoff area
RMSE	=	root mean square error
$RMSE_s$	=	systematic root mean square error
$RMSE_u$	=	unsystematic root mean square error
R_p	=	reproductive period
RSE	=	rainfall storage efficiency (%)
S	=	stone mulch
ΔS	=	water stored in the root zone (mm)
SaCl	=	sandy clay
SaClLm	=	sandy clay loam
SASAS	=	South African Society for Atmospheric Sciences
SASCP	=	South African Society of Crop Production
SASHS	=	South African Society for Horticultural Science
SADC	=	Southern African Development Community
SbOr	=	IRWH with stone mulch in basin and organic mulch on the runoff area
SbSr	=	IRWH with stone mulch in basin and stone mulch on the runoff area
Se_b	=	amount of sediment collected in basins from bare runoff area (g m^{-2})
Se_s	=	amount of sediment collected in basins from stone runoff area (g m^{-2})
Se_o	=	amount of sediment collected in basins from organic mulch runoff area (g m^{-2})
SES	=	socio-economic status
SF		
SbSr	=	soil water content at first severe stress (mm)
SMS	=	sunflower-maize-sunflower crop rotation
SPAC	=	soil-plant-atmosphere continuum
SSSSA	=	Soil Science Society of South Africa
SWAMP	=	Soil Water Management Programme
SWE	=	soil water extraction
SWNM	=	Soil Water and Nutrient Managment
suffix f	=	fallow
suffix gf	=	growing season plus fallow period
t	=	time after the drainage starts at a root zone water content of fSat (hrs)
T	=	temperature (^oC)
T	=	time after saturation (hours)
TA	=	Technical Assistant
TESW	=	total extractable soil water (mm)
$\Delta TN_{(sys)}$	=	change in total nitrogen of the storage medium (kg N ha^{-1})
$TN_{i(sys)}$	=	total nitrogen input of the system (kg N ha^{-1})
$TN_{o(sys)}$	=	total nitrogen outputs of the system (kg N ha^{-1})
$TNS_{b(150})$	=	total nitrogen measured at the beginning of the treatment for the 0 - 50 mm soil layer
$TNSe_{(150})$	=	total nitrogen measured at the end of the treatment for the 0 - 50 mm soil layer
TSF	=	integrated stress index
UFS	=	University of the Free State

Va	=	Vlakspruit/Arcadia-Lonehill ecotope
V_p	=	vegetative period
WC	=	soil water content for the root zone (mm)
WC_{cc}	=	soil water content of current crop
WC_p	=	soil water content at planting
WC_{pc}	=	soil water content at harvest of the previous crop
WCT	=	Water Conservation Technologies
$WC_{T/F}$	=	water content at tasseling / flowering
WRC	=	Water Research Commission
WUE	=	water use efficiency (mm)
WUE_{ET}	=	water use efficiency in terms of water used for evapotranspiration (mm)
WUE_T	=	water use efficiency in terms of water used for transpiration (mm)
X	=	intercept of the drainage curve on the vertical soil water content axis, i.e. the point indicating “field saturation”
x	=	aridity index for the fallow period
x	=	infiltration ratio BA:RA
x	=	soya seed yield (ton ha^{-1})
Y	=	water content of the root zone at time T (mm)
Y	=	grain yield (kg ha^{-1})
y	=	cumulative evaporation from the soil during fallow period (mm)
y	=	seed yield (kg ha^{-1})
y	=	nitrogen advantage in kg N ha^{-1}
Yb	=	total biomass (kg ha^{-1})
Yg	=	grain yield (kg ha^{-1})
Yrel	=	relative crop yield
λ	=	stress weighting factor
Z	=	slope of the drainage curve

1 INTRODUCTION

1.1 THE PROBLEM AND PROPOSED SOLUTION

In the semi-arid areas of Southern Africa, scarce water supplies and low soil fertility are two of the main factors limiting food production. Irrigation agriculture is currently the biggest consumer of South Africa's scarce water resources. Savings on irrigation water through efficient farming practices will free precious water supplies for human and industrial consumption. Assisting small-scale farmers to optimally utilize the water resources at their disposal is therefore of critical importance. The mission of the Department of Agriculture in the Free State is to create a better life for the people in the Free State through self-reliance and utilization of agriculture and other resources within a sustainable living environment. The farming objective is to produce food to sustain approximately four to five family members.

Developing communities are the most seriously affected by the resultant unsatisfactory level of food security and sustainability, which prevails in these areas. In South Africa, as is the case in other developing countries, levels and incidence of poverty tend to be disproportionately high amongst the rural population. The poorest of the rural households mostly live in semi-arid and arid areas and rely on rainfed agriculture for their livelihoods, often farming on marginal and fragile soils. In dry areas, lack of adequate water poses a major constraint to increasing agricultural production and attempts to develop other economic activities. However, many agricultural scientists agree that with the use of appropriate production techniques, especially those that encourage conservation of water and soil resources, it is possible to increase and sustain agricultural output in semi-arid areas (Hatibu, 2002). In relation to smallholder agricultural needs in the semi-arid regions of the Southern African Development Community (SADC), Kronen (1994) accentuates the need to develop water harvesting and water conservation techniques. She estimates that 10 million people live in these areas. In the Free State there are a large number of households living on small-holdings under similar conditions (Department of Agriculture - Free State, 1996). In particular, various water conservation techniques, among them rainwater harvesting, are seen as having the potential for increasing available moisture for successful crop production in semi-arid areas. While in many cases the biophysical properties of such techniques are well understood and their ability to increase yield proven, the lack of their widespread use remains a mystery.

In central South Africa a large area east of Bloemfontein (750 000 ha), sometimes termed the "resettlement area", has been earmarked for developing farmers. There is a large population in the scattered villages and the two towns of Thaba Nchu and Botshabelo. The area is marginal for crop production because of relatively low and erratic rainfall and dominantly clay soils on which the precipitation (rainfall) use efficiency (PUE) is low because of high losses due to runoff (R) and evaporation from the soil surface (Es). The production technique (Figure 1.1) developed by the ARC-ISCW Glen team (Hensley, Botha, Anderson, Van Staden & Du Toit, 2000), that combines the advantages of water harvesting, no-till, basin tillage and mulching on high drought risk clay soils, reduced total runoff to zero and Es considerably.

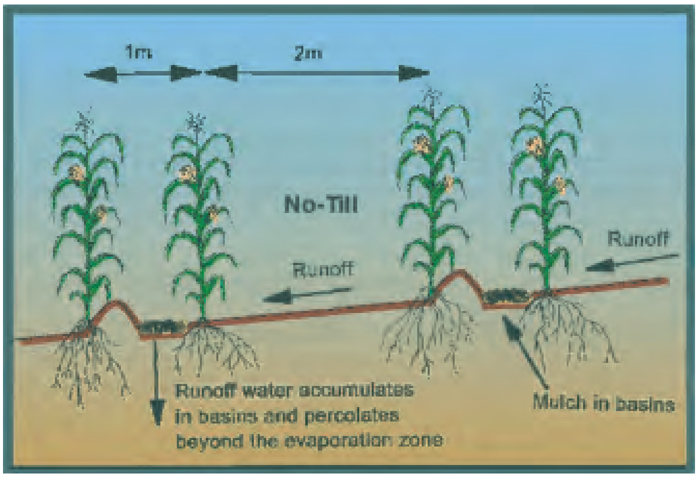

Figure 1.1 A diagrammatic representation of the in-field rainwater harvesting technique.

The specific advantages of each of these techniques in the in-field rainwater harvesting (IRWH) technique are considered to be:

(a) basin tillage minimizes overall runoff from the land;

(b) water harvesting from the untilled, crusted soil on the 2 m wide inter-crop row area serves to concentrate runoff water in the basins, and by so doing promotes infiltration of as much water as possible past the Es sensitive surface zone, and so minimizes the loss due to Es;

(c) mulch in the basins minimizes Es.

The main water loss is considered to be Es. Bennie, Strydom & Vrey (1994) claimed that between 60 % and 85 % of the rainfall evaporates before it could make any contribution to production in semi-arid and arid areas. Because this production technique that employs a combination of water harvesting and basin tillage reduced the ex-field runoff from a land to zero, soil loss from the land will also be stopped. Soil movement from the runoff strip into the basins, however, may be a problem in the long-term in relation to sustainable crop production. It is hypothesised that mulch (organic or stone mulch) on the runoff area will depress soil movement and therefore promote sustainability and higher crop yields.

The technical question that needs to be answered can be stated as follows:

- Can the IRWH technique decrease Es to a reasonable level through mulch combinations on the runoff area and in the basin area?

The second question that needs to be answered can be stated as follows:

- Will the farmers in rural villages use the IRWH technique?

1.2 PROJECT OBJECTIVES

- To evaluate, for small plots on clay soils in semi-arid areas, different water conservation crop production techniques which will enhance precipitation (rainfall) use efficiency (PUE), promote food security, and ensure sustainable productivity.
- To develop the capacity, as technical assistants in this research field, of three previously disadvantaged young people.

- To transfer the technology as effectively as possible by means of demonstration plots and information days to, (a) Department of Agricultural officials (especially those of the Free State Research and Extension section), (b) the owners of small areas of land, and (c) those who have access to communal land.

1.3 TERMINOLOGY

Some terms contained in this report need to be described to ensure a full understanding of terminology.

Precipitation (rainfall) use efficiency (PUE)

PUE is a focal point in the title and objective 1 of this project, therefore a good understanding of the concept is important. PUE is a valuable parameter to compare the efficiency with which different water conservation techniques conserve water or the ability to turn rainwater into food (Hensley *et al.*, 2000). This parameter is further defined in Section 2.3.2.7.

Food security

According to Brown (2000), Fisher (2000) and Wiebe (2000) food security can be defined as a strategy to provide access for all persons in a community to an affordable, nutritionally adequate and culturally acceptable diet (food) needed for a healthy life. For people in developing countries who are dependent on what they grow themselves, it involves the production of an adequate quantity and variety of food in keeping with their need for protein, calorie and vitamin intake. For urban dwellers or others not directly involved in the production of food, it is essential that they have sufficient income to buy food. Food security programmes confront hunger and poverty. The purpose and scope of these programmes should be to:

- meet the food needs of low income people;
- increase the food self-reliance of communities; and
- promote comprehensive responses to local food, farm and nutrition issues.

Sustainability

Sustainability is used to describe the appropriate use of crop systems and agricultural inputs supporting those activities that maintain economic and social viability while preserving the high productivity quality of land. The requirements for sustainable crop production according to Smyth & Dumanski (1993) are the following five points:

- agronomic productivity (improved production)
- risk – security (reduction in the level of risk)
- conservation techniques (conservation of natural resources)
- economic viability
- social acceptability

In-field Rainwater Harvesting (IRWH)

Water harvesting in its broadest sense will be defined as the "collection of runoff for its productive use". Runoff can be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. A wide variety of water harvesting techniques for many different applications are known. Productive uses include provision of domestic and stock water, concentration of runoff for crops, fodder and tree production (Siegert, 1993).

Classification of water harvesting techniques is as varied as the terminology. Different authors use different names and often disagree about definitions. A general classification has been established by Oweis, Hachum & Kijne (1999) where they define water harvesting as the process of concentrating rainfall as runoff from a larger area for use in a smaller target area. They subdivided water harvesting further as runoff farming water harvesting and supplemental irrigation water harvesting. Runoff farming water harvesting is subdivided into micro-catchment runoff farming, mini-catchment runoff farming and macro-catchment runoff farming. Hensley *et al.* (2000) claimed that in-field water harvesting is relevant to the term mini-catchment runoff farming of Oweis *et al.* (1999). Henceforth it is suggested that in-field water harvesting be replaced by in-field rainwater harvesting (IRWH).

2 PROCEDURE

The on-station field experiments were conducted at the Glen experimental research station (28º57` S, 26º20` E), 25 km north east of Bloemfontein. The on-farm field experiments were conducted on two farmers' fields in the resettlement area between Thaba Nchu and Excelsior. These sites are on the farms Khumo (29º04` S, 26º56` E) of Mr. Thekisho and Vlakspruit (29º05` S, 26º54` E) of Mr. Ramagaga. These selected ecotopes are representative of many thousands of hectares of land in the Free State Province on which a large number of rural households exist.

2.1 EXPERIMENTAL PLAN

2.1.1 Statistically designed experiments on two blocks (A & B) on the Glen/Bonheim ecotope

The main objective of this study was to achieve the first aim of the project, using on-station field experiments. This aim was to evaluate, for small plots on clay soils in semi-arid areas, different water conservation crop production techniques (based on Figure 1.1), which will enhance precipitation use efficiency (PUE), promote food security and ensure sustainable productivity.

A randomised block design with 2 crops, 8 treatment combinations and 3 replicates was employed. Crops were planted annually. Two crops were grown in rotation: maize and sunflower. The treatments were as follows:

- organic mulch in the basins, bare runoff area **(*ObBr*)**, with low level of fertilizer **(Lo)**
- organic mulch in the basins, stones on the runoff area **(*ObSr*)**, with low level of fertilizer **(Lo)**
- organic mulch in the basins, organic mulch on the runoff area **(*ObOr*)**, with low level of fertilizer **(Lo)**
- stones in the basins, organic mulch on the runoff area **(*SbOr*)**, with low level of fertilizer **(Lo)**
- ***ObBr***, with high level of fertilizer **(Hi)**
- ***ObSr***, with high level of fertilizer **(Hi)**
- ***ObOr***, with high level of fertilizer **(Hi)**
- ***SbOr***, with high level of fertilizer **(Hi)**

Plot construction is shown in Figure 2.1. The plots laid out for the previous experiment, as described by Hensley *et al.* (2000), were now used again in this experiment with the adding of various mulching and fertilizer treatments.

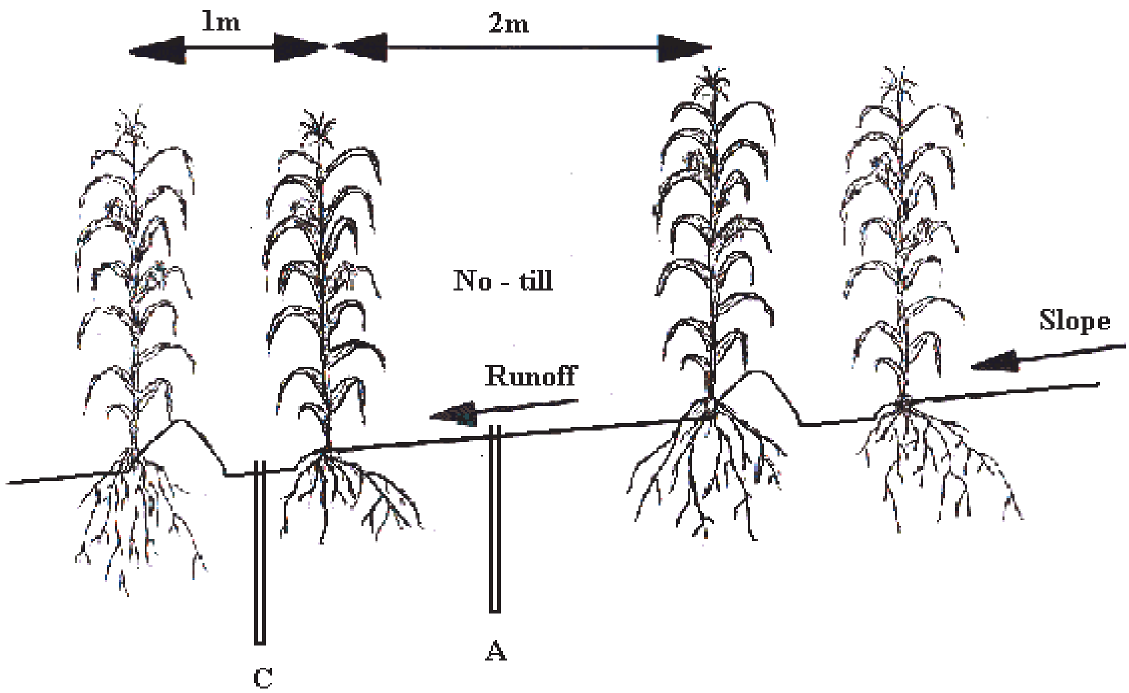

Figure 2.1 The distribution of access tubes (A and C) in the plots. The same plant distribution was used in the conventional treatment.

The technique consists of promoting rainfall runoff on a 2 m wide strip between alternate crop rows, storing the runoff water in the basins where it infiltrates deep into the soil below the surface layer from which evaporation takes place. The purpose of the mulch treatments (organic and stone) in the basins is to suppress evaporation. Mulch (organic and stone) on the 2 m wide runoff strip has a dual-purpose, firstly to reduce or suppress soil movement, and therefore promote sustainability, and secondly to suppress evaporation from the soil surface. The crops may benefit during dry seasons from the water stored relatively far from the plants, which is unavailable early in the growing season. Herbicides were used to control weeds and no-till was employed. Crops were hand planted and manually harvested.

The experimental plan of the replications (R1, R2, R3) and treatments used in block A is presented in Figure 2.2. Two crops grown in rotation on block A: sunflower (1999/2000), maize (2000/2001) and sunflower (2001/2002).

Block A

R1	*ObSr* (Hi)	*ObOr* (Lo)	*SbOr* (Lo)	*ObOr* (Hi)	*ObSr* (Lo)	*ObBr* (Hi)	*SbOr* (Hi)	*ObBr* (Lo)	
R2	*ObBr* (Lo)	*ObSr* (Lo)	*ObOrR* (Hi)	*SbOr* (Lo)	*ObOr* (Lo)	*SbOr* (Hi)	*ObBr* (Hi)	*ObSr* (Hi)	N ➔
R3	*ObBr* (Hi)	*ObOr* (Hi)	*ObSr* (Lo)	*ObOr* (Lo)	*ObBr* (Lo)	*SbOr* (Lo)	*ObSr* (Hi)	*SbOr* (Hi)	

Figure 2.2 Experimental plan of the replications and treatments in block A (1999/2000 = sunflower; 2000/2001 = maize; 2001/2002 = sunflower).

The experimental plan of the replications and treatments used in block B is presented in Figure 2.3. Two crops grown in rotation on block B: maize (1999/2000), sunflower (2000/2001) and maize (2001/2002).

Block B

R1	*SbOr* (Lo)	*SbOr* (Hi)	*ObBr* (Lo)	*ObSr* (Lo)	*ObOr* (Lo)	*ObBr* (Hi)	*ObSr* (Hi)	*ObOr* (Hi)	
R2	*ObSr* (Hi	*ObOr* (Lo)	*SbOr* (Hi)	*ObBr* (Hi)	*SbOr* (Lo)	*ObSr* (Lo)	*ObOr* (Hi)	*ObBr* (Lo)	N ➔
R3	*SbOr* (Hi)	*ObOr* (Lo)	*ObOr* (Hi)	*ObBr* (Lo)	*ObSr* (Hi)	*ObBr* (Hi)	*ObSr* (Lo)	*SbOr* (Lo)	

Figure 2.3 Experimental plan of the replications and treatments in block B (1999/2000 = maize; 2000/2001 = sunflower; 2001/2002 = maize).

2.1.2 Socio-economic study on two blocks (C & D) on the Glen/Bonheim ecotope

The main aim on these two blocks was to demonstrate the advantages of the in-field rainwater harvesting (IRWH) technique compared to conventional tillage (*CON*) to the Department of Agriculture officials (extension officers), owners of small areas of land and those who have access to communal land. The second aim was to demonstrate crop rotation with a legume compared to mono-cropping. All fertilizer was applied at planting at a moderate level. See section 2.2 for details.

A semi-statistical design was employed. Three tillage techniques were included: Block C

- ***ObBr*** treatment (see 2.1.1); maize and dry beans planted annually in rotation (6 plots, 3 for beans and 3 for maize)
- stones in the basins and stones on the runoff area **(*SbSr*)** - new treatment; maize and dry beans planted annually in rotation (6 plots, 3 for beans and 3 for maize)
- normal conventional tillage **(*CON*)**; maize and dry beans planted annually in rotation (6 plots, 3 for beans and 3 for maize)
- normal conventional tillage (*CON*); maize planted annually (3 plots)
- normal conventional tillage (*CON*); beans planted annually (3 plots)

Each treatment was replicated three times. An experimental plan of the replications and treatments applied in block C is presented in Figure 2.4.

Block C

ObBr (B-M-B)	*ObBr* (B-M-B)	*SbSr* (B-M-B)	*SbSr* (B-M-B)	*SbSr* (B-M-B)	*SbSr* (M-B-M)	*SbSr* (M-B-M)	*SbSr* (M-B-M)	
ObSr (B-M-B)	*ObBr* (M-B-M)	*ObBr* (M-B-M)	*ObBr* (M-B-M)	*CON* (M-B-M)	*CON* (M-B-M)	*CON* (M-B-M)	*CON* (M-M-M)	N ➔
CON (B-M-B)	*CON* (B-M-B)	*CON* (B-M-B)	*CON* (B-B-B)	*CON* (B-B-B)	*CON* (B-B-B)	*CON* (M-M-M)	*CON* (M-M-M)	

M-B-M = maize (1999/2000) - beans (2000/2001) - maize (2001/2002)
B-M-B = beans (1999/2000) - maize (2000/2001) - beans (2001/2002
M-M-M = maize (1999/2000) - maize (2000/2001) - maize (2001/2002)
B-B-B = beans (1999/2000) - beans (2000/2001) - beans (2001/2002)

Figure 2.4 Experimental plan of the replications and treatments in block C.

Construction of the water harvesting plot is shown in Figure 2.1. Seedbed preparation for all the crops on the *CON* treatments consisted of ploughing, followed by a rotavator and then discing with an offset disc. The same seedbed preparation was used every year on the *CON* plots. The same row spacing was used as shown in Figure 2.1. Both chemical and mechanical weed control was used on the *CON* plots. Where necessary, insects were controlled by spraying on all the treatments.

Block D consisted of the same treatments and replications as Block C but here the maize was replaced with sunflower. An experimental plan of the replications and treatments applied in block D is presented in Figure 2.5.

Block D

SbSr (S-B-S)	*SbSr* (S-B-S)	*SbSr* (B-S-B)	*SbSr* (B-S-B)	*SbSr* (B-S-B)	*ObBr* (S-B-S)	*ObBr* (S-B-S)	*ObBr* (S-B-S)	
SbSr (S-B-S)	*ObBr* (B-S-B)	*ObBr* (B-S-B)	*ObBr* (B-S-B)	*CON* (B-B-B)	*CON* (B-B-B)	*CON* (B-B-B)	*CON* (S-S-S)	N ➔
CON (S-B-S)	*CON* (S-B-S)	*CON* (S-B-S)	*CON* (B-S-B)	*CON* (B-S-B)	*CON* (B-S-B)	*CON* (S-S-S)	*CON* (S-S-S)	

S-B-S = sunflower (1999/2000) – dry beans (2000/2001) - sunflower (2001/2002)
B-S-B = dry beans (1999/2000) - sunflower (2000/2001) – dry beans (2001/2002
S-S-S = sunflower (1999/2000) - sunflower (2000/2001) - sunflower (2001/2002)
B-B-B = dry beans (1999/2000) – dry beans (2000/2001) – dry beans (2001/2002)

Figure 2.5 Experimental plan of the replications and treatments in block D.

2.1.3 On-farm demonstration plots in the vicinity of Thaba Nchu

The main objective of the two on-farm demonstration plots was to clearly demonstrate the benefits of the IRWH technique over *CON* tillage to Department of Agriculture officials (extension officers), owners of small areas of land and those who have access to communal land. The demonstration plots were also used to gather more information for achieving the first aim of the project.

The demonstration plots were also used to obtain the information required by the University of the Free State (UFS) team regarding the socio-economic implications of employing these techniques; and to determine the area of land and manpower needed to provide food security for an average size rural family. These aspects are treated separately in another report entitled: "Socio economic impact study on water conservation techniques in semi-arid areas", where the two collaborating institutions (UFS and ARC-ISCW Glen) constituted the project team. To get a complete perspective it is suggested that the report of Kundhlande, Groenewald, Baiphethi, Viljoen, Botha, Van Rensburg & Anderson (2003) should be read as well.

A semi-statistical design was employed in the on-farm trials at Khumo and Vlakspruit with sunflower. Four tillage treatments and three replications were used. The treatments were (see 2.1.1 for details):

- *CON*
- *ObBr*
- *ObSr*
- *SbOr*

A uniform moderate fertilizer application was applied. Production techniques were the same as those already described under Section 2.1.2. The experimental plan of the replications and treatments used on the demonstration plots at Khumo with sunflower is presented in Figure 2.6.

CON	*ObBr*	*ObSr*	*SbOr*
CON	*ObBr*	*ObSr*	*SbOr*
CON	*ObBr*	*ObSr*	*SbOr*

N ➔

Figure 2.6 Experimental plan of the replications and treatments at Khumo.

The experimental plan of the replications and treatments applied on the demonstration plots at Vlakspruit with sunflower is presented in Figure 2.7.

N ➘

CON	*SbOr*	*ObSr*	*ObBr*
CON	*SbOr*	*ObSr*	*ObBr*
CON	*SbOr*	*ObSr*	*ObBr*

Figure 2.7 Experimental plan of the replications and treatments at Vlakspruit.

2.1.4 Community cropping activities

After a number of contact sessions were held with the rural small-scale farmers to introduce the new farming technology, through pre- and post-harvest focus group discussions and a number of other technology exchange sessions, it was decided that it was time to take the IRWH technique to the people. In order to bring IRWH to the communities, the ARC-ISCW Glen personnel and the socio-economic team of the UFS visited the DOA office in Thaba-Nchu and the senior extension officer, Mr. Moshodi Marumo, was informed of the intentions of the team. He was asked to assist in the selection of at least three villages that needed immediate attention in terms of poverty alleviation and those that would represent the diversity of the economic activities and geographic position in the Thaba-Nchu area. The Thaba-Nchu area is divided into three parts, namely southern, northern and central regions. For purposes of improved delivery of services and communication between the farmers, extension officers, the ARC-ISCW and UFS teams, it was suggested that it would be best to select a village from each region.

The extension officer selected Yoxford in the southern region, Talla in the northern region and Paradys from the central region. Feloane was inevitably selected as the fourth village and as a second in the central region because the residents had already indicated tremendous keenness to implement the IRWH technique. The activities in these communities regarding the IRWH during the 2001/2002 and 2002/2003 growing seasons are discussed in detail Sections 9.9 and 9.10.

2.2 AGRONOMIC INFORMATION AND ACTIVITIES

Crop and fertilization details for the three growing seasons (1999/2000 - 2001/2002) are presented in Tables 2.1 and 2.2 respectively.

Planting was done by hand in all cases. It was unfortunately not possible to use the same cultivar each year. During the 1999/2000 growing season Kranskop was used as the dry bean cultivar because the cultivar originally selected (PAN 148) was not available at that time. From the 2000/2001 growing season onwards PAN 148 was used instead of Kranskop, as it is preferable for this region. During the 1999/2000 and 2000/2001 growing seasons the maize cultivar PHB 33V08 was used and replaced in the last growing season (2001/2002) with PHB 3394, a very similar cultivar recommended by Pioneer.

Table 2.1 Crop details for the on-station and on-farm experiments over three growing seasons (1999/2000 - 2001/2002).

Ecotope	Block	Crop	Cultivar	Plant population (plants ha^{-1})	Planting date	Harvest date
Glen/ Bonheim	A	Sunflower	SNK74	33 333	28/01/00	14/06/00
		Maize	PHB33V08	22 000	04/01/01	24/05/01
		Sunflower	SNK74	33 333	18/12/01	26/04/02
	B	Maize	PHB33V08	22 000	07/01/00	06/06/00
		Sunflower	SNK74	33 333	05/01/01	16/05/01
		Maize	PHB3394	22 000	19/12/01	23/04/02
	C	Maize	PHB33V08	22 000	07/01/00	06/06/00
			PHB33V08	22 000	04/01/01	25/05/01
			PHB3394	22 000	19/12/01	25/04/02
		Beans	Kranskop	133 333	09/02/00	11/06/00
			PAN148	133 333	09/01/01	05/06/01
			PAN148	133 333	20/12/01	22/04/02
	D	Sunflower	SNK74	33 333	28/01/00	14/06/00
			SNK74	33 333	05/01/01	17/05/01
			SNK74	33 333	18/12/01	25/04/02
		Beans	Kranskop	133 333	09/02/00	11/06/00
			PAN148	133 333	09/01/01	05/06/01
			PAN148	133 333	20/12/01	22/04/02
Khumo/ Swartland		Sunflower	SNK74	33 333	31/01/00	04/07/00
			SNK74	33 333	19/01/01	25/05/01
			SNK74	33 333	06/12/01	18/04/02
Vlakspruit/ Arcadia		Sunflower	SNK74	33 333	31/01/00	05/07/00
			SNK74	33 333	17/01/01	21/05/01
			SNK74	33 333	12/12/01	19/04/02
Talla	Homestead	Beans	PAN148	133 333	29/11/01	16/04/02
Paradys	Cropland	Sunflower	SNK74	33 333	10/01/02	27/05/02
Yoxford	Cropland	Maize	PHB3394	22 000	22/12/01	28/05/02
	Homestead	Maize	PHB3394	22 000	22/12/01	30/04/02
	Homestead	Maize	PHB3394	22 000	22/12/01	30/04/02
		Beans	PAN148	133 333	22/12/01	30/04/02
Feloanè	Cropland	Maize	PHB3394	22 000	03/12/01	19/04/02
		Sunflower	SNK74	33 333	03/12/01	19/04/02
	Homestead	Maize	PHB3394	22 000	29/11/01	17/04/02
	Homestead	Maize	PHB3394	22 000	11/12/01	17/04/02
		Beans	PAN148	133 333	11/12/01	17/04/02

Table 2.2 Fertilization details for the on-station and on-farm experiments over three growing seasons (1999/2000 - 2001/2002).

Ecotope	Crop	Block	Fertilizer treatment	Target yield (kg ha^{-1})	Fertilizer (kg ha^{-1})		
					N*1	P*2	K*3
Glen/Bonheim	Sunflower	A	High	2 500	90	15	0
	Sunflower	A	Low	1 000	15	5	0
	Maize	B	High	4 000	70	20	0
	Maize	B	Low	1 500	15	5	0
	Maize	C	Medium	2 750	40	0	0
	Beans	C	Medium	1 500	15	0	0
	Sunflower	D	Medium	1 750	50	0	0
	Beans	D	Medium	1 500	15	0	0
Khumo/Swartland	Sunflower	-	Medium	1 750	50	15	10
Vlakspruit/Arcadia	Sunflower	-	Medium	1 750	50	10	0
Paradys	Sunflower	-	Medium	1 750	50	40	0
Talla	Beans	-	Medium	1 500	15	12	0
Feloane	Sunflower	-	Medium	1 750	50	32	0
	Maize	-	Medium	2 750	40	40	0
Yoxford	Maize	-	Medium	2 750	40	10	0

*1 Nitrogen
*2 Phosphate
*3 Potassium

The amount of fertilizer applied was based on the analyses of soil samples taken prior to each growing season. All the fertilizer was applied at planting. Ammonium nitrate was used as the N-source and super phosphate as the P-source. The amount of P applied varied between 0 and 40 kg ha^{-1}. In general the soil K status was very high and hence K application was ignored, except in the case of the Vlakspruit/Arcadia ecotope.

2.3 MEASUREMENTS

The six water balance processes identified in equation 2.1 (Bennie, 1984) play an important role in the functioning, productivity and stability of the soil-plant-atmosphere continuum (SPAC). For good understanding of the system, which is crucial to the development of technological options for sustainable management of soil and water resources, it is necessary that these processes be monitored. Good understanding will promote optimisation of these processes and so enhance sustainable crop production.

Water for yield (mm) = water gains (mm) - water losses (mm)

$$Ev = (P \pm \Delta S) - (Es \pm R + D) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where:	Ev	=	evaporation from the crop (transpiration)
	P	=	precipitation
	ΔS	=	change in soil water content
	Es	=	evaporation from the soil surface
	R	=	runoff (-); run on (+)
	D	=	deep drainage

To monitor these processes, soil, plant and climate measurements were taken regularly during the growing season.

2.3.1 Soil parameters

2.3.1.1 Soil water content of the root zone (θr)

To monitor the soil water content of the root zone (θr), neutron water meter (NWM) access tubes were installed to a depth of 1.3 m, i.e. to a greater depth than that of the root zone. NWM access tubes (A and C) were located as shown in Figure 2.1.

Measurements of θr were carried out before planting, at planting, and during the growing season at 300 mm depth intervals starting at 150 mm. A Campbell Pacific 503 DR NWM was used. This procedure ensures that the different pedological layers in the soil have been adequately represented. The NWM was calibrated for every soil layer by using gravimetric soil water measurements (θm) and bulk densities of the soil (Robinson & Hubbard, 1990). A range of NWM counts for every soil layer, under wet and dry conditions, was made, and at the same time samples for θm determinations were taken close to the NWM access tubes. The θm values for every soil layer were multiplied with the appropriate bulk density value to give the volumetric soil water content (θv) of that soil layer. The linear relation between NWM counts and the θv values provided the calibration equation.

2.3.1.2 Drained upper limit of available water (DUL)

DUL is the highest field measured water content of a soil after it has been thoroughly wetted and allowed to drain until drainage becomes practically negligible, i.e. when the water content decrease in the profile is about 0.1 to 0.2 % per day (Ratliff, Ritchie & Cassel, 1983).

DUL was determined on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes in a previous study (Hensley *et al.*, 2000). The procedure used at the latter two ecotopes was innovative and has special relevance to the vertisol duplex and pseudo-duplex soils which are common around Thaba Nchu. As it was not described in the previous study, details are presented here. A representative site was chosen near the experiments. An area of 4 m x 4 m was levelled. A trench 700 mm deep was dug around the levelled plots and galvanized iron (GI) sheets inserted in the trench to isolate the "monolith" from the surrounding soil. The trench was filled in again with soil around the GI sheet so that it was pressed as firmly as possible against the sides of the “monolith”. A smectite rich clay slurry was poured into the gap between the GI sheet and the sides of the “monolith”, to prevent leakage of water downwards through this gap. The purpose of the GI sheet was to prevent lateral water movement that is especially prone to occur at the transition between the A and the less permeable B-horizon. A low earth wall was made around the area to prevent runoff water from entering. Three NWM access tubes (1.5 m long), spaced at about 0.75 m from each other, were installed in the centre of the area. The water content of the whole profile was measured before any addition of water. Measurements were made at 300 mm intervals at the following depths (mm): 150, 450, 750, 1050 and 1350. A water cart was used to fill the plots with water, and keep them full until continuous NWM readings showed that the wetting front had reached about 1.2 m, the bottom of the root zone. Addition of water was then discontinued. The time was recorded when the last surface water had disappeared into the soil, and the water content of the whole profile was then measured. The plots were then carefully covered with a plastic sheet. Care was taken to ensure that there was a good seal around the protruding access tubes to prevent wetting by rain. The water content of the root zone plotted against time after saturation describes the drainage curve. DUL for the root zone (0 - 1200 mm) was taken as the water content when the change in θr became negligible. The water content of each soil layer at that stage gave the DUL value for the individual layers. Since the DUL plot was free of vegetation, and covered by a plastic sheet to prevent evaporation, DUL depends solely on the properties of the soil profile. Crop and climate influences are excluded.

The DUL determination on the Glen/Bonheim ecotope was repeated for the purpose of this study and an improved value obtained compared to the one reported by Hensley *et al.,* (2000).

2.3.1.3 Crop modified upper limit of available water (CMUL)

CMUL describes the maximum amount of water available from the root zone for a particular crop at a particular growth stage and at a particular evaporative demand (Hattingh, 1993; Hensley, Hattingh & Bennie, 1993). CMUL is always more than DUL because water can be taken up by plants while percolation is occurring within the root zone. The critical factor is the drainage rate of the root zone and how it changes with time, i.e. the shape of the drainage curve. Although crop models make allowance for the available water above DUL, estimated values are generally used for the drainage rate. CMUL is based on a field measured drainage curve and was determined as described by Hattingh (1993). An exponential equation that describes the drainage curve was fitted (equation 2.2) and differentiated to give the drainage rate (equation 2.3).

$$Y = X - Z(\ln t) \quad \text{...(2.2)}$$

where: Y = water content (mm) of the root zone at time t
X = intercept of the drainage curve on the Y axis, i.e. the point indicating "field saturation".
Z = slope of the drainage curve
t = time after saturation (hours)

$$\frac{dY}{dT} = Z\frac{1}{t} \text{ (mm hr}^{-1}\text{)} \quad \text{...(2.3)}$$

The evapotranspiration (ET) rate of the different crops (mm hour^{-1}) during the course of the field experiment was determined. The time after saturation (T) at which the drainage rate is equal to the ET rate was obtained by substituting the relevant ET rate for the drainage rate in equation 2.3. CMUL was then obtained by substituting this value of T into equation 2.2.

2.3.1.4 Lower limit of plant available water (LL)

LL is the lowest field-measured water content of a soil after plants have stopped extracting water and are at or near premature death, or have become dormant as a result of water stress (Ratliff *et al.,* 1983). Since LL depends on soil, crop and climate characteristics, it is not meaningful to speak of the LL value of a soil on its own. LL needs to be related to a specific crop-ecotope.

The LL for each crop was determined during the course of the growing seasons of this study. It was taken as the lowest NWM reading for each soil layer measured over the three growing seasons.

2.3.1.5 Evaporation curve

Evaporation is the process by which water in the soil is changed to a vapour or gas and lost to the atmosphere (Van der Watt & Van Rooyen, 1990). The symbol Es will be used for this process.

An evaporation curve was determined for the Glen/Bonheim ecotope on the same 4 m x 4 m area used to determine DUL, after the drainage curve measurements had been completed. The plastic sheet was removed and the profile was filled again with water to a depth of 600 mm. As soon as the last surface water has infiltrated into the soil, NWM readings were taken of the 0 - 300 mm and 300 - 600 mm soil layers. The soil surface was left bare so that Es could take place. For the first two days readings were taken early in the morning and late in the afternoon. Thereafter readings were taken at the same time every morning for about a week, followed by less frequent readings until the change in the water content was minimal.

A representative site was also chosen close to the 4 m x 4 m DUL area where gravimetric soil water (θm) measurements were taken at the same time as the NWM readings for the Es curve. This plot was given the same preparatory treatment as the Es plot. No galvanized plates were installed around it. Samples for gravimetric measurements were taken for the same depths and at the same times as the NWM readings.

The evaporation curve was determined during the winter and to provide information for the fallow period, and also during the summer as we are dealing here with summer crops (sunflower, maize and dry beans), where Es plays an important role during the growing season. During the course of the Es measurements, due to the procedure being used here, water losses from the soil surface between saturation and DUL occurred in two directions, i.e. upwards by Es and downwards by drainage (D). The water content decrease during this period, i.e. Es + D, was subdivided by subtracting values for D obtained from the drainage curve made at the same site. The measurements for the Es curve obtained by the two methods (NWM and θm) were integrated in order to provide the most reliable result possible.

2.3.1.6 Bulk density (BD)

The BD of each soil layer in the root zone was measured using a core sampler. These values are needed to convert θm values to volumetric soil water content (θv) values for the NWM calibration and for the Es curve. BD can also give an indication of any soil compaction in the root zone and is needed for the crop model input dataset. Since we are dealing here with expanding clay soils, which have BD values that vary with water content, core samples were taken at a fixed water content, i.e. at DUL. Detailed measurements for the 0 - 1200 mm soil layers were carried out at 300 mm depth intervals.

2.3.1.7 Slope

The slope of each ecotope was determined by using a dumpy level.

2.3.1.8 Runoff (R)

The aim of the runoff plots is to simulate runoff from the different treatments. Three separate runoff plots that represent the tillage treatments used in the on-station experiments, each 2 m long and 3 m wide, were laid out on the Glen/Bonheim and Glen/Swartland ecotopes. The Glen/Swartland is similar to the Glen/Bonheim ecotope with 38 % clay in the orthic A-horizon. It is situated about 300 m from the Glen/Bonheim ecotope. Runoff was measured with automatic tipping bucket runoff meters. The runoff area of all three runoff plots was constructed in the same way as the different treatments of the field experiment. The three runoff plots were:

- runoff measured on a flat surface with minimum surface storage (bare);
- runoff measured with organic reed mulch on the flat surface with minimum surface storage (mulch); and
- runoff measured with an inorganic stone mulch on the flat surface with minimum surface storage (stones).

2.3.1.9 Deep drainage (D)

Deep drainage (D) is defined as the loss of water from the deepest soil layer of the root zone, and therefore out of reach of crop roots. D only occurs when the soil water content of the deepest soil layer exceeds DUL. It can be estimated by interpreting soil water extraction diagrams during the growing season in relation to the drainage curve.

2.3.1.10 Rainfall storage efficiency

Rainfall storage efficiency (RSE) was calculated using the equation of Mathews & Army (1960).

$$RSE = \frac{\theta_{p(n)} - \theta_{h(n-1)}}{P_f} * 100 \quad (\%) \quad \text{..(2.4)}$$

where: $\theta_{p(n)}$ = root zone water content at planting of the current crop (mm).
$\theta_{h(n-1)}$ = root zone water content at harvesting of the previous crop (mm)
P_f = rainfall during the fallow season (mm)

RSE describes the ability of the soil to store water in the soil profile during the fallow season.

2.3.1.11 Determination of Ev

The procedure proposed by Tanner & Sinclair (1983) was adopted. The following transpiration efficiency coefficients (k) values were used for maize, sunflower and dry beans respectively: 9.5 g m^{-2} mm^{-1}, 4.5 g m^{-2} mm^{-1} and 4.2 g m^{-2} mm^{-1}. These are the values proposed by Tanner & Sinclair (1983), Chapman, Hammer & Meinke (1993) and Walker, Ogindo & Hensley (2001).

2.3.1.12 Soil movement towards the basins

In order to make a quantitative prediction of water and soil movement from the runoff area towards the basins within the proposed conservation techniques, separate 3 x 2 m plots were prepared. Three treatments were applied to represent the specified surface conditions on the runoff area of blocks A and B, i.e., a bare surface (bare), a maize mulch (mulch) and a stone mulch (stones). Water and sediment were collected in a 120 litre drum using a galvanized gutter to direct the flow of the suspension.

The sediment in the suspension was determined by the following procedure: The bulk of the collected suspension was carefully transferred to a calibrated 25 litre container without disturbing the sediment in the drum, and leaving about 100 mm of the suspension in the drum. For every 25 litre of bulk suspension, two samples were taken to determine its sediment load. The last 100 mm of the suspension in the receiving drum was then stirred thoroughly, and while stirring five samples were taken. The rest of the suspension was then carefully transferred to the calibrated 25 litre container to determine the volume. All the samples were weighed before the water was evaporated in an oven. After drying (104 °C) the samples were weighed again and the amount of sediment calculated.

The method was verified as follows: One kilogram of oven dry soil was mixed with 10 litre of water. After a settling time of 2 hours the sample procedure described above was followed. It was concluded that the procedure was acceptable because the recovery was 97 %, indicating an error of only 3 %.

2.3.1.13 Organic carbon and N content in the surface soil

Soil analyses were employed to measure the influence of the different kinds of surface treatments on the organic carbon and N content of the surface soil in the basins. Soil samples were taken prior the start of the 1999/2000 growing season at 50 mm depth intervals for the first 300 mm. Samples were dried in the oven in glass bottles and then sealed and left in a safe place until the end of the experiment when the measurements were repeated. The same procedure was followed at the end of the experiment (end of 2001/2002 growing season) and all samples taken at a soil depth of 0 - 100 mm were analysed at the ARC-ISCW laboratories in Pretoria.

2.3.1.14 Soil temperature

Soil temperature is also needed to enhance the understanding of the process of evaporation from the soil surface. During the 2001/2002 growing season temperature sensors were installed at depths of 25 mm and 75 mm below the soil surface under the different types of surface covering to study the influence of different mulch types on soil temperature. Temperature sensors were installed on the runoff area and in the basins in treatments where maize was planted.

2.3.2 Plant parameters

2.3.2.1 Critical growth stages

The critical growth stages of the maize, sunflower and beans were recorded throughout the growing season.

2.3.2.2 Visual symptoms

Visual symptoms were used to identify plant water stress (Turner, 1986; Laker, Ceulemans & Vanassche, 1991). Any visual stress symptoms were recorded for all three crops.

2.3.2.3 Biomass

For sunflower and maize 6 rows, each 1 m long, and 9 rows, each 1m long, for the beans were harvested to determine the final above-ground biomass from each replication. Biomass is expressed as oven dry material in kg ha^{-1}. Results were used to determine Ev.

2.3.2.4 Grain yield

The grain yield for maize and sunflower was determined by harvesting 6 rows, each 4 m in length, and for the beans 9 rows, each 4 m long, from each replication. The grain was weighed oven-dry and adjusted to 13 % water content and expressed as kg ha^{-1}.

2.3.2.5 Harvest index (HI)

Harvest index was calculated as the ratio of grain yield to the total above-ground biomass yield (Bennie, Strydom & Vrey, 1998).

$$HI = \frac{Yg}{Yb} \quad \text{..} (2.5)$$

where: HI = harvest index
Yg = grain yield (kg ha^{-1})
Yb = total above-ground biomass (kg ha^{-1})

2.3.2.6 Water use efficiency (WUE)

Water use efficiency was determined with the equation used by Hillel (1972), Passioura (1983) and Tanner & Sinclair (1983).

$$WUE = \frac{Y}{(Ev + Es)} \quad \text{..} (2.6)$$

Where: Y = grain yield (kg ha^{-1})
Ev + Es = evapotranspiration (mm)

Where Ev has been determined, WUE was expressed more meaningfully as Y/Ev. WUE therefore measures the efficiency with which a particular crop can convert the water available to it, during a particular growing season, into yield.

2.3.2.7 Precipitation use efficiency (PUE)

A realistic definition of PUE that is useful for comparing different water conservation production techniques needs to be a function of water losses (R + Es + D) during the growing season, RSE, and WUE. An appropriate definition of PUE that meets these requirements has been proposed by Hensley, Snyman & Potgieter (1990). It is formulated by combining equations 2.1, 2.4 and 2.6. The final equation is:

$$PUE_{fg} = \frac{Y}{\theta_{h(n-1)} - \theta_{p(n)} + D_g + R_g + (\frac{Y}{WUE}) + (\frac{\theta_{p(n)} - \theta_{h(n-1)}}{RSE})} \quad (\text{kg ha}^{-1}\ \text{mm}^{-1})....(2.7)$$

where: PUE_{fg} = rainfall use efficiency (kg ha^{-1} mm^{-1}) over the preceding fallow period and the current growing season

suffix g = growing season

Other symbols are as in equations 2.1, 2.4 and 2.6.

The value of equation 2.7 is that it shows that PUE includes WUE and RSE. A simplified form is:

$$PUE_{fg} = \frac{Y}{P_g + P_f + (\theta_{h(n-1)} - \theta_{h(n)})} \quad (\text{kg ha}^{-1}\ \text{mm}^{-1})......................(2.8)$$

The denominator includes all the water used during the period between the previous harvest and the current harvest, including that extracted from the soil, i.e. it has the same numerical value as the denominator in equation 2.7. As explained by Gregory (1989), PUE defined in this way is not strictly an efficiency term as used in mechanics and physics, i.e. “the ratio of useful work performed to the total energy expended or heat taken in” (The Concise Oxford Dictionary: 9th Edition, 1995). Notice that in this strict definition of efficiency the units of the numerator and denominator are the same, i.e. energy units in this case. The result is a unitless ratio with a maximum value of 1.0, reached when the efficiency is 100 %. This is elegant as one is provided with an absolute and universal reference value against which all determinations can be compared. It is possible to define PUE in a similar way i.e. with the numerator and denominator having the same units. This has been made possible by the ability, where the necessary data is available, of determining Ev via the biomass, the transpiration coefficient (k), and the mean saturation deficit during sunshine hours (SD) of the growing season (Tanner & Sinclair, 1983; Gregory, 1989; Hattingh, 1993). Equation 2.9 is therefore defined as a fully acceptable, meaningful and yet simple and easily usable definition of PUE.

$$PUE_{fg} = \frac{Ev}{P_g + P_f} ....(2.9)$$

Since the units of both Ev and (P_g + P_f) are mm, PUE becomes a unitless ratio. The only measurements required are rainfall, biomass and SD. This eliminates the root zone water content values needed for equation 2.8.

3.3.2.8 Nitrogen use efficiency

2.3.2.8.1 Nitrogen agronomic use efficiency

The nitrogen agronomic use efficiency (NAE kg seed kg^{-1} N applied) is defined as the average yield increase per unit of applied N:

$$NAE = \frac{(Y_i - Y_{i-1})}{(N_i - N_{i-1})} \quad \text{(2.10)}$$

where

Y = grain yield (kg ha^{-1})

N_i = nitrogen application (kg N ha^{-1})

The seed yields for maize and sunflower at zero N application were 2612 and 2031 kg ha^{-1}, respectively.

2.3.2.8.2 Nitrogen recovery efficiency

The nitrogen recovery efficiency (NRE) % was calculated on an incremental basis:

$$NRE = \frac{(NR_i - NR_{i-1})}{(N_i - N_{i-1})} * 100 \quad \text{(2.11)}$$

where:

NR = nitrogen recovered was estimated using measured dry matter yields and nitrogen concentrations obtained from the literature as indicated in Section 6.3 (kg N ha^{-1})

N = nitrogen application (kg N ha^{-1})

The average dry matter yields for maize and sunflower obtained at the zero N application plots were 6306 and 5079 kg N ha^{-1}, respectively.

2.3.3 Climatic variables

Weather parameters, namely wet and dry bulb air temperature, solar radiation, wind speed and direction and rainfall, were measured with an automatic weather station. Reference crop evaporation (ETo) was determined with the Penman-Monteith equation.

2.3.4 Long-term evaluation of production techniques

This was achieved by comparing long-term cumulative distribution functions of yield using a crop yield prediction model and long-term climate data. Testing model performance against measured data was done by using the statistical procedures proposed by Willmott (1981). The model tested was CYP-SA (Hensley *et al.,* 2000). This model was used for each ecotope, together with long-term daily climate data, to construct cumulative probability functions

(CPFs) of crop yields to quantify the risk in the long-term associated with each production technique.

2.3.5 Statistical analyses

Data of all yield and water balance parameters was subjected to regression analyses using the NCSS 2000 Statistical System for Windows to determine the deference between the various treatments.

2.3.6 Participatory Rural Appraisal (PRA)

PRA surveys were conducted in the selected villages using well-structured questionnaires. The main objective of the PRAs was to assess people’s needs, opportunities and problems and to seek solutions. The survey gathered information on household characteristics (e.g., household size, educational level of the head of the household, household wealth and income), farming practices, household food intake and expenditure, use of agricultural support services and households’ opinions on production and support services constraints. Results of the formal household interviews are discussed in Chapter 9.

3 ECOTOPE CHARACTERIZATION

The term ecotope can be defined as an area of land on which the natural resources (climate, topography and soil) that influence yield are reasonably homogeneous (MacVicar, Scotney, Skinner, Niehaus & Loubser, 1974).

It is not possible to do detailed research work on every ecotope used for crop production in a country. To maximize research efficiency it is therefore necessary that attention is focussed on carefully selected benchmark ecotopes. To ensure efficient extrapolation of the results obtained on these ecotopes to all the others (i.e. pedotransfer actions), it is desirable that the main ecotope characteristics that affect productivity be characterized in detail (Hensley *et al.*, 2000). The Glen/Bonheim-Onrus ecotope (28º57` S, 26º20` E) (on-station) is characterized in more detail than the two on-farm ecotopes, Khumo/Swartland-Amandel (29º04` S, 26º56` E) and Vlakspruit/Arcadia-Lonehill (29º05` S, 26º54` E), in the Thaba Nchu area. These selected ecotopes are representative of more than half a million hectares of land in the Free State Province, especially between the two towns of Thaba Nchu and Botshabelo on which a large number of rural households exist.

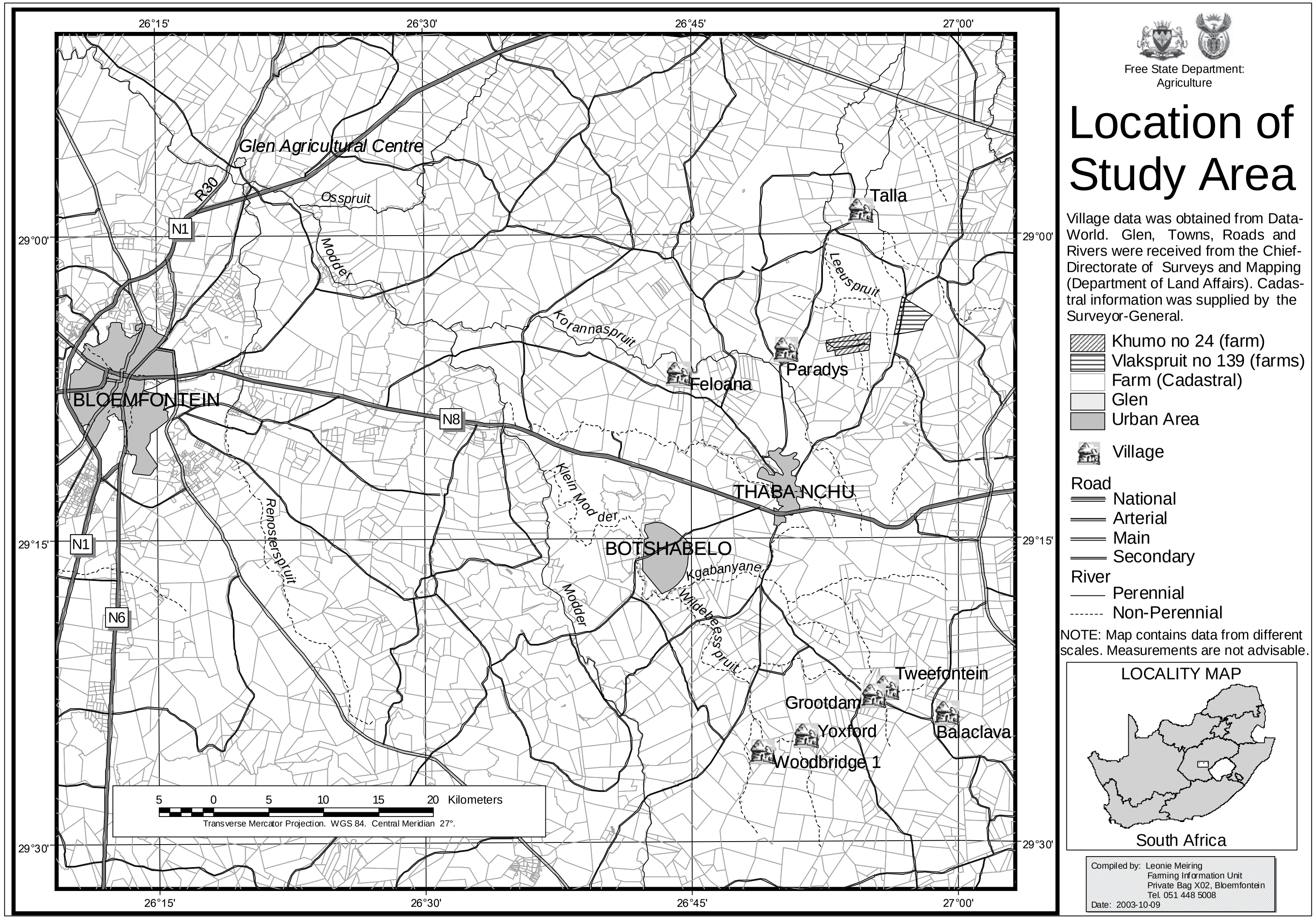

Figure 3.1 Locality map showing the position of Glen and Thaba Nchu area where the on-station and on-farm field trials were carried out.

3.1 GLEN/BONHEIM-ONRUS ECOTOPE (Bo)

3.1.1 Climate

Rainfall and temperature data for Glen has been recorded for 81 years (1922-2003) and class A-pan evaporation data for 42 years (1958-2000). Monthly mean values are presented in Table 3.1 for the period 1922 - 2003.

The high evaporative demand and relatively low rainfall makes this a semi-arid climate, with worst conditions for crop production generally occurring during December and January. Rainfall during these months is generally very erratic with much of it in the form of high intensity rainfall events. March rainfall is the second highest and also the most reliable, with the additional advantage that this month also has the lowest evaporative demand of the summer growing season. This feature can be used to advantage by planting crops with a short growing season early in January. Low temperatures are experienced during the winter, coupled with very little rain. In this sort of climate there is generally no shortage of radiation and hence the high evaporation from the soil surface.

Table 3.1 Long-term monthly and annual climate data from the Glen meteorological station (ARC-ISCW data); Rain and temperature data: 1922 - 2003; Evaporation: 1958 – 2000.

Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Long-term total / mean
Rain (mm)	8.1	11.6	19.3	49.0	68.2	66.6	83.4	77.6	80.7	49.3	19.9	9.0	542.7
Evap*[1] (mm)	93.5	140.6	197.5	239.1	256.0	291.6	276.5	207.7	177.1	126.1	110.6	81.9	2198.2
MaxT*[2]	17.8	20.6	24.4	25.4	28.3	30.2	30.8	29.5	27.4	23.9	20.5	17.9	24.8
Min T	-1.6	0.9	5.2	9.2	12.0	14.0	15.3	14.8	12.6	7.8	2.8	-1.1	7.5
Ave. T	8.1	10.7	14.8	17.5	20.1	22.0	23.0	22.1	19.9	15.8	11.6	8.2	16.2
AI*[3]	0.087	0.083	0.098	0.205	0.266	0.228	0.302	0.374	0.456	0.391	0.180	0.110	0.232

*[1] Class A pan
*[2] T = temperature in ^{o}C; mean values for the month
*[3] Aridity index = rain/pan evaporation

3.1.2 Topography

The experimental plots are located on an upper foot slope terrain unit with a 1 % slope and a westerly aspect.

3.1.3 Soil

Pedological characteristics

A detailed profile description together with analytical data is presented in Appendices 3.1 and 3.2 respectively. Important features are summarised in Table 3.2. The soil is classified, according to the Soil Classification Working Group (1991), as belonging to the Onrus Family of the Bonheim Form. It forms part of the land type Ea39c. It is a dark brown clay soil overlying $CaCO_3$ enriched sandstone saprolite at a depth of 800 mm. The parent material of the solum is a mixture of dolerite and sandstone colluvium, with dolerite dominating. The underlying saprolite is sufficiently weathered to a depth of at least 1200 mm and offers no significant impedance to root development to that depth. The effective root zone is considered to be 0 - 1200 mm. The soil has a high clay content (45 %) and strong structure with a high portion of smectite clay minerals resulting in a high CEC (24 - 25 $cmol^+ kg^{-1}$ soil). Dry spells cause large cracks that penetrate deep into the soil. Additionally, the surface soil has a high plasticity index of between 21 and 33, and self-mulching properties, which promote erosion when high intensity rain falls on the dry soil. In the surface soil the exchangeable Na content is fortunately low (0.7 $cmol^+ kg^{-1}$ soil) and it cannot therefore be blamed for exacerbating the swell-shrink properties. However, the relatively high exchangeable Mg content (11 - 12 $cmol^+ kg^{-1}$ soil) may promote cracking.

Soil water extraction and drainage characteristics

The high water holding capacity of the root zone is expressed by the high drained upper limit of plant available water (DUL) value of 456 mm. The equivalent for a loamy sand soil would be of the order of 180 mm. In spite of the high clay content and strong structure of the B-horizon, root water extraction to the lower limit of plant available water (LL) is shown to be very similar from each 300 mm layer to the bottom of the root zone.

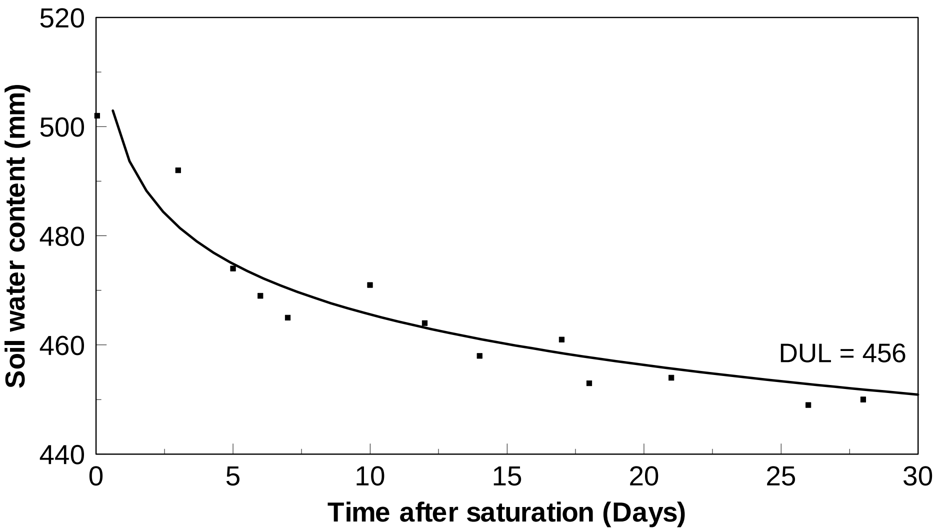

Figure 3.2 Drainage curve for the Glen/Bonheim-Onrus ecotope: root zone 1200 mm.

A drainage curve for the whole root zone, which provides the information for determining DUL, is presented in Figure 3.2. Equation 3.1 provides a mathematical description of the curve and enables the drainage rate at any time after field saturation (fSat) to be calculated.

$$Y = 511.55 - 8.92 (\ln t) \quad r^2 = 0.80 \qquad (3.1)$$

where:

Y	=	water content of the root zone (mm)
t	=	time after the drainage starts at a root zone water content of fSat (hrs)

Equation 3.1 makes it possible to make estimates of D after periods of heavy rain. This is necessary to quantify the water balance (equation 2.1). For these estimates to be reliable, another factor needs to be taken into account. When the water content of the root zone (θr) exceeds DUL, D does not necessarily start. The water above DUL, percolating slowly through the root zone, that is taken up by plant roots is catered for by the crop modified upper limit (CMUL) concept (Hattingh, 1993). Using that procedure the CMUL value for maize is 485 mm, i.e. 29 mm above DUL. The CMUL concept as originally formulated is, however, inadequate as it assumes equal distribution of extraction in terms of Es + Ev (evapotranspiration) from each of the soil layers. Since the intensity of root ramification is greater in the surface soil, and decreases with depth, the rate of soil water extraction is expected to follow the same pattern (Hensley *et al.*, 2000).

Table 3.2 The soil component of the Glen/Bonheim-Onrus ecotope. The effective root zone for the crops recorded is considered to be 0 - 1200 mm.

PROFILE DETAIL						SOIL WATER EXTRACTION PROPERTIES								
						BEANS			MAIZE			SUNFLOWER		
Diag Horizon	Colour	Clay (%)	BD ($g\ cm^{-3}$)	Depth (mm)	DUL (mm)	LL (mm)	TESW[*1] (mm)	CMUL (mm)	LL (mm)	TESW[*1] (mm)	CMUL (mm)	LL (mm)	TESW[*1] (mm)	CMUL (mm)
ml	DkBr	45	1.30	300	122	40	82		39	83		45	77	
vp	DkBr	43	1.45	600	123	74	9		74	49		67	56	
vp	DkBr	40	1.45	900	106	70	36		74	32		67	39	
so	Mottl.	38	1.45	1200	105	65	40		76	29		61	44	
Total					456	249	207	476	263	193	485	240	216	485

[*1] Total extractable soil water (mm)

Another factor that needs to be considered when estimating D is the water content of the deepest layer ($\theta_{900-1200}$). Only if this exceeds $DUL_{900-1200}$ one can be sure that D has occurred. This principle was used in this study.

Equation 3.2 describes the drainage curve for the 0 - 300 mm layer for Bo. Symbols are the same as for equation 3.1.

$$Y = 142.56 - 3.84 (\ln t) \quad r^2 = 0.83 \quad (3.2)$$

Evaporation characteristics with different soil surface treatments

In the semi-arid crop production areas in the central part of South Africa, the problem of low and erratic rainfall is exacerbated by two major unproductive soil water losses, *viz*. R and Es. These losses hamper the efficient use of available water for crop production (equation 2.1). D is negligible in these clay soils. R can be controlled by basins and in-field rainwater harvesting, leaving Es which needs to be minimized, both during the fallow and growing periods. Appropriate mulching techniques can reduce Es.

Botha, Anderson, Van Staden, Van Rensburg, Beukes & Hensley (2001) quantified the influence of different mulches on evaporation from the soil surface. Field experiments were laid out on the Glen/Bonheim-Onrus ecotope at the same experimental area where this study was conducted. Four treatments with three replications were used on 2 m x 2 m plots as follows: (a) bare soil, (b) stone mulch covering 50 % of the soil surface, (c) reed mulch covering 50 % of the soil surface, and (d) reed mulch covering 100 % of the soil surface. The results indicate the following:

- Es curves for different treatments for the 0 - 300 mm soil layer on the Bo determined during the summer are presented in Figure 3.3. The amount of mulch restricted Es. The 100 % reed mulch was the most effective in reducing Es (ΣEs = 127 mm) below the bare soil value of 150 mm. It was followed by the 50 % reed mulch (ΣEs = 134 mm), and 50 % stone mulch (ΣEs = 135 mm). It seems that surface mulch definitely contributes to more available soil water that could lead to higher yields and fewer crop failures.

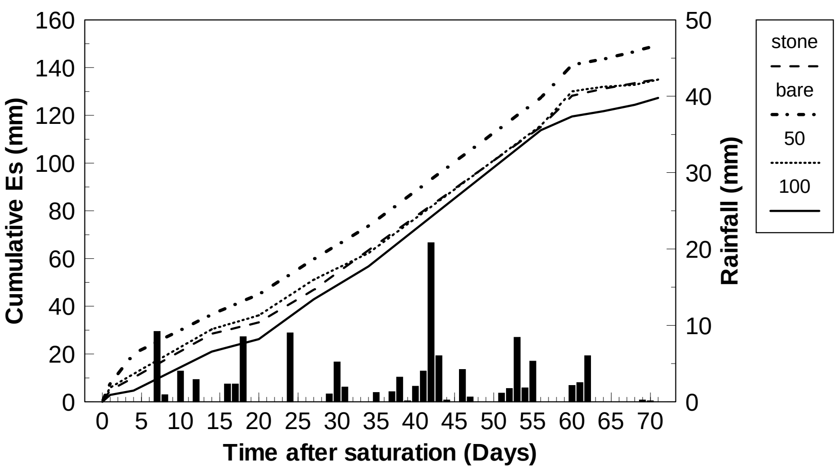

Figure 3.3 Summer evaporation curves for various surface treatments on the Bo ecotope 0 - 300 mm layer (after Botha *et al.,* 2001).

- Winter evaporation curves for different treatments using the 0 - 300 mm layer on Bo are presented in Figure 3.4. The bare treatment lost the most water, followed by the 50 % reed mulch, 50 % stone and then the 100 % reed mulch. The trends are similar to the summer curves, but differ in magnitude. The higher Es values of the latter are *inter alia* due to the greater frequency and magnitude of rainfall events, and the higher energy supply during the summer, as explained in more detail below.

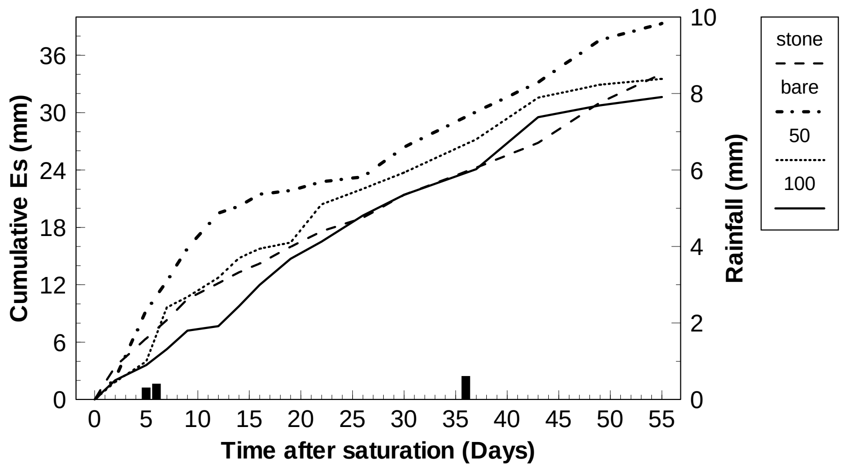

Figure 3.4 Winter evaporation curves for various surface treatments on the Bo ecotope 0 - 300 mm layer (after Botha *et al.*, 2001).

- During the summer rain season Es oscillates continually between the first and second phases, Es1 and Es2 respectively. Es1 is strongly controlled by Eo and climate therefore plays a dominant role. This phase generally ceased after about 3 days. Es2, which is controlled by the hydraulic properties of the soil, is much slower. This phenomenon explains the deviation in the shape of the summer Es curves compared to the classic shape of an Es curve more clearly evident in the winter Es curves.

3.2 KHUMO/SWARTLAND-AMANDEL ECOTOPE (Ks)

3.2.1 Climate

Daily rainfall for a nearby farm "North Bend" at latitude 29^o 04' 30" and longitude 26^o 5' is available from 1913 to 1984. It is situated about 2 km N of Vlakspruit and about 4 km W of Khumo. Long-term monthly average rainfall from "North Bend" is presented in Table 3.3.

Table 3.3 Long-term monthly rainfall for North Bend (represents the Khumo/Swartland and Vlakspruit/Arcadia ecotopes).

Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Long term total
Rain (mm)	11	13	23	48	77	69	91	81	88	57	20	10	588

Ks is situated in a semi-arid region with low and erratic rainfall where conditions are marginal for crop production. The average total long-term rainfall may appear to be adequate for the production of a cash crop but the intensities and distribution are of such a pattern that the rainwater received during the crop growth cycle is inadequate to support a good harvest.

3.2.2 Topography

The experimental plots are located on an upper foot slope terrain unit with a straight, 2 % slope in a northerly direction.

3.2.3 Soil

Pedological characteristics

A detailed profile description together with analytical data is presented in Appendices 1.3 and 1.4. This ecotope is part of the Db37 land type. The soil is classified as belonging to the Amandel Family of the Swartland Form. It is a dark brown soil with 17 % clay in the A-horizon, with a clear transition to the B-horizon that overlies $CaC0_3$ enriched sandstone saprolite at a depth of 700 mm. The soil has a strong structure in the B-horizon and a high content of smectite clay minerals that cause large cracks that penetrate deep into the soil when it is very dry.

Soil water extraction and drainage characteristics

Important features are summarised in Table 3.4. The high water holding capacity of the root zone is expressed by the high DUL value of 385 mm. The low value of the 0 - 300 mm layer (69 mm) compared to the Glen/Bonheim ecotope (122 mm) is because of a coarser texture. The DUL value of 69 mm is high for an Orthic A-horizon with a clay content of 17 %. This also accentuates the importance of a field determined DUL. The restrictive influence of the strongly structured B-horizon on root water extraction, and therefore presumably on root ramification, is disclosed by the lower total extractable soil water value in the 300 - 600 mm layer compared to the deeper layers.

Table 3.4 The soil component of the Khumo/Swartland-Amandel ecotope. The effective root zone is considered to be 0 - 1200 mm.

PROFILE DETAIL						SOIL WATER EXTRACTION PROPERTIES (SUNFLOWER)		
Diag Horizon	Colour	Clay (%)	BD (g cm^{-3})	Depth (mm)	DUL (mm)	LL (mm)	TESW (mm)	CMUL (mm)
ot	DkBr	17.5	1.50	300	69	31	38	
vp	DkBr	52.2	1.43	600	103	58	45	
vp	DkBr	45.2	1.42	900	110	60	50	
so	Mottl.	42.17	1.54	1200	103	56	47	
Total					385	205	180	423

A drainage curve for the whole root zone, which provides the information for determining DUL and CMUL, is presented in Figure 3.5. Equation 3.3 provides a mathematical description of the curve and enables the drainage rate at any time after field saturation (fSat) to be calculated.

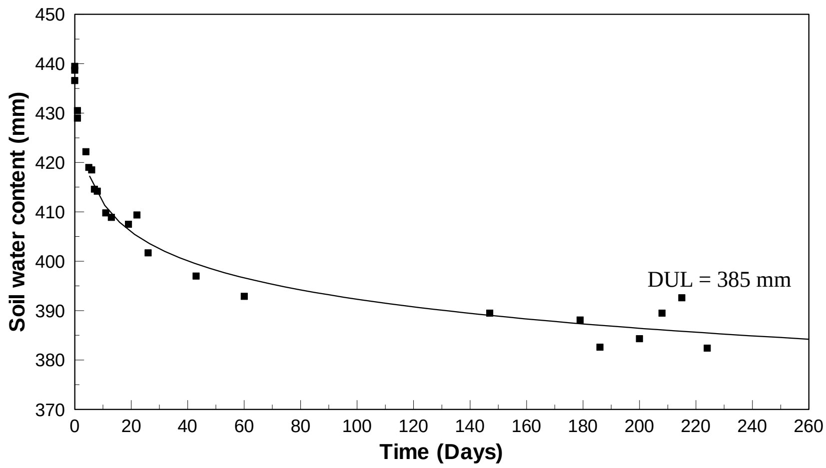

Figure 3.5. Drainage curve for the Khumo/Swartland-Amandel ecotope: root zone 1200 mm.

Y = 446.64 - 6.84 (ln t)…………….................r^2 = 0.95.............…...(3.3)

where:

Y = water content of the root zone (mm)

t = time (hrs) after drainage started, i.e. root zone water content at fSat.

Equation 3.3 can be used to calculate drainage out of the root zone after a heavy rainstorm has occurred. This is necessary to quantify the water balance (equation 2.1).

Equation 3.4 describes the drainage curve for the 0 - 300 mm layer. Symbols are the same as for equation 3.3.

$$Y = 102.06 - 3.70 (\ln t) \ldots\ldots\ldots\ldots r^2 = 0.93 \ldots\ldots\ldots\ldots (3.4)$$

Evaporation characteristics

The evaporation curve from a bare soil surface for the Khumo/Swartland ecotope measured with θr for the 0 - 300 mm layer during summer is presented in Figure 3.6. Es oscillates continually between the first and second phases, Es1 and Es2 respectively, during the summer measuring period due to the summer rain. The 0 - 300 mm soil layer lost 170 mm during a 70 day period.

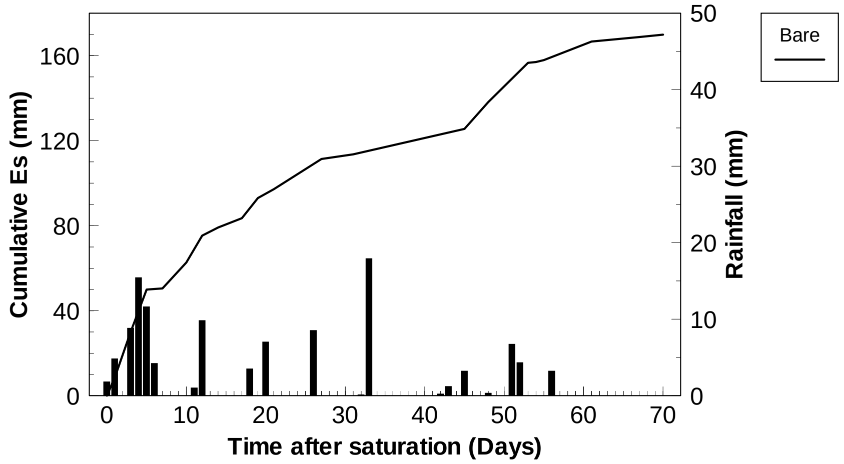

Figure 3.6 Evaporation curve for a bare surface during the summer on the Khumo/Swartland ecotope measured with θr: 0 - 300 mm layer

3.3 VLAKSPRUIT/ARCADIA-LONEHILL ECOTOPE (Va)

3.3.1 Climate

Since the ecotope is situated about five kilometres from Ks, the climate is as described under 3.2.1.

3.3.2 Topography

The plots are located on an upper foot slope terrain unit with a straight, 3 % slope in a north-westerly direction.

3.3.3 Soil

Pedological characteristics

A detailed profile description together with analytical data is presented in Appendices 1.5 and 1.6. The Va - ecotope also occurs in the land type Db37 and the soil is classified as belonging to the Lonehill Family of Arcadia Form. It is a vertic soil with 42 % clay in the A-horizon.

Soil water extraction and drainage characteristics

Important features are summarised in Table 3.5. The water holding capacity of the 0 - 1200 mm root zone is high, giving a DUL value of 456 mm. The high value for the 0-300 mm layer (113 mm) is similar to the Bo (122 mm), which gives an enormous $TESW_{0\text{-}300\ mm}$ (76 mm) for sunflower, similar to that of the Bo (77 mm).

As in the case of Bo and Ks, water extraction is effective to the bottom of the root zone although most of the water for plant growth is extracted from the top soil layers.

Table 3.5 The soil component of the Vlakspruit/Arcadia-Lonehill ecotope. The effective root zone is considered to be 0 - 1200 mm.

PROFILE DETAIL						SOIL WATER EXTRACTION PROPERTIES (SUNFLOWER)		
Diag horizon	Colour	Clay (%)	BD (g cm^{-3})	Depth (mm)	DUL (mm)	LL (mm)	TESW (mm)	CMUL (mm)
ve	DkBr	42.1	1.38	300	113	37	76	
ve	DkBr	53.5	1.43	600	109	75	34	
ve	DkBr	53.5	1.44	900	119	75	44	
ve	DkBr	53.5	1.49	1200	115	71	44	
Total					456	261	195	479

A drainage curve for the whole root zone, which provides the information for determining DUL and CMUL, is presented in Figure 3.7. Equation 3.5 provides a mathematical description of the curve and enables the drainage rate at any time after field saturation (fSat) to be calculated.

$$Y = 490.77 - 4.53 (\ln t) \qquad r^2 = 0.91 \qquad (3.5)$$

where:

Y = water content of the root zone (mm)

t = time (hrs) after drainage started, i.e. root zone water content at fSat.

Equation 3.5 can be used to calculate drainage out of the root zone after a rainstorm. This is necessary to quantify the water balance (equation 2.1).

Equation 3.6 describes the drainage curve for the 0 - 300 mm layer. Symbols are the same as for equation 3.5.

$$Y = 136.08 - 3.04 (\ln t) \ldots\ldots\ldots\ldots r^2 = 0.96 \ldots\ldots\ldots (3.6)$$

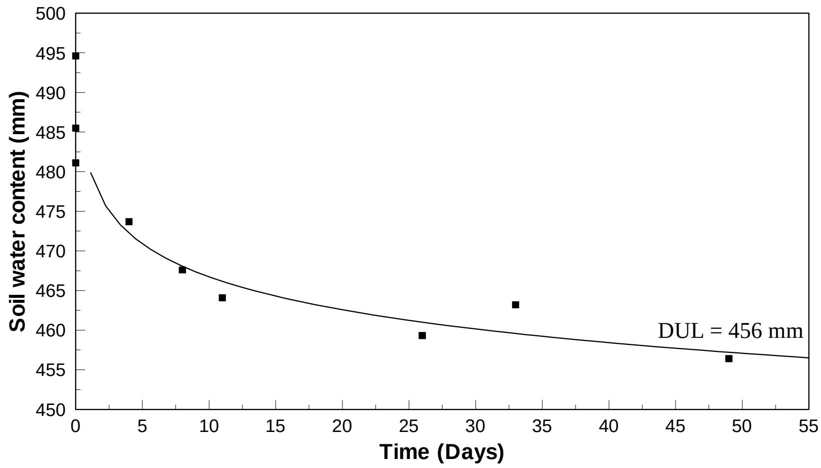

Figure 3.7 Drainage curve for the Vlakspruit/Arcadia-Lonehill ecotope: root zone 1200 mm.

Evaporation characteristics

The evaporation curve from a bare soil surface for the Vlakspruit/Arcadia ecotope measured with θr for the 0 - 300 mm layer during summer is presented in Figure 3.8. Es oscillates continually between the first and second phases, Es1 and Es2 respectively, during the summer measuring period due to the summer rain. The water content of the 0 - 300 mm soil layer started with a water content close to DUL and lost 170 mm during a 70 day period. This proves the importance to minimizing soil water loss to Es.

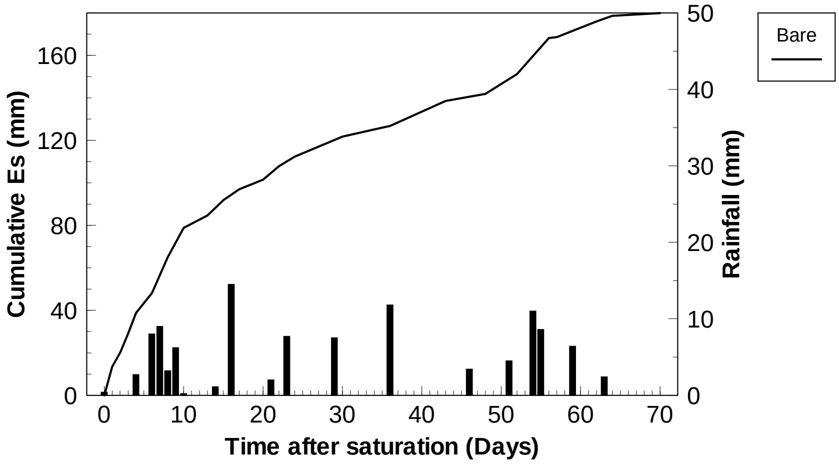

Figure 3.8 Evaporation curve for a bare surface during the summer on the Vlakspruit/Arcadia ecotope measured with θr: 0 - 300 mm layer.

3.4 RURAL VILLAGES IN THE THABA NCHU - BOTSHABELO AREA

Profile pits had been dug at each of the sites in the rural villages where the IRWH technique was demonstrated during the 2000/2001 growing season. The villages are Feloanè, Talla, Paradys and Yoxford. Each one was described briefly, the objective being to record the main characteristics relevant to crop production using the IRWH production technique. From a pedological view point the descriptions were not detailed, but nevertheless done with sufficient detail to identify Form and Family. Samples were taken of each horizon. To save time in the field, soil colour was read later. Soil analyses were done at the Free State Department of Agriculture laboratory at Glen.

Profile descriptions for the different profiles in the rural villages around Thaba Nchu are presented in Appendices 1.7 - 1.12. The important interpretations and comments are summarized in Table 3.6. No profile description is presented for Yoxford cropland (C). The brief, essential information about this soil was obtained from another study.

All the soils recorded in Table 3.6 have two prominent characteristics in common. They all have medium textured (SaClLm or SaCl) orthic topsoils around 200 mm deep, and fairly dark coloured B-horizons with a high clay content (60 - 70 %), strong structure, and are generally classified as pedocutanic. The profiles at Paradys (C) and Yoxford (C) are slightly typical in having a transitional B1-horizon overlying the typical pedocutanic horizon. A third feature which is found in all the soils, excepting Feloanè (C), is the occurrence of signs of wetness (hydromorphy) lower down in the profile. This feature indicates that during times, probably infrequently, when rainfall greatly exceeds evapotranspiration, water is retained in the soil for long periods. This is considered to be an advantage for the IRWH technique.

In the Land Type Survey of South Africa, pedocutanic horizons are frequently recorded as constituting root depth limiting material, e.g. Eloff (1984). The reason is presumably the high clay content with a large component of swelling 2:1 clay minerals, and resultant strong structure. These features are considered to produce an inhospitable medium for root growth. As these soils dry out the structural units become very hard and impenetrable to roots. Flattened roots are frequently found on ped faces in these horizons. These roots presumably entered cracks in fairly dry soil, and became squashed when the soil became wet and expanded. Pedocutanic horizons are very common in semi-arid areas and are a characteristic feature of all the soils described in Table 3.6. Even the Pinedene soil has a non-diagnostic pedocutanic B2-horizon. Soil forming conditions in the Thaba Nchu area are clearly very favourable for the formation of pedocutanic horizons. Frequent dolerite dykes and sills provide base-rich material and the intermittent rain coupled with high temperatures provide the frequent wetting and drying cycles necessary for the formation of smectites. Under natural conditions the dense mass of grass roots in the top ±300 mm of soil would cause rapid drying of this horizon after each rainfall event. It is postulated therefore that the subsoil horizons would only become thoroughly wet rather infrequently. This would suppress the intensity of weathering and hence favour the formation of 2:1 clay minerals. The signs of wetness at the bottom of the B-horizons of most of the soil profiles show that there are times when the soil profile has in fact become thoroughly wet, and probably dried out rather slowly because of the relatively shallow root system of the grasses. This would provide the time needed for the results of reducing conditions, due to a high degree of saturation, to manifest itself in the form of the grey colours visible in these horizons, and hence the classification as Sepanè Form of so many of the soils.

The soil water regime of these soils as described above under natural conditions would probably be fairly similar when cropped using *CON* tillage, with the degree and speed of drying after a rainfall event exacerbated by the bare soil surface frequently cultivated to remove weeds. With the IRWH technique, however, the water regime is drastically altered. Assuming that runoff from the bare strip is approximately 32 % of the rainfall (Du Plessis & Mostert, 1965) the “rainfall” in the basin area becomes increased by approximately 64 %, resulting in an increase of around 350 mm. Under these conditions spring rains before planting would produce a moist B-horizon reasonably hospitable for roots. The very high water storage capacity of these B-horizons, aided by an impermeable layer at the bottom of the B (proved by the signs of wetness), will ensure that severe drying will be far less frequent and therefore far less harmful than under natural conditions or *CON* tillage.

Although the criteria widely used in the Land Survey of South Africa regarding pedocutanic horizons and rooting depth are probably valid for *CON* tillage, it seems that they are inappropriate where IRWH is practised.

As a first approximation it seems that for soils of the Sepanè, Swartland, Bonheim, Arcadia and Pinedene Forms an effective rooting depth of around 1 000 mm, of which at least 700 mm is soil, can be considered as a minimum requirement for satisfactory maize, bean and sunflower production in the Thaba Nchu area. Valsrivier Form soils will generally, by definition, be deeper than this and are therefore also suitable. These tentative criteria are based on crop yields obtained at Feloanè, Paradys and Yoxford for a growing season during which the rainfall can be considered as moderate in amount and distribution.

There is still some uncertainty about the suitability of Sterkspruit Form soils for maize and sunflower production in the Thaba Nchu area using the IRWH technique. Roots generally do not like an abrupt transition, but this problem may be ameliorated in a soil that is thoroughly wet, which should generally be the case close to the basins in IRWH. It is significant that in the profile at Yoxford homestead (H) - Lazarus the A/B transition was verging on abrupt, with the structure of the B-horizon showing a strong tendency towards prismatic, both features of Sterkspruit Form. The maize yield at this site was 4371 kg ha^{-1} during the 2001/2002 season, notably under good management by the owner. The very dense maize stover mulch, which he had placed in the basins, would certainly have reduced evaporation to a minimum. Although the bean yields obtained on the Sterkspruit soil at Talla were disappointingly low, the cause may have been partly due to poor management. Future maize and sunflower yields at this site should provide valuable evidence regarding the suitability of Sterkspruit soil for IRWH.

Table 3.6 Essential information about representative soils of four rural communities in the Thaba Nchu area.

Profile No.	Site*[1]	Slope (%)	Soil Form	Family	EERD*[2] (mm)	Depth limiting material	A-horizon		PAWSC*[3]	Comments
							Depth (mm)	Clay (%)		
1	Feloanè (H) (Motaung)	3	Sepanè	Ramabesa	1100	Hard sandstone	150	38	high	Good maize yields prove that this is a good soil for IRWH. Supporting evidence is provided by signs of wetness 500-1100 mm.
2	Feloanè (C)	0	Valsrivier	Aliwal	1200+	Not reached	450	-	high	Good for IRWH, although lack of slope may be a slight disadvantage.
3	Talla (H)	2	Sterkspruit	Smithfield		Not reached	200	24		Reliable evidence for EERD and PAWSC for Sterkspruit Form soils like this is not yet available. Abrupt transition from A to B horizon is a disadvantage
4	Paradys (C)	2	Sepanè	Ramabesa	1000	Hard sandstone	200	22	high	Signs of wetness in the B2 advantageous for IRWH. Likely that the soil in this land is quite variable
5	Yoxford (H) (Gloria)	2	Sepanè	Ramabesa	750	Hard sandstone/ mudstone	200	30	high	Signs of wetness in the B2 advantageous for IRWH
6	Yoxford (H) (Lazarus)	2	Sepanè	Ramabesa	1300	Hard mudstone	200	-	high	Signs of wetness in the B2 advantageous for IRWH
7	Yoxford (C)		Pinedene		at least 800	Not reached	400	-	high	Signs of wetness in the lower layer advantageous for IRWH

*[1] = The first word is the name of the community; H = homestead with the name of the owner in brackets; C = cropland;
*[2] = estimated effective rooting depth
*[3] = plant available water storage capacity

4 WATER HARVESTING THROUGH IN-FIELD RUNOFF

4.1 INTRODUCTION

Runoff in general has produced a negative perspective amongst crop farmers, and rightfully so, because valuable water and soil are lost in the process. Various short- and long-term runoff studies have been conducted in the past 50 years not only to determine the extent of these losses, but also to investigate measures to counter the negative impacts on water and soil conservation. Some of the most important studies reported in South Africa are Haylett (1960), Du Plessis & Mostert (1965), and Bennie, Strydom & Vrey (1998). The Haylett experiment stretched over a period of 27 years in Pretoria on a red sandy loam soil (Hutton) with two slopes (3.8 % and 7 %), and three cultivation techniques, *viz.* mono-crop maize with conventional tillage, conventional bare tilled plots and bare untilled. The mean annual long-term rainfall for the site is 730 mm. Runoff, expressed as a percentage of the mean annual rainfall, amounted to 24 %, 25 % and 48 % respectively for the three production techniques when the datasets for the two slopes are combined. According to their measurements the soil losses through runoff on mono-crop maize with conventional tillage amounted to 7 500 kg ha^{-1} $year^{-1}$ or a loss of 0.5 mm of topsoil per year (assuming that bulk density is 1 500 kg m^{-3}). The situation for the conventional bare was even worse, soil losses amounted to 9 800 kg ha^{-1} or 0.7 mm loss of top soil per year. These results demonstrate how susceptible a soil is to erosion by water. Soil erosion is a problem of worldwide concern because of its consequences regarding the loss of soil productivity and increased potential for sediment pollution in streams, lakes and water reservoirs (Agassi, 1990).

Du Plessis & Mostert's experiment at the Glen Agricultural Development Institute near Bloemfontein ran for 17 years. It was conducted on a red sandy loam soil with 8.5 % clay and a 5 % slope (Tukulu soil form) which had been described in detail by Zere (2003). They reported runoff losses of 8.5 %, 10.3 % and 31.9 % of annual rainfall for the mono-crop maize with conventional tillage, conventional bare tilled plots and no-till bare treatments respectively. Soil erosion on the mono-crop maize conventional treatments amounted to 8 600 kg ha^{-1} or 0.6 mm loss of topsoil per year. The conventional bare treatment was even worse, with a loss of 13 200 kg ha^{-1} of soil, or 0.9 mm topsoil per year. Bennie *et al*. (1998) measured runoff over a number of years on soils with varying textures at four localities in the central part of South Africa. They selected only rain events of more than 2 mm of known rainfall intensity. Runoff estimates amounted to 25 % of the rainfall from conventional bare tilled plots.

These results have certainly helped to establish an awareness towards runoff and its negative impact on crop production. On the other hand, other users such as municipalities, the Department of Water Affairs, etc. depend heavily on runoff to fill the dams and hence to lower their enterprise risks. These users perceive runoff in a positive light. Irrigation farmers have the most balanced view on runoff; they depend on runoff as a production resource and would like to see full dams, yet will take measures to counter surface runoff from irrigation lands. Baumhardt, Wendt & Moore (1988) claim that maximizing infiltration is the most effective way to decrease losses of rainwater by runoff and evaporation. Morin & Benyamini (1990) propagated basin tillage systems with large surface storage capacities to prevent runoff and maximize infiltration. Hensley *et al.* (2000) reported over a period of 3 years on the Glen/Bonheim and Glen/Swartland ecotopes, runoff losses of 32 % of measured rainfall from bare plots (3 m x 20 m). McPhee

(1988) stated that for optimal resource conservation and development, farmers and agricultural advisors must have a knowledge of the important characteristics of agricultural soils, such as depth, fertility, texture and soil erodibility. Special measures, like conservation tillage practices or no-till, have to be taken when erodible soils are used for annual cropping. High runoff and erosion rates are associated with the formation of soil crusts. The high runoff rates caused by crusting promote transport of soil. It is known that raindrop impact can cause surface compaction and it therefore contributes to the formation of soil crusts. Hensley *et al.* (2000) developed an IRWH method to combine the advantages of basin tillage, no-till and mulching. Ex-field runoff, which occurs on *CON* plots, was stopped completely with this technique.

In-field runoff can be harnessed positively and used to enhance agronomic and conservation sustainability. Hensley *et al.* (2000) started with preliminary trials to investigate in-field runoff. They measured runoff from a 2 m untilled runoff strip of the IRWH system on the Glen/Bonheim and Glen/Swartland ecotopes for a short period and found runoff to be 39 % and 35 % of the measured rainfall respectively, with an average of 37 %. Results indicated that 35 – 39 % of rainfall could be harvested from the runoff strips, hence increasing the rainfall efficiency.

Seeing that the IRWH system was able to stop not only runoff but also soil erosion, the aims of this section will be: (i) to characterize the effect of mulches on water harvesting with in-field runoff processes, and (ii) to determine the impact of sedimentation, as affected by mulches, on the maintenance of the system.

4.2 RAINFALL CHARACTERISTICS

The average annual long-term rainfall for Glen, for the period 1922 to 2002, is 545 mm. Rainfall during December and January is generally very erratic with much of it in the form of high intensity rainfall events. The rainfall during March is the second highest, with a long-term average of 80.7 mm. The average total long-term rainfall may appear to be adequate for the production of a cash crop but the intensities and distribution are of such a pattern that the water available during the crop growth cycle is inadequate to support a good crop. The long-term rainfall pattern (81 year period, 1922 - 2003) on the Glen/Bonheim ecotope is characterized in Table 4.1. Of all the rainfall events, 75 % were less than 10 mm, contributing 31 % of the total rainfall. Only 9 % of the rainfall events occurred in the form of heavy thundershowers of more than 20 mm, representing 40 % of the total rainfall amount. Adequate soil water storage during these storms is therefore essential for good crop yields.

Table 4.1 Characterization of the rainfall pattern at Glen from January 1922 to June 2003.

Parameter	Rainfall classes				Total
	0 – 10 mm	11 – 20 mm	21 – 30 mm	>30 mm	
Amount of rainfall (mm)	13564	12954	6833	10607	43958
% of total	30.8	29.4	15.5	24.0	100
Number of rainfall events	4335	944	281	246	5806
% of total	74.6	16.2	4.8	4.2	100

4.3 THE EFFECT OF MULCH ON IN-FIELD RUNOFF

The in-field runoff results, as influenced by different mulch treatments (bare; maize stalks and reeds as organic mulch, and stones), for both the Glen/Bonheim and Glen/Swartland ecotopes, are summarised in Table 4.2.

Table 4.2 Rainfall and in-field runoff on two Glen ecotopes for the 1999/2000, 2000/2001 and 2001/2002 seasons with three different mulch treatments. The runoff plots size was 2 m x 3 m.

Ecotope	Glen/Bonheim							Glen/Swartland						
Season	Rain	In-field runoff						Rain	In-field runoff					
		Bare		Stone		Organic			Bare		Stone		Organic	
	mm	mm	%*1	mm	%*1	mm	%*1	mm	mm	%*1	mm	%*1	mm	%*1
99/00	479	110	30*2	59	12	16	3	489	167	38*3	80	16	11	2
00/01	544	255	47	175	32	26	5	544	214	39	124	23	16	3
01/02	591	280	47	168	28	54	9	567	228	40	115	20	32	6
Average	538	215	43	134	25	32	6	533	203	39	106	20	20	4

*1 = runoff as % of rainfall
*2 = % based on a total rainfall of 362.6 mm
*3 = % based on a total rainfall of 444 mm

Glen/Bonheim

A few runoff events were not recorded during the 1999/2000 season on the Glen/Bonheim ecotope, due to repairs being made on the tipping bucket meter of the bare runoff area. However, it can be stated that the number of recorded events is representative of the season. The results of the first season indicate that runoff was lower in all the treatments, compared to the following two years. This can probably be attributed either to the fact that the establishing of the experiment was newly established (i.e. soil crust not yet fully formed), and/or low rainfall intensities during the rain events. The runoff averages strongly indicate that water harvesting is influenced by mulching in a particular manner. The bare treatments stimulate runoff (43 %) through the formation of a surface crust, which is a natural characteristic of this soil. On the other hand, an organic mulch enhances infiltration rather than runoff. The average runoff from the organic mulch was almost 7 times less than the bare plot. Stones exhibit characteristics that fall between organic mulch and bare. In this case the average runoff was 25 % of the rainfall.

Glen/Swartland

For the Glen/Swartland ecotope only two rainfall events were not recorded and that amount of rainfall was excluded in the calculation of the percentage runoff. Although the two ecotopes are only about 600 m from each other, there is a small difference in total rainfall between them. Mulching affected runoff in a similar manner to that on the Bonheim. Bare enhanced runoff, which amounted to 39 % of the annual rainfall, while stones and organic mulch produced 20 % and 4 % runoff respectively.

When comparing the two ecotopes it is clear that on both ecotopes the total runoff on the bare plot is of the order of 40 % of the total rainfall during the summer season. Runoff from the area covered with stones is in the order of 20 %, and on the area covered with mulch only about 5 %. It is noticeable that there is quite a large increase in runoff from the organic mulch when comparing the 2000/2001 and 2001/2002 seasons on both ecotopes. This is an indication of the decomposition of organic mulch on the runoff area. It can also partly be attributed to a difference in the rainfall distribution pattern during these two seasons. The general trend that applies to both ecotopes over the three seasons is that stones greatly reduced runoff on the runoff area when compared to bare, but runoff is much more in comparison with mulch on the runoff area.

The implication of the results is that with the IRWH technique it is possible to harvest an extra 40 % of the seasonal rainfall with a bare runoff area. This water could be stored in the soil volume below the basins. Most of this water will infiltrate below the evaporation zone, and so be available for transpiration. With stones on the runoff area a considerable amount of rainwater will run off, but the amount which infiltrates into the runoff area will be considerable more than on the bare runoff area. The organic mulch on the runoff area has the smallest amount of runoff, in other words the smallest contribution of the three treatments to extra water storage in the basin. Of the three treatments, mulch will contribute the most to water infiltration in the runoff area. Both mulch treatments will have a reduced evaporation component from the soil on the runoff area, compared to a bare treatment. The question is: which combination of effects will be the most beneficial for crop production?

All the runoff events measured (dependent variable) on the Glen/Bonheim and Glen/Swartland ecotopes over the three years (2000 - 2002) were plotted in Figure 4.1 against the corresponding rainfall (independent variable). A linear function for each treatment was fitted through the data to obtain equations to estimate water harvesting from the 2 m runoff area (Equations 4.1, 4.2 and 4.3). These equations were applied in the crop model CYP-SA to estimate the water harvested through in-field runoff (IR).

$IR_b = -0.87915 + 0.47417 \times P$………..($r^2 = 0.64$)…....……………………………….(4.1)
$IR_s = -0.66351 + 0.29001 \times P$………..($r^2 = 0.51$)….………………………………....(4.2)
$IR_o = -0.2124 + 0.07684 \times P$…………($r^2 = 0.55$)..…………………………………...(4.3)

Where:

IR_b = water harvested from 2 m bare runoff surfaces (mm)
IR_s = water harvested from 2 m stone runoff surfaces (mm) IR_o = water harvested from 2 m organic runoff surfaces (mm)

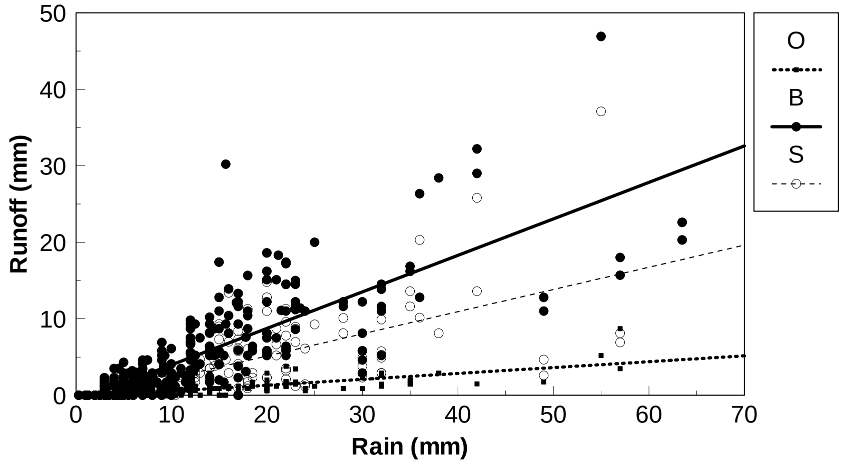

Figure 4.1 Runoff data from the different treatments plotted against the corresponding measured rainfall measured per day on the Glen/Bonheim and Glen/Swartland ecotopes (O = organic; B = bare; S = stones).

4.4 MULCH EFFECTS ON SEDIMENTATION IN BASINS

The advantage of the IRWH system is that ex-field runoff can be stopped completely if the system is correctly designed. No erosion from the field as a whole will therefore occur. However, due to the movement of the water on the crusted soil surface, soil movement occurs from the runoff area into the basin. This affects the sustainability of the system.

The amounts of sediment collected in the basins of the respective treatments on the Glen/Bonheim ecotope are presented in Table 4.3. The results were determined on separate runoff plots and show that the most soil transportation occurred on the bare surface treatment, followed by the stone and mulch treatments. It is therefore concluded that mulch on the runoff area will be the best treatment in terms of sustainability regarding the surface storage capacity of the basin. The capacity of the basins with a bare runoff area will be reduced relatively quickly, and progressively lose their designed water storage capacity. The land will then eventually have the same surface characteristics as with *CON*. It must be emphasized that the IRHW technique, if not properly designed, (i.e. the capacity of the basin must be able to hold the runoff from the biggest rainstorm), and implemented in terms of the contour layout, has the potential to be more detrimental than *CON* in terms of erosion.

Table 4.3 The amounts of sediment (g m^{-2} $season^{-1}$) collected in the basin of the respective treatments on the Glen/Bonheim ecotope (O = organic; B = bare; S = stones).

Season	Sediment load (g m^{-2} $season^{-1}$)		
	B	S	O
00/01	4204	1673	539
01/02	3244	2242	562
Average	3724	1958	551

The following assumptions were made in an attempt to calculate the number of seasons that would cause the basins to completely silt up:

1) The bulk density of the deposited material is 1.5 g cm^{-3}.
2) Stones in the basins occupy 50 % of its volume.
3) Mulches in the basins occupy 40 % of its volume.
4) Average basin size initially is 3 m long, 1 m wide and 0.1 m deep, serving a runoff area of 6 m^2 (2 m x 3 m).

Results are presented in Table 4.4.

Table 4.4 Estimates of the time required for the silting-up process in the basins with different treatments.

Procedure	Treatment					
	*BbBr**1	*ObBr*	*SbSr*	*SbOr*	*ObSr*	*ObOr*
1. Volume of basin (cm^3)	300 000	180 000	150 000	150 000	180 000	180 000
2. Amount of sediment needed to fill basin (g)	450 000	270 000	225 000	225 000	270 000	270 000
3. Average sediment load per season (g)*2 (Table 4.3)	22 344	22 344	11 748	3 306	11 748	3 306
4. Number of seasons for basins to become filled with silt	20	12	19	68	23	82

*1 = Bare basin, bare runoff area
*2 = Since the area of the runoff strip is 6 m^2 the value in Table 4.3 must be multiplied by six

The actual realization of the theoretical results in Table 4.4 will be influenced by:

1. The decomposition rate of the organic mulch.
2. Deterioration of the ridge. After the basin is made, the rainfall intensity of the first two or three rain events is critical in this regard.
3. Although no-till is practised, chemical weed and pesticide control must be done. To prevent trampling, which causes deterioration of the mulch on the runoff area, it should preferably not be walked on. Stones on the runoff area impair walking there.

Consequently the ridge of the basin becomes the most preferred place to walk, causing it to be flattened.

4. The rainfall pattern per season in terms of intensity and amount.
5. The size of the basin.
6. The frequency and extent of basin maintenance options.

Sedimentation results indicate that the *ObOr* treatment is the most sustainable in terms of maintaining the surface storage capacity of the basin over time. It is followed by the *SbOr*, *ObSr*, *BbBr*, *SbSr*, and *ObBr* treatments. These results also indicate that the *BbBr*, *ObBr*, *ObSr* and *SbSr* treatments are relatively non-sustainable in terms of maintaining the surface storage capacity of the basins over time. For these treatments maintenance will be needed. It is also necessary to realize that long before the basins are full of sediment, their storage capacity will be below the threshold value needed to prevent them overflowing during high intensity storms of long duration. The need for a certain amount of maintenance to the basins is therefore inevitable.

The choice of treatment should not be based on these results only. It is necessary to also consider the measured crop yields, the socio-economic aspects associated with each treatment, and maintenance costs involved in keeping the water/storage capacity of the basins at an adequate level.

All the measured sediment data (dependent variable) on the Glen/Bonheim ecotope over two years (2001 - 2002) was plotted in Figure 4.2 against the corresponding measured rainfall (independent variable) and a linear function for each treatment was fitted through the data to obtain equations to predict sedimentation in the basins from the 2 m no-till area (Equations 4.4, 4.5 and 4.6).

$$Se_b = -221.355 + 55.2770 \times P \quad (r^2 = 0.64) \qquad (4.4)$$

$$Se_s = -115.128 + 28.9705 \times P \quad (r^2 = 0.57) \qquad (4.5)$$

$$Se_o = -65.6549 + 10.4807 \times P \quad (r^2 = 0.44) \qquad (4.6)$$

Where:

Se_b = amount of sediment collected in basins (g m^{-2}) from a bare runoff area

Se_s = amount of sediment collected in basins (g m^{-2}) from a stone runoff area

Se_o = amount of sediment collected in basins (g m^{-2}) from an organic mulch runoff area

Although these correlations are very useful as first approximations, the low r^2 values are revealing. They expose the important influence which rainfall amount above the intensity equal to the final infiltration rate of the crusted soil, have on runoff and sediment load. A fruitful avenue for future research is revealed here – especially for model building purposes. An appropriate model could make this valuable information extrapolateable to a wide range of ecotopes in Sub-Saharan Africa.

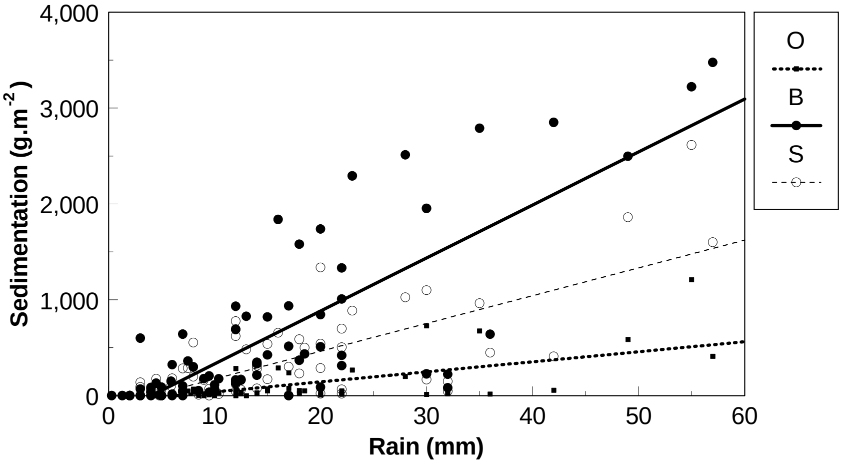

Figure 4.2 Sedimentation data from the different treatments plotted against the corresponding measured rainfall measured per day on the Glen/Bonheim ecotope (O = organic; B = bare; S = stones).

4.5 LONG-TERM RUNOFF PREDICTIONS FOR IRWH SYSTEMS

Cumulative probability functions (CPFs) of simulated runoff from the *CON* and IRWH production techniques on the Glen/Bonheim ecotope are presented in Figure 4.3. The organic mulch, stone and bare treatments have a 20 % probability that runoff of 22 mm, 90 mm and 156 mm will not be exceeded, respectively; or in other words on these treatments there is a 80 % probability of harvesting in-field runoff water into the basins of 22 mm, 90 mm and 156 mm per year, respectively. The closer the graph is to the right hand bottom corner of the figure the higher is the runoff potential of the production strategy. The CPF graph also indicates that *CON* tillage has an 80 % probability of losing 40 mm of rainwater per year to ex-field runoff. This implies that the organic mulch, stone and bare treatments have a 62 mm, 130 mm and 196 mm rainwater advantage in the basins, respectively, above *CON*, due to the total stoppage of ex-field runoff and their ability to harvest in-field runoff and store it in the basins. At a lower probability (50 %) the organic mulch, stone and bare treatments have a 50 % probability of harvesting 29 mm, 116 mm and 199 mm runoff per year, respectively. At the same probability level *CON* has a 50 % probability of losing 55 mm of rainwater to ex-field runoff. In practice it means that a farmer using IRWH with the organic mulch, stone and bare treatments would have a rainwater advantage in the basins of 84 mm, 171 mm and 254 mm per year respectively above *CON*, which can contribute to much higher crop yields. It is necessary, however, to appreciate that crop yield responses are not directly correlated with these “rainwater advantage” values for a number of reasons. Data and explanations are presented in other parts of this report, which show that water retained on the runoff strip in the organic mulch treatment, for example, is advantageous compared to the bare treatment, which has the highest runoff into the basins.

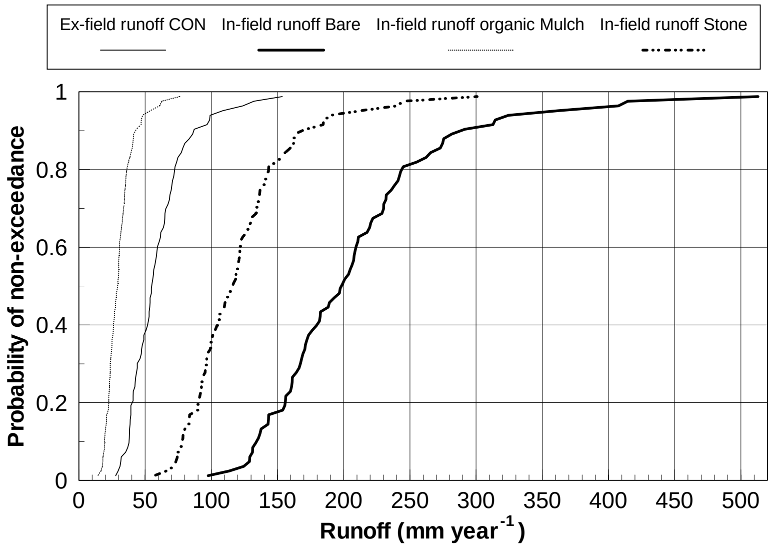

Figure 4.3 CPF graphs of predicted long-term runoff from the Glen/Bonheim - Onrus ecotope. The rainfall data used are for the 81 year period, 1922 – 2003.

4.6 SUMMARY

The main focus in this chapter is the characterization of precipitation/in-field runoff relationships as influenced by mulches in the in-field rain water harvesting and basin tillage (IRWH) system. As point of departure, negative perceptions of runoff amongst crop production farmers, extension officers and researchers need to be changed. Runoff is defined by van der Watt & van Rooyen (1990) as water "lost" by surface flow. This gives runoff a negative connotation. The driving force behind water harvesting is precisely to turn the "loss" into a "gain" by collecting the water in various structures, depending on the magnitude of the catchment area. Hensley *et al.* (2000) developed such a surface structure based on a 2:1 ratio of runoff area to catchment area. The catchment area is normally 1 m wide in the form of a basin, while no-till is applied in the runoff area. The IRWH system is regarded as a special form of water harvesting, categorised as mini-catchment runoff farming by Oweis *et al.* (1999), and particularly for clayey soils in semi-arid areas. The ability of the system to convert water into seed yield by stopping ex-field runoff is well demonstrated in Hensley *et al.* (2000), where the technique was compared to conventional tillage (*CON*). Seed yield advantages above *CON* varied between 20 and 30 % depending on the year and crop type. During the research phase of the technique it was realized that the full agronomic potential had not yet been reached and therefore the need for this follow-up project. Part of the answer had been identified, i.e. the advantage of harnessing the runoff process or surface redistribution of water in the system.

The results of this project reveal the importance of surface redistribution of water with regard to crop yield. There is a need for more research in this connection, which could yield valuable results, especially for small-scale farmers and home-gardeners for whom the IRWH system has proved to be very acceptable. Runoff is divided into ex-field and in-field runoff. Lessons from ex-field runoff studies, especially where bare surfaces were used, is generally applicable to the IRWH system. Note should be taken that the two systems also differ widely in their mechanism of producing runoff water. In-field runoff refers to the transportation of water over a short distance of 2 m, while ex-field runoff occurs on areas of much greater size. It has been possible to establish practical linear relationships that describe the precipitation/in-field runoff process on bare, maize residue and stone mulch runoff strips. These relationships have been used to determine the water harvesting potential on a typical clay soil in a semi-arid area on a long-term basis.

Results of long-term predictions of in-field water harvesting indicated that organic mulch, stone and bare treatments have an 80 % probability of harvesting 22 mm, 90 mm and 156 mm every year, respectively, compared to the *CON* tillage, which has a very high probability of losing 40 mm of rainwater every year by runoff. This implies that the organic mulch, stone and bare treatments harvested 62 mm, 130 mm and 196 mm more rainwater respectively than *CON*, due to the total stoppage of ex-field runoff and the ability of harvesting rainwater in-field.

As indicated, ex-field runoff was completely stopped by the IRWH system and hence also soil erosion. An area of concern that influences the sustainability of the IRWH system is the siltation of the basins through the in-field runoff process. Sediment measurements and estimates have revealed that the basins will take between 12 and 82 years to become filled if no sediment is removed. The period depends on the type of mulch on the runoff area and also in the basins. Mulch on the runoff area restricts sediment movement, depending on mulch type, while mulch type in the basin influences the capacity of the basin to absorb sediment. However, it is also necessary to realize that all the IRWH techniques will need some degree of maintenance, to prevent overflowing during heavy rainstorms. It is essential that the volume of the basins be maintained above a critical threshold value to prevent this happening.

5 EVALUATION OF MULCH COMBINATIONS ON WATER CONSERVATION WITH IRWH SYSTEMS ON THE GLEN/BONHEIM ECOTOPE

5.1 INTRODUCTION

During the technical research phase of the IRWH technique (1997-1999), it was realized that its full agronomic potential had not yet been reached. It was hypothesized that the factors that restrict the potential of IRWH to convert rainwater into food could probably be attributed to: (i) unnecessary water losses due to evaporation; and (ii) inefficient surface redistribution of water. The proposed solution was to introduce mulches in the system, applied in various combinations on the runoff area and in the basin area.

The effect of mulches on evaporation has been thoroughly studied in two successive projects on the Glen/Bonheim and Glen/Swartland ecotopes (Botha *et al.*, 2001; Van Rensburg, Nhlabathi, Anderson, Botha, Van Staden & Kuschke, 2003). These results indicate that, amongst other factors, (i) mulch type *per se* influenced evaporation rate similarly; and (ii) that percentage ground cover is an important surface characteristic that controls evaporation from the soil surface (Es). Classical evaporation studies clearly indicate that evaporative demand, which depends on humidity, temperature and wind speed, is an important factor to take into account. Evaporation studies in South Africa have shown that the length of the drying cycle is also an important factor determining the ability of mulches to reduce evaporation. Hoffman (1997) estimated that mulching loses its water conservation advantage when the drying cycles exceed 15 - 20 days during the fallow period under semi-arid conditions. Berry & Mallett (1988) found that maize residue, covering greater than 70 % of the surface, reduced evaporation considerably under sub-humid conditions provided the drying period was shorter than 14 days.

Under semi-arid conditions, phase two of the evaporation process dominates most of the time. This implies that Es is largely controlled by the hydraulic characteristics of the soil matrix (Hillel, 1972). Hoffman (1997) states that cumulative evaporation increases with increased silt plus clay content. On the other hand, a simple model proposed by Stroosnijder & Kone (1982), cited by Stroosnijder (2003), indicates that soil hydraulic properties are not of primary importance in comparison to other factors such as potential evapotranspiration, leaf area index and length of drying cycle. They used a constant that apparently worked well for a wide spectrum of soils that ranged from sand to clay in their simple model to predict cumulative evaporation from a soil surface.

The runoff process has been discussed in Chapter 4 where runoff was divided into in-field runoff and ex-field runoff. In-field runoff is regarded as one of the most important processes in the IRWH system in relation to improving yields through mulching. From the results in Chapter 4 it can be concluded that the type of mulch plays an important role in the precipitation/in-field runoff relationship. Theoretically it can be stated that mulches that provide the most beneficial infiltration ratio between the runoff area and the basin should produce the highest yields. However, it is not practically possible to measure infiltration directly on both areas. The common factor determining the fate of water where mulches are introduced is infiltration. The water balance statement can be expressed for the runoff area and basins as follows, assuming that the profile was dry or near the lower limit of plant available water (LL) at the start of the estimation:

Runoff area:
Precipitation – in-field runoff = infiltration = transpiration – evaporation – drainage………..(5.1)
Basin area:
Precipitation + in-field runoff = infiltration = transpiration – evaporation – drainage………..(5.2)

The general objective of this chapter is to evaluate the IRWH techniques in terms of their ability to convert water into food in a sustainable manner. Various combinations of mulch types in the basins and on the runoff area of the IRWH system have been proposed for maize and sunflower production. The indicators of crop response to mulching used were seed yield, dry matter production, harvest index, transpiration and various water use efficiency indices. Amongst other things, the role of mulches both on the runoff area and in the basins will be discussed in relation to the fallow period and important crop growth stages.

5.2 CLIMATE

For the analysis of the water balance components of the experiments the production season was divided into three periods, *viz*. (i) the fallow period (F_p) which stretched from harvesting of the previous crop until planting of the next crop; (ii) the vegetative period (V_p) which represents the period from planting to flowering; and (iii) the reproductive period (R_p) which represents the time from flowering until harvest. This provides an opportunity to analyze the three periods separately and also the combined effect on the growing season (G_p), i.e. $V_p + R_p$, and the overall production period (P_p), i.e. $F_p + V_g + R_p$.

The aridity index (AI) value, summarised in Table 5.1, was used to characterize the climatic conditions experienced during the experimental period from the start of the 1999/00 season to the end of the 2001/02 season. Comparing the mean AI values of the G_p in Table 5.1 for maize and sunflower with the corresponding long-term means, reveals that the climatic conditions were slightly better for production during the experimental period than projected by the long-term mean. What is of significance is the fact that the climatic conditions for the R_p, which has a major influence on the actual yield of the crop in particular, were considerably more favourable than the equivalent long-term means. The climatic conditions for the V_p can be considered as being typical for the ecotope, *viz*. with mean AI values of 0.30 and 0.33 for maize and sunflower, respectively. The AI values for the fallow period (0.30 and 0.31), show that conditions were very favourable for water conservation by mulching in comparison to the long-term, with a mean AI value of 0.17 for both crops. The AI values for the fallow period of the 1999/00 season were excluded in the estimation of the experimental average due to the late start of the experiment.

5.3 WATER BALANCE COMPONENTS

5.3.1 Precipitation

As in the case of the AI, rainfall was also divided into the selected periods (Table 5.1).

Table 5.1 Precipitation (P), potential evaporation (Eo) and aridity index (AI) for the three production seasons in relation to the long-term (LT) mean, where F_p = fallow period, V_p = vegetative period, R_p = reproductive period, G_p = crop growing period and P_p = production period; Glen/Bonheim ecotope.

Crop	Parameter	Season	Period				
			F_p	V_p	R_p	G_p	P_p
Maize	P (mm)	99/00	157	95	133	228	385
		00/01	234	82	199	280	514
		01/02	360	161	86	247	607
		mean	297	113	139	252	507
		LT mean	228	161	145	306	535
	Eo (mm)	99/00	315	347	229	646	961
		00/01	1143	465	290	755	1898
		01/02	863	352	301	653	1516
		mean	1003	388	297	685	1707
		LT mean	1361	533	395	928	2289
	AI	99/00	0.50*	0.27	0.45	0.35	0.40
		00/01	0.20	0.18	0.69	0.37	0.27
		01/02	0.42	0.46	029	0.38	0.40
		mean	0.30	0.30	0.47	0.37	0.29
		LT mean	0.17	0.30	0.37	0.33	0.23
Sunflower	P (mm)	99/00	205	109	70	179	384
		00/01	232	82	198	280	513
		01/02	360	161	87	248	608
		mean	296	117	118	236	560
		LT mean	221	175	108	283	504
	Eo (mm)	99/00	427	340	123	463	890
		00/01	1086	508	217	725	1811
		01/02	841	373	292	665	1507
		mean	965	407	211	618	1658
		LT mean	1311	534	284	819	2129
	AI	99/00	0.48*	0.32	0.57	0.39	0.43
		00/01	0.21	0.16	0.91	0.39	0.28
		01/02	0.43	0.43	0.30	0.37	0.40
		mean	0.31	0.31	0.59	0.38	0.34
		LT mean	0.17	0.33	0.38	0.35	0.24

* Excluded from mean

Results indicate that the average rainfall over the three seasons was approximately 50 mm lower than the long-term mean for the G_p period of both crops. Water shortage occurred mostly in the vegetative period. From the means for the experimental period, it is clear that both crops received approximately 70 % of the long-term mean for the V_p period rainfall. Considering rainfall during the R_p of sunflower, the crop received almost double the mean rainfall during the 00/01 season, while for the other two seasons (99/00 and 01/02), there was a water shortage of approximately 20 and 35 %, respectively, in comparison to the long-term mean. The rainfall during the R_p period of maize for the 01/02 season was approximately 40 % less than the long-term mean. Thus, the generally good cropping conditions indicated by the higher AI values can be attributed to lower potential evaporation rather than good rains (Table 5.1).

5.3.2 In-field runoff and infiltration

In the introduction of this chapter, and also in Chapter 4, it was stressed that the surface redistribution of water in the IRWH system is one of the major processes influencing the water regime of the root zone and hence the yield. The impact of mulch type on the runoff area on water harvesting in the basins, can be estimated with the following infiltration equations for the runoff area (I_{RA}) and the basin area (I_{BA}):

$$I_{RA} = P - IR \qquad (5.3)$$

$$I_{BA} = P + IR \qquad (5.4)$$

where

P = precipitation (mm)

IR = in-field runoff which can be estimated with Equation 4.1 for bare, Equation 4.2 for stone and Equation 4.3 for organic mulch on the runoff area

Results obtained with these equations are summarized in Appendix 5.1. For example the infiltration ratio during the fallow period for the basin area (BA) *versus* the runoff area (RA) can then be calculated as demonstrated with the 99/00 – *ObBr* treatment for maize:

$$I_{RA} = 157 \text{ mm} - 58 \text{ mm} = 99 \text{ mm}$$

$$I_{BA} = 157 \text{ mm} + (2 \times 58) \text{ mm} = 273 \text{ mm water}$$

The infiltration ratio, *viz*. infiltration of BA to the infiltration of RA, is: 273: 99 = 2.75:1 or a 2.75 ratio, which indicates that for every 1 mm of water that infiltrates in the runoff area, 2.8 mm will infiltrate in the basin area. The infiltration ratios estimated for all the treatments are summarized in Table 5.2.

The infiltration ratio for *ObBr* varied between 2.37 and 2.99 during the duration of the maize experiment, irrespective of the periods. Inspection of the *ObOr* data revealed considerable lower values than obtained for *ObBr*. The infiltration ratio for *ObOr* varied between 1.13 and 1.19 over the experimental period, reflecting a much higher infiltration on the runoff area in comparison to *ObBr*. The infiltration ratio for stones on the runoff area (*ObSr*) falls between the bare and organic mulch treatment, and varies between 1.58 and 1.92. The same trend was observed for sunflower, *viz*. *ObBr* > *ObSr* > *ObOr*, with mean values varying between 2.54 and 2.76, 1.72 and 1.82 and 1.15 and 1.17, respectively, over the experimental period.

Table 5.2 Infiltration ratio of the basin area to the runoff area for different treatments during different seasons on the Glen/Bonheim ecotope.

Crop	Periods	Season	Treatment			
			ObBr	*ObOr*	*ObSr*	Mean
Maize	F_p	99/00	2.78	1.17	1.82	1.92
		00/01	2.71	1.17	1.79	1.89
		01/02	2.80	1.17	1.84	1.94
		Mean	2.76	1.17	1.81	1.91
	V_p	99/00	2.47	1.14	1.67	1.76
		00/01	2.77	1.17	1.82	1.92
		01/02	2.62	1.16	1.76	1.85
		Mean	2.62	1.16	1.75	1.84
	R_p	99/00	2.37	1.13	1.64	1.71
		00/01	2.99	1.19	1.92	2.03
		01/02	2.73	1.17	1.81	1.90
		Mean	2.69	1.16	1.79	1.88
	G_p	99/00	2.41	1.14	1.64	1.73
		00/01	2.93	1.18	1.92	2.00
		01/02	2.66	1.16	1.81	1.87
		Mean	2.67	1.16	1.79	1.87
	P_p	99/00	2.55	1.15	1.72	1.81
		00/01	2.83	1.18	1.85	1.95
		01/02	2.74	1.17	1.81	1.91
		Mean	2.71	1.17	1.79	1.89
Sunflower	F_p	99/00	2.77	1.17	1.82	1.92
		00/01	2.72	1.17	1.80	1.90
		01/02	2.80	1.17	1.84	1.94
		Mean	2.76	1.17	1.82	1.92
	V_p	99/00	2.24	1.12	1.58	1.65
		00/01	2.76	1.17	1.82	1.92
		01/02	2.62	1.16	1.76	1.85
		Mean	2.54	1.15	1.72	1.80
	R_p	99/00	2.49	1.14	1.69	1.77
		00/01	3.00	1.19	1.92	2.04
		01/02	2.70	1.17	1.79	1.89
		Mean	2.73	1.17	1.80	1.90
	G_p	99/00	2.33	1.13	1.62	1.69
		00/01	2.93	1.18	1.89	2.00
		01/02	2.65	1.16	1.77	1.86
		Mean	2.64	1.16	1.76	1.85
	P_p	99/00	2.56	1.15	1.72	1.81
		00/01	2.83	1.18	1.85	1.95
		01/02	2.74	1.17	1.81	1.91
		Mean	2.71	1.17	1.79	1.89

* *SbOr* was excluded because *ObOr* will give the similar results (mulch on the runoff area is used for both treatments)

5.3.3 Soil water content and drainage

5.3.3.1 Fallow period

The maize and sunflower cultivars that were used during this experiment were all short growing season cultivars, i.e. ± 120 days from planting to maturity. This implies a fallow period of 7 to 8 months. Conservation of water during this period is essential in semi-arid environments. The water content of the root zones at harvest and planting for each treatment are summarised in Table 5.3. Two aspects are important, *viz*. (i) the rainfall storage efficiency (RSE) during the period; and (ii) plant available water at planting (PAW_p). RSE was calculated according to the method described in Section 2.3.1.11, and summarized in the water use efficiency table (Table 5.7). Mulch treatments did not affect the RSE significantly in any of the years, irrespective of the crops. However, there are large differences in RSE values between years, which reflect climatic differences, especially rainfall distribution patterns, between the fallow seasons. Linear regression between RSE and AI showed that RSE increased with increasing AI values, as described by Equation 5.5:

$$y = 192.2*x - 47.8 \ldots\ldots\ldots\ldots\ldots r^2 = 0.90 \ldots\ldots\ldots\ldots\ldots (5.5)$$

where

y = RSE (%)

x = AI

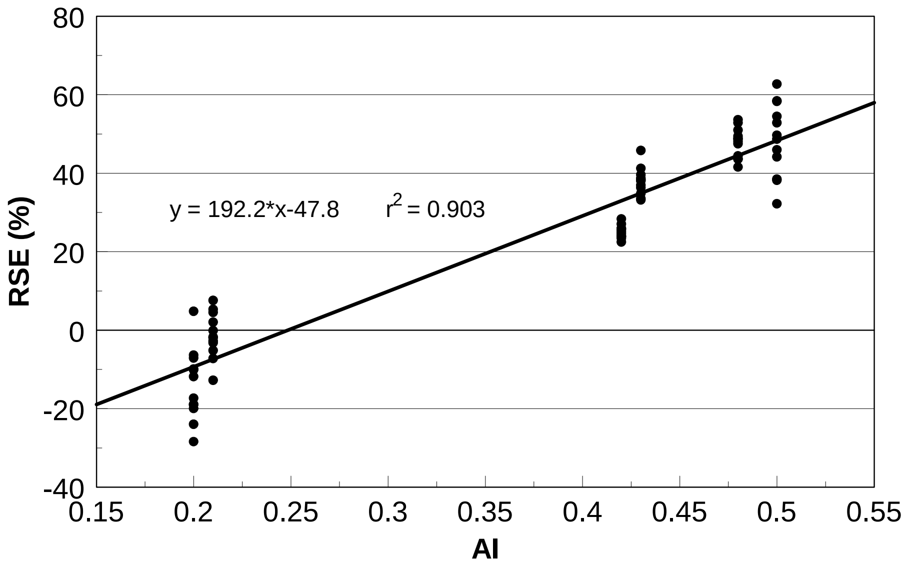

Figure 5.1 Relationship between RSE and AI (n = 72)

The statistical analysis of water content at planting (WC_p) indicates that mulch type did not significantly affect the WC_p during any season, irrespective of crop type. On average, the PAW_p varied between 96 and 155 mm for maize and between 136 and 231 mm for sunflower for different seasons. The PAW_p for a crop is shown to be directly related to the water content at harvest of the previous crop (WC_{pc}), as described by the following equations:

Maize: $y = 5.3106x – 0.0071814x^2 - 825.87$…….……………….$r^2 = 0.86$ ………(5.6)
Sunflower: $y = 2.0794x – 0.0016179x^2 + 353.87$…...…………...$r^2 = 0.96$………..(5.7)

where

y = PAW_p (mm)
x = WC_{pc} (mm)

Both these relationships indicate that pre-plant water advantage (PPWA) increases with an increase in water content at harvesting of the previous crop, but that the advantage declines as WC_{pc} approaches DUL.

Table 5.3 Mean water content (WC, mm) for the root zone (0 – 1200 mm) at various stages during the production period; PAW at planting (PAW_p), and at tasseling/flowering ($PAW_{T/F}$); WC at harvesting of previous crop (WC_{pc})

Crop	Water content (WC, mm)	Season	Treatment				
			ObBr	*ObOr*	*ObSr*	*SbOr*	Mean
Maize	WC_{pc}	99/00	325^{a}	294^{a}	303^{a}	311^{a}	308^{a}
		00/01	288^{a}	288^{a}	286^{a}	292^{a}	289^{a}
		01/02	375^{a}	339^{a}	398^{a}	394^{a}	377^{a}
		Mean	329	307	329	332	324
	WC_p	99/00	400^{a}	381^{a}	391^{a}	406^{a}	395^{a}
		00/01	364^{a}	359^{a}	376^{a}	375^{a}	369^{a}
		01/02	405^{a}	415^{a}	418^{a}	418^{a}	414^{a}
		Mean	390	385	395	400	393
	WC_{CC}	99/00	311^{a}	315^{a}	320^{a}	327^{a}	318^{a}
		00/01	374^{a}	412^{a}	406^{a}	412^{a}	401^{a}
		01/02	310^{a}	331^{a}	327^{a}	327^{a}	324^{a}
		Mean	332	353	351	355	348
	PAW_p	99/00	137^{a}	118^{a}	128^{a}	143^{a}	132^{a}
		00/01	101^{a}	96^{a}	113^{a}	112^{a}	106^{a}
		01/02	142^{a}	152^{a}	155^{a}	155^{a}	151^{a}
		Mean	127	122	132	137	130
	$PAW_{T/F}$	99/00	54^{a}	45^{a}	51^{a}	62^{a}	53^{a}
		00/01	42^{a}	57^{a}	53^{a}	57^{a}	52^{a}
		01/02	64^{a}	78^{a}	73^{a}	101^{a}	79^{a}
		Mean	53	60	59	73	61
Sunflower	WC_{pc}	99/00	313^{a}	328^{a}	330^{a}	338^{a}	328^{a}
		00/01	311^{a}	315^{a}	320^{a}	327^{a}	318^{a}
		01/02	374^{a}	413^{a}	406^{a}	412^{a}	401^{a}
		Mean	333	352	352	358	349
	WC_p	99/00	376^{a}	384^{a}	391^{a}	394^{a}	386^{a}
		00/01	384^{a}	382^{a}	394^{a}	394^{a}	389^{a}
		01/02	450^{a}	464^{a}	471^{a}	463^{a}	462^{a}
		Mean	403	410	419	417	412
	WC_{CC}	99/00	288^{a}	288^{a}	286^{a}	292^{a}	289^{a}
		00/01	375^{a}	399^{a}	398^{a}	394^{a}	392^{a}
		01/02	317^{a}	327^{a}	330^{a}	330^{a}	326^{a}
		Mean	327	338	338	331	334
	PAW_p	99/00	136^{a}	144^{a}	151^{a}	154^{a}	146^{a}
		00/01	144^{a}	142^{a}	154^{a}	154^{a}	149^{a}
		01/02	210^{a}	224^{a}	231^{a}	223^{a}	222^{a}
		Mean	163	170	179	177	172
	$PAW_{T/F}$	99/00	66^{a}	70^{a}	70^{a}	70^{a}	69^{a}
		00/01	32^{a}	29^{a}	31^{a}	37^{a}	32^{a}
		01/02	65^{a}	88^{a}	63^{a}	67^{a}	71^{a}
		Mean	54	62	55	58	57

Different superscripts within a row refer to statistically significant differences at P = 0.05; similar letters are not statistically different.

5.3.3.2 Growing season

Maize – vegetative period

The changes in soil water contents during the growing season of maize are presented in Figures 5.2, 5.3 and 5.4 for the 99/00, 00/01 and 01/02 seasons, respectively. The water management borders, *viz*. the crop modified upper limit (CMUL), drained upper limit (DUL) and the lower limit (LL) of plant available water (PAW) are also included in the graphs. Comparing the vegetative periods of the three seasons revealed that the 01/02 season has a considerably higher PAW_p compared to the other two seasons. The AI is also the highest, 0.46 in comparison to the 0.27 and 0.18 for the 99/00 and 00/01 seasons, respectively (Table 5.1). The worst climatic conditions were associated with the V_p of the 00/01 season, with only 82 mm of rain and a cumulative Eo of 465 mm. However, according to the soil water content trends (Figure 5.3), the plants did not experience any serious water stress. In fact, Table 5.3 indicates that the maize from the 00/01 season still had between 42 and 57 mm plant available water at the beginning of tasseling. There are no clear trends in the water content patterns of the different treatments during the vegetative period, except that *ObBr* had the lowest water content during the last two seasons. According to the DUL and CMUL limits, no significant drainage could have occurred during any of the seasons during the vegetative period.

Maize – reproductive period

As is often the case in a semi-arid environment, climatic conditions can change dramatically in a short time. For example, during the 00/01 season there was a change from bad during the V_p/R_p transition period (days of year 60 to 80 – Figure 5.3) to very favourable in the R_p after day of year (DOY) 80. The crop received 199 mm of rain during R_p, while the corresponding Eo amounted to only 290 mm. This caused the root zone water content of all the treatments to rise sharply in response (Figure 5.2). The water content of the *ObBr* treatment remained significantly lower than other treatments during the last two seasons. Climatic conditions became unfavourable towards the end of the 01/02 season. The water content declined to close to the LL limit, before rain recharged the profile at the end of the period (Figure 5.3). The *ObBr* treatment showed the lowest water content during this period, but the difference between treatments was not significant at tasseling. Comparing the water content trends of the 99/00 season, the *ObBr* treatment fluctuates between the *SbOr* and *ObOr* treatments. The water content was relatively constant until DOY 118, when a series of four rain events boosted the soil water content. A characteristic of this period is the high frequency of small rain events, i.e. 34 events compared to the 15 of the 01/02 season (Appendix 5.2). As can be seen from the DUL and CMUL limits of 456 mm and 485 mm, respectively, the water content was never close to the limit at which drainage would occur during any of the seasons.

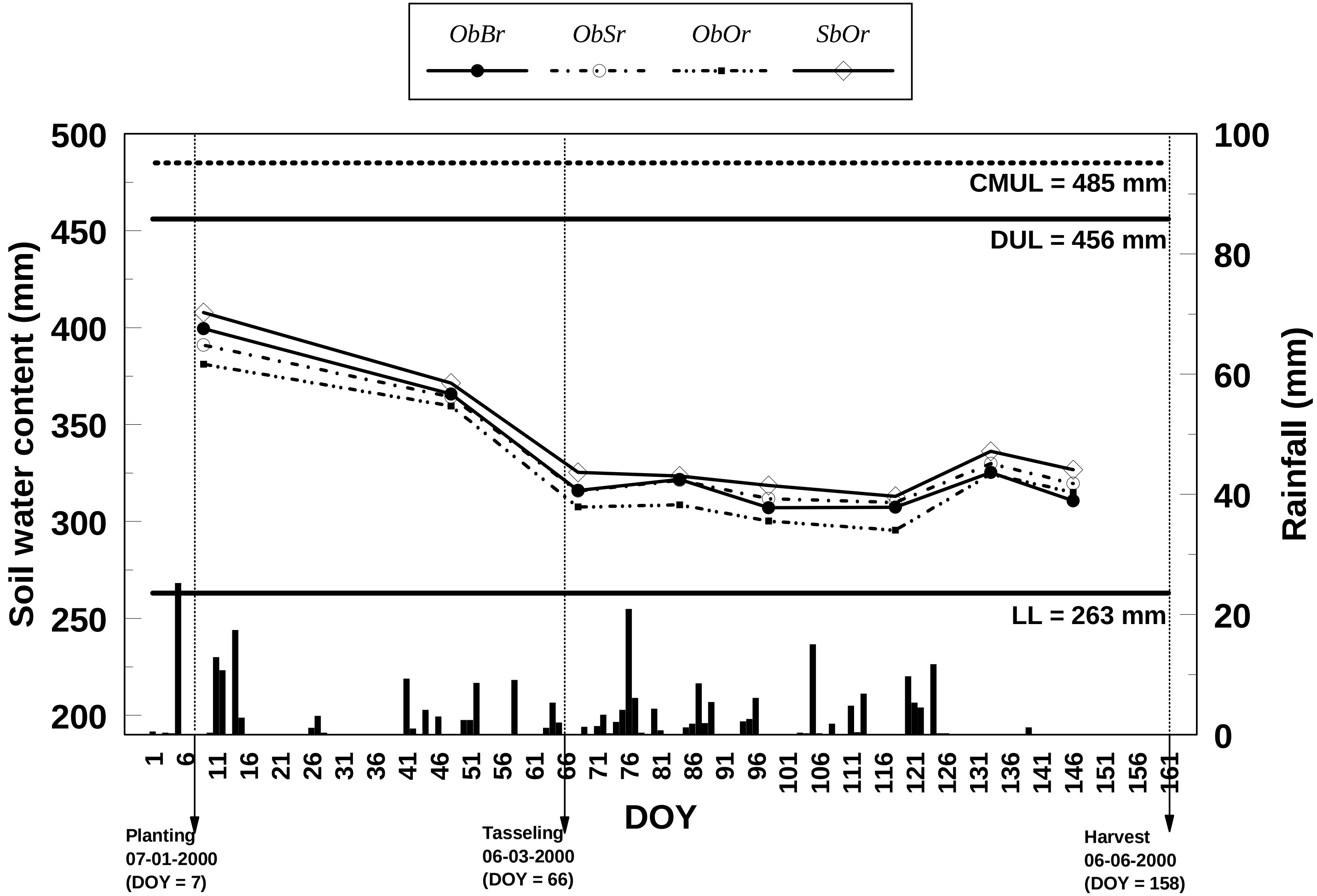

Figure 5.2 Changes in the soil water content of the maize root zone (0 – 1200 mm) during the 99/00 season; Glen/Bonheim ecotope

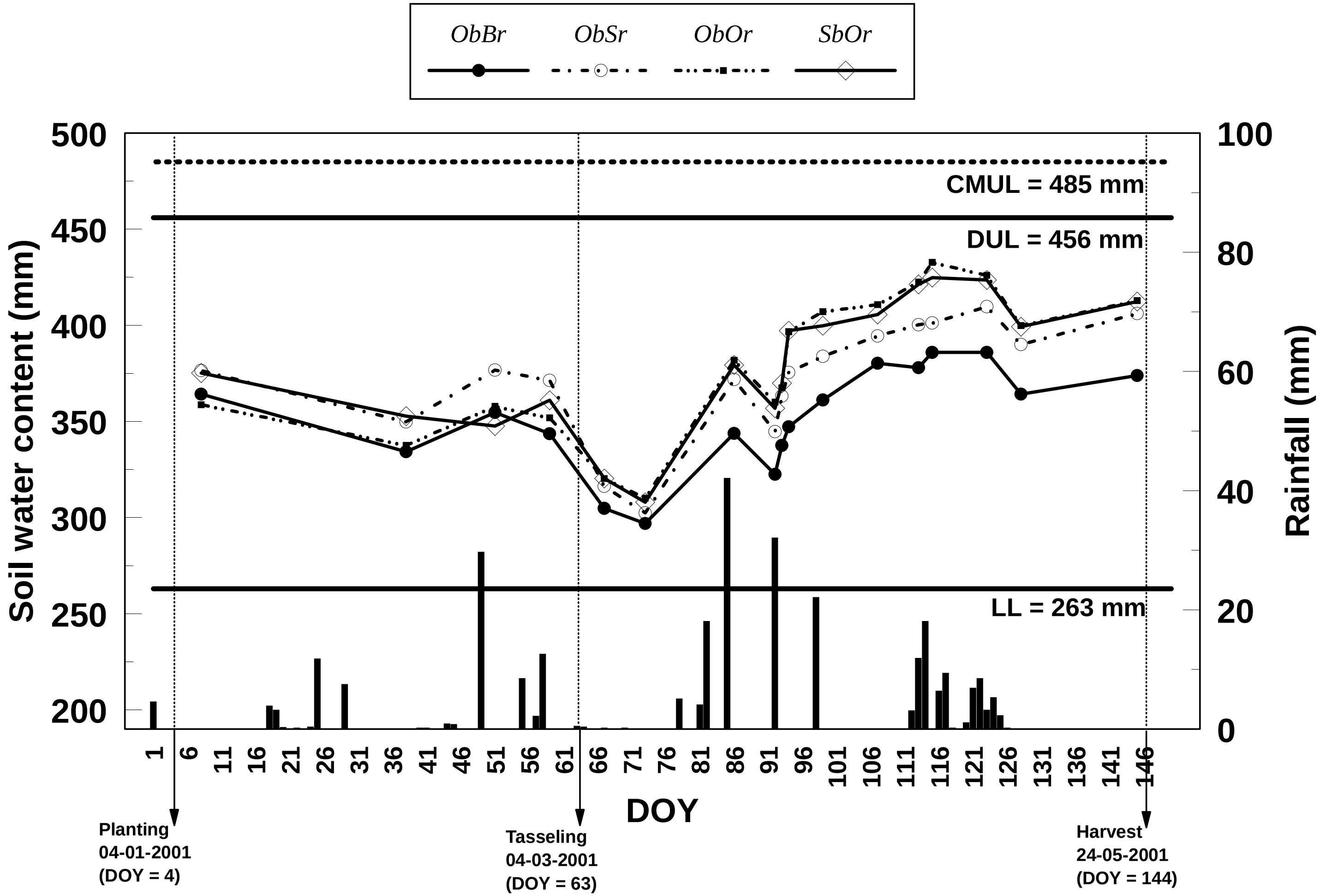

Figure 5.3 Changes in the soil water content of the maize root zone (0 – 1200 mm) during the 00/01 season; Glen/Bonheim ecotope

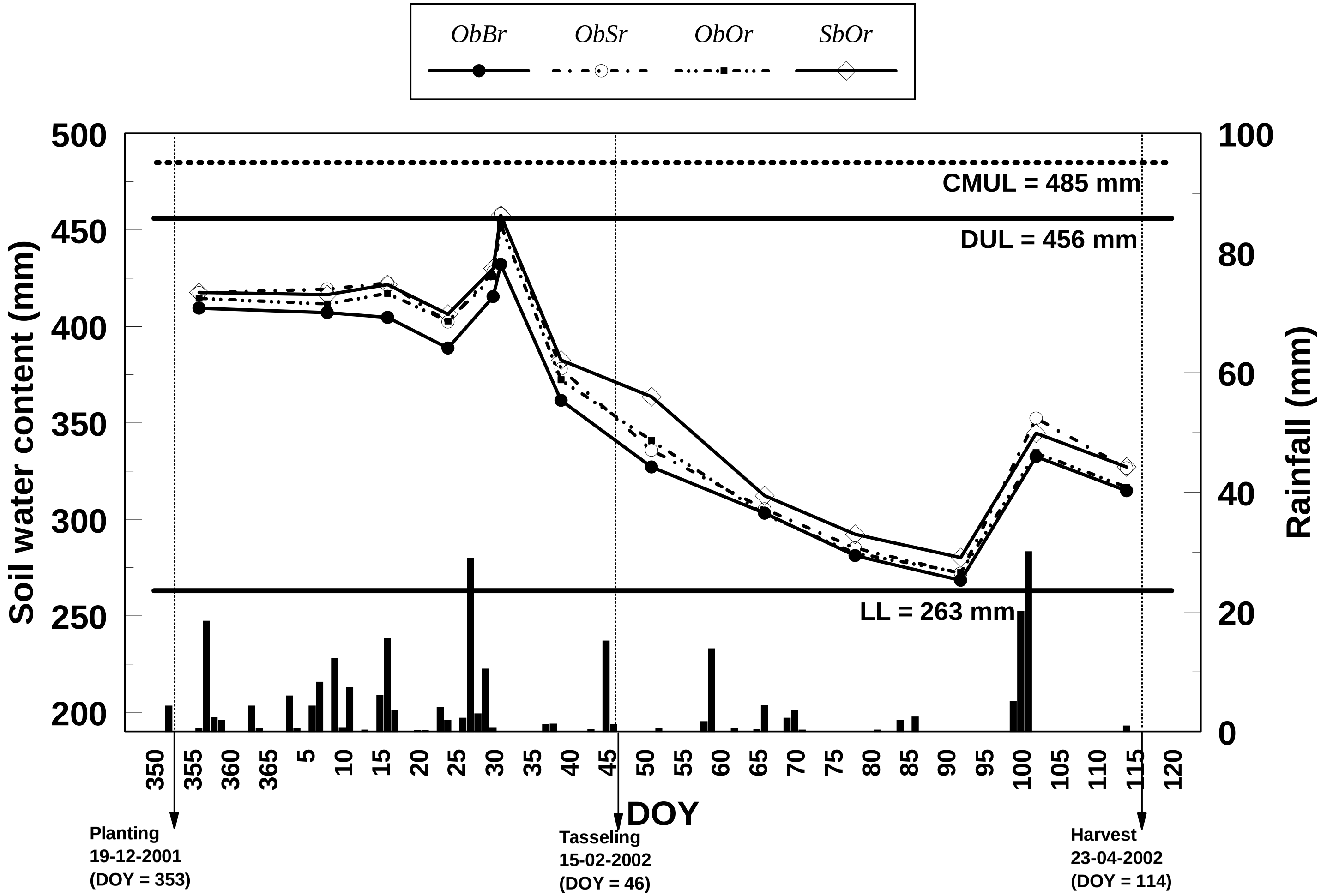

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Figure 5.4 Changes in the soil water content of the maize root zone (0 – 1200 mm) during the 01/02 season; Glen/Bonheim ecotope

Sunflower - vegetative period

The soil water content pattern is depicted for the various treatments in Figures 5.5, 5.6 and 5.7 for the 99/00, 00/01 and 01/02 seasons, respectively. Comparing the climatic conditions of the V_p, using the corresponding AI values, reveals that the most favourable crop production conditions occurred during the 01/02 season (AI = 0.42), followed by the 99/00 (AI = 0.32) and the 00/01 season (AI = 0.32). The water contents at flowering were considerably lower than at planting for all treatments and seasons (Table 5.3). This indicates that rainfall was not sufficient to maintain the crop water demand, and the crop had to rely on the soil to supply the water deficit. Fortunately, the water supply by rain and soil water together was enough in all the seasons to protect the crop from severe water stress. This is clearly shown by water content patterns (Figures 5.5, 5.6 and 5.7), which were always above LL. Except for the *ObBr* treatment, which had the lowest water content values during the 99/00 and 01/02 seasons, there was no consistent trend in the soil water patterns of the other treatments during the three seasons. At the beginning of the 01/02 season the water content of some of the treatments was slightly higher than DUL but not higher than CMUL. Hence, it was estimated that drainage was insignificantly low during this period.

Sunflower – reproductive period

Due to unfavourable conditions during the R_p of the 99/00 and 01/02 seasons, the crop depended heavily on stored water in the profile to maintain the crop water demand. In both cases almost 80 % of the total available water had been extracted towards the end of the growing season (Figures 5.5 and 5.7). There was no clear differentiation in the water content trends between the treatments in any of the seasons. Sunflower planted in the 00/01 season experienced an exceptionally good season, with 19 rainfall events providing 198 mm compared to a very low corresponding Eo of 216 mm (Appendix 5.2). It can be confidently stated that no deep drainage occurred during the R_p in any season. The change in water content for each measuring event is available in Appendix 5.4 as part of the water balance statement.

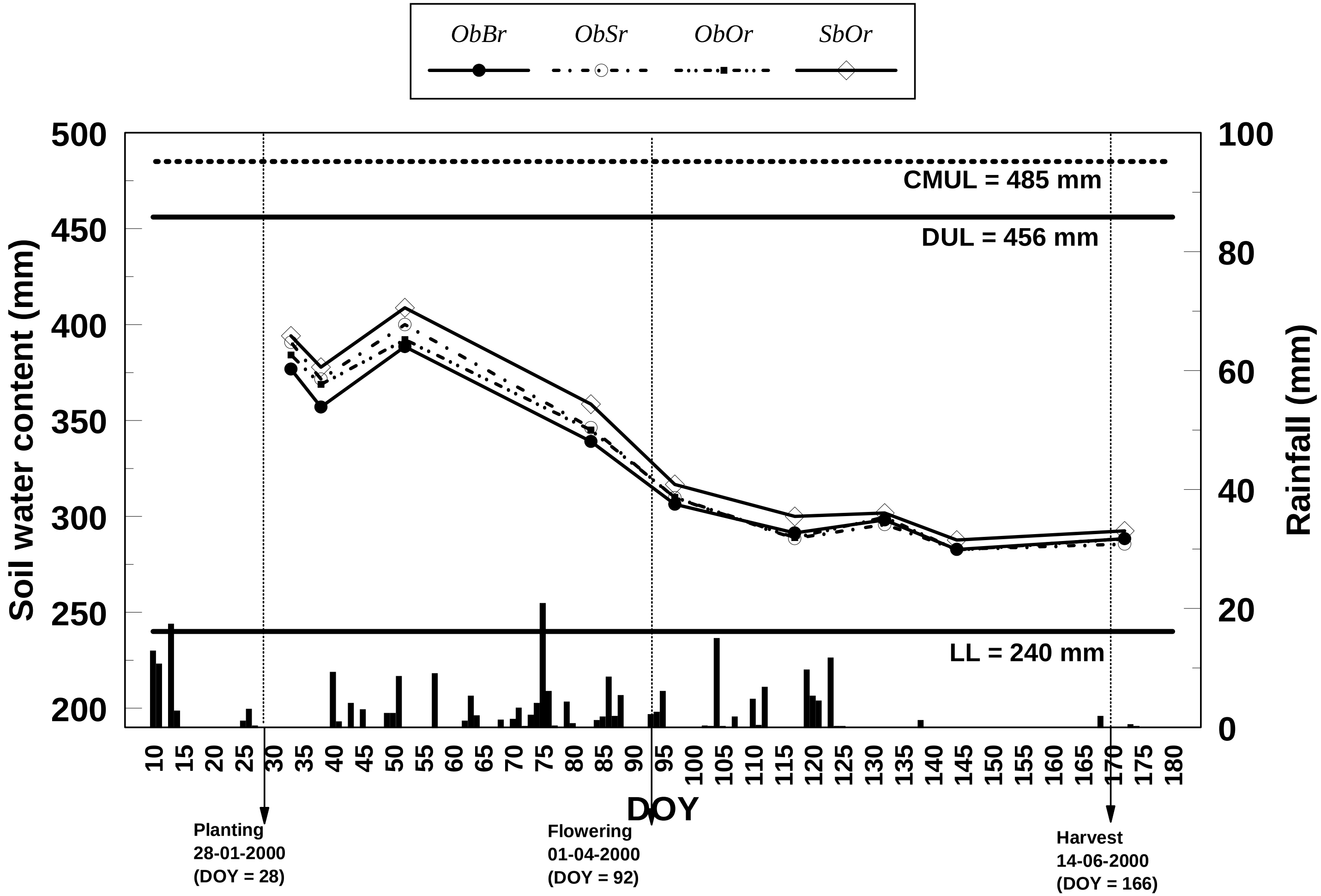

Figure 5.5 Changes in the soil water content of the sunflower root zone (0 – 1200 mm) during the 99/00 season; Glen/Bonheim ecotope

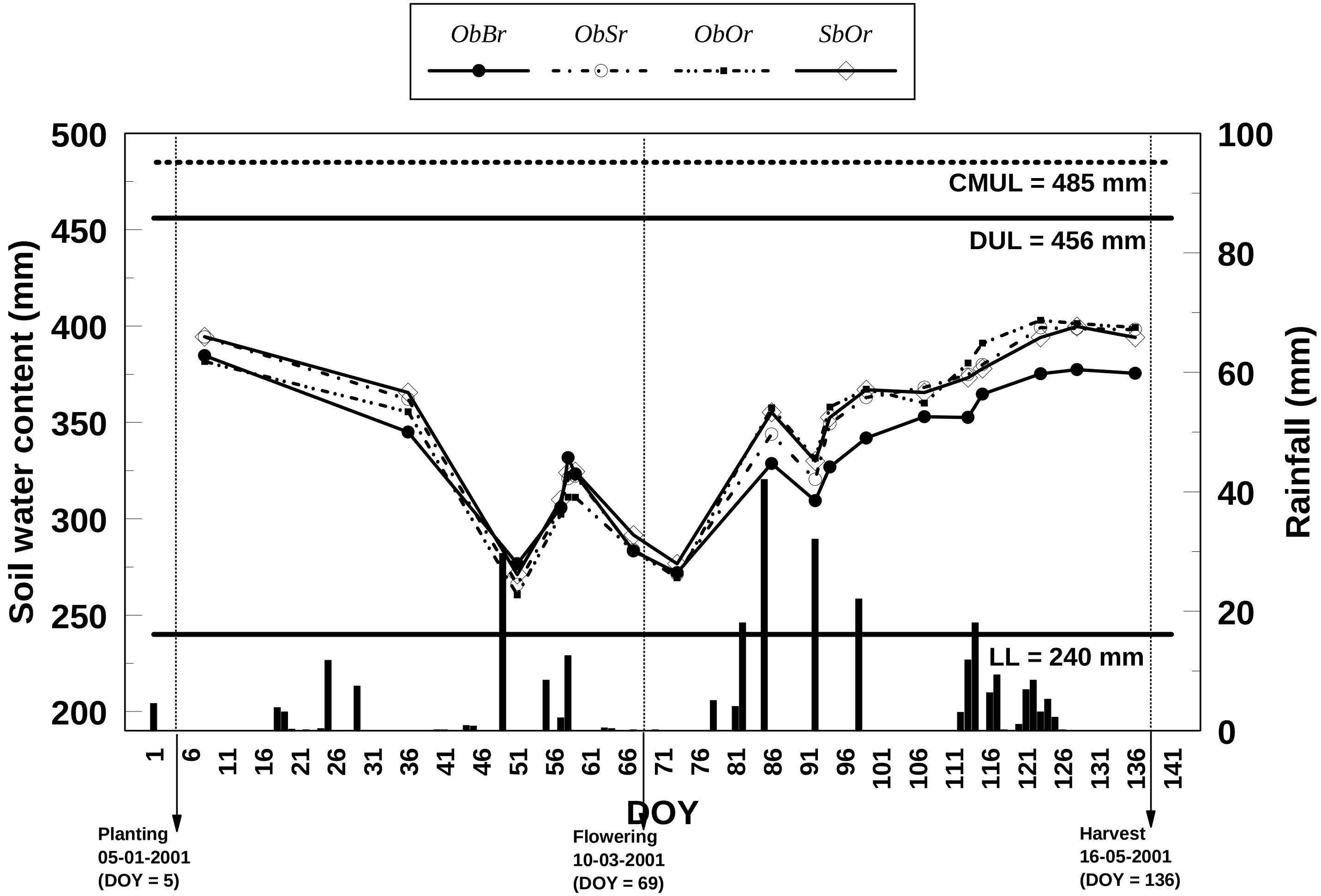

Figure 5.6 Changes in the soil water content of the sunflower root zone (0 – 1200 mm) during the 00/01 season; Glen/Bonheim ecotope

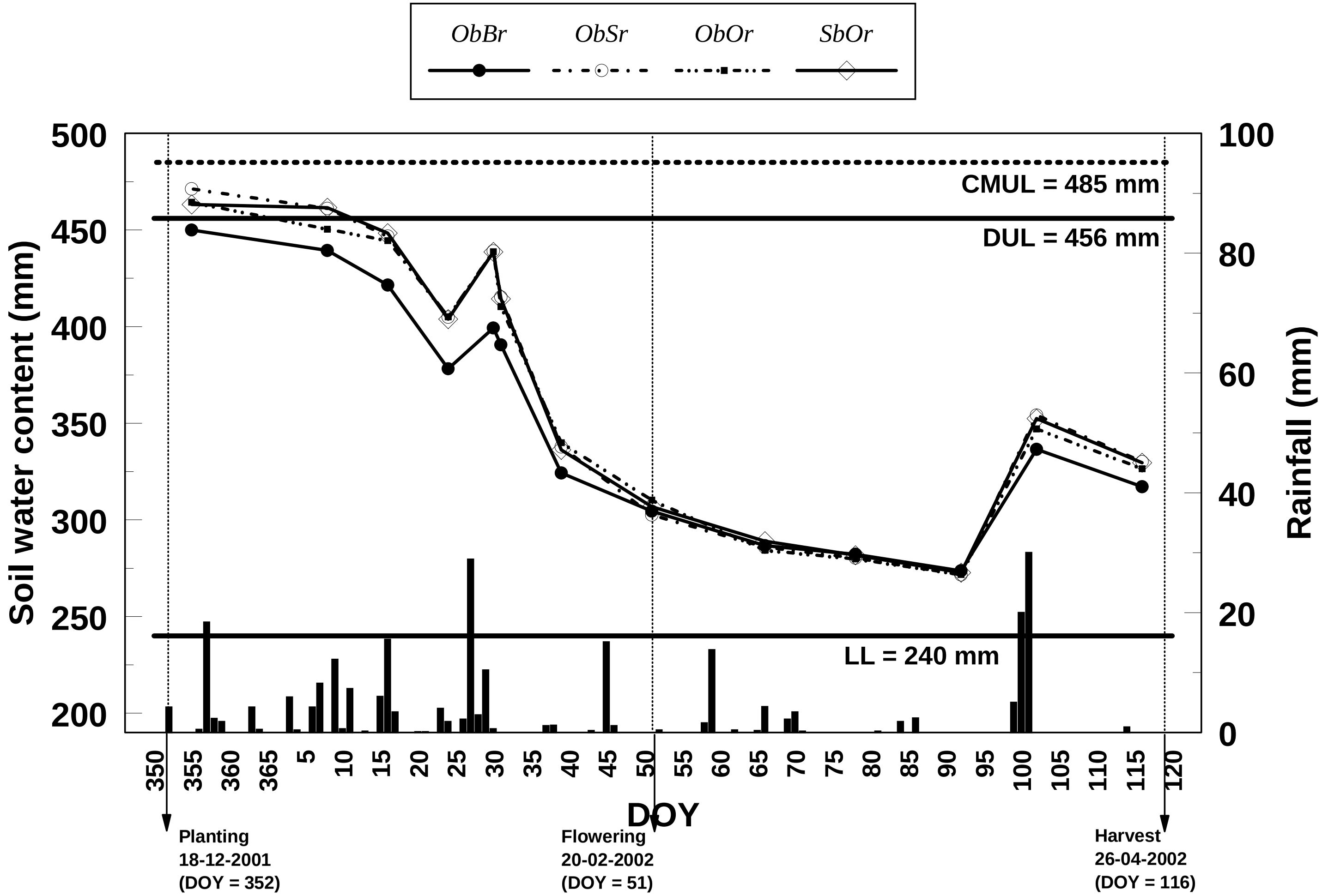

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Figure 5.7 Changes in the soil water content of the sunflower root zone (0 – 1200 mm) during the 01/02 season; Glen/Bonheim ecotope

5.3.4 Evaporation and evapotranspiration

5.3.4.1 Fallow period

From the discussion in Section 5.3.3.1 it is clear that treatments with mulch on the runoff area are not consistently able to conserve more water than the *ObBr* treatment during the fallow season. RSE is shown to depend heavily on AI of the particular season, while PAW_p depended on the water content at harvesting of the previous crop. The cumulative evaporation from the soil (ΣEs) for the fallow period varied between 62 and 345 mm, depending on the season (Table 5.4). The low values for the 99/00 season are due to the relatively short fallow period in comparison to the other seasons. When the 99/00 season is excluded from the estimations, a very strong linear relationship was obtained between AI and ΣEs for the combined data set of the 00/01 and 01/02 seasons, irrespective of crop type:

$$y = 9.44 + 726x \quad r^2 = 0.96 \qquad (5.8)$$

where

y = cumulative evaporation from the soil during the fallow period (ΣEs mm)

x = aridity index for the fallow period (AI_f)

The cumulative rain of the fallow period (P_f) correlated strongly with the corresponding evaporation from the soil surface (ΣEs), irrespective of season or crop type:

$$y = -116.5 + 1.20x \quad r^2 = 0.98 \qquad (5.9)$$

where

y = cumulative evaporation from the soil during the fallow period (ΣEs mm)

x = precipitation during the fallow period (P_f)

Equation 5.9 predicts that evaporation will increase as rainfall increases. Estimates with these equations showed that 46 % of the rainfall evaporates under low rainfall conditions and as much as 88 % can evaporate under high rainfall conditions during the fallow period, irrespective of mulch combinations. This is probably due to the length of the drying cycles after each rainfall event.

5.3.4.2 Growing period

Maize: Evapotranspiration (ET) was estimated with the water balance equation as described in Section 2.3. ET was then separated into its components, *viz.* evaporation from the soil (Es) and transpiration (Ev), using the method described in Section 2.3.1.12. These components are summarised in Table 5.4 for all the treatments. The ET of maize varied between 226 and 343 mm during the three seasons. The *ObBr* treatment produced the highest ET in all seasons, while *ObOr* had the lowest. This result was statistically significant in the 01/02 season. The ET values for the *ObSr* and *SbOr* treatments are very similar.

Table 5.4 Cumulative evaporation (Es) and transpiration (Ev) for the fallow period (F_p) and growing period (G_p) for the three seasons as influenced by mulching; Glen/Bonheim ecotope.

Crop	Period	Parameter	Season	Treatment				
				ObBr	*ObOr*	*ObSr*	*SbOr*	Mean
Maize	F_p	Es	99/00	82^{a}	70^{a}	69^{a}	62^{a}	71
			00/01	158^{a}	163^{a}	143^{a}	151^{a}	154
			01/02	330^{a}	345^{a}	341^{a}	316^{a}	333
			Mean	190	193	184	176	186
	G_p	Ev	99/00	84^{a}	82^{a}	88^{a}	80^{a}	84
			00/01	99^{a}	115^{b}	123^{b}	113^{b}	113
			01/02	113^{a}	123^{a}	121^{a}	116^{a}	118
			Mean	99	107	111	103	105
		Es	99/00	233^{a}	212^{a}	212^{a}	228^{a}	221
			00/01	171^{b}	111^{b}	127^{ba}	130^{ba}	135
			01/02	230^{a}	208^{b}	217^{ba}	222^{ba}	219
			Mean	211	177	185	193	192
		ET	99/00	317^{a}	294^{a}	300^{a}	308^{a}	305
			00/01	270^{a}	226^{a}	250^{a}	243^{ba}	247
			01/02	343^{b}	331^{a}	338^{ab}	338^{ab}	338
			Mean	310	284	296	296	297
Sunflower	F_p	Es	99/00	141^{a}	148^{a}	144^{a}	149^{a}	146
			00/01	158^{a}	166^{a}	158^{a}	165^{a}	162
			01/02	284^{a}	308^{a}	295^{a}	309^{a}	299
			Mean	194	207	199	208	202
	G_p	Ev	99/00	144^{a}	170^{a}	172^{a}	182^{a}	167
			00/01	153^{a}	158^{a}	166^{a}	173^{a}	163
			01/02	170^{a}	182^{a}	188^{a}	181^{a}	180
			Mean	156	170	175	179	170
		Es	99/00	124^{a}	105^{a}	112^{a}	99a	110
			00/01	136^{a}	105^{a}	110^{a}	108^{a}	115
			01/02	211^{a}	204^{a}	202^{a}	201^{a}	205
			Mean	157	138	141	136	143
		ET	99/00	268^{b}	275^{ab}	284^{a}	281^{ab}	277
			00/01	279^{b}	263^{a}	276^{ab}	281^{ab}	275
			01/02	381^{a}	386^{a}	390^{a}	382^{a}	385
			Mean	313	308	317	315	313

Different superscripts within a row refer to statistically significant differences at P = 0.05; values with similar letters are not statistically different.

Comparing the mean ET from *ObOr* and *ObSr* with that obtained from *ObBr* reveals that stone on the runoff strip induced a 5 and 8 % lower ET than the bare and organic mulch treatments, respectively. The mean Es values during the G_p indicate that stone and organic mulch on the runoff strip conserved 12 and 16 % more water respectively, than to the *ObBr* treatment through the suppression of Es. Water conserved this way was available for transpiration as indicated by the 8 and 12 % increase in mean Ev of the *ObOr* and *ObSr* treatments, respectively, in comparison with the *ObBr* treatment.

Sunflower: The ET results were statistically inconsistent over the seasons. The *ObBr* treatment was significantly lower than *ObSr* during the 99/00 season, but in the 00/01 season it was significantly higher. This is difficult to explain. For the 01/02 season *ObBr* again had a lower ET than *ObSr*, but this time not statistically significant. Comparing the mean ET values for organic mulch (*ObOr*) and stones (*ObSr*) on the runoff area, relative to bare (*ObBr*), reveals small differences; *ObSr* having 1 % higher and *ObOr* 2 % lower ET than *ObBr*, respectively. Inspection of the mean Es values of the same treatments, showed that *ObSr* and *ObOr* reduced Es by 10 and 12 %, respectively , compared to *ObBr*. Apparently, water conserved this way led to 9 and 12 % increases, respectively, in transpiration (Ev) in comparison to the *ObBr* treatment. The results showed that *ObBr* produced the highest Es and lowest Ev for all the seasons.

5.3.4.3 Production period

Cumulative soil surface evaporative losses during the production period are summarized in Table 5.5 for maize and sunflower and compared to rainfall. The 99/00 season was excluded from these results due to its short fallow period, which affects the annual Es. Evaporation was expressed as a percentage of the rainfall over the same period.

Table 5.5 The relationship between cumulative evaporation and rainfall for the production period (fallow + growing season) for the different treatments during two seasons; Glen/Bonheim ecotope.

Crop	Season	Parameter	Treatment				
			ObBr	*ObOr*	*ObSr*	*SbOr*	Average
Maize	00/01	Es (mm)	329	274	270	281	289
	01/02	Es (mm)	560	553	558	538	552
	mean	Es (mm)	444	413	414	410	421
	mean	P (mm)	560	560	560	560	560
		Es/P (%)	79	74	74	73	75
Sunflower	00/01	Es (mm)	294	271	268	273	277
	01/02	Es (mm)	495	512	497	510	504
	mean	Es (mm)	395	392	383	392	391
	mean	P (mm)	560	560	560	560	560
		Es/P (%)	71	70	68	70	69

These results show that the evaporation process dominates over all the other water processes. Water loss through evaporation is shown to amount to 75 % of the annual rainfall for maize and 69 % for sunflower over the two production periods tested. Mulch placement on the runoff area reduced evaporation by 5 – 6 % for maize and 1 - 3 % for sunflower. Assuming that the methodology of separating Es and Ev is correct, this result clearly indicates that evaporation remains the most important process to be studied in the quest for maximizing precipitation use efficiency. An interesting possibility is the introduction of plastic on the runoff area, or a 100 % stone or gravel mulch. If the evaporation could be reduced by a further 25 %, yields could be doubled. Attention should be given to the socio-economic and agronomic aspects of artificial mulch options.

5.4 YIELD RESPONSE

Grain and biomass yields as affected by mulch treatments are summarised in Table 5.6 for maize and sunflower. The harvest index (HI) is also included in the table.

5.4.1 Maize

Seed yields varied between 2543 and 3962 kg ha^{-1} over the three years. A very strong yield trend was established in each of the three seasons, *viz. ObSr* >*ObOr* > *SbOr* > *ObBr*.

Table 5.6 Seed yield, biomass and harvest index for maize and sunflower as affected by mulch treatments during the three seasons.

Crop	Parameter	Season	Treatment				
			ObBr	*ObOr*	*ObSr*	*SbOr*	Mean
Maize	Seed (kg ha^{-1})	99/00	3455^{b}	3519^{b}	3962^{a}	3500^{b}	3609
		00/01	2543^{a}	2908^{b}	3098^{b}	2731^{a}	2820
		01/02	3281^{a}	3325^{a}	3607^{a}	3288^{a}	3375
		Mean	3093	3251	3556	3173	3268
	Biomass (kg ha^{-1})	99/00	7565^{a}	7408^{a}	7911^{a}	7186^{a}	7518
		00/01	6505^{b}	7606^{a}	8143^{a}	7427^{c}	7420
		01/02	7273^{a}	7916^{a}	7797^{a}	7460^{a}	7612
		Mean	7114	7643	7950	7358	7516
	Harvest index	99/00	0.46^{a}	0.48^{a}	0.50^{a}	0.49^{a}	0.48
		00/01	0.39^{a}	0.38^{a}	0.38^{a}	0.37^{a}	0.38
		01/02	0.45^{a}	0.42^{a}	0.46^{a}	0.44^{a}	0.44
		Mean	0.43	0.43	0.45	0.43	0.44
Sunflower	Seed (kg ha^{-1})	99/00	1879^{a}	2190^{a}	2346^{b}	2251^{a}	2167
		00/01	1716^{a}	1971^{b}	2138^{c}	1882^{b}	1927
		01/02	2340^{a}	2519^{b}	2704^{c}	2622^{b}	2546
		Mean	1978	2227	2396	2252	2213
	Biomass (kg ha^{-1})	99/00	6089^{a}	7148^{a}	7245^{a}	7686^{a}	7042
		00/01	4672^{a}	4804^{a}	5045^{a}	5283^{a}	4951
		01/02	5184^{a}	5560^{a}	5736^{a}	5543^{a}	5506
		Mean	5315	5837	6009	6171	5833
	Harvest index	99/00	0.31^{a}	0.31^{a}	0.33^{a}	0.30^{a}	0.31
		00/01	0.37^{a}	0.42^{a}	0.43^{a}	0.36^{a}	0.40
		01/02	0.46^{a}	0.45^{a}	0.48^{a}	0.48^{a}	0.47
		Mean	0.38	0.39	0.41	0.38	0.39

Different superscripts within a row refer to statistically significant differences at P = 0.05; values with similar letters are not statistically different.

The mean yields indicate that *SbOr*, *ObOr* and *ObSr* produced 3, 5 and 15 % more seed, respectively, than *ObBr*. The 15 % increase was statistically significant in two of the three years. Biomass yield varied between 6505 and 8143 kg ha^{-1}, but did not support the trend found with seed yield. In fact, the statistical results revealed no significant difference between the mulch treatments over all the seasons. The harvest index varied between 0.37 and 0.50 during the three seasons. Values for the 00/01 season were lower than the other years, but can still be considered high for dryland maize. These values indicate that water supply in the vegetative period was sufficient to meet the crop water demand, hence no severe water stress occurred.

5.4.2 Sunflower

The seed yield trend as projected by the mean of the experiment is almost the same as for maize except that *ObOr* and *SbOr* change positions, *viz*. *ObSr* > *SbOr* > *ObOr* > *ObBr*. The *ObSr* treatment was in two of the three years significantly higher than the *ObBr* treatment. Seed yields varied between 1716 and 2704 kg ha^{-1} over the three seasons. Organic (*ObOr*) and stone (*ObSr*) mulch on the runoff area increased the yield by 13 and 21 %, respectively in comparison with the bare surface (*ObBr*). Biomass yield did not respond in the same way as grain yield, excepting that *ObBr* produced the lowest yields in all the years. Biomass yields varied from 4672 to 7686 kg ha^{-1}, without any significant difference between treatments in any of the seasons. The harvest index varied between 0.3 and 0.48 over the three seasons and the index of the 99/00 season was lower than the other two seasons. The lower harvest index is probably due to the replanting of the crop during the last week in January, which probably restricted the reproductive growth period.

5.5 WATER USE EFFICIENCY

Apart from the rainfall storage efficiency (RSE), which was discussed in Section 2.3.1.11, four other forms of water use efficiencies for maize and sunflower are summarised in Table 5.7. Estimations of these efficiencies are based on the methodology described in Sections 2.3.2.6. and 2.3.2.7.

5.5.1 Water use efficiency based on ET (WUE_{ET})

This is probably the most popular form of water use efficiency, especially for irrigation purposes. Water use efficiency is expressed as seed yield (Y = kg seed ha^{-1}) per unit evapotranspiration (ET, mm) (Bennie *et al*., 1988; Van Rensburg, 1996; Bennie *et al*., 2000).

$$WUE_{ET} = Y/ET \quad (5.10)$$

The results indicate that the WUE_{ET} varied between 9.4 and 13.2 kg seed ha^{-1} mm^{-1} during the three seasons for maize and between 5.9 and 8.2 kg grain ha^{-1} mm^{-1} for sunflower. A common efficiency trend was observed, *viz*. *ObSr* >*ObOr* >*SbOr* > *ObBr*, during all the seasons for both the crops. *ObBr* was significantly lower than *ObSr* for most of the seasons for both crops. The mean WUE_{ET} of maize indicates that *ObSr*, *ObOr* and *SbOr* are 23, 15 and 8 % more efficient in converting water into grain yield than *ObBr*, respectively. For sunflower it was 21, 17 and 14 %, respectively.

Table 5.7 Various water use efficiencies for maize and sunflower as affected by mulch treatments during the three seasons: Glen/Bonheim ecotope.

Crop	WUE indicators	Season	Treatment				
			ObBr	*ObOr*	*ObSr*	*SbOr*	Mean
Maize	RSE (%)	99/00	57^{a}	42^{a}	46^{a}	51^{a}	49
		00/01	-4^{a}	-23^{b}	-13^{ab}	-15^{ab}	-14
		01/02	26^{a}	51^{a}	25^{a}	25^{a}	32
		Mean	26	23	19	20	22
	PUE_{fg} (kg ha^{-1} mm^{-1})	99/00	8.7^{a}	9.7^{a}	10.8^{a}	9.5^{a}	9.7
		00/01	5.9^{a}	7.5^{bc}	7.9^{c}	6.9^{b}	7.1
		01/02	4.9^{a}	4.9^{a}	5.3^{a}	4.9^{a}	5.0
		Mean	6.5	7.4	8.0	7.1	7.3
	PUE_{a} (kg ha^{-1} mm^{-1})	99/00	9.0^{a}	9.1^{a}	10.3^{a}	9.1^{a}	9.4
		00/01	5.0^{a}	5.7^{bc}	6.0^{c}	5.3^{b}	5.5
		01/02	5.4^{c}	5.5^{a}	5.9^{a}	5.4^{a}	5.6
		Mean	6.5	6.7	7.4	6.6	6.8
	WUE_{ET}	99/00	10.9^{b}	12.0^{ab}	13.2^{a}	14.4^{b}	12.0
		00/01	9.4^{a}	12.4^{bc}	12.9^{b}	11.2^{ac}	11.5
		01/02	9.6^{a}	10.0^{ab}	10.7^{b}	9.7^{ab}	10.0
		Mean	10.0	11.5	12.3	10.8	11.2
Sunflower	RSE (%)	99/00	43^{a}	47^{ab}	51^{b}	50^{ab}	48
		00/01	4^{a}	-8^{b}	-2^{ab}	0^{ab}	-2.0
		01/02	37^{a}	38^{a}	39^{a}	37^{a}	38
		Mean	28	26	29	29	28
	PUE_{fg} (kg ha^{-1} mm^{-1})	99/00	4.6^{a}	5.2^{a}	5.5^{a}	5.2^{a}	5.1
		00/01	3.8^{a}	4.6^{bc}	4.9^{c}	4.2^{ab}	4.4
		01/02	3.5^{a}	3.6^{a}	4.0^{b}	3.8^{ab}	3.7
		Mean	4.0	4.5	4.8	4.4	4.4
	PUE_{a} (kg ha^{-1} mm^{-1})	99/00	4.9^{a}	5.7^{a}	6.1^{a}	5.9^{a}	5.7
		00/01	3.4^{a}	3.8^{bc}	4.2^{c}	3.7^{ab}	3.8
		01/02	4.0^{a}	4.1^{ab}	4.7^{b}	4.3^{a}	4.3
		Mean	4.1	4.5	5.0	4.6	4.6
	WUE_{ET}	99/00	7.0^{a}	8.0^{a}	8.2^{a}	8.0^{a}	7.8
		00/01	5.9^{a}	7.8^{c}	7.7^{c}	6.7^{b}	7.0
		01/02	6.1^{a}	6.5^{b}	6.9^{ab}	6.9^{b}	6.6
		Mean	6.3	7.4	7.6	7.2	7.1

Different superscripts within a row refer to statistically significant differences at P = 0.05; values with similar letters are not statistically different

5.5.2 Precipitation use efficiency based on annual rainfall (PUE_a)

This is probably the simplest way of expressing the efficiency of converting rainwater into food. It is based on the simple principle that the system that produced the highest yield per unit area represents the best practice. The assumption is made that water conserved by restricting losses, although not directly measured, will be reflected in the higher yield obtained. For maize the efficiency varied between 5.0 and 10.3 kg seed ha^{-1} mm^{-1} rain during the three seasons. A common trend of *ObSr* > *ObOr* > *SbOr* > *ObBr* was observed during the experimental period. The mean efficiency indicated that *ObSr*, *ObOr* and *SbOr* are 14, 3 and

2 % more efficient in converting rainwater into seed than the *ObBr* treatment, respectively. *ObSr* was for most of the seasons significantly better than the *ObBr*. The same trend was observed for sunflower except that *SbOr* is slightly better than *ObOr*. *ObSr* was significantly better than *ObBr* during the 00/01 and 01/02 season. The values varied between 3.4 and 6.1 kg seed ha^{-1} mm^{-1} rain.

5.5.3 Precipitation use efficiency based on the complete water balance (PUE_{fg})

This indicator makes use of the water balance to predict the water losses by making use of intensive soil water measurements through the fallow and growing period of the crop. For maize the efficiencies varied between 4.9 and 10.8 kg seed ha^{-1} mm^{-1}. A common trend of *ObSr* > *ObOr* > *SbOr* > *ObBr* was observed for maize and sunflower. *ObSr* was significantly better than *ObBr* during the 00/01 and 01/02 seasons for sunflower.

5.6 DISCUSSION

The infiltration ratio estimated for the growing season (Section 5.3.2) was correlated using a third order polynomial function with corresponding relative seed yield of maize and sunflower, irrespective of season. Yields were expressed as a fraction of the maximum yield obtained per season. The corresponding curve (Equation 5.10) is presented in Figure 5.8. It indicates a sharp increase in yield as the infiltration ratio increases from 1 to 1.7, whereafter it decreases sharply towards 3. Infiltration ratios between 2.4 and 3 are associated with the *ObBr* treatments, indicating good conditions for water harvesting in the basins.

$$Y_{rel} = -0.0004788 + 1.3842506x - 0.5953291x^2 + 0.07436617x^3 \quad \text{....(5.11)}$$

Where:

Y_{rel} = relative crop yield

x = infiltration ratio BA:RA

Despite the good water harvesting characteristics of the *ObBr* treatment, as reflected by the infiltration ratio that varied between 2.6 and 3, lower relative yields (0.8 – 0.9) were obtained. Lower yields can be attributed directly to water loss through evaporation from the runoff area due to shallow infiltration depths. Hoffman (1997) determined that the top 0 – 100 mm of the profile is the most “active” zone in supplying water to the atmosphere through the evaporation process. The drying cycle of this layer is very short in semi-arid conditions. Consequently, the depths of infiltration need to be greater than 100 mm in order to contribute directly towards transpiration and hence yield. Hensley *et al.* (2000) determined that the total extractable soil water (TESW) for the topsoil (300 mm) varies between 30 and 42 mm depending on the crop type. From this data the average TESW was calculated to be 35 mm or 11.7 mm per 100 mm, suggesting that rain events greater than 12 mm will contribute directly to transpiration. Estimations with Equation 5.3 suggested that the rain events > 22 mm will meet this condition. In these experiments the number of rainfall events that were > 22 mm during the growing season was very low and varied between 0 and 4 (Appendix 5.2).

Conversly, in the basins the situation is totally different. Rainfall > 9 mm will create infiltration depths > 100 mm, due to the water harvesting process. The number of rainfall events per growing period that were > 9 mm varied between 9 and 10 events. Mulch addition in the basin also contributes to the effectiveness of the system. It decreases the evaporation rate, hence extending the drying cycle period, which gives the crop a better chance to extract water from the 0 - 100 mm layer. In the final analysis of the *ObBr* treatment, it seems if the runoff area below the 100 mm soil depth can be seen as "assurance" water, helping the crop through extended drying cycles that often occur in dryland crop production.

Organic mulch on the runoff area provides the necessary protection against evaporation, but it also reduces runoff to the basin area. The infiltration ratio of the *ObOr* treatment varied between 1.13 and 1.18 for both crops (Table 5.2), resulting in relative crop yields that varied between 0.91 and 0.93 as estimated with Equation 5.10. Estimations, using Equation 5.3, revealed that rain events > 12 and > 16 mm will lead to infiltration depths >100 mm in the basin and runoff area, respectively. The *ObOr* treatment performed better than the *ObBr* treatments, illustrating better control over the evaporation component.

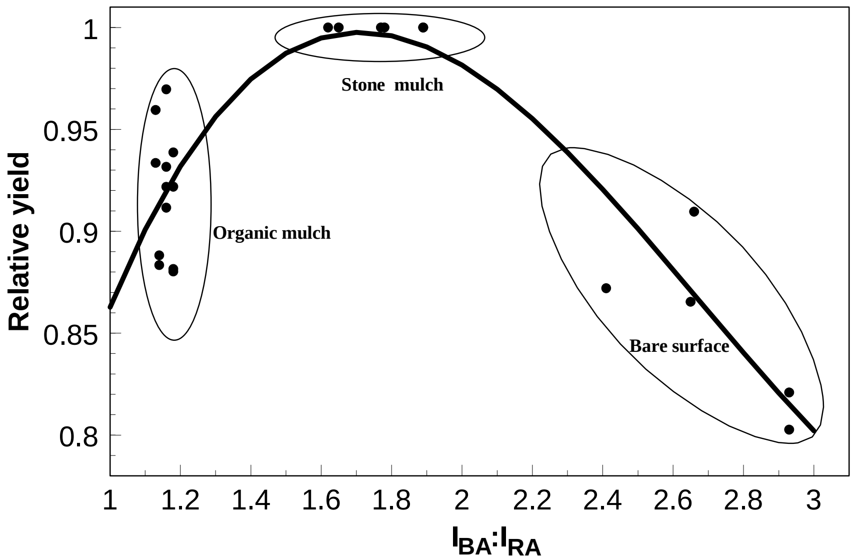


Figure 5.8 Relationship between the infiltration ratio **(**I_{BA}: I_{RA}) (Equations 5.3 and 5.4) and relative crop yield (maize and sunflower) as affected by mulch combinations; Glen/Bonheim ecotope for the three growing seasons 99/00; 00/01 and 01/02

Using the relative yield as indicator, it seems that the *ObSr* treatment with an infiltration ratio that varied between 1.62 and 1.92 for both crops (Table 5.2) produced the best balance between water harvesting and restriction of evaporation. With this treatment it is estimated that rainfall events that are > 10 mm will produce soil water storage deeper than 100 mm in the basin and runoff area.

5.7 SUMMARY

Conclusions on soil water contents for the fallow period are based on the results of the 00/01 and 01/02 season because the 99/00 fallow season lasted only 4 months in comparison with the normal 7 to 8 months period. The mean plant available water at planting varied between 122 and 179 mm of water for the treatments, which is an indication of water conservation during the fallow period. However, the statistical results revealed that mulch on the runoff area was not able to conserve consistently more water than the bare, which served as a control. Linear regression showed that there is a strong relationship between:

(i) Aridity index (AI) and rainfall storage efficiency (RSE); r^2 = 0.93.

(ii) Plant available water at planting and water content of the profile measured at harvesting of the previous crop; $r^2 = 0.96$.

(iii) Cumulative evaporation from the soil surface and the corresponding AI; $r^2 = 0.96$.

(iv) Cumulative evaporation and corresponding rainfall; $r^2 = 0.98$.

The mean cumulative evaporation of the treatments varied between 221 and 257 mm, irrespective of crop type. RSE varied between 5 and 21 % against a background of a mean rainfall of 298 mm for the fallow period.

Evaporation was separated from evapotranspiration during the growth period of the crop for all the seasons, using the method of Tanner & Sinclair (1983) to estimate transpiration. The average cumulative evaporation from the soil surface (ΣE_s) values obtained indicated that stone and organic mulch on the runoff area conserved more water by suppression of Es for both maize and sunflower in comparison to the bare runoff treatment. The ΣEs were 211 and 157 mm for maize and sunflower, respectively. Stones on the runoff area reduced evaporation by 12 and 10 % for maize and sunflower, respectively. Organic mulch reduced evaporation by 16 and 12 %, respectively, in comparison with the bare. Water conserved this way contributed towards higher cumulative transpiration and hence higher seed yield for both crops. A common trend for the various precipitation use efficiencies (PUE_a, PUE_{ET} and PUE_{pg}) was obtained for maize, *viz.* organic mulch in the basin and stone on the runoff area (*ObSr*) > organic mulch in the basin and organic mulch on the runoff area (*ObOr*) > stones in the basin and organic mulch on the runoff area (*SbOr*) > organic mulch in the basin and a bare runoff area (*ObBr*), whilst for sunflower, *ObOr* and *SbOr* changed positions. The precipitation use efficiency of the *ObSr* treatment was in most seasons significantly higher than *ObBr* for both crops.

The in-field rainwater harvesting and basin tillage (IRWH) techniques were also analyzed in terms of the infiltration ratio of the basin versus the runoff area. Results obtained for the growing season correlated well with the relative yields ($r^2 = 0.98$), indicating that yield increased sharply as the infiltration ratio increases from 1 to 1.7. The curve also showed a sharp decrease in yield as the ratio increases towards an infiltration ratio of 3. The optimum infiltration ratio is associated with stones on the runoff area and varies between 1.62 and 1.89 for both the crops during the seasons. The infiltration ratio of the *ObBr* treatment varies between 2.3 and 3, which actually represents the highest water harvesting potential, but yet it produced the lowest yield. The lower yields can be attributed towards the surface redistribution of water, which simulates additional evaporation. It was estimated that rainfall events should be > 12 mm to penetrate the soil deeper than 100 mm under conditions without runoff. For the bare runoff area, the rainfall must be greater than 22 mm to compensate for the loss from the runoff area due to in-field runoff. Ninety percent of the rainfall events are less than 20 mm and hence end up in the 0 – 100 mm soil depth, which is the main water source for evaporation. For organic mulch and stones on the runoff area, the rainfall limit decrease from 22 mm (bare) to 16 and 10 mm, respectively, hence reducing the potential for evaporation.

6 EVALUATION OF NITROGEN FERTILIZER APPLICATION TOWARDS CONSERVATION AND AGRONOMIC SUSTAINABILITY

6.1 INTRODUCTION

Inputs and outputs of natural veld, be it water or nutrients, are naturally in balance (Cameron, De Jong & Chang, 1978). When natural veld, such as on the Glen/Bonheim ecotope, is transformed into a crop production system through ploughing, many physical, chemical and biological properties of the topsoil also change (Fried, Tanji & Van de Pol, 1976). The disturbed system will tend towards a new equilibrium in the long run, trying to balance the inputs and outputs (Stroosnijder, 2003). The actual time to equilibrium will vary depending on climate and agronomic activities such as cultivation, fertilizer practices, mulching etc. Meisinger & Randall (1991) state that near steady state conditions are generally achieved by the continued application of the same soil-crop-water management practices over a long period (5 – 20 years).

In the previous chapters the influence of mulching combinations on the delicate balance between precipitation and in-field runoff have been discussed in an attempt to establish an optimum with regard to infiltration in both the runoff area, and in the basin, of the IRWH system. Mulch reduces the evaporation component making more water available to the roots. This increases the transpiration component of the water balance. Higher transpiration alone does not always lead to higher yields. Van Rensburg (1996) illustrated with a range of water and nitrogen application levels that nitrogen-stressed plants transpired as much water as plants grown under optimum nutrient levels. When the nitrogen application levels are optimized, together with the available water, the water use efficiencies of maize and wheat increased between 40 and 65 %, depending on the level of available water. The same principle was also demonstrated by other researchers, *viz*. Sharma, Kar & Cheema (1990); Spiertz & De Vos (1983) and Stutler, James, Fullerton, Wells & Shipe (1981).

The fine balance between available water and nitrogen is an important aspect in sustainable agriculture. Available water controls crop response to nitrogen (Isfan, 1984; Rhoads, 1984; Oberlê & Keeney, 1990; Van Rensburg, Du Preez & Bennie, 2001). Communal farmers in the target area for this research east of Bloemfontein almost ignore fertilizing practices. This is not only due to their lack of financial resources, but also through their experience of no yield advantages being gained by fertilizer application. Water losses through runoff and evaporation on these clayey soils dominate the hydrological cycle, decreasing plant available water to critically low levels, where crops cannot respond to fertilizers. The application of the IRWH technique increases the available water significantly, to the point where nutrients such as nitrogen may restrict potential yields.

The specific objectives of this chapter are (i) to characterize crop response to two levels of nitrogen applications; (ii) to estimate water and nitrogen efficiencies; and (iii) to construct a N-budget as an aid towards developing N-fertilizer recommendations for maintaining agronomic and conservation sustainability.

6.2 YIELD-WATER USE RESPONSE TO NITROGEN APPLICATION

Two levels of nitrogen were applied in both the sunflower-maize-sunflower (SMS) crop rotation and maize-sunflower-maize (MSM) rotation experiments on block A and block B respectively. The 15 kg N ha^{-1} represented the recommended level (Nrec.), while the 90 kg N ha^{-1} level represented the high (Nh) level. The results of the various indicators of crop response to nitrogen, *viz*. seed yield, biomass and harvest index are summarized for both experiments in Table 6.1. The values are means of the four IRWH treatments. Supportive measurements concerning the water balance components and water use efficiencies are also included in Table 6.1. Seed yields, which are regarded as the most important indicator, are presented in Figures 6.1a and 6.1b for the SMS and MSM rotations, respectively. An additional nitrogen treatment was introduced during the second year of experimentation to represent the natural nitrogen supply capacity of the ecotope, *viz*. 0 kg N ha^{-1} or No level.

Results from block A (Figure 6.1) indicate that the high nitrogen application within the SMS rotation significantly influences seed yield response. Maize that followed sunflower responded negatively, while sunflower responded positively when it followed maize. This can be explained by the ability of the crops to extract water from the potential rooting zone. Sunflower, with its much lower lower limit of plant available water (LL-PAW) in comparison to maize (Hensley *et al.*, 2000), has the ability to extract more water from the profile (Table 6.1 and Table 3.2).

If rain does not recharge the profile, the crop following sunflower will start the season with a disadvantage in terms of available water. A good example is the 01/02 season, where the average water content at planting (WC_p) of block A was 49 mm higher than the corresponding treatment in block B. Consequently, sunflower started the 01/02 season with a PAW_p of 222 mm. Adding the PAW_p to the rainfall of 249 mm for the growing season (Pg) gives a high level of water availability. It is known that crop nitrogen demand increases with an increase in available water (Van Rensburg, 1996) and hence in that experiment the crop yield responded positively to nitrogen application at all levels of water application (significant at $P = 0.05$).

Under water limiting conditions, as experienced by sunflower (PAW_p + Pg = 325 mm) during the 99/00 season (block A), the high nitrogen application led to significant yield losses due to water stress. Shaw & Laing (1962), Eck (1984) and Van Rensburg, Du Preez & Bennie (1997) showed that high N application induces over-stimulation of vegetative growth, which increases the transpiration rate. This can deplete the stored water in the profile to a level that creates plant water stress during critical growth stages.

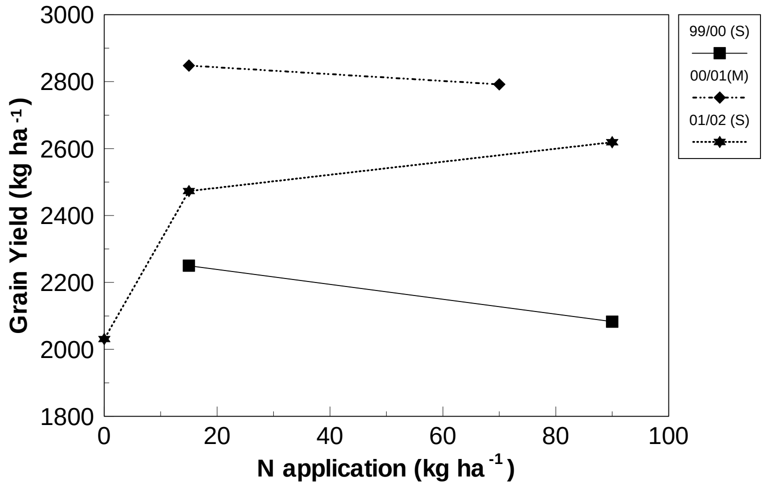
Table 6.1 Various crop and water parameters for treatments in blocks A and B.

Parameter	Rotation*	Block A		Rotation*	Block B	
		Nitrogen levels			Nitrogen levels	
		Nrec	Nh		Nrec	Nh
Seed (kg ha^{-1})	99/00 (S)	2250[a]	2083[a]	99/00 (M)	3607[a]	3612[a]
	00/01 (M)	2848[a]	2792[a]	00/01 (S)	1921[a]	1932[a]
	01/02 (S)	2473[a]	2619[b]	01/02 (M)	3330[a]	3421[a]
Biomass (kg ha^{-1})	99/00 (S)	6810[a]	7272[a]	99/00 (M)	7627[a]	7409[a]
	00/01 (M)	7619[a]	7221[b]	00/01 (S)	5103[a]	4800[a]
	01/02 (S)	5179[a]	5832[b]	01/02 (M)	7617[a]	7605[a]
Precip. for fallow period (Pf, mm)	99/00 (S)	205[a]	205[a]	99/00 (M)	157[a]	157[a]
	00/01 (M)	234[a]	234[a]	00/01 (S)	232[a]	232[a]
	01/02 (S)	360[a]	360[a]	01/02 (M)	360[a]	360[a]
Precip. for grow. season (Pg, mm)	99/00 (S)	179[a]	179[a]	99/00 (M)	228[a]	228[a]
	00/01 (M)	280[a]	280[a]	00/01 (S)	280[a]	280[a]
	01/02 (S)	249[a]	249[a]	01/02 (M)	248[a]	248[a]
Water content at planting (WC_p, mm)	99/00 (S)	385[a]	388[a]	99/00 (M)	395[a]	394[a]
	00/01 (M)	372[a]	366[a]	00/01 (S)	389[a]	388[a]
	01/02 (S)	460[a]	464[a]	01/02 (M)	414[a]	413[a]
Plant available water at plant (PAW_p, mm)	99/00 (S)	145[a]	148[a]	99/00 (M)	148[a]	148[a]
	00/01 (M)	215[a]	210[a]	00/01 (S)	149[a]	148[a]
	01/02 (S)	220[a]	224[a]	01/02 (M)	167[a]	166[a]
Drainage (D, mm)	99/00 (S)	0[a]	0[a]	99/00 (M)	0[a]	0[a]
	00/01 (M)	0[a]	0[a]	00/01 (S)	0[a]	0[a]
	01/02 (S)	0[a]	0[a]	01/02 (M)	0[a]	0[a]
Evaporation from soil (Es, mm)	99/00 (S)	116[a]	104[a]	99/00 (M)	221[a]	221[a]
	00/01 (M)	136[a]	134[a]	00/01 (S)	113[a]	116[a]
	01/02 (S)	213[a]	196[b]	01/02 (M)	215[a]	223[b]
Transpiration (Ev, mm)	99/00 (S)	162[a]	173[a]	99/00 (M)	85[a]	82[a]
	00/01 (M)	116[a]	110[b]	00/01 (S)	167[a]	157[a]
	01/02 (S)	170[a]	191[b]	01/02 (M)	118[a]	118[a]
PUE_{fg} (kg seed ha^{-1} mm^{-1})	99/00 (S)	5.28[a]	4.97[a]	99/00 (M)	9.61[a]	9.67[a]
	00/01 (M)	7.14[a]	6.98[a]	00/01 (S)	4.37[a]	4.43[a]
	01/02 (S)	3.62[a]	3.83[a]	01/02 (M)	4.99[a]	5.02[a]
PUE_a (kg seed ha^{-1} mm^{-1})	99/00 (S)	5.85[a]	5.36[a]	99/00 (M)	9.14[a]	9.16[a]
	00/01 (M)	7.66[a]	7.63[a]	00/01 (S)	4.93[a]	4.98[a]
	01/02 (S)	5.37[a]	5.64[a]	01/02 (M)	8.04[a]	8.27[a]
N-agron. effic. (NAE**)	99/00 (S)	14.6[a]	0.58[a]	99/00 (M)	66[a]	14.2[b]
	00/01 (M)	15.7[a]	2.57[b]	00/01 (S)	-	-
	01/02 (S)	29.5[a]	3.20[b]	01/02 (M)	47.9[a]	11.55[b]
N-recov. effic. (NRE, %)	99/00 (S)	+100[a]	34[b]	99/00 (M)	81[a]	17[b]
	00/01 (M)	81[a]	12[b]	00/01 (S)	-	-
	01/02 (S)	11[a]	12[a]	01/02 (M)	80[a]	17[b]

*(S) = sunflower; (M) = maize
** kg grain ha^{-1} (kg N applied per ha)$^{-1}$ or kg seed kg^{-1} N applied

Results from the MSM rotation-experiment (Block B) showed no significant response to the high nitrogen application level. On the other hand, it seems that at least the maize (01/02 season) responded positively to the low nitrogen application. The yield increased from 2 612 kg ha^{-1} with no N added to 3 330 kg ha^{-1} when 15 kg N ha^{-1} was applied. Comparing this yield with the 99/00 season leads to the conclusion that the 15 kg N application represents the optimum N level for the ecotope when the available water (PAW_p + Pg) fluctuates between 370 and 420 mm.

(a)



(b)

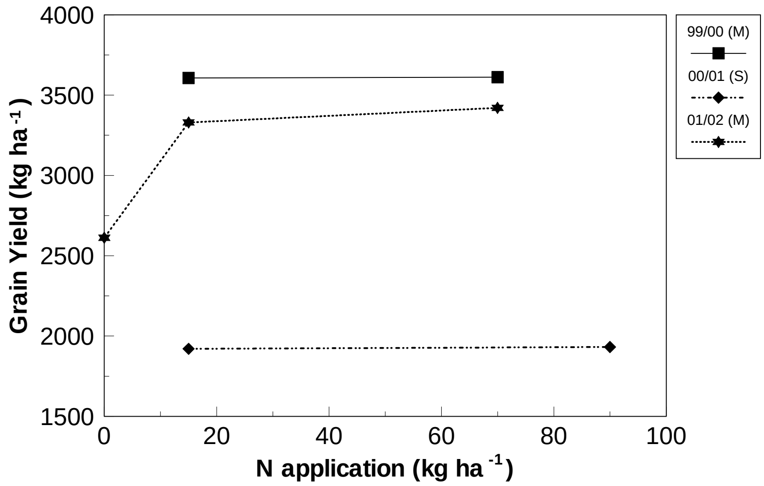


Figure 6.1 Yield response to N application for the (a) SMS rotation (block A) and (b) MSM rotation (block B).

6.3 WATER AND NITROGEN USE EFFICIENCY

6.3.1 Water use efficiency

There are various methods of expressing water use efficiency (WUE) and nitrogen use efficiency (NUE). WUE has been defined by Hensley *et al.* (2000) as precipitation use efficiency (PUE) for the combined fallow and growing season (fg) which measures the efficiency with which a particular crop production technique can convert available water during the production period (p_p) into yield (Section 2.3.2.6). An even simpler way, although crude because it does not take into account the water stored in the profile at the beginning and end of the production period is to express yield in terms of the annual rainfall (PUE_a). Farmers relate more easily to this term and it is also easily obtainable from automatic weather stations. The two parameters are summarised in Table 6.1. The PUE_a for maize varies between 7.63 and 9.16 kg seed ha^{-1} mm^{-1} rain in the three years. High nitrogen levels did not influence the PUE_a of maize significantly, mainly due to (i) the high nitrogen supply capacity

(NSC) of the ecotope (PUE of No = 6.3 kg ha^{-1} mm^{-1}), and (ii) the availability of the water that controlled crop response to high nitrogen applications. The average PUE_a for the Nh treatments was 5.32 kg seed ha^{-1} mm^{-1} rain versus the 5.38 of the Nrec level. Precipitation use efficiency expressed in the more scientific way, *viz.* PUE_{fg}, is approximately 1 unit lower in comparison to estimates made with PUE_a.

6.3.2 Nitrogen use efficiency

According to Bock (1984), the efficiency with which nitrogen is used by crops can be expressed as nitrogen agronomic efficiency (NAE, kg seed ha^{-1} kg^{-1} N applied), nitrogen recovery efficiency (NRE, kg N uptake ha^{-1} kg^{-1} N applied) and physiological efficiency (kg seed ha^{-1} kg^{-1} N uptake). In this study, agronomic and recovery efficiency have been used as indicators of nitrogen efficiency. For the calculation of NAE for maize and sunflower it has been assumed that the yields obtained at the No (01/02) treatments are representative of the other two seasons except the sunflower of the 00/01 treatment block B. The yield in that case was unusually low and therefore abnormal. Nitrogen uptake was calculated using N concentrations obtained from local and international literature. For N in maize and sunflower biomass the values used were 0.92 % and 1.37 %, respectively. The NAE varied for maize between 15.7 and 47.9 kg seed kg^{-1} N applied for the Nrec level and between 2.57 and 14.2 kg seed kg^{-1} N for the Nh level. For sunflower, NAE varied between 14 and 29.5 kg seed kg^{-1} N at the Nrec level and between 0.58 – 3.24 kg seed kg^{-1} N for the Nh level. The NAE results of both crops supported the conclusion that the Nrec level was more efficient per kg N applied in converting nitrogen into seed yields. The average Nrec levels were 43.2 and 22.05 kg seed kg^{-1} N applied for maize and sunflower, respectively. The maize result is in the same range reported by Van Rensburg *et al.* (2001) (37.5 kg seed kg^{-1} N) under optimum water and nitrogen supplying conditions for a 3 m deep Bainsvlei Amelia soil type. As expected the RE of the applied nitrogen was high for the Nrec level: maize varied between 81 an 82 %, while sunflower varied between 11 and 100 %. These values are certainly high but not unrealistic. N recovery depends heavily on the availability of water during the growing season. Van Rensburg *et al.* (1997) showed that maize and wheat under optimum water conditions could recover applied N at an efficiency of 75 and 64 %, respectively. Low NRE-values are associated with (i) very dry conditions during the vegetative growth phase which limited water uptake (Craswell & Strong, 1976), and (ii) with extremely high N applications in relation to available water as experienced with the Nh treatments that varied between 12 and 34 % for sunflower and between 12 and 17 % for maize.

6.4 NITROGEN BUDGET

An attempt has been made to construct nitrogen budgets for all the treatments in blocks A, B and C for the three year experimental period. The N-budget is based on the concept of the conservation of mass that simply states that the N-inputs into a particular system less the N-outputs equals the change of the total N stored within the system (Meisinger & Randall, 1991). N-budgets can vary from very simple statements to very complex ones, depending on the goal, system boundaries, and appropriate estimates of the N-flows across the system. The aim of this budget is to assess the nitrogen within the IRWH system in terms of its conservation and agronomic sustainability.

Historically the Glen/Bonheim - Onrus ecotope, where the experiment is located, was used for extensive sheep farming until the winter of 1996. During that winter the whole land was ploughed, followed by a rotovator and disc tillage in the spring. The IRWH plots were then prepared using a basin tillage plough for constructing the basin areas of the system. The final construction of the basins and runoff areas was done by hand using spades and rakes. Thereafter the plots were left undisturbed. Weeds and pests were controlled by hand spraying using appropriate chemicals. On the other hand, the *CON* plots were ploughed and disced annually before planting. Weeds were controlled both mechanically and chemically on these plots. Monocrop maize, sorghum and sunflower production were practised until the start of the 99/01 growing season on blocks A, B and C, respectively (Hensley *et al.*, 2000). The current crop rotation on block A (SMS), block B (MSM) and block C (SSS), and their treatments, are fully described in Section 2.1.

6.4.1 N-inputs

Secondary input processes, such as N received through annual precipitation, dry deposition of N (ammonia absorption), N in the seed at planting, and non-symbiotic N_2 fixation, have been excluded from these budgets. This is due to large uncertainties in estimating these quantities and their relatively insignificant contribution to the total N-inputs in comparison to primary processes. Primary inputs, *viz.* fertilizer application, mulching practices and symbiotic N_2 fixation were estimated over the three seasons within a cropping system as follows:

(i) N-fertilizer application: The cumulative actual fertilizer applied over the three growing seasons is summarized in Table 6.2 for all the treatments, which varies between 45 and 250 kg N ha^{-1} for block A treatments, 45 to 230 kg N ha^{-1} for block B and between 53 and 123 kg N ha^{-1} for block C.

(ii) Crop residue additions to basins: After harvesting the seed, the residue was applied in the basins to maintain the required 60 % surface coverage to control evaporation from the soil. This was done annually to compensate for the decomposition of the previous year's material. Nitrogen added in this way was estimated using the amount of crop residue harvested and its appropriate N content. For maize, sunflower and beans, N-concentrations of 0.74 % (Van Rensburg, 1996), 0.7 % (Nel, Loubser & Hammes, 2000) and 1.9 % (Meisinger & Randall, 1991), respectively, were used. In the case of the Nh level treatments for blocks A and B, where N was applied in luxurious amounts, a correction factor of 15 % of the estimated total N was added (Table 6.2).

(iii) Mulches on runoff area: Organic mulch in the form of maize residue was applied at a rate of approximately 1 000 kg ha^{-1} on the relevant runoff areas of the IRWH plots. This was done to maintain the 60 % surface coverage as part of the treatment combinations as explained in Section 2.1. In this case N was estimated by using the rate of application and the mentioned N-concentration of maize residue (Table 6.2).

(iv) Symbiotic N_2 fixation: Symbiotic N_2 fixation converts atmospheric N_2 gas into plant N through symbiotic bacteria living in root nodules of certain plants, primarily legumes. The mass of symbiotically fixed N depends on many genetic and environmental factors including plant species, available soil N, crop management, soil water availability, type of fixing bacteria, and soil chemical environment (Legg & Meisinger, 1982). Several studies indicated a nitrogen advantage from legumes to succeeding crops in spite of removal of crop residue (i.e. Danso & Popastylianou, 1992; Bloem & Barnard, 2001). Specific values for beans could not be found in local literature. Consequently, the soybean model proposed by Bloem & Barnard, 2001) was used to estimate the amount of N fixed:

$$y = 9.54 * x - 0.58 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.1)$$

where:

x = soya seed yield in ton ha^{-1}

y = nitrogen advantage in kg N ha^{-1}

Soya seed yield was replaced by beans without any change to the coefficient of the equation (Table 6.2).

Table 6.2 Estimated N-inputs (kg N ha^{-1}) for the seasons 1999/00 – 2001/02.

Block	Treatment	Crop rotation	Fertilizer	Mulch in basins	Mulch on runoff area	Sym. N_2 Fixation	Total N ($TN_{i\ (sys)}$)
A	*ObBr* N_{rec}	SMS	45	76	-	-	121
	N_h	SMS	250	81	-	-	331
	ObSr N_{rec}	SMS	45	94	-	-	139
	N_h	SMS	250	91	-	-	341
	ObOr N_{rec}	SMS	45	88	28	-	161
	N_h	SMS	250	93	28	-	371
	SbOr N_{rec}	SMS	45	0	28	-	73
	N_h	SMS	250	0	28	-	278
B	*ObBr* N_{rec}	MSM	45	80	-	-	125
	N_h	MSM	230	81	-	-	311
	ObSr N_{rec}	MSM	45	83	-	-	128
	N_h	MSM	230	78	-	-	308
	ObOr N_{rec}	MSM	45	86	28	-	159
	N_h	MSM	230	78	28	-	336
	SbOr N_{rec}	MSM	45	0	28	-	73
	N_h	MSM	230	0	28	-	258
C	*CON*	MMM	123	0	-	-	123
	CON	BBB	53	0	-	18	71
	CON	BMB	78	0	-	7	85
	CON	MBM	98	0	-	5	103
	ObBr	MBM	98	88	-	9	195
	ObBr	BMB	78	77	-	15	170
	SbSr	MBM	98	0	-	10	108
	SbSr	BMB	78	0	-	19	97

* S = sunflower; M = maize and B = beans

The individual components of the N input for the system during the measuring period are summarised in Table 6.2. The total inputs ($TN_{i(sys)}$) of the Nrec, which varies between 73 and 161 kg N ha^{-1} for both the A and B blocks, are significantly lower than the Nh, which varied between 258 to 371 kg N ha^{-1}. Inputs in block C varied from 71 to 123 kg N ha^{-1} for the *CON* treatments, while the IRWH treatments varied between 97 and 95 kg N ha^{-1}.

6.4.2 N-outputs

The primary nitrogen output processes used to describe the outflow of nitrogen from the system are: seed yield harvested, ammonia losses though fertilization, decomposition of mulch in the basins and on the runoff area, and denitrification (Table 6.3):

(i) Seed yield N: N removed through harvesting of the seed was estimated using the amount of seed harvested in a particular treatment and the appropriate nitrogen concentration reported in the literature, *viz.* maize = 1.2 % (Van Rensburg, 1996), sunflower = 2.7 % (Nel *et al*., 2000) and beans = 4 % (Meisinger & Randall, 1991).

(ii) Luxurious uptake: It was assumed that N-concentrations of the crops associated with Nh application level would be higher than the average reported in literature. This was done in the light of the high NAE and NRE values estimated in Section 6.3. Luxurious amounts estimated in this way are listed as an additional N output in Table 6.3.

(iii) Ammonia losses: Ammonia volatilization is a complex process involving biological and chemical reactions within the soil, and physical transport of N out of the system. Ammonia loss through fertilizers is influenced by method of N-application, N source, soil pH, CEC and weather conditions (Meisinger & Randall, 1991). Precise estimates of ammonia loss are only possible with direct measurements, which were not planned for this study. Given the high clay content and CEC of the soil, fertilizer placement depth (3-5 cm), the dry weather conditions and the N sources (ammonium nitrate during 99/00 season and limestone ammonium nitrate for the last two seasons), it was estimated that ammonia loss is approximately 10 % of the fertilizer amount applied (Meisinger & Randall, 1991).

(iv) Ammonium loss from decomposed crop residue and mulches: Mulch left on the surface of the basins and runoff areas is subjected to decomposition and hence ammonia volatilization. A rough estimate over the long-term should be between 20 and 45 % (Meisinger & Randall, 1991). For this study (short-term) a value of 20 % was assumed which does not seem to be unrealistic for the mulch practices adopted. The material was placed on the soil surface and never incorporated in the soil.

(v) Nitrate leaching: Continuous soil water content measurements during the study period suggested that there was no significant drainage in blocks A, B and C. Consequently, nitrate loss through leaching is assumed to be zero.

(vi) Denitrification: Denitrification was not measured and depends heavily on the availability of oxygen, which is controlled mainly by soil water content. Firestone (1982) stated that denitrification can occur even in well-drained soils. Oxygen deficits can develop locally due to high oxygen uptake rates by soil microbes as they oxidize readily available carbon or due to long oxygen diffusion paths into the centre of soil aggregates. Denitrification is most likely to occur when soil temperature is above 10 °C and the soil pH is above 5 (Legg & Meisinger, 1982). Seeing that nitrate leaching is insignificantly low, it can be assumed that nitrate availability will not limit denitrification. Following the default guideline values given by Meisinger & Randall (1991) for soils with < 2 % organic matter, which are somewhat poorly drained, it seems that approximately 6 to 20 % of the applied N is subjected to denitrification. The lower end of the range was used to estimate denitrification losses.

Table 6.3 Estimates of N-outputs (kg N ha^{-1}) for the various crop production system over the 1999/00 – 2001/02 growing period.

Block	Treatment	Crop* rotation	Harvested from seed	Luxurious uptake	NH_3 losses from			Denitrification	Total N ($TN_{o(sys)}$)
					Fertilizer	Mulch in basin	Mulch on runoff area		
A	*ObBr* N_{rec}	SMS	148	0	5	15	0	3	173
	N_h	SMS	173	26	25	16	0	15	255
	ObSr N_{rec}	SMS	160	0	5	19	0	3	185
	N_h	SMS	167	25	25	18	0	15	250
	ObOr N_{rec}	SMS	142	0	5	18	6	3	174
	N_h	SMS	175	26	25	19	6	15	266
	SbOr N_{rec}	SMS	165	0	5	0	6	3	177
	N_h	SMS	162	24	25	0	6	15	232
B	*ObBr* N_{rec}	MSM	125	0	5	16	0	3	149
	N_h	MSM	130	20	23	16	0	14	199
	ObSr N_{rec}	MSM	148	0	5	17	0	3	173
	N_h	MSM	151	23	23	16	0	14	227
	ObOr N_{rec}	MSM	137	0	5	17	6	3	168
	N_h	MSM	135	20	23	16	6	14	214
	SbOr N_{rec}	MSM	133	0	5	0	6	3	147
	N_h	MSM	133	20	23	0	6	14	196
C	*CON*	MMM	77	0	12	0	0	7	96
	CON	BBB	79	0	5	0	0	3	87
	CON	BMB	53	0	8	0	0	5	66
	CON	MBM	77	0	10	0	0	6	93
	ObBr	MBM	125	0	10	18	0	6	159
	ObBr	BMB	98	0	8	15	0	5	126
	SbSr	MBM	143	0	10	0	0	6	159
	SbSr	BMB	121	0	8	0	0	5	134

* S = sunflower; M = maize and B = beans

6.4.3 Changes in N storage of the system

The percentage carbon in the A-horizon was measured in the virgin soil (veld) during 1998, assuming that it represents the situation prior to ploughing of the site in 1996. The change in percentage carbon for the 0 - 150 mm layer over the period 1996 until 2002 is depicted for block A, B and the *CON* treatments of block C in Figure 6.2.

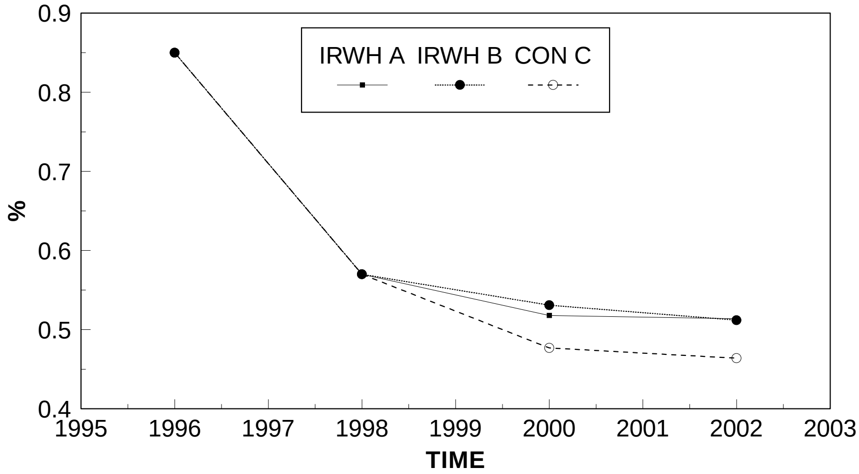


Figure 6.2 Carbon decline in the Glen/Bonheim-Onrus ecotope as affected by IRWH and *CON* treatments.

From this trend it is clear that the % carbon declined by approximately 30 % with the change from extensive farming to dryland farming (ploughing). Many researchers (Du Toit, Du Preez, Hensley & Bennie, 1984; Du Toit & Du Preez, 1995) observed the same phenomena when drastic changes, as experienced here, are introduced. The carbon processes are drastically influenced by ploughing, and the system responds accordingly. The carbon content tends towards a new lower equilibrium which depends on long-term activities. The two IRWH treatments (blocks A and B) showed similar trends over time, and appeared to have stabilized at a higher C percentage compared to the *CON* treatments. Carbon declined by 45 % over the total period for the *CON* treatments and 40 % for the IRWH treatments. The relevant question here concerns the fate of the nitrogen mineralized from the organic matter.

The simple N-mass conservation statement has been used to analyze the situation:

$$TN_{i(sys)} - TN_{0(sys)} = \Delta TN_{sys} \quad \text{………………….………………………...………(6.2)}$$

where:

$TN_{i(sys)}$	=	total nitrogen inputs (kg N ha^{-1}) of system
$TN_{o(sys)}$	=	total nitrogen outputs (kg N ha^{-1}) of system
ΔTN_{sys}	=	change in total nitrogen of the storage medium (kg N ha^{-1})

The estimated change in N for the system (ΔTN_{sys}) is summarized in Table 6.5. However, the change in storage of nitrogen for the 150 mm topsoil was characterized by means of soil samples taken at the beginning and end of the experimental period. Several studies have indicated that the top 150 mm soil is most sensitive to nitrogen changes (Prinsloo, Wiltshire & Du Preez, 1990; Wiltshire & Du Preez, 1993). Soil samples were taken at ± 25 and ±75 mm depths in the basins and runoff areas separately. Data was pooled using a weighted average method [(2 x value of runoff area + 1 * value of basin area)/3] to represent the system at 0 - 150 mm. The results for the total nitrogen measured at the beginning ($TNS_{b(150)}$) and end ($TNS_{e(150)}$) are listed in Table 6.4 for all the treatments.

Table 6.4 Measured nitrogen % for the 0-150 mm topsoil at the beginning ($TNS_{b(150)}$) and end ($TNS_{e(150)}$) of the experiments.

Block	Treatment	$TNS_{b(150)}$	$TNS_{e(150)}$	$\Delta TNS_{(150)}$)
A	*ObBr* N_{rec}	0.060	0.045	-0.015
	N_h	0.060	0.052	-0.008
	ObSr N_{rec}	0.058	0.048	-0.010
	N_h	0.057	0.048	-0.009
	ObOr N_{rec}	0.061	0.049	-0.012
	N_h	0.060	0.048	-0.013
	SbOr N_{rec}	0.061	0.048	-0.013
	N_h	0.061	0.050	-0.011
B	*ObBr* N_{rec}	0.057	0.049	-0.008
	N_h	0.066	0.053	-0.017
	ObSr N_{rec}	0.060	0.050	-0.010
	N_h	0.060	0.052	-0.008
	ObOr N_{rec}	0.066	0.052	-0.014
	N_h	0.061	0.052	-0.009
	SbOr N_{rec}	0.058	0.051	-0.007
	N_h	0.059	0.051	-0.008
C	*CON*-M$\underline{\text{B}}$M	0.057	0.44	-0.013
	CON-B$\underline{\text{B}}$B	0.053	0.047	-0.006
	ObBr-M$\underline{\text{B}}$M	0.062	0.056	-0.006
	SbSr- M$\underline{\text{B}}$M	0.059	0.052	-0.007
	CON-B$\underline{\text{MB}}$	0.053	0.051	-0.002
	CON-M$\underline{\text{M}}$M	0.054	0.044	-0.010
	ObBr-B$\underline{\text{MB}}$	0.064	0.059	-0.005
	SbSr-B$\underline{\text{MB}}$	0.061	0.054	-0.0007

* S = sunflower; M = maize and B = beans

The $\Delta TNS_{(150)}$) values were converted to kg N ha^{-1}, using a bulk density 1.3 g cm^{-3} and the results are summarised in Table 6.5. All the treatments in blocks A to C showed a negative response, indicating a net loss of nitrogen from the 0 – 150 mm soil layer. The losses varied between 156 and 293 kg N ha^{-1} in block A, between 137 and 332 kg N ha^{-1} for block B and between 39 and 254 kg N ha^{-1} for treatments of block C. Most of the apparent losses are probably still in the profile at depths greater than the 150 mm soil layer ($TNS_{150-1200}$). Changes in total nitrogen of the crop-soil climate system (ΔTN_{sys}) can also be expressed as:

$$\Delta TN_{sys} = \Delta TNS_{150} + \Delta TNS_{150-1200} \ldots\ldots(6.3)$$

$$\Delta TNS_{150-1200} = \Delta TNsys - \Delta TNS_{150} \ldots\ldots(6.4)$$

Substitution with Equation 6.1 gives

$$\Delta TNS_{150-1200} = TN_i - TN_{0} - \Delta TNS_{150} \ldots\ldots(6.5)$$

Example: *ObBr* (SMS) from Table 6.5

$TN_{i(sys)}$ = 121 kg N ha^{-1}
$TN_{o(sys)}$ = 173 kg N ha^{-1}
ΔTNS_{150} = -293 kg N ha^{-1}

$$\Delta TNS_{150\text{-}1200} = 121 - 173 - (-293)$$
$$= 241 \text{ kg N ha}^{-1}$$

Table 6.5 Short-term N-budget (3 years) for the various crop production systems (kg N ha^{-1}).

Block	Treatment	Crop* rotation	Total N-Input ($TN_{i(sys)}$)	Total N-Output ($TN_{0(sys)}$)	ΔTN_{sys}	Soil analysis ΔTNS_{150}	Residual N
A	*ObBr* N_{rec}	SMS	121	173	-52	-293	241
	N_h	SMS	331	255	+76	-156	232
	ObSr N_{rec}	SMS	139	185	-46	-195	149
	N_h	SMS	341	250	+91	-178	269
	ObOr N_{rec}	SMS	161	174	-13	-234	221
	N_h	SMS	371	266	+105	-253	358
	SbOr N_{rec}	SMS	73	177	-104	-254	219
	N_h	SMS	278	232	46	-215	341
B	*ObBr* N_{rec}	MSM	125	149	-24	-156	131
	N_h	MSM	311	199	+112	-332	341
	ObSr N_{rec}	MSM	128	173	-45	-195	150
	N_h	MSM	308	227	+81	-156	237
	ObOr N_{rec}	MSM	159	168	-9	-273	264
	N_h	MSM	336	214	+122	-178	300
	SbOr N_{rec}	MSM	73	147	-74	-137	131
	N_h	MSM	258	196	+62	-156	281
C	*CON*	MMM	123	96	+27	-195	263
	CON	BBB	71	87	-16	-117	149
	CON	BMB	85	66	+19	-39	89
	CON	MBM	103	93	+10	-254	310
	ObBr	MBM	195	159	+17	-117	153
	ObBr	BMB	170	126	+29	-98	142
	SbSr	MBM	108	159	-51	-136	163
	SbSr	BMB	97	134	-37	-136	177

*S = sunflower; M = maize and B = beans

The results of the example indicate that there was a loss of 293 kg N ha^{-1} from the top 150 mm of the soil. On the other hand, the analysis on the total system revealed that only 173 kg N ha^{-1} could be accounted through losses described from the nitrogen sources summarized in Table 6.5. A total of 121 kg N ha^{-1} was added to the system over the three years. The final analysis indicates that 241 kg N ha^{-1} has moved below the 150 mm soil depth. The rest of the treatments all showed a net movement downwards into the rooting zone. Drainage results (Table 6.1) were estimated as zero for all treatments and hence also zero nitrate leaching. Thus, it can be safely stated that between 149 and 358 kg N ha^{-1} has moved into the root zone in the treatments of block A, between 131 and 341 kg N ha^{-1} for block B and between 89 and 310 kg N ha^{-1} in block C. There was no difference in trend between the treatments in block A and B, except that the average of the N_{rec} treatments was approximately 100 kg N ha^{-1} lower than the N_h treatments. Nitrogen accumulated below the 0 - 150 mm layer should be available as residual nitrogen to the next crop, unless drainage and hence nitrate leaching occur. It is suggested that a cover crop or green manure crop should be introduced to secure the nitrogen in the organic form.

Soil samples were taken at various depths in the profile, but were not analyzed for nitrate due to the high cost involved. Consequently, the predictions made with the mass balance equations could not be directly verified. Indirect estimations, using nitrogen supply capacity values, suggested that the predictions were reasonable.

6.4.4. Nitrogen supply capacity

Nitrogen supply capacity (NSC) represents an ecotope's ability to supply nitrogen to a crop. The best way to measure it is by introducing a zero nitrogen treatment. Nitrogen taken up by the crop in a non-water-stress environment is probably the best indicator of the NSC of the ecotope (Van Rensburg, 1996). This term includes both the residual nitrogen at the beginning of planting and also mineralization during the crop growing period. Unfortunately, the N-zero treatments (*BbBr*) were only introduced in the second year of the experiment in block A and B. From the total biomass yields and nitrogen concentrations obtained from the literature it was estimated that N-uptake for maize amounted to 58 kg ha^{-1} (6306 kg dry matter x 0.0092 kg N ha^{-1} dry matter) and sunflower to 69 kg ha^{-1} (5 057 kg dry matter ha^{-1} x 0.0137 kg N ha^{-1} dry matter). If it can be assumed that the NSC for maize and sunflower are also valid for the 99/00 and 01/02 season, then the total N supplied through mineralization and residual nitrogen (cumulative nitrogen supply capacity, CNSC) can be estimated for the SMS and MSM crop rotation as follows:

$$CNSC_{SMS} = NSC_{99/00} + NSC_{00/01} + NSC_{01/02} \quad (6.6)$$
$$= 69 + 58 + 69$$
$$= 196 \text{ kg N ha}^{-1}$$
$$SNSC_{MSM} = 58 + 69 + 58 = 185 \text{ kg N ha}^{-1}$$

6.4.5 Application of simple input-output budget

As indicated, ΔTN_{sys} for the system can be calculated with Equation 6.1 using the system input ($TN_{i(sys)}$) and output ($TN_{o(sys)}$). In this analysis the organic and inorganic N fraction are excluded.

The changes in total nitrogen of the system (ΔTN_{sys}) are summarized in Table 6.5 for the various treatments. Results from ΔTN_{sys} estimates of both blocks A and B suggest that there was a net loss of nitrogen in all the N_{rec} treatments irrespective of mulch combinations. The losses varied between 13 and 104 kg N ha^{-1} over the period for block A and between 9 and 74 kg N ha^{-1} for block B. On the other hand, the N_h treatments showed a positive balance indicating a build-up of nitrogen in the profile. The values ranges from 76 to 126 kg N ha^{-1} for block A and between 81 and 122 kg N ha^{-1} for block B. Nitrogen build-up in the profile in this way can contribute to the organic nitrogen fraction through immobilization processes on the long term. Whether the small-scale farmer can financially afford this, is a relevant practical question and a balance between conservation and production should be recommended. Taking into account that the losses occurred over a period of three years, the N_{rec} should be adjusted to a final rate of 20, 30, 32 and 50 kg N ha^{-1} yr^{-1} for the *ObOr, ObSr, ObBr* and *SbOr* treatments in block A, respectively. N-applications in block B should be adjusted to 18, 23, 30 and 40 kg N ha^{-1} yr^{-1} for the *ObOr*, *ObBr*, *ObSr* and *SbOr* treatments, respectively.

The change in total nitrogen for the various treatments in block C revealed that there is a net loss of nitrogen in the BBB system, due mainly to the fact that the crop residue was removed after harvest. All the other *CON* treatments ended with a positive nitrogen budget, suggesting that the N-fertilizer applied can be adjusted downwards with 9, 6 and 3 kg N ha^{-1} yr^{-1} for the MMM, BMB and MBM treatments, respectively. Comparing the IRWH system indicates that the nitrogen should be adjusted upwards with 17 and 12 kg N ha^{-1} yr^{-1} to ensure sustainable nitrogen practices on the two *SbSr* treatments, *viz.* MBM and BMB, respectively. On the other hand, the two bare treatments need a downward adjustment of 6 and 10 kg N ha^{-1} yr^{-1} for the MBM and BMB, respectively. The various N-budgets show clearly the importance of the impact of N additions through crop residue, mulches and fertilizer in relation to the outputs.

6.5 SUMMARY

Mulching has increased the level of available water in the rooting zone of the in-field water harvesting and micro-basin tillage (IRWH) system. This chapter has focused on the response of the crop to nitrogen application against the background of higher available water levels. Two levels of nitrogen application were applied, a recommended level (15 kg N ha^{-1}) and a "high" level (70 kg N ha^{-1} for maize and 90 kg N ha^{-1} for sunflower). Where the available water (plant available water at planting + rainfall during the growing season) was greater than approximately 470 mm, sunflower responded positively to high nitrogen levels (significant at $P = 0.05$). Maize did not respond to the high N level, probably due to: (i) the lower available water levels which varied between 376 and 404 mm, and (ii) the high nitrogen supply capacity (NSC) for the crop-soil system of 58 kg N ha^{-1}. The NSC for sunflower was estimated as 69 kg N ha^{-1}. Both crops responded to 15 kg N ha^{-1} compared to the zero N_o. Nitrogen application increased the precipitation use efficiency (PUE_a) by 21 % and 27 % for sunflower and maize, respectively. The N_o values for sunflower and maize were 4.42 and 6.31 kg N ha^{-1} mm^{-1} respectively. The nitrogen agronomic efficiency and nitrogen recovery efficiency were both high at the Nrec level for maize and sunflower in all the years.

The N-budget study reveals that a large amount of nitrogen was released by mineralization when the veld was transformed to a crop production system by ploughing. It is estimated that the total C % declined by approximately 30 % during the initial preparation of the land, with a visible trend for the C level to stabilize at approximately 0.5 % for the IRWH system, and 0.45 % for the conventional tillage (*CON*) system. The N-budget also indicates that the nitrogen recommended level (Nrec) of 15 kg N ha^{-1} needs to be slightly increased, depending on the mulch combinations and crop rotation systems, if agronomic and conservation sustainability are to be maintained in the long run. The N-budget also indicates that between 150 and 360 kg N ha^{-1} has moved from the top 150 mm down into the root zone, presumably available as residual N for the next crop. Estimating the cumulative nitrogen supply capacity (NSC) for the various cropping systems indirectly validated this trend. It is recommended that cover crops or green manure could be used to capture this residual N, and make it available in an organic form.

7 ON-FARM AND ON-STATION DEMONSTRATION OF WATER CONSERVATION TECHNIQUES: MULCHING AND CROP ROTATIONAL EFFECTS

7.1 INTRODUCTION

Demonstration of the best agricultural practices is not a new concept, in fact it was one of the primary tasks of the first extension officers employed in 1866 in Western European countries. Extension officers were allocated to defined areas in which they demonstrated recommended new practices to farmers to show that the farmers themselves could perform the tasks that they were advocating. The United States of America authorized the creation of agricultural experimental stations in 1862, usually in association with the land-grant colleges. These colleges began actively to disseminate their knowledge obtained from on-station experimentation among farmers, either through farmers meetings or through written information (Bembridge, 1991). Seaman A. Knapp (as cited by Bembridge, 1991) initiated so-called grassroots demonstrations or on-farm demonstrations in the early 1900s. South Africa modelled the USA concept to some extent. The government of the Cape appointed in 1910 the first "demonstrators" to teach improved methods of cultivation to small-scale farmers. By 1948 there were 255 agricultural demonstrators employed in the developing areas. Several agricultural colleges were also established, since the erection of the first school of agriculture in Teko (Transkei) in 1905. One of these colleges is the current Glen Agricultural College, where the in-field rainwater harvesting on-station demonstrations trials are located.

Commercial farmers, not only in South Africa but all over the world, benefit tremendously from these extension programmes. Unfortunately, the record of agricultural production by farmers in the rural areas of Southern Africa compares unfavourably with that of their colleagues in the commercial sector. Many reasons were identified to be seen as challenges for rectifying the problems experienced in the small-scale farming sector. Some of the socio-economic reasons given corresponded with those identified by various authors summarized in an FAO (1993) report elsewhere in Africa. One of the key areas identified is the development of appropriate technology for improving small-scale farming systems. This chapter will focus on the technical aspects observed during the demonstration of the IRWH system. The demonstrations were conducted on two farms located in the Thaba Nchu area and also on the Glen/Bonheim – Onrus ecotope located at the Glen Agricultural College. It should be mentioned that the main functions of the demonstration trials were (i) to assist farmers in adopting an attitude conducive to acceptance of the IRWH technology change; (ii) to disseminate agronomic IRWH information to farmers; (iii) training of extension personnel; and (iv) to support the socio-economic research team with the necessary information to conduct their research study. The socio-economic component obtained from blocks C and D (on-station) will be published in a separate WRC report, entitled "Socio-economic study on water conservation techniques in semi-arid areas", while the technology exchange events and demonstration and application in rural villages are covered in Chapters 9 and 10 of this report.

The specified objectives of this chapter are (i) to compare *CON* with different mulch combinations on the runoff area and in the basins of the IRWH technique (on-farm demonstration experiment), and (ii) to evaluate the introduction of a legume (beans) as part of a crop rotation strategy for the IRWH system (on-station demonstration).

7.2 ON-FARM DEMONSTRATION OF THE IRWH TECHNIQUE

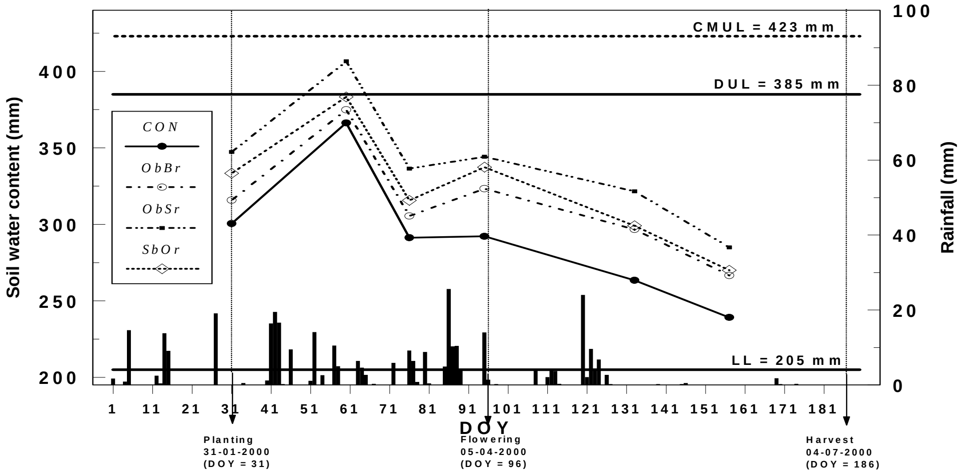
Two ecotopes were selected for the on-farm demonstration of the water conservation techniques, *viz.* the Khumo/Swartland – Amandel ecotope and the Vlakspruit/Arcadia – Lonehill ecotope. Both these ecotopes are located in the Thaba Nchu district and a detail description of each ecotope is available in Sections 3.2 and 3.3, respectively. The experimental layout and supportive agronomic information are available in Sections 2.1.3 and Section 2.2, respectively.

7.2.1 Khumo/Swartland – Amandel ecotope

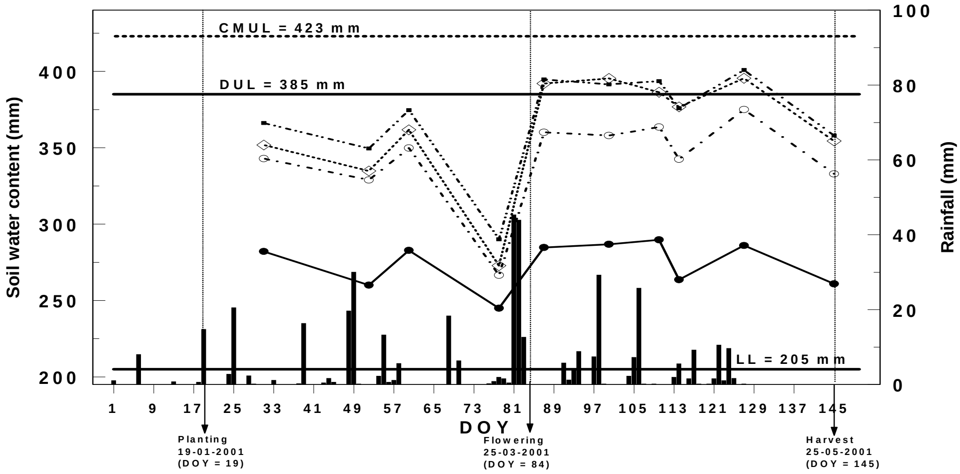
Crop response indicators, *viz.* seed yield, biomass yield and harvest index, are summarized in Table 7.1 for the various water conservation treatments, comprising *CON*, *ObBr*, *SbOr* and *ObSr*. All the IRWH techniques (*ObBr*, *SbOr* and *ObSr*) produced significantly higher seed yields than the *CON* treatment, irrespective of season. The mean seed yield for *CON* over the experimental period was 1822 kg ha^{-1}. Comparing the three IRWH techniques revealed that there is a consistent trend during the experimental period (Section 5.6), *viz*. *ObSr* > *SbOr* > *ObBr*. The mean seed yields for the observed trend were 1893, 1822 and 1737 kg ha^{-1}, respectively. There were no statistical differences between treatments, except for the 99/00 season where *ObSr* > *ObBr*. The mean biomass yield also reflected the trend and differences between the IRWH treatments were not significant during the course of the three seasons. The mean biomass yields were 5483, 5221 and 4831 kg ha^{-1}, respectively. Biomass for *CON* (mean = 4289 kg ha^{-1}) was significantly lower than at least the *ObSr* and *SbOr* treatments in two out of the three seasons. The harvest index did not differ between treatments within a season, but there were large differences from one season to the next. The mean for all the treatments was 0.21 during the 99/00 season, 0.33 for 00/01 and 0.52 for the 01/02 season, which summarized crop conditions during the experimental period. A lower harvest index generally reflects unfavourable cropping conditions during the reproductive growth period in comparison to the vegetative period.

The crop received 280, 378 and 364 mm rain during the fallow period of 99/00, 00/01 and 01/02, respectively. The changes in soil water content during the growing season (Appendix 7.1) are presented in Figures 7.1a, b and c for the 99/00, 00/01 and 01/02 seasons, respectively. The soil water content at planting showed a consistent trend of *ObSr* > *SbOr* > *ObBr* > *CON* during the experimental period. The PAW_p -values in Table 7.1 also reflect the general trend, *viz.* *ObSr* > *SbOr* > *ObBr* > *CON* and were 185, 163, 157 and 93 mm, respectively. However, the IRWH treatments did not differ significantly from each other, but only from the *CON* treatment, except during the first season when the experiment was established. The water disadvantage at planting experienced by the *CON* treatment increases as the growing season progressed, as indicated by the soil water content patterns during the vegetative period. Ex-field runoff was zero for the IRWH treatments and 25, 48 and 24 mm for the *CON* treatment for the 99/00, 00/01 and 01/02 seasons, respectively. Drainage was zero for all treatments, irrespective of season.

a)



b)



c)

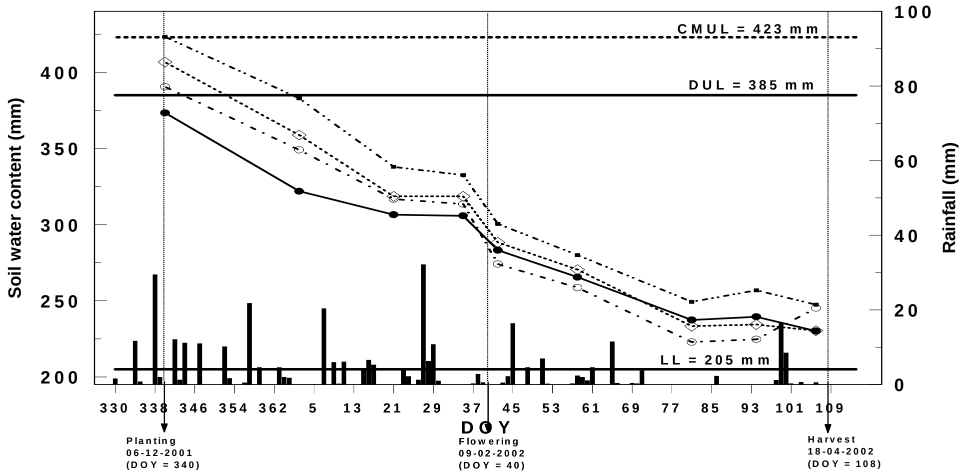


Figure 7.1 Measured changes in the soil water content of the root zone (0 – 1200 mm) during the (a) 1999/2000, (b) 2000/01 and (c) 2001/02 growing seasons on the Khumo/Swartland ecotope. The crop planted was sunflower.

Table 7.1 Various crop and water related variables obtained from water conservation techniques demonstrated on the Khumo/Swartland - Amandel ecotope.

Parameter	Year	Treatment (Mulch x rotation; s = sunflower)			
		CON	*ObBr*	*ObSr*	*SbOr*
Seed (kg ha^{-1})	99/00	1049^{b}	1315^{a}	1578^{c}	1504^{ac}
	00/01	978^{b}	1362^{a}	1441^{a}	1345^{a}
	01/02	1829^{b}	2535^{a}	2661^{a}	2618^{a}
	Mean	**1285**	**1737**	**1893**	**1822**
Biomass (kg ha^{-1})	99/00	5234^{b}	6060^{ab}	7319^{a}	7038^{a}
	00/01	3598^{a}	3783^{a}	4195^{a}	3771^{a}
	01/02	3915^{b}	4650^{ab}	4931^{a}	4854^{ab}
	Mean	**4249**	**4831**	**5483**	**5221**
Harvest Index	99/00	0.20^{a}	0.22^{a}	0.21^{a}	0.21^{a}
	00/01	0.27^{a}	0.36^{a}	0.34^{a}	0.36^{a}
	01/02	0.47^{a}	0.55^{a}	0.54^{a}	0.54^{a}
	Mean	**0.31**	**0.37**	**0.37**	**0.37**
Pf (mm)	99/00	288	288	288	288
	00/01	302	302	302	302
	01/02	361	361	361	361
	Mean	**317**	**317**	**317**	**317**
Pg (mm)	99/00	275	275	275	275
	00/01	384	384	384	384
	01/02	276	276	276	276
	Mean	**312**	**312**	**312**	**312**
ΔS (mm)	99/00	61	49	62	64
	00/01	21	10	8	-3
	01/02	82	181	212	188
	Mean	**55**	**80**	**94**	**83**
PAW$_{p}$ (mm)	99/00	96^{b}	111^{a}	142^{a}	128^{ab}
	00/01	77^{b}	138 ^{a}	161^{a}	147^{a}
	01/02	107^{b}	222 ^{a}	254^{a}	213^{a}
	Mean	**93**	**157**	**185**	**163**
ET (mm)	99/00	312^{a}	325^{a}	338^{a}	339^{a}
	00/01	357^{a}	394^{a}	392^{a}	381^{a}
	01/02	333^{a}	457^{b}	487^{b}	463^{b}
	Mean	**334**	**392**	**406**	**394**
WUE$_{ET}$ (kg seed ha^{-1} mm^{-1})	99/00	3.4^{b}	4.0^{ab}	4.7^{a}	4.4^{a}
	00/01	2.7^{b}	3.5^{ab}	3.7^{a}	3.5^{a}
	01/02	5.5^{a}	5.5^{a}	5.5^{a}	5.7^{a}
	Mean	**3.9**	**4.3**	**4.6**	**4.5**
PUE$_{fg}$ (kg seed ha^{-1} mm^{-1})	99/00	**-**	**-**	**-**	**-**
	00/01	1.5^{a}	2.2^{b}	2.4^{b}	2.2^{b}
	01/02	2.7^{a}	3.5^{b}	3.5^{b}	3.5^{b}
	Mean	**2.1**	**2.8**	**2.9**	**2.9**
PUE$_{a}$ (kg seed ha^{-1} mm^{-1})	99/00	1.9^{a}	2.3^{b}	2.8^{b}	2.7^{b}
	00/01	1.4^{a}	2.0^{b}	2.1^{b}	2.0^{b}
	01/02	2.9^{a}	4.0^{b}	4.2^{b}	4.1^{b}
	Mean	**2.1**	**2.8**	**3.0**	**2.9**

* Different superscripts refer to statistically significant differences at P = 0.05; values with similar letters are not statistically different.

The efficiency of the IRWH system in comparison to the *CON* is clearly visible in the soil water content response to rainfall events just before flowering during the 00/01 season. There was a sharp rise in the soil water content due to water harvesting in the basins relative to the *CON* treatment. This boosted the water supply of the IRWH systems throughout the reproductive period, giving yields that varied between 1315 and 1578 kg seed ha^{-1}. The highest yields were obtained during the 01/02 season of the experiment. Inspection of the water content patterns of the 01/02 season clearly demonstrate the value of the profile as a water storage medium, even for the *CON*. The water content was near or above the DUL at planting for all treatments. As the season progressed, the water content gradually declined in response to the water deficit induced by the rain shortage relative to the crop water demand. The stored water played an essential role towards meeting the crop water demand during the reproductive period. The crop almost extracted all the available water from the profile as it approached the end of the season. Water supplied this way led to higher water use efficiencies as indicated by the WUE_{ET}, PUE_a and PUE_{fg} values of the 01/02 season. A common WUE response was observed for the various indices, *viz. ObSr* > *SbOr* > *ObBr* > *CON*, except for the 01/02 season. In all these cases at least *ObSr* and *SbOr* were significantly higher than *CON*.

7.2.2 Vlakspruit/Arcadia – Lonehill ecotope

Important crop growth parameters, *viz.* seed yield, biomass yield and harvest index, as well as water related variables are summarized in Table 7.2. The results of the soil water contents during the growing seasons are presented in Figure 7.2 a, b, and c for the 99/00, 00/01 and 01/02 season, respectively. The soil water content data is presented in Appendix 7.2.

The records revealed that the three rainfall seasons were normal and above normal with ample opportunities to harvest water in the basins. The total rainfall for the 99/00, 00/01 and 01/02 seasons was 532, 807 and 623 mm, respectively. It was estimated that 52, 64 and 58 % of the total rainfall felt during the fallow period. According to the rainfall storage efficiency, the IRWH treatments were able to conserve more water than the *CON* treatments in two of the three seasons. The mean RSE was 18, 17, 15 and 4 % for *ObSr*, *ObBr*, *SbOr* and *CON*, respectively (data not shown). Comparing *ObSr* and *SbOr* with the *ObBr* treatments indicated that mulch on the runoff area did not affect the RSE significantly in any of the years.

The statistical analysis of PAW_p also reflected the same results: (i) mulches did not affect the available water in any of the seasons, and (ii) the IRWH systems provided significantly more available water at planting. The mean PAW_p for the IRWH systems was 80, 113 and 91 mm higher during the 99/00, 00/01 and 01/02 seasons, respectively, than the corresponding *CON* values. Ex-field runoff was zero for the IRWH treatments and 25, 48 and 21 mm for the *CON* treatment for the 99/00, 00/01 and 01/02 seasons, respectively. Drainage was zero for all treatments irrespective of season.

Table 7.2 Various crop and water related variables obtained from water conservation techniques demonstrated on the Vlakspruit/Arcadia - Lonehill ecotope.

Parameter	Year	Treatment			
		CON	*ObBr*	*ObSr*	*SbOr*
Seed (kg ha^{-1})	99/00	1062^{b}	1706^{a}	1944^{a}	1814^{a}
	00/01	1116^{b}	1506^{a}	1623^{a}	1498^{a}
	01/02	1389^{b}	2878^{a}	3117^{a}	3079^{a}
	Mean	**1189**	**2030**	**2228**	**2130**
Biomass (kg ha^{-1})	99/00	5041^{b}	6860	9443^{a}	7858^{ac}
	00/01	3578^{b}	5501^{a}	6040^{a}	6174^{a}
	01/02	3686^{b}	5480^{a}	5988^{a}	5818^{a}
	Mean	**4102**	**5947**	**7157**	**6617**
Harvest Index	99/00	0.21^{b}	0.25^{a}	0.21^{b}	0.23^{ab}
	00/01	0.31^{a}	0.27^{ab}	0.27^{b}	0.24^{b}
	01/02	0.38^{b}	0.53^{a}	0.52^{a}	0.53^{a}
	Mean	**0.30**	**0.35**	**0.33**	**0.33**
Pf (mm)	99/00	280	280	280	280
	00/01	378	378	378	378
	01/02	364	364	364	364
	Mean	**341**	**341**	**341**	**341**
Pg (mm)	99/00	252	252	252	252
	00/01	429	429	429	429
	01/02	259	259	259	259
	Mean	**313**	**313**	**313**	**313**
ΔS (mm)	99/00	27	56	66	57
	00/01	-62	-26	-20	-27
	01/02	67	135	129	121
	Mean	**11**	**55**	**58**	**50**
PAW_p	99/00	68^{b}	150^{a}	145^{a}	150^{a}
	00/01	27^{b}	138^{a}	140^{a}	142^{a}
	01/02	144^{a}	234^{a}	225^{a}	235^{a}
	Mean	**78**	**78**	**170**	**176**
ET (mm)	99/00	253^{b}	308^{a}	318^{a}	308^{a}
	00/01	319^{b}	402^{a}	409^{a}	401^{a}
	01/02	305^{b}	394^{a}	388^{a}	380^{ab}
	Mean	**292**	**368**	**371**	**363**
WUE_{ET} (kg seed ha^{-1} mm^{-1})	99/00	4.2^{b}	5.5^{a}	6.1^{a}	5.9^{a}
	00/01	3.5^{a}	3.7^{a}	4.0^{a}	3.7^{a}
	01/02	4.6^{b}	7.3^{a}	8.0^{a}	8.1^{a}
	Mean	**4.1**	**5.5**	**6.0**	**5.9**
PUE_{fg} (kg seed ha^{-1} mm^{-1})	99/00	-	-	-	-
	00/01	1.5^{b}	2.1^{a}	2.2^{a}	2.1^{a}
	01/02	2.2^{b}	4.2^{a}	4.5^{a}	4.5^{a}
	Mean	**1.8**	**3.2**	**3.4**	**3.3**
PUE_a (kg seed ha^{-1} mm^{-1})	99/00	2.0^{b}	3.2^{a}	3.7^{a}	3.4^{a}
	00/01	1.4^{b}	1.9^{a}	2.0^{a}	1.9^{a}
	01/02	2.2^{b}	4.6^{a}	5.0^{a}	4.9^{a}
	Mean	**1.9**	**3.2**	**3.6**	**3.4**

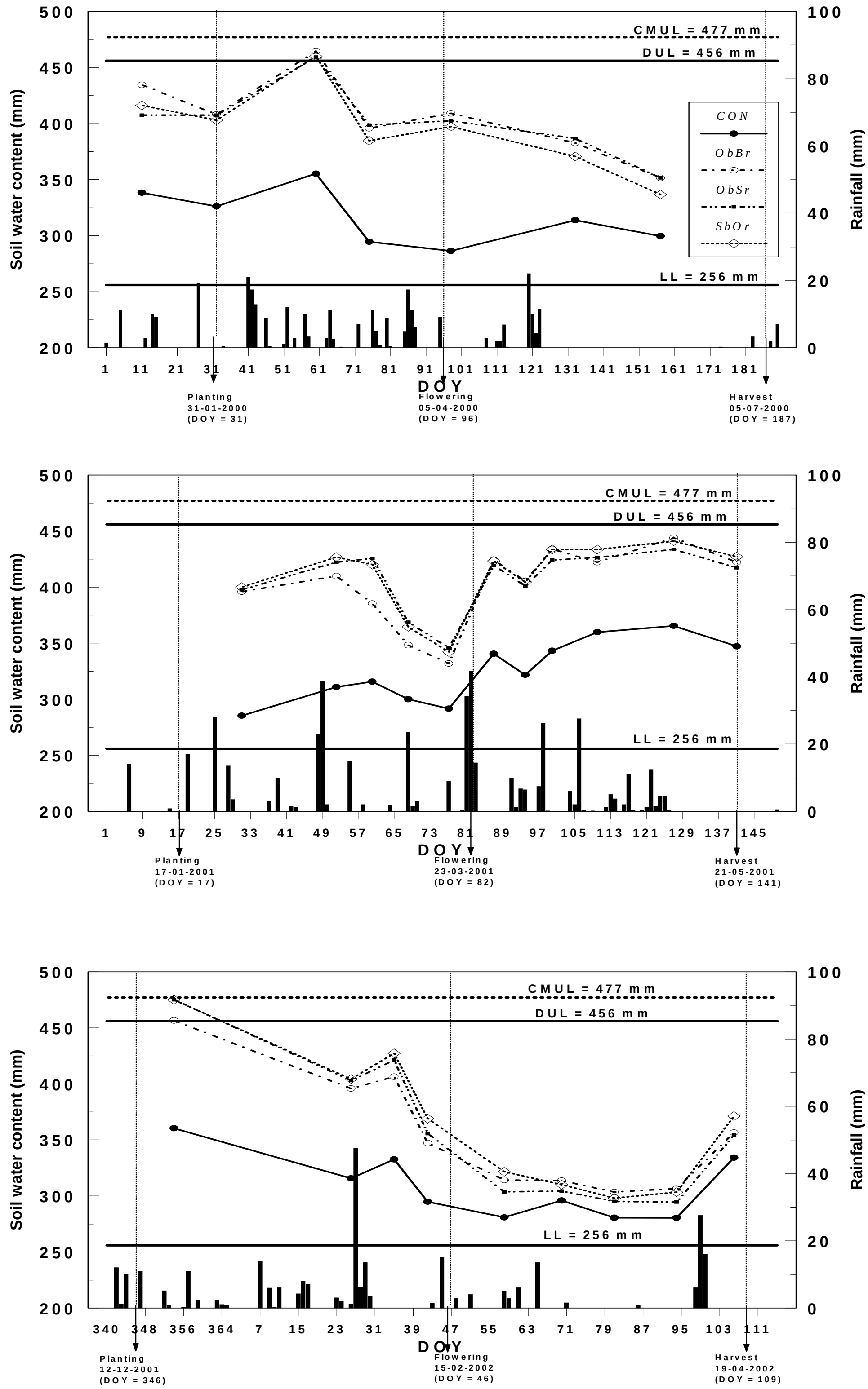
* Different superscripts refer to statistically significant differences at P = 0.05; values with similar letters are not statistically different

This trend can also be seen in the soil water pattern lines. What is of importance is the fact that the *CON* system clearly demonstrated in all the seasons how difficult it is to recharge the profile during the crop growing season, when the crop was planted at low PAW levels. There was a considerable difference in the available water content during the V_p of the three IRWH treatments versus the *CON*. In fact, the soil water patterns of all the seasons clearly indicated, from prior to flowering onwards, that the *CON* treatment depends heavily on rain as the sole supplier of water to meet the crop water demand. This induced crop water stress in all the seasons in comparison with the IRWH systems. The reduction in seed yield was estimated to be 41, 30 and 54 % relative to the mean yields obtained from the IRWH treatments for the 99/00, 00/01 and 01/02 seasons, respectively. The mean yields for the IRWH treatments were 1821, 1542 and 3025 kg ha^{-1} for the three seasons, respectively. The seed and biomass yields of the IRWH treatments were significantly higher than the *CON* in all the seasons.

The differences in ET between the IRWH treatments were non-significant, although a mean trend of *ObSr* > *SbOr* > *ObBr* was observed. The mean ET of the three IRWH treatments per season was 311, 404 and 387 mm for the 99/00, 00/01 and 01/02 seasons, respectively. On the other hand, all the IRWH treatments, except *SbOr* of the 01/02 season, induced a significantly higher ET than the *CON*, irrespective of the season. It was estimated that the reduction in ET amounted to 19, 20 and 11 %, respectively, relative to the mean ET per season.

The water use efficiency results (WUE_{ET}, PUE_a and PUE_{fg}) indicate a common trend for the IRWH treatments, *viz*. *ObSr* > *SbOr* > *ObBr*. Differences between these treatments were not significant. The experimental means of the IRWH treatments concerning WUE_{ET}, PUE_a and PUE_{fg} were 5.8, 3.4 and 3.3 kg seed ha^{-1} mm^{-1}, respectively. The corresponding means of the *CON* treatment were 4.1, 1.9 and 1.9 kg seed ha^{-1} mm^{-1}, respectively. This indicates that the IRWH systems are between 41 and 73 % more effective in converting water into food, depending on the WUE indicator used. This conclusion can be confirmed by the fact that all the WUE indicators were significantly higher than the *CON* treatment for all the seasons except 00/01 (WUE_{ET}).

a)



b)

c)

Figure 7.2 Measured changes in the soil water content of the root zone (0 – 1200 mm) during the (a) 1999/2000, (b) 2000/01 and (c) 2001/02 growing seasons on the Vlakspruit /Arcadia ecotope. The crop planted was sunflower.

7.3 ON-STATION DEMONSTRATION OF CROP ROTATIONAL SYSTEMS

The agronomic data obtained for the bean-maize rotation (block C) and the bean-sunflower rotation (block D) are summarized in Tables 7.3 and 7.4, respectively. The volumetric soil water content for the treatments of the two rotational systems are summarized in Appendices 7.3 and 7.4, respectively.

7.3.1 Monoculture versus rotational cropping: conventional tillage

7.3.1.1 Monoculture beans versus beans after maize or sunflower (rotation)

Three treatments from block C and D were selected to illustrate the effect of mono versus rotational cropping with conventional tillage, *viz.* mono bean (B_{mon}), beans in rotation with maize (B_{rm}) or sunflower (B_{rs}). These treatments can be identified as *CON*-BBB (block C, *CON*-MBM (block C) and *CON*-SBS (block D), respectively, in original experimental layout describe in Section 2.1.2. The soil water contents of the root zone for the 00/01 and 01/02 seasons are presented in Figure 7.3 a and b, respectively. The water content levels at planting showed a trend of B_{mon} >B_{rm} and B_{rs} for both seasons. This can be attributed to the effect of the preceding crop's ability to extract water from the root zone as the surface conditions (*CON*) were similar for the treatments during the fallow period. The cumulative rainfall during the fallow period for the 00/01 and 01/02 seasons was 232 and 360 mm, respectively. The corresponding rainfall storage efficiency (RSE) was small, *viz*. the mean of B_{mon} = -1 %;, B_{rm} = 16 % and B_{rs} = 1 %, stressing the disadvantage of the *CON* systems in general to store water.

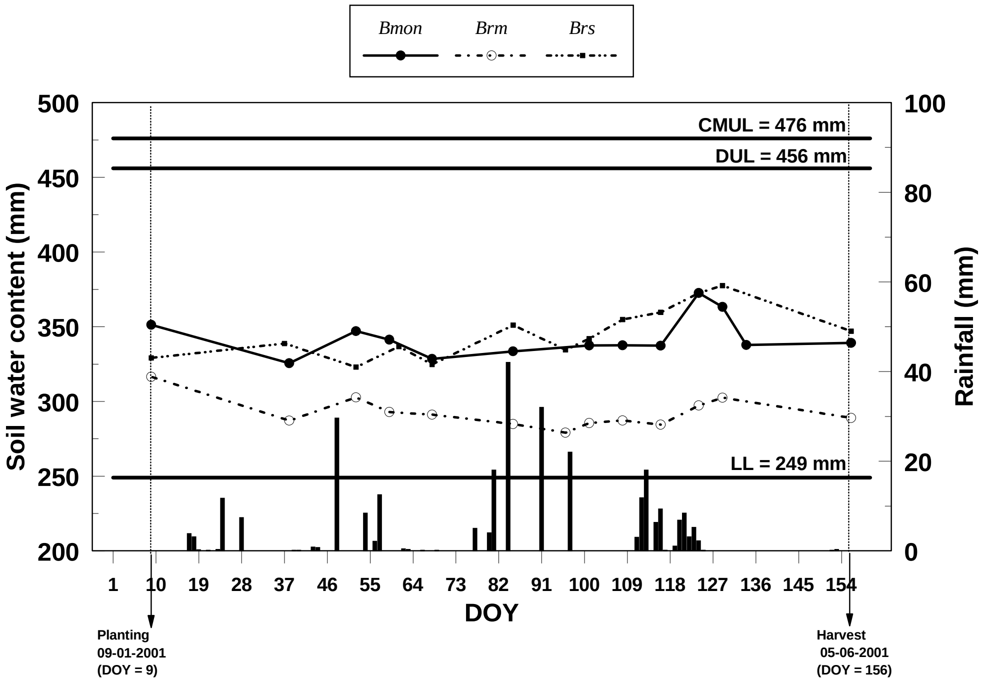
Table 7.3 Various crop and water related variables obtained from water conservation techniques demonstrated on block C of the Glen/Bonheim – Onrus ecotope.

Parameter	Year	Treatments							
		Mono cropping		Crop rotation (beans and maize)					
		B_{mon}	M_{mon}	B_{rm}			M_{rb}		
		CON	*CON*	*CON*	*ObBr*	*SbSr*	*CON*	*ObBr*	*SbSr*
Seed ($kg\ ha^{-1}$)	00/01	841	^{A}1604	542^{a}	953^{b}	1136^{c}	^{A}1489^{a}	2693^{b}	3570^{c}
	01/02	639	^{A}1704	381^{a}	931^{b}	1021^{b}	^{A}1521^{a}	3396^{b}	3940^{b}
	mean	740	1654	462	942	1079	1505	3045	3755
Biomass ($kg\ ha^{-1}$)	00/01	2023	^{A}4290	1380^{a}	2521^{b}	2826^{b}	^{A}4218^{a}	7169^{b}	8248^{b}
	01/02	1528	^{A}3900	1270^{a}	1953^{b}	2511^{c}	^{A}4203^{a}	6894^{b}	8452^{c}
	mean	1776	4095	1325	2237	2669	4211	7031	8350
Harvest index	00/01	0.42	^{A}0.37	0.39^{a}	0.38^{a}	0.40^{a}	^{A}0.35^{a}	0.38^{a}	0.43^{a}
	01/02	0.42	^{A}0.44	0.30^{a}	0.48^{b}	0.41^{b}	^{B}0.36^{a}	0.49^{a}	0.47^{b}
	mean	0.42	0.41	0.35	0.43	0.40	0.35	0.44	0.45
Pf (mm)	00/01	232	232	232	232	232	232	232	232
	01/02	360	359	360	360	360	359	359	359
	mean	296	296	296	296	296	296	296	296
Pg (mm)	00/01	280	280	281	280	280	280	280	280
	01/02	248	248	248	248	248	248	248	248
	mean	265	265	265	225	264	265	265	265
PAW_p (mm)	00/01	102	^{A}52	71^{a}	142^{b}	144^{b}	^{A}143^{a}	118^{a}	138^{a}
	01/02	56	^{A}79	47^{a}	165^{b}	179^{b}	^{B}68^{a}	130^{b}	233^{c}
	mean	79	66	59	154	162	106	124	189
ΔS (mm)	00/01	12	-8	28	-10	-20	3	-26	-5
	01/02	-21	70	109	73	81	87	143	139
	mean	-5	31	69	32	31	45	59	67
R_{EX} (mm)	00/01	32	32	32	0	0	32	0	0
	01/02	16	16	16	0	0	16	0	0
	mean	24	24	24	0	0	24	0	0
D (mm)	00/01	0	0	0	0	0	0	0	0
	01/02	0	0	0	0	0	0	0	0
	mean	0	0	0	0	0	0	0	0
ET (mm)	00/01	260	^{A}241	275^{a}	270^{b}	261^{b}	^{A}251^{a}	254^{b}	275^{c}
	01/02	210	^{A}302	341^{a}	320^{a}	329^{a}	^{B}319^{a}	391^{a}	387^{a}
	mean	236	272	309	296	295	285	323	331
RSE (%)	00/01	5	^{A}-9	1^{a}	-11^{a}	-2^{a}	^{A}12^{a}	-4^{a}	-8^{a}
	01/02	-6	^{A}13	30^{a}	20^{a}	23^{a}	^{B}24^{a}	40^{a}	39^{a}
	mean	-1	2	16	5	11	18	18	16
WUE_{ET} ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	3.2	^{A}6.6	2.0^{a}	3.5^{b}	4.4^{c}	^{A}5.9^{a}	10.6^{b}	13.0^{c}
	01/02	3.0	^{A}6.0	1.1^{a}	2.9^{b}	3.1^{b}	^{B}4.8^{a}	8.6^{b}	10.2^{b}
	mean	3.1	6.3	1.6	3.2	3.8	5.4	9.6	11.6
PUE_a ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	1.6	^{A}3.1	1.1^{a}	1.9^{b}	2.2^{c}	^{A}2.9^{a}	5.2^{b}	6.7^{c}
	01/02	1.1	^{A}2.8	0.6^{a}	1.5^{b}	1.7^{b}	^{A}2.5^{a}	5.6^{b}	6.5^{b}
	mean	1.4	2.3	0.9	1.7	2.0	2.7	5.4	6.6
PUE_{fg} ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	1.6	^{A}1.1	1.1^{a}	2.2^{b}	2.2^{c}	^{A}2.9^{a}	5.3^{b}	7.0^{c}
	01/02	1.1	^{A}3.2	0.6^{a}	1.5^{b}	1.7^{c}	^{A}2.5^{a}	5.5^{b}	6.5^{c}
	mean	1.4	2.2	0.9	1.9	2.0	2.7	5.4	6.8

Table 7.4 Various crop and water related variables obtained from water conservation techniques demonstrated on block D of the Glen/Bonheim – Onrus ecotope

Parameter	Year	Crop rotation (beans and sunflower)						
		S_{mon}	B_{rs}			S_{rb}		
		CON	*CON*	*ObBr*	*SbSr*	*CON*	*ObBr*	*SbSr*
Seed ($kg\ ha^{-1}$)	00/01	$^{A}543$	586^{a}	939^{b}	1286^{c}	$^{A}582^{a}$	1049^{b}	1211^{c}
	01/02	$^{A}1442$	318^{a}	692^{b}	699^{b}	$^{B}1956^{a}$	2712^{b}	2748^{b}
	mean	993	452	816	993	1269	1881	1980
Biomass ($kg\ ha^{-1}$)	00/01	$^{A}1482$	1610^{a}	2767^{b}	3114^{b}	$^{A}1492^{a}$	2402^{b}	2997^{b}
	01/02	$^{A}3827$	1233^{a}	1997^{b}	2096^{b}	$^{A}3826^{a}$	5848^{b}	5843^{b}
	mean	2655	1422	2382	2605	2659	4125	4420
Harvest index	00/01	$^{A}0.37$	0.36^{a}	0.34^{a}	0.41^{a}	$^{A}0.39^{a}$	0.44^{a}	0.40^{a}
	01/02	$^{A}0.51$	0.26^{a}	0.35^{a}	0.33^{a}	$^{A}0.51^{a}$	0.46^{a}	0.47^{a}
	mean	0.44	0.31	0.35	0.37	0.45	0.45	0.44
Pf (mm)	00/01	232	232	232	232	232	232	232
	01/02	360	360	360	360	360	360	360
	mean	296	296	296	296	296	296	296
Pg (mm)	00/01	280	280	280	280	280	280	280
	01/02	248	248	248	248	248	248	248
	mean	264	264	264	264	264	264	264
PAW_p (mm)	00/01	$^{A}38$	54^{a}	96^{a}	117^{a}	$^{A}27^{a}$	86^{ab}	96^{b}
	01/02	$^{A}56$	79^{a}	70^{b}	112^{b}	$^{A}96^{a}$	54^{a}	112^{a}
	mean	47	67	83	115	62	70	104
ΔS (mm)	00/01	-22	-22	-1	-2	-73	-39	-34
	01/02	45	30	-14	20	46	-14	43
	mean	12	4	-7.5	9	-14	-27	4.5
R_{EX} (mm)	00/01	32	32	0	0	32	0	0
	01/02	16	16	0	0	16	0	0
	mean	24	24	0	0	24	0	0
D (mm)	00/01	0	0	0	0	0	0	0
	01/02	0	0	0	0	0	0	0
	mean	0	0	0	0	0	0	0
ET (mm)	00/01	$^{A}226$	226^{a}	279^{a}	279^{a}	$^{A}176^{a}$	242^{a}	247^{a}
	01/02	$^{A}277$	261^{a}	233^{a}	267^{a}	$^{A}278^{a}$	233^{a}	291^{a}
	mean	252	244	256	273	227	238	269
RSE (%)	00/01	-9	-9	-17	-1	-31	-17	-14
	01/02	13	8	-4	6	13	-4	12
	mean	-3	-0.5	-10.5	3	-1	-11	-1
WUE_{ET} ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	$^{A}2.4$	2.6^{a}	3.9^{a}	4.3^{a}	$^{A}3.3^{a}$	3.9^{b}	5.2^{b}
	01/02	$^{A}7.1$	1.3^{a}	3.0^{b}	2.6^{b}	$^{A}5.2^{a}$	11.6^{b}	9.4^{b}
	mean	4.8	2.0	3.5	3.5	4.3	7.8	7.3
PUE_a ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	0.9	1.0^{a}	1.6^{b}	2.2^{b}	$^{A}1.0^{a}$	1.8^{b}	2.0^{b}
	01/02	2.4	0.5^{a}	1.1^{b}	1.2^{b}	$^{A}3.2^{a}$	4.5^{b}	4.5^{b}
	mean	1.7	0.8	1.4	1.7	2.1	3.2	3.3
PUE_{fg} ($kg\ seed\ ha^{-1}\ mm^{-1}$)	00/01	$^{A}1.1$	1.1^{a}	2.0^{b}	2.5^{b}	$^{A}1.1^{a}$	2.0^{b}	2.4^{b}
	01/02	$^{A}3.2$	0.5^{a}	1.1^{b}	1.2^{b}	$^{B}2.2^{a}$	3.1^{b}	4.5^{b}
	mean	2.2	0.8	1.6	1.9	1.7	1.6	3.5

a)



b)

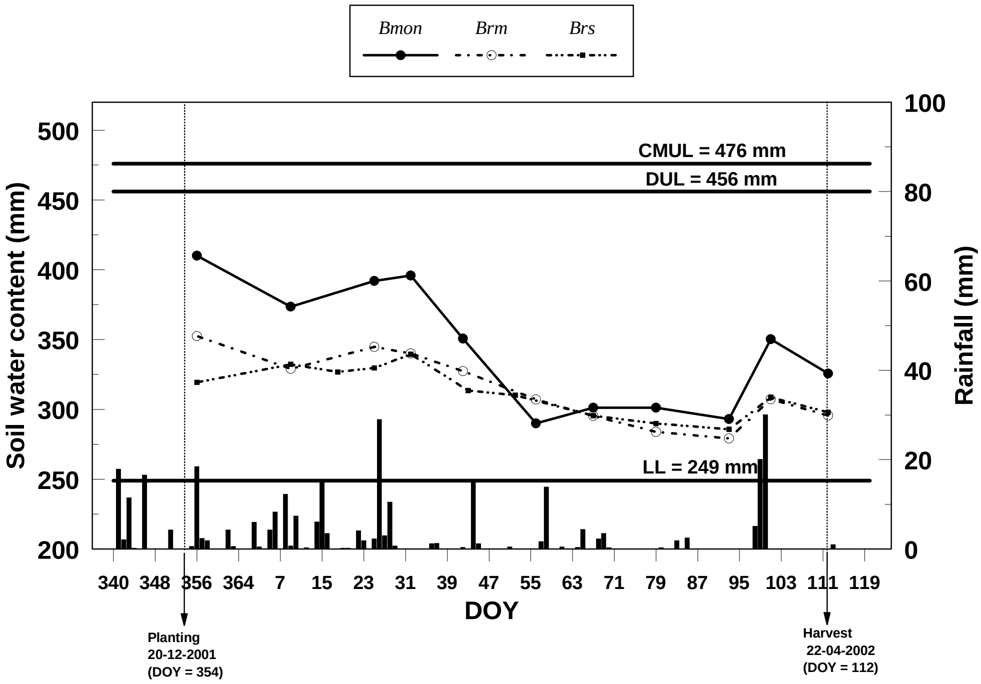
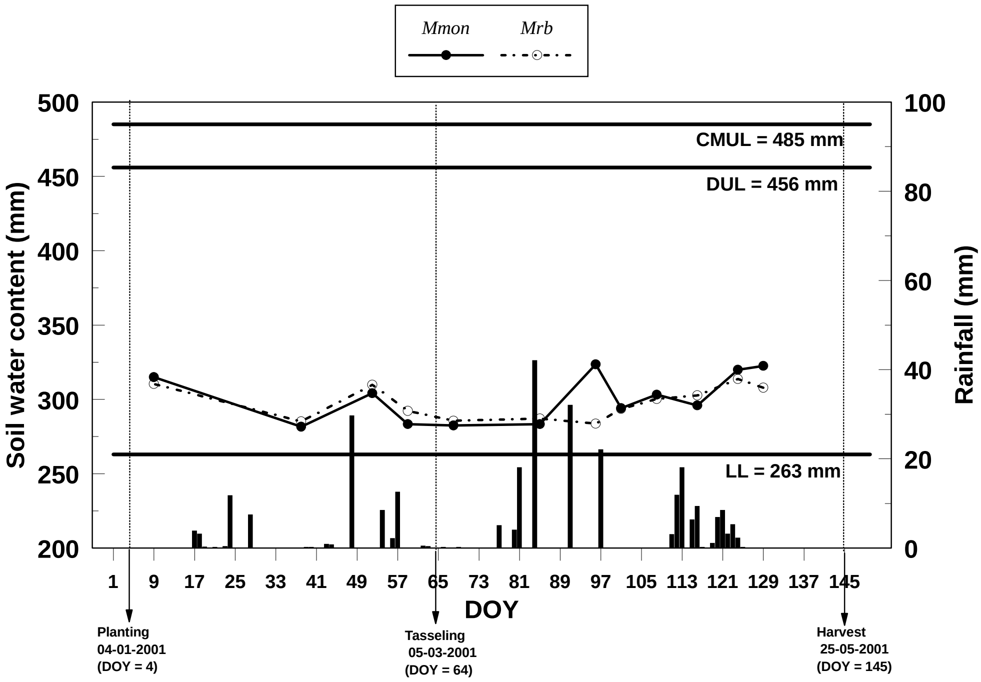


Figure 7.3 Measured changes in the water contents of the root zone (0 – 1200 mm) for monoculture beans (B_{mon}), beans after maize (B_{rm}) and beans after sunflower (B_{rs}) during the (a) 00/01 and (b) 01/02 growing seasons on the Glen/Bonheim–Onrus ecotope.

7.3.1.2 Monoculture maize versus maize after beans

Monoculture maize (M_{mon}) was compared to maize after beans (M_{rb}) by using the results in Table 7.3 and the soil water content as presented in Figure 7.4 a and b for the two seasons, respectively. In this case, it seems as if the PAW at planting was similar for the treatments of 00/01 growing season, while the M_{mon} was slightly lower in the 01/02 season. The water content lines showed similar patterns for the treatments. Soil water levels were close to the LL during the vegetative period of the 00/01 season. The water levels responded slightly to a series of rainfall events that occurred from DOY 75. Seed and biomass yields of M_{mon} and M_{rb} did not differ significantly as expected from the soil water depletion patterns. The same conclusion was made for the 01/02 season. In this case, the soil water content of both treatments decreased gradually from planting towards deep into the reproductive period. Both treatments went below the LL, indicating severe water stress from approximately DOY 65 to 98. The statistical results on these WUE indicators showed no difference between treatments. The mean WUE_{ET}, PUE_a and PUE_{fg} were 6.3, 2.3 and 2.2 for M_{mon}, respectively, and 5.4, 2.7 and 2.7 for M_{rb}, respectively.

a)



b)

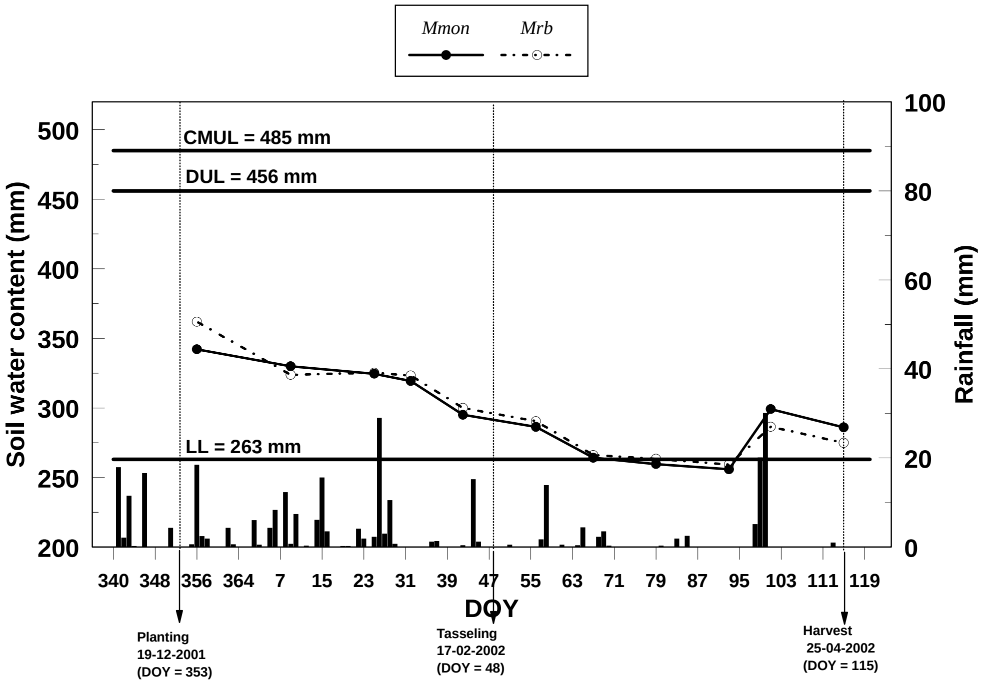


Figure 7.4 Measured changes in the water contents of the root zone (0 – 1200 mm) for monoculture maize (M_{mon}) versus maize after beans (M_{rb}) during the (a) 00/01 and (b) 01/02 growing seasons on the Glen/Bonheim–Onrus ecotope.

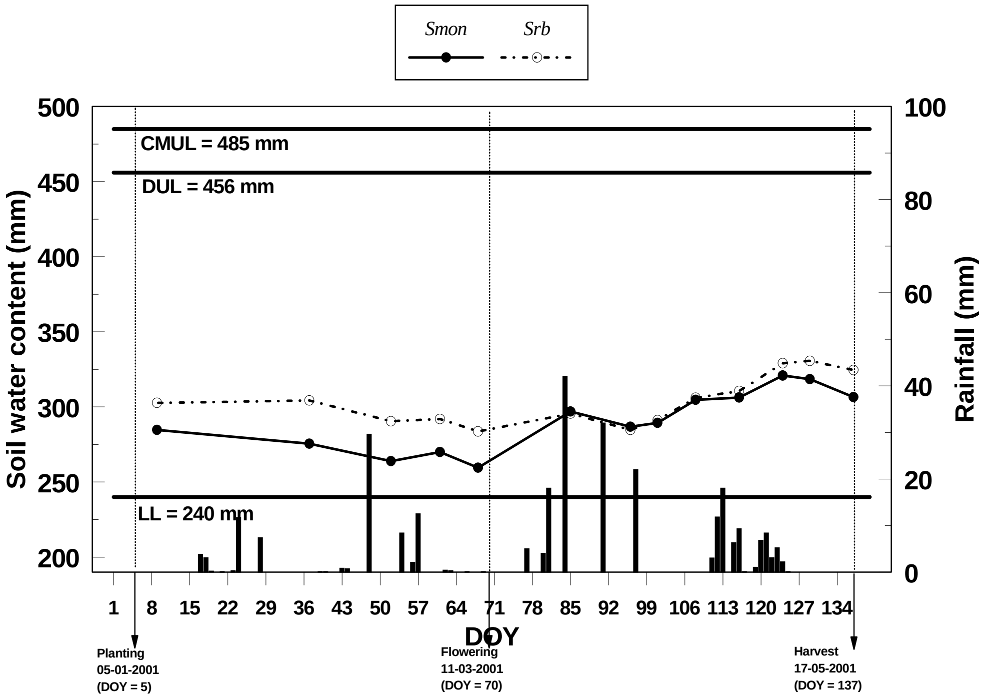
7.3.1.3 Monoculture sunflower versus sunflower after beans

Monoculture sunflower (S_{mon}) was compared to a bean sunflower rotation (S_{rb}) and the results of the soil water contents are depicted in Figures 7.5 and 7.6 for the 00/01 and 01/02 seasons, respectively. In both the seasons, more so in the 01/02 season, the S_{rb} treatment started the growing season with a slightly higher water content, which probably helped to obtain a slight seed and biomass advantage above the S_{mon} treatment. However, this advantage was not significantly. Yields of both treatments were extremely low during the 00/01 season, *viz.* 543 and 582 kg ha^{-1} for the S_{mon} and S_{rb} treatments, respectively. The soil water content lines reflected this yield as the water content was near the LL during the whole vegetative and most sensitive growth stage (flowering). On the other hand, crop conditions during the vegetative period of the 01/02 season were more favourable than in the 00/01 season. This helped both treatments to establish a higher potential yield at flowering, whereafter both treatments depended heavily on timely rains. The seed yields were 1442 and 1956 kg ha^{-1} for the S_{mm} and S_{rb} treatments, respectively.

The soil water content lines clearly showed no potential for drainage for both treatments, irrespective of the season. Runoff was estimated to be 32 and 16 mm for the 00/01 and 01/02 season, respectively, for both treatments. ET was not significant for both seasons. None of the WUE indicators were significantly different. The mean WUE for S_{mm} was 4.8, 1.7 and 2.2 kg ha^{-1} mm^{-1}, based on WUE_{ET}, PUE_a and PUE_{fg}, respectively. For S_{rb} it was 4.3, 2.1 and 1.7 kg ha^{-1} mm^{-1}, respectively.

The beans received 280 and 248 mm rain during the 00/01 and 01/02 growing season, respectively. Drainage was zero and runoff was estimated to be 32 and 16 mm during the growing seasons, respectively. Soil water levels were relatively low during the 00/01growing season for all treatments, with B_{mon} slightly higher than B_{rm} and B_{rs}.

a)



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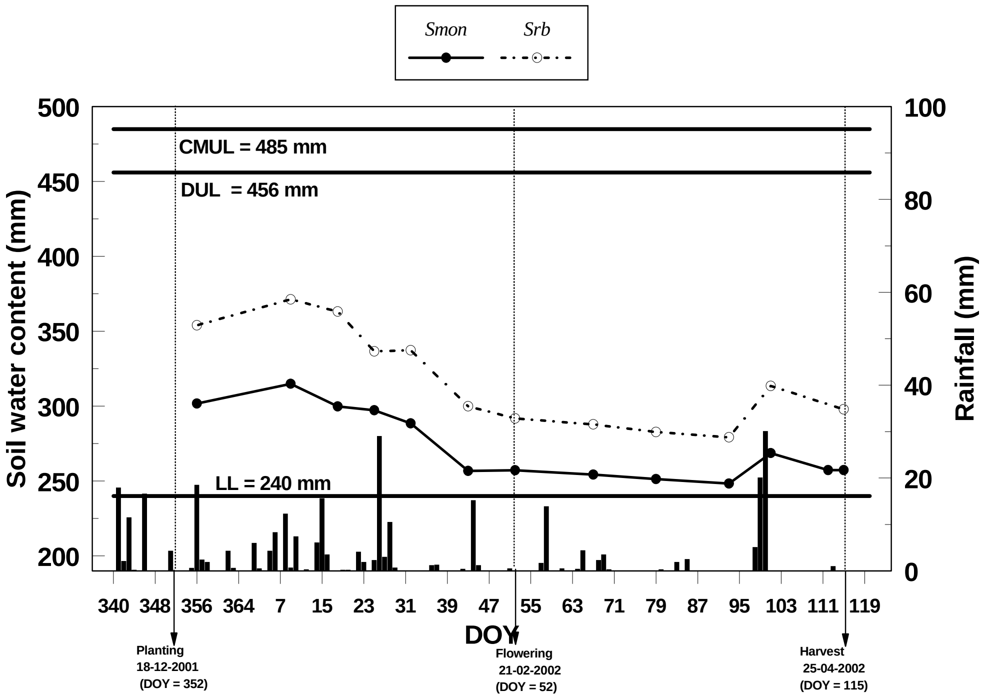


Figure 7.5 Measured changes in the water contents of the root zone (0 – 1200 mm) for monoculture sunflower (S_{mon}) versus sunflower after beans (S_{rb}) during the (a) 00/01 and (b) 01/02 growing seasons on the Glen/Bonheim – Onrus ecotope.

7.3.2 Comparison of water conservation techniques response to crop rotational practices

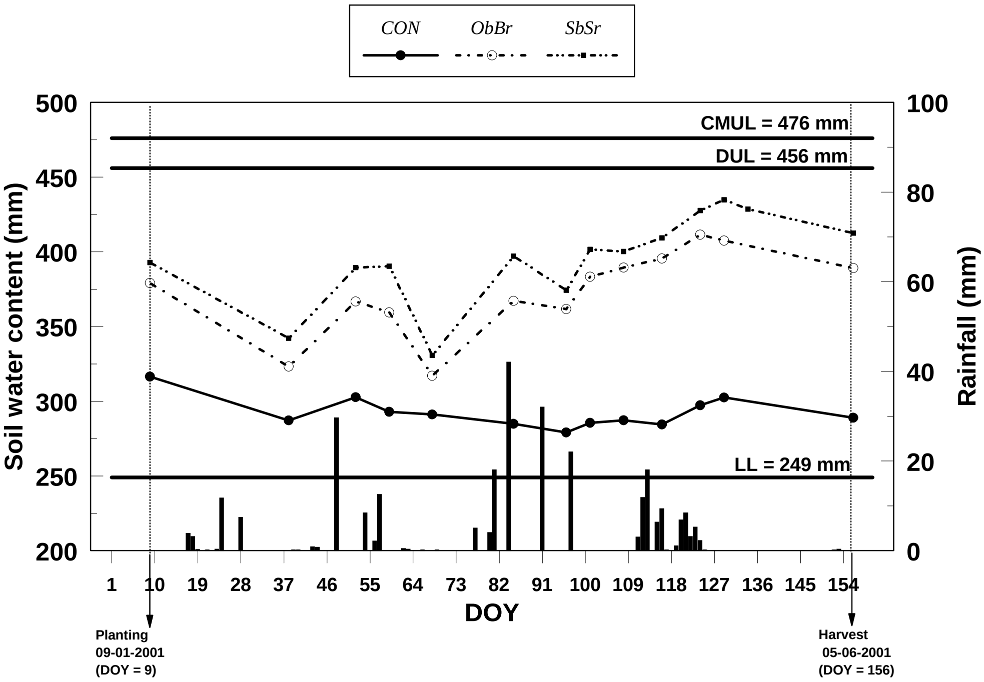
7.3.2.1 Beans after maize

Three water conservation techniques, *viz*. *CON*, *ObBr* and *SbSr,* were compared with regard to their crop performance. In this case, the preceding crop was maize and the relevant crop variables are summarized in Table 7.3 as B_{rm} treatments. Changes in the water content of the root zone are depicted in Figure 7.6 for the three treatments during the growing seasons of (a) 00/01 and (b) 01/02. Ex-field runoff was estimated to be 32 and 16 mm for the *CON* treatment of the 00/01 and 01/02 growing seasons, respectively. Drainage was zero for all the treatments during the 00/01 season. There was a potential for drainage just after planting in the 01/02 season as the water content lines of the IRWH treatment went above the CMUL. It was argued that the water would become available through capillary forces later in the season and hence drainage was assumed to be zero.

The PAW at planting of the two IRWH treatments was significantly higher than the *CON* in both the seasons. This water advantage helped the crops to reach the optimum yield levels near and above 1 ton ha^{-1} and the trend of *SbSr* > *ObBr* > *CON* was observed for both seasons for seed and biomass yield. The two IRWH treatments were significantly larger than the *CON*. The seed yield of *SbSr* was also significantly higher than *ObBr* during the 00/01 season. This yield trend is also reflected in the soil water lines during the growing seasons. The characteristic of the IRWH systems to conserve water and its effect on yield are clearly visible in both seasons: (i) during the 01/02 season the stored water in the profile of the two IRWH treatments supported the crop to maintain an optimum evapotranspiration level to ensure optimum yield; and (ii) in the 00/01 season the water content rises sharply from DOY 70 onwards in response to the water harvested in the basins, giving the next crop a pre-plant water advantage.

A very strong trend in water use efficiency was observed in both seasons, irrespective of the WUE indicator, *viz. SbSr* > *ObBr* > *CON*. WUE_{ET}, PUE_a and PUE_{fg} of *SbSr* and *ObBr* were in other years significantly higher than *CON*. During the first season there was a significant difference observed between *SbSr* and *ObBr*.

a)



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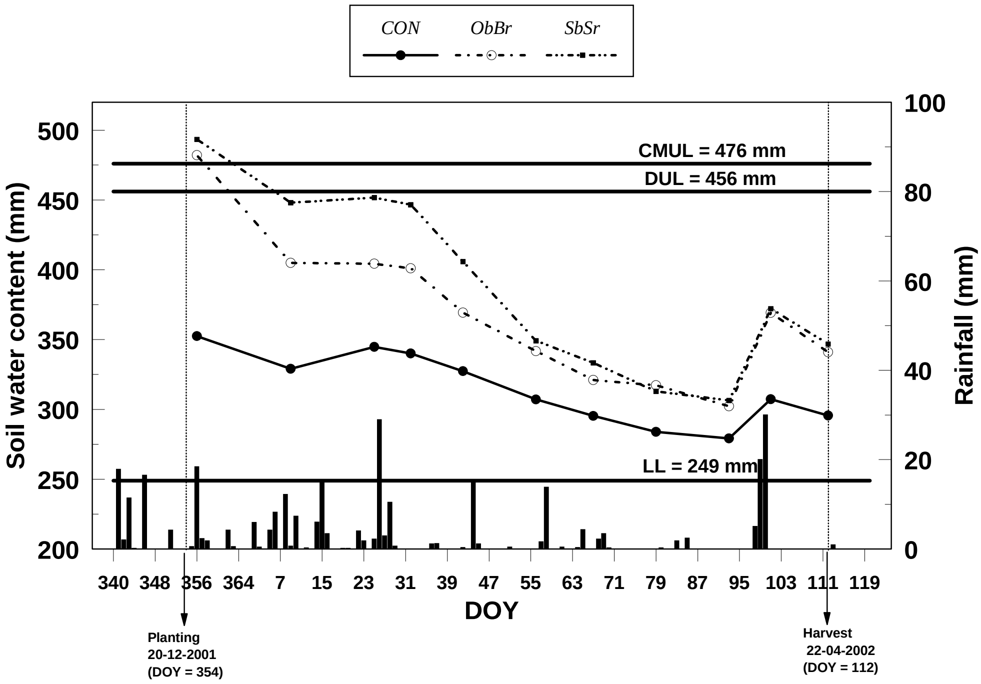


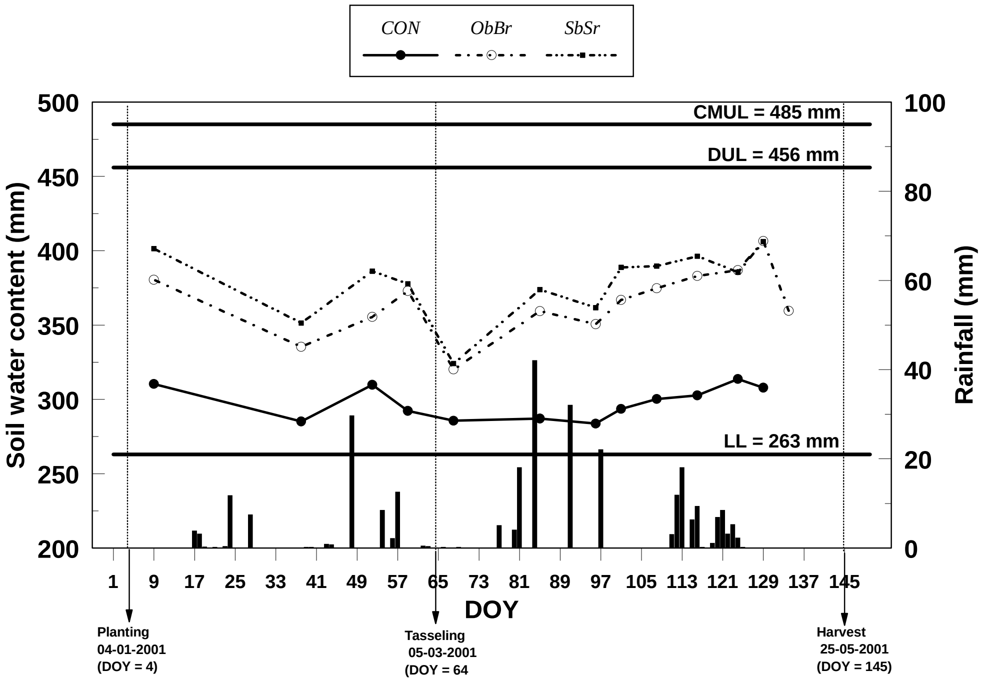
Figure 7.6 Changes in the water contents of the root zone (0 – 1200 mm) for beans planted in a crop rotation system with maize during the (a) 2000/01 and (b) 2001/02 growing seasons on the Glen/Bonheim-Onrus ecotope with three cultivation treatments.

7.3.2.2 Maize after beans

Three maize treatments, *viz*. *CON*, *ObBr* and *SbSr* from block C, were compared in terms of their crop performance. Beans was the preceding crop. Seed yields varied between 2693 and 3940 kg ha^{-1} for the two IRWH treatments over the two seasons, while the yields for *CON* were 1489 and 1521 kg ha^{-1} for the 00/01 and 01/02 seasons, respectively. As in the case of the beans in the previous section, a strong trend in seed and biomass yield was observed, *viz*. *SbSr* > *ObBr* > *CON*. Both the *SbSr* and *ObBr* yields were significantly higher than *CON*. The *SbSr* treatment was also significantly higher than *ObBr* during the 00/01 season. The change in soil water content during the season supported the observed yield trend. The ability of the IRWH system to capture, store and supply water are clearly visible in both the graphs (Figure 7.7), as explained with beans in the previous section.

The WUE indicators produced the same trend as observed with the yields, *viz*. *SbSr* > *ObBr* > *CON*. The WUE_{ET} varied between 8.6 and 11.6 kg ha^{-1} mm^{-1} over the two seasons for the two IRWH treatments, while for *CON* it was 4.8 and 5.4 kg ha^{-1} mm^{-1} for the 00/01 and 01/02 seasons, respectively. PUE_a varied between 5.2 and 6.7 over the two seasons for the IRWH treatments and for *CON* reached values of 2.5 and 2.7 kg ha^{-1} mm^{-1} for the 00/01 and 01/02 seasons, respectively. PUE_{fg} varied between 5.3 and 70 kg ha^{-1} mm^{-1} for the IRWH treatments, while for *CON* it amounted to 2.9 and 2.5 kg ha^{-1} mm^{-1} for the 00/01 and 01/02 seasons, respectively. *SbSr* and *ObBr* were significantly better than *CON* in both seasons, irrespective of the WUE indicator.

a)



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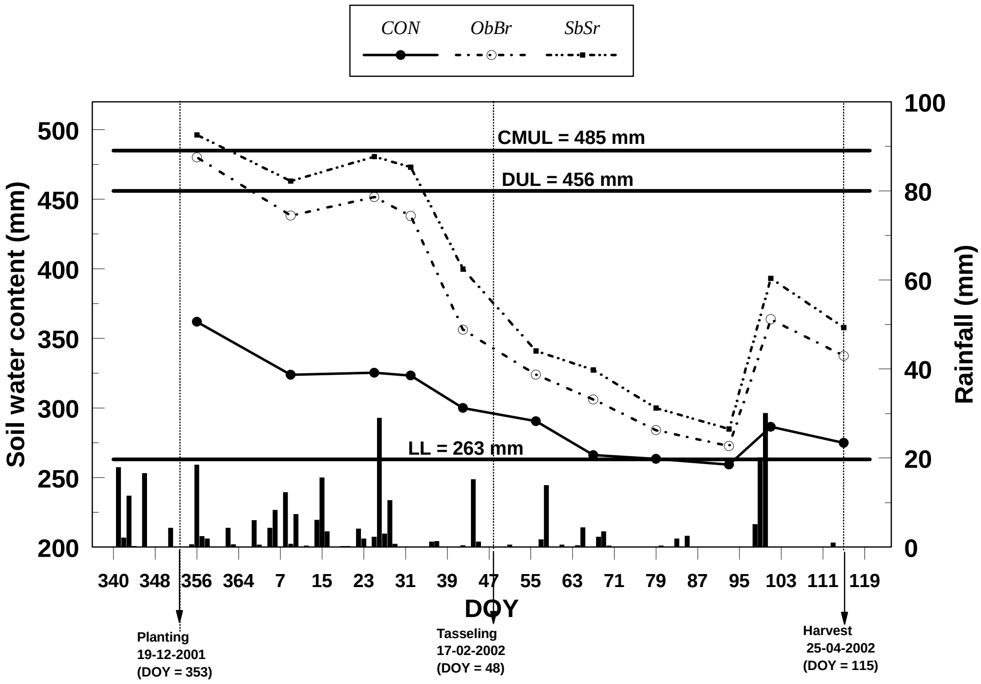
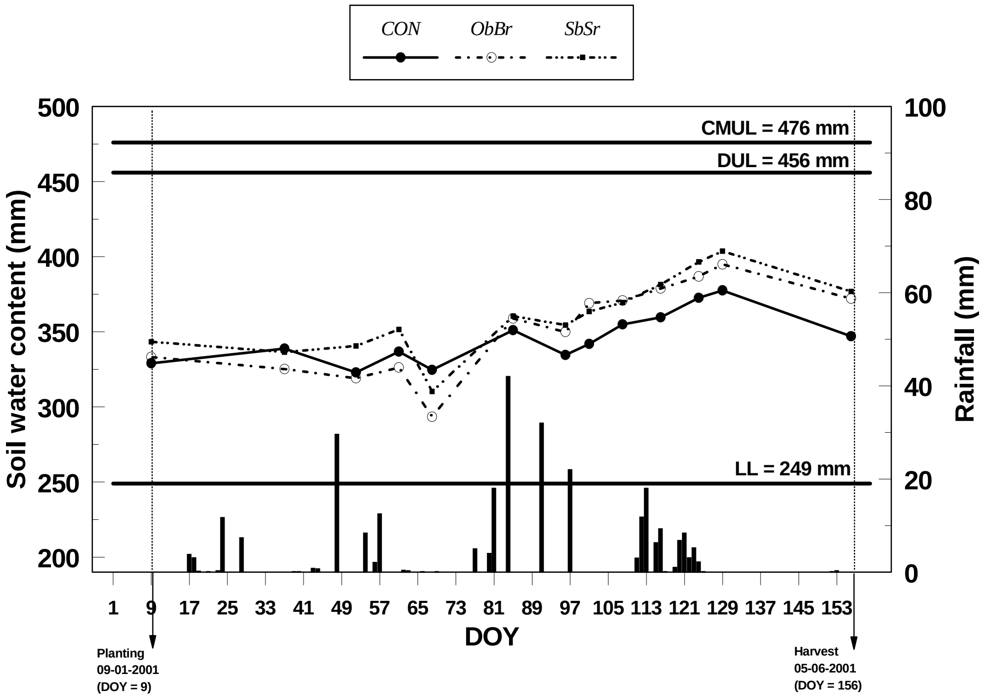


Figure 7.7 Changes in the water contents of the root zone (0 – 1200 mm) for maize planted in a crop rotation system with beans during the (a) 2000/01 and (b) 2001/02 growing seasons on the Glen/Bonheim – Onrus ecotope with three cultivation treatments.

7.3.2.3 Beans after sunflower

The soil water contents of the three selected treatments of block D, *viz*. *CON*, *ObBr* and *SbSr*, are presented in Figure 7.8 for the (a) 00/01 and (b) 01/02 growing seasons, respectively. Results of the parameters measured or estimated are summarized in Table 7.4. Yield trends for seed and biomass are similar, *viz. SbSr* > *ObBr* > *CON*. In both seasons *CON* was significantly lower than the two IRWH treatments. The mean seed yields were 993, 816 and 452 kg ha^{-1}, respectively, which is slightly lower than the corresponding yields obtained for beans after maize (Section 7.3.2.1). This is expected due to the lower PAW at planting associated with planting after sunflower, which has the ability to explore the soil volume for water. A very good example is the soil water content at planting for the 00/01 season. In this case there were no significant differences between the three treatments. On the other hand, the 01/02 season showed a significantly higher PAW_p for the two IRWH treatments in comparison to the *CON*. This can be attributed to the 128 mm more rainfall that fell during the fallow period of the 01/02 season. Rainwater captured through the in-field water harvesting process during the fallow period supported the crop thoughout the season. The obtained WUE showed the same trends and magnitude as beans after maize.

a)



b)

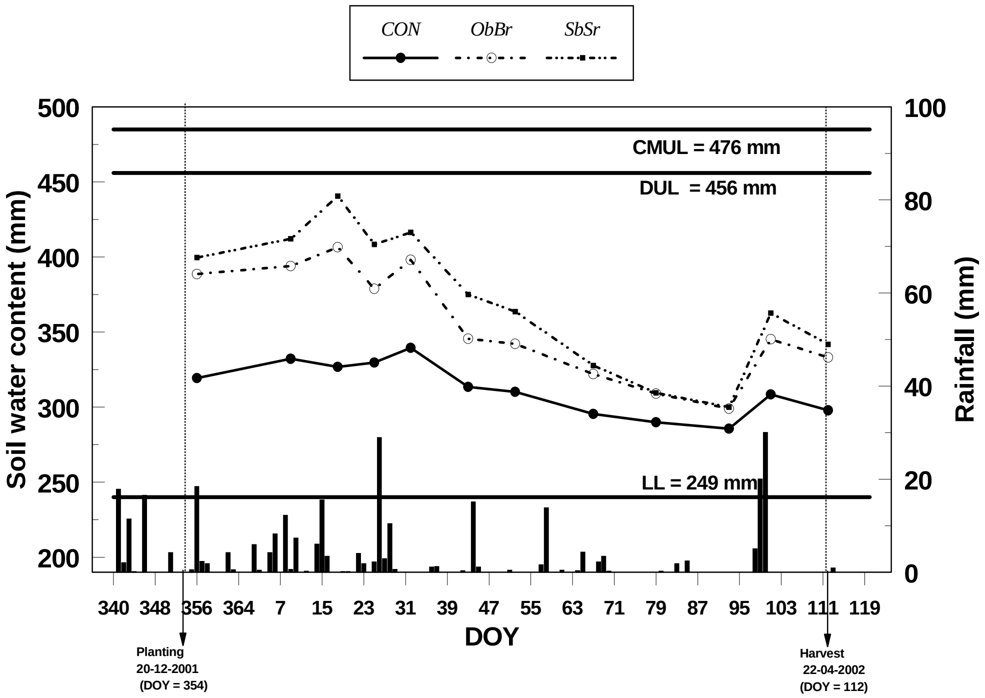


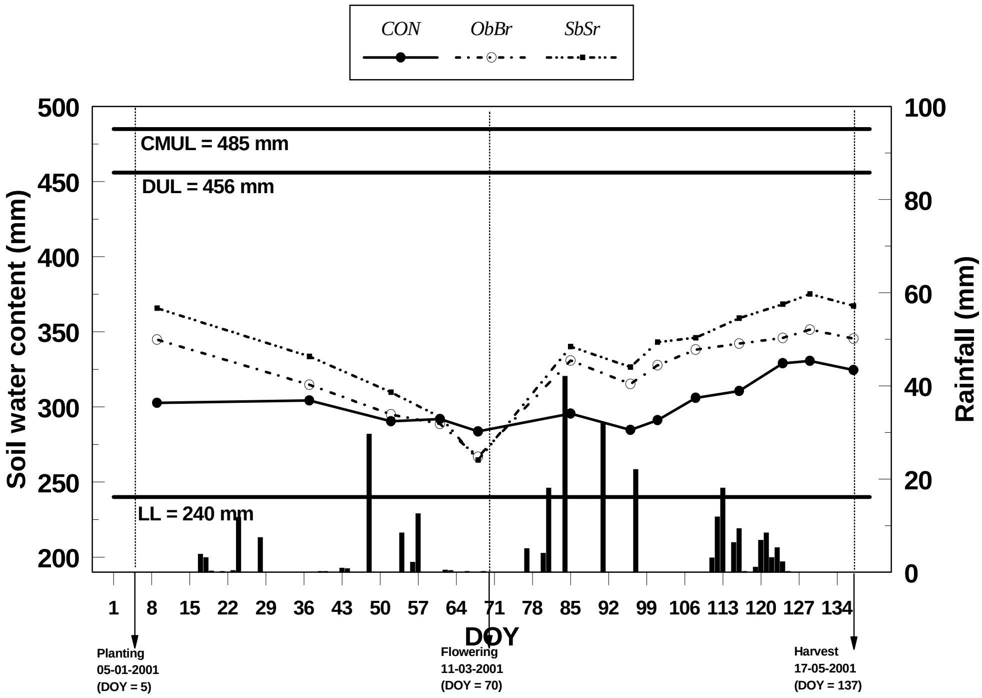
Figure 7.8 Changes in the water contents of the root zone (0 – 1200 mm) for beans planted in a crop rotation system with sunflower during the (a) 2000/01 and (b) 2001/02 growing seasons on the Glen/Bonheim - Onrus ecotope with three cultivation treatments.

7.3.2.4 Sunflower after beans

Results for the three treatments, *viz*. *CON* > *ObBr* and *SbSr*, of block D are summarized in Table 7.4. Soil water contents are presented in Figure 7.9 for the (a) 00/01 and (b) 01/02 seasons, respectively. Sunflower planted in the 01/02 season started with higher PAW values than the 00/01 season, mainly due to the higher rainfall during the fallow period of the 01/02 season. This made a considerable difference in the water supply to the crop and hence the yield. The *SbSr*, *ObBr* and *CON* yielded 127, 158 and 236 % more seed, respectively, during the 01/02 season than in the 00/01 season. This was achieved despite a rising water content during the reproductive period of the 00/01 season. The relatively dry vegetative period probably restricted plant growth to an extent that it could not reach its full potential at flowering. A short dry spell before and after flowering (DOY 58 – 75) had aggravated the problem of water supply to the crops of all the treatments. However, the yield trend of *SbSr* > *ObBr* > *CON* was again prominent in both seasons.

The statistical results for the various WUE indicators showed that both *SbSr* and *ObBr* were significantly better than *CON* in converting water into food. The WUE based at ET varied between 3.7 and 11.6 kg ha^{-1} mm^{-1} for the IRWH treatments, while the *CON* converted 3.3 and 5.2 kg ha^{-1} mm^{-1} for the 00/01 and 01/02 seasons, respectively. PUE_a varied between 1.8 and 4.5 for the IRWH treatments whilst the mean for *CON* was 21 kg ha^{-1} mm^{-1}. PUE_{fg} varied between 2.0 and 4.5 kg ha^{-1} mm^{-1} for the IRWH treatments, while the mean was 1.7 kg ha^{-1} mm^{-1} for *CON*.

a)



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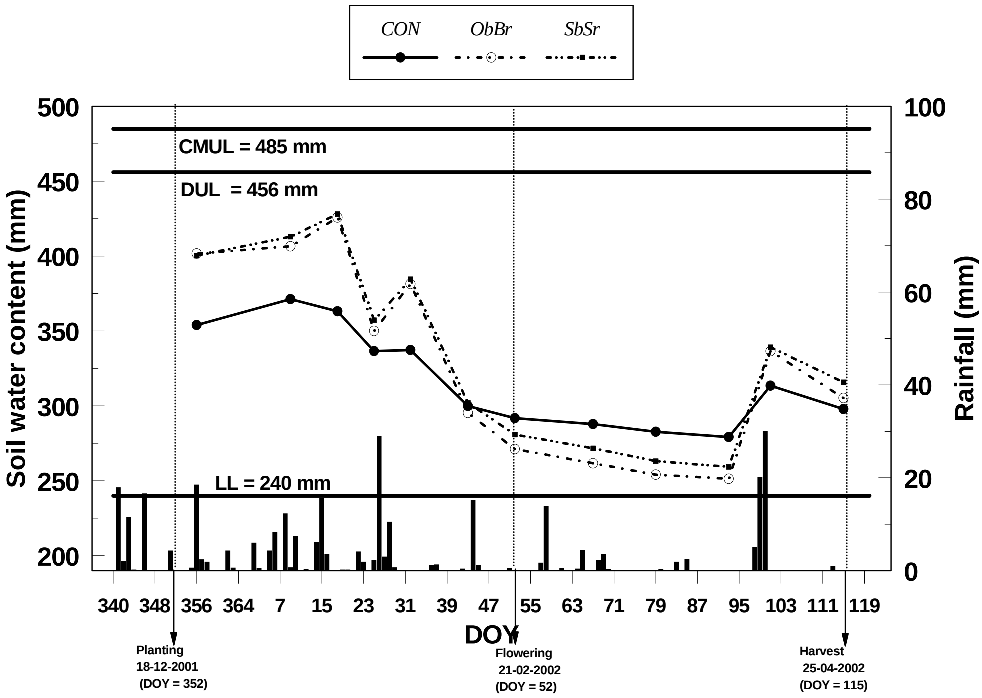


Figure 7.9 Changes in the water contents of the root zone (0 – 1200 mm) for sunflower planted in a crop rotation system with beans during the (a) 2000/01 and (b) 2001/02 growing seasons on the Glen/Bonheim-Onrus ecotope with three cultivation treatments.

7.4 SUMMARY

Two in-field rainwater harvesting (IRWH) demonstration trials over a period of three seasons, managed by the technical team in co-operation with the farmers, were conducted in the Thaba Nchu area, *viz*. Khumo/Swarland-Amandel ecotope and Vlakspruit/Arcadia-Lonehill ecotope. Treatments were selected to demonstrate water conservation advantages with the IRWH technique in comparison to conventional tillage (*CON*). Mulches were also introduced as a measure to conserve more water for cop production. Results of both experiments showed the advantage of the IRWH system in conserving water during the fallow period as well as during the growing season. Plant available water at planting was significantly higher in all the IRWH treatments in comparison with the *CON* treatment. Water conserved during the fallow period led to better plant establishment, while water conserved during the growing period led to higher sunflower yields, ET and water use efficiencies. Mulching also restricted evaporation, although differences were not always significant. Yields and water use efficiencies increased where stones and crop residue were placed on the runoff areas in comparison with the bare runoff area. Results also indicated that stone mulching is superior to organic mulching treatments.

As part of the further development programming of the IRWH system, crop rotational strategies were investigated at the Glen experimental station. Bean-maize rotation (Block C) and bean-sunflower rotation (Block D) were executed for both the *CON* and IRWH systems over a period of three growing seasons. Only the data obtained with the last two seasons were used, as the first season served to establish the required cropping sequence. For those farmers who still want to continue with *CON*, results indicated that monoculture beans performed better than rotation with maize or sunflower. These phenomena can probably be attributed to the water extraction ability of the different crops. Maize, but more so sunflower, has a larger rooting density and soil depth penetration ability than beans and hence a higher potential to exploit the root zone for water, leaving the profile with water levels near the lower limit of plant available water (LL) at the end of the growing season. Soil water content measurements on the *CON* treatments have shown how difficult it is to recharge the profile during the fallow period as well as the growing season when the crop is planted at low levels of plant available water (PAW).

Crop rotation strategies, *viz*. beans planted after maize or sunflower, maize planted after beans and sunflower planted after beans, were analyzed comparing *CON* versus the IRWH systems (*SbSr* and *ObSr*). Yields and water use efficiency results showed clearly the advantage of the IRWH system above the *CON*, irrespective of rotation strategy. The same results also showed that the mulch combination of stones in the runoff area and basin is a more efficient strategy than where the runoff area was bare with mulch in the basin.

8 LONG-TERM SIMULATED YIELDS: RESULTS AND DISCUSSION

8.1 INTRODUCTION

A crop model can be defined as a quantitative scheme for predicting the growth, development and yield of a crop, given a set of genetic coefficients and relevant environmental variables (Monteith, 1996). Crop models have many current and potential uses for answering questions in research, crop management, and policy (Boote, Jones & Pickering, 1996). Researchers can use these models as research tools to conduct research faster and more cost-effectively, while the extension officers and producers can use them to determine the risk involved in certain production practices, especially in dry areas with erratic rainfall (Hensley & Snyman, 1991). The farmer can use a model to assist in pre-season and in-season management decisions on cultivation practices, fertilization, irrigation and pesticide use (Bennie, Coetzee, van Antwerpen, van Rensburg & Burger, 1988; Bennie, Strydom & Vrey, 1998; De Jager & Singels, 1990). Crop models can assist policy makers by predicting soil erosion, leaching of agrochemicals, effects of climatic change, and by making large-area yield forecasts (Schulze, 1995). Simulation models are used to estimate potential yield in new areas, to forecast yields before harvest, to estimate sensitivity of crop production to climate change, and to compare management options, technology level, and performance of varieties (Muchow, Hammer & Carberry, 1990).

While crop models cannot produce all the answers to crop production problems, when reasonably constructed they can be important heuristic tools in teaching, research, and in management. They can be used to test hypotheses and the validity of standard practices, thereby allowing the user to reason more consistently about factors or conditions that deserve thought by students, additional experimental study by researchers, or more attention from growers. Observation, experimentation, and experience cannot be replaced by crop models, but they can be well supported by them. Because of the large number of situations where the heuristic function of crop models can be a crucial if not an indispensable tool, crop modelling can be expected to have a productive future (Sinclair & Seligman, 1996).

A valuable property of models is their ability to utilize long-term climate data to provide long-term yield simulations, which can serve to quantify risk. Before crop models were available, land use decisions had to be based on the results of field experiments at a limited number of sites and generally over relatively few seasons. This procedure has serious limitations, which can be largely overcome by the judicious use of crop models, providing they are reliable. Other valuable applications of crop models are their use to extrapolate results to ecotopes on which field experiments have not been conducted, and their use together with long-term climate data to identify the most profitable production techniques under current economic and technology conditions, e.g. which crop, best planting date, best population, best variety, best rotation etc.

To be able to make reliable recommendations concerning the best production techniques for a crop on a particular ecotope it is desirable to have long-term yields. The need for this is accentuated for ecotopes in semi-arid areas where rainfall is marginal and also erratic with regard to amount, distribution and intensity. The use of crop models with long-term climate data to achieve this objective has been widely used in agriculture for more than a decade. However, the application of this strategy for the production techniques used in this study requires more than standard crop modelling procedures. The latter will be satisfactory for the *CON* treatment. However, for IRWH, to correctly simulate the soil water regime in the region of the basins requires that one is able to correctly predict R from the runoff strip (bare, or covered with stone or organic mulch) for each rainfall event recorded in the long-term weather data set. Where mulch (stone or organic) is applied in the basins or on the runoff area, the suppression of Es by the mulch needs also to be taken into account. In addition, the effect of the different mulches on the interaction between runoff, infiltration and evaporation from the soil surface in the basins and on the runoff area needs to be quantified.

For sunflower the stress model developed by J.J. Botha and presented in Hensley *et al.* (2000) was used, and also adapted to cater for mulches on the untilled 2 m runoff area that influence runoff, infiltration and evaporation from the soil surface. The sunflower model was adapted to cater for maize and dry beans.

The model is based on a similar principle to that used by Rasmussen & Hanks (1978). The difference is that in this case the degree of stress is denied as the “dryness” of the root zone rather than an estimated ET/Eo value as used by Rasmussen & Hanks (1978). An example of one "run" is presented in Appendix 8.1.

A reliable field measured value of total extractable soil water (TESW = DUL - LL) is of fundamental importance. The level of stress being experienced by the crop is defined as the fraction of TESW (FTESW) present at any particular time. Although FTESW is a satisfactory parameter to describe stress while the soil is drying, it is not satisfactory after a rainfall event, which may, for example, just wet the top 0 - 300 mm soil layer. In that situation the crop will suffer relatively little stress while it depletes the water in the surface soil, even if the rest of the root zone is relatively dry. An adaptation to cater for this situation has been introduced. It is based on field measurements of ET/Eo on relatively dry soils after rainfall events. The adapted FTESW value is designated as $FTESW_{aa}$. Allowance is also made for D to occur when θr exceeds CMUL.

An $FTESW_{aa}$ value is calculated for each day and an average taken for periods of 10 days for dry beans and 15 days for sunflower and maize to give a stress factor (SF) for that period. The growing season is subdivided into ten 10-day periods for dry beans and eight 15-day periods for sunflower and maize, and a stress weighting factor (λ) allocated to each period in accordance with its importance in relation to yield determination. An integrated stress index, or factor, termed TSF is obtained as a multiplicative summation of the SF values for the individual periods each raised to the power of λ.

8.2 DETAILED DESCRIPTION OF THE MODEL

The model has been named CYP-SA, standing for Crop Yield Prediction for Semi-Arid areas. The inputs required by the model are DUL, LL, CMUL, P, Eo and θp. Details are presented in Appendix 8.2 concerning the various processes and parameters. An example of the calculation of the integrated stress factor (ISF) for a particular treatment for one season on an ecotope is presented in Appendix 8.1.

8.3 VALIDATION OF THE MODEL

8.3.1 Dry beans

Dry bean yields on the Bo from all treatments from blocks C and D during the 00/01 season were used to formulate the dry bean model. ISF values were calculated for each data set and a regression analysis performed of measured yields (Y) against the ISF values. The result was:
Y = (402.5764)+(704.6899)*(ISF)………………………..………………….. (r^2 = 0.73)

The next step was validation of the CYP-SA dry bean model on the Glen/Bonheim ecotope with measured yield data from all the treatments on blocks C and D for the 99/00 and 01/02 seasons. Results of model reliability tests using the procedure of Willmott (1981) are presented in Figure 8.1. Willmott (1982) points out that in a "good" model the $RMSE_s$ should approach zero, while the D-index should approach one. The difference between the $RMSE_u$ and $RMSE_s$ is a measure of the potential accuracy of the model. The $RMSE_s$ should be as small as possible; a large $RMSE_s$ indicates bias. The $RMSE_u$ should be as close as possible to the RMSE, indicating that the deviations of simulated from measured values are random. Whether accuracy or potential accuracy is evaluated, no single measure can describe model performance, and therefore an array of complementary measures should be used as suggested by Willmott (1982). According to Willmott (1982) the use of scatter plots (1:1 graphs), in conjunction with an array of complementary measures, is useful in evaluating model performance.

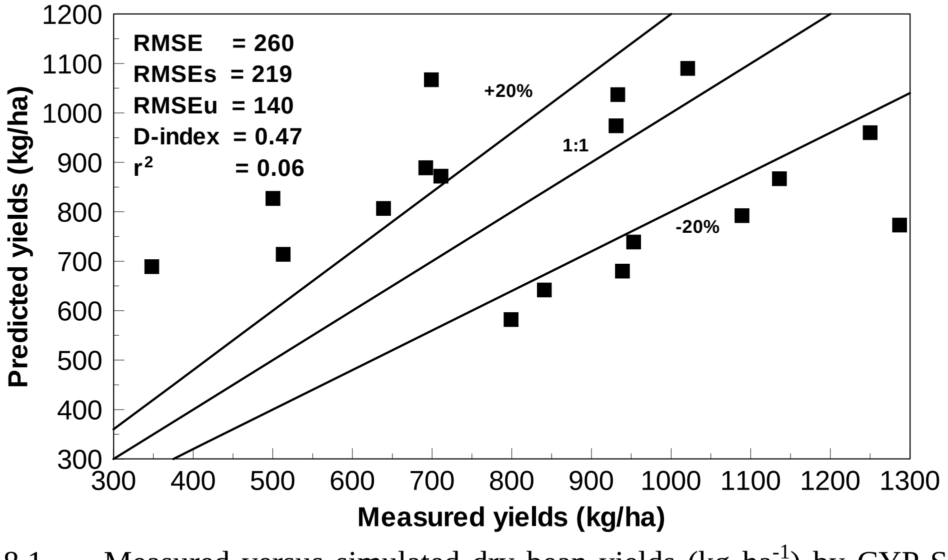


Figure 8.1 Measured versus simulated dry bean yields (kg ha^{-1}) by CYP-SA for all the treatments on the Glen/Bonheim ecotope during the 99/00 and 01/02 growing seasons.

Statistical evaluation of model performance was carried out with the MODEVAL program (Houston & Berry, 1996). The following values for the different statistical parameters were used to provide approximate guidelines for the assessment: $RMSE_s$ < 65 % of RMSE, D-index > 0.8, r^2 > 0.8 indicates good agreement; deviations from these values indicate less satisfactory agreement. The model performance was not very good or accurate. The systematic error ($RMSE_s$) was 84 % of RMSE, and D-index and r^2 values were low (not satisfactory) at 0.47 and 0.06 respectively. However, it must be taken into consideration that

CYP-SA is a soil water management program developed primarily for use by researchers in this specific project to differentiate between different treatments. Dry beans are also very difficult to simulate, especially on clay soils in the semi-arid area. Dry beans have the ability when it is too dry to flower they almost stop growing and when it is wet enough to start flowering. It must be mentioned that the aim of CYP-SA was not to create a new model to compete with existing models, it was only developed because we are dealing here with a very complicated system. Ritchie (1997) mentioned at the experimental site after seeing the IRWH system that it is a very complicated system where the runoff area and catchment area (basins) should be modelled separately. To complicate the whole system even more, mulch (organic and stone) were added to the runoff area and in the basins. At this stage none of the existing models can simulate such a complicated system. So a simple stress model was developed specifically for this system. However, when used correctly it can provide useful information for decision-making regarding agricultural water management. This is the use of CYP-SA in this study, for decision-making regarding agricultural production techniques.

8.3.2 Maize

Maize yields on the Glen/Swartland ecotope from all treatments (*CON*, *BbBr* and *ObBr*) for the 96/97, 97/98 and 98/99 seasons were used to formulate the model. ISF values were calculated for each data set and a regression analysis performed of measured yields (Y) against the ISF values. The result was:

$$Y = 10772.60*(1+((-0.3478)-1)*EXP(-(0.5460)*((ISF)-(-0.3091))))^{(1/1-(-0.3478))} \ldots\ldots (r^2 = 0.97)$$

The next step was to validate the CYP-SA maize model on the Glen/Bonheim (99/00 -01/02) ecotope with measured yield data from all the treatments. Results of model reliability tests using the procedure of Willmott (1981) are presented in Figure 8.2.

The performance of the model was very good. The systematic error ($RMSE_s$) is 49 % of RSME, lower than the threshold value of 65 % used by modellers. The D-index and r^2 values were good at 0.95 and 0.83 respectively, both higher than 0.80 which indicates good agreement.

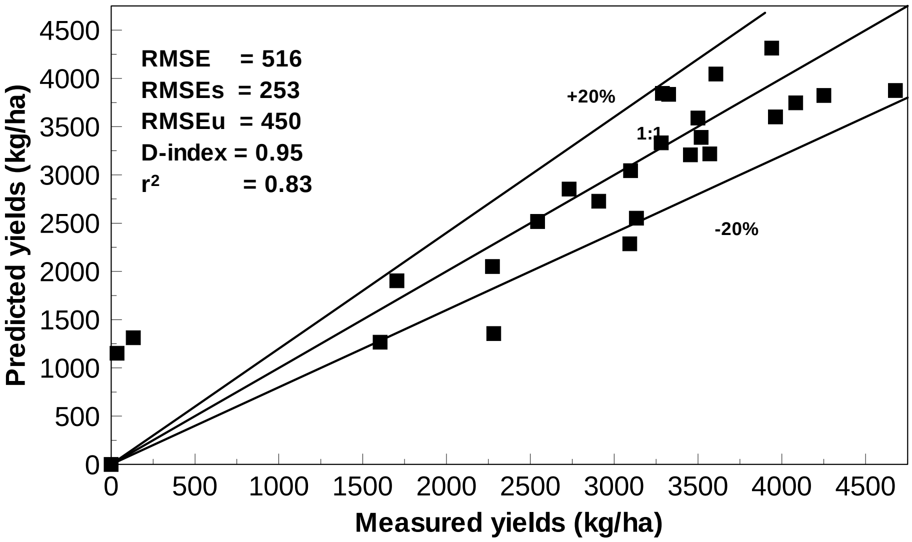


Figure 8.2 Measured versus simulated maize yields (kg ha^{-1}) by CYP-SA for all the treatments on the Glen/Bonheim ecotope during the 99/00 - 01/02 seasons.

8.3.3 Sunflower

Sunflower yields on the Glen/Bonheim and Glen/Swartland ecotopes from all the treatments (*CON*, *BbBr* and *ObBr*) for the 97/98 and 98/99 seasons from Hensley *et al.* (2000) were used to calibrate the model. ISF values were calculated for each data set and a regression analysis performed of measured yields (Y) against the ISF values**.** The result was:

Y = (ISF*6188.56)-1607.37……………………………………………………… (r^2 = 0.81)

The next step was validation of the CYP-SA sunflower model on the Glen/Bonheim (99/00 - 01/02), Khumo/Swartland (97/98 - 01/02) and Vlakspruit/Arcadia (97/98 - 01/02) ecotopes with measured yield data from all the treatments. Results of model reliability tests using the procedure of Willmott (1981) are presented in Figure 8.3.

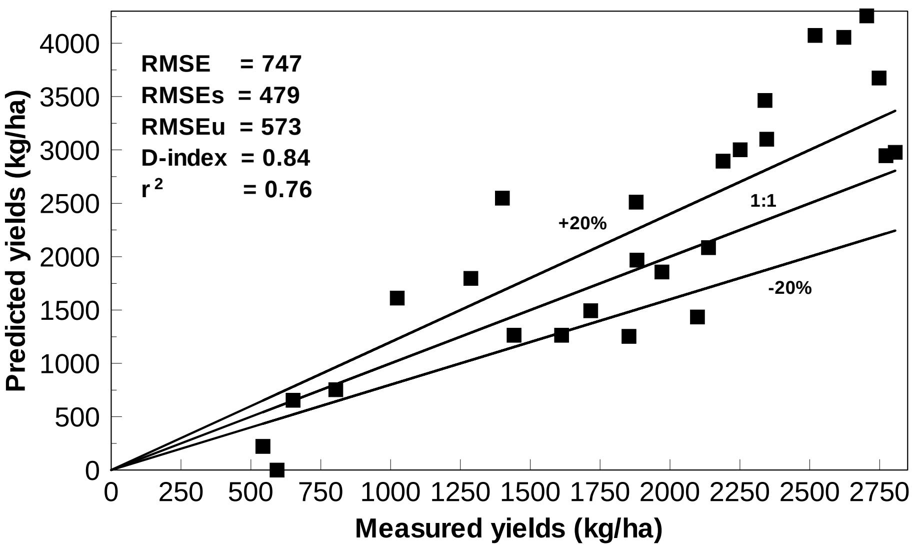


Figure 8.3 Measured versus simulated sunflower yields (kg ha^{-1}) by CYP-SA for all the treatments on the Glen/Bonheim (99/00 - 01/02), Khumo/Swartland (97/98 - 01/02) and Vlakspruit/Arcadia (97/98 - 01/02) ecotopes.

The model performed reasonably well. The D-index and r^2 values are good, 0.84 and 0.76 respectively, while the systematic error ($RMSE_s$) was 64 % of RMSE, which is lower than the threshold value of 65 %. The model simulates the yields reasonably accurately, although it seems that the model under-predicts some of the lower yields and tends to over-predict the higher yields.

8.4 LONG-TERM RISK ASSESSMENT - YIELD

A valuable property of crop models is their ability to utilize long-term climate data to provide long-term yield simulations that can serve to quantify risk. Although the dry bean results showed that the dry bean model needs to be improved before it can be used with confidence for making important land use decisions, long-term yields have nevertheless been computed for dry beans to demonstrate the value of this strategy.

A problem that arises when making long-term simulations is that the water content at planting (θ_p) in each of the growing seasons is unknown. Another problem is that the models do not simulate the water balance well during fallow seasons. The result is that if one makes an uninterrupted long-term simulation including fallow seasons, and starting with an estimated initial water content in the first year, the water content at planting in any particular year could be incorrect by a significant amount. An alternative strategy has been employed here. The same θ_p value (½ full) was used for all treatments each year. A weakness of this procedure is that it will generally under-estimate θ_p for IRWH. Spring rains before planting will generally cause this treatment to have a higher θ_p than *CON*. The planting date was taken as 17 December every year. In spite of the weaknesses in this strategy it will expose marginal and unsatisfactory treatments. It could also be used to identify suitable ecotopes and production techniques.

8.4.1 Glen/Bonheim

8.4.1.1 Dry beans

All statistical tests on cumulative probability functions were done with the Kolmogorov-Smirnov procedure.

Cumulative probability functions (CPFs), of simulated long-term dry bean yields on the Glen/Bonheim ecotope starting with a half-full root zone water content at planting for different treatments are presented in Figure 8.4. The probability presented in the figure is that of non-exceedance of the specified yield intercept on the graph. For example, for the *CON* treatment it is simulated that when starting with a half-full profile there is a 25 % (cumulative probability = 0.25) chance that a yield of 600 kg ha^{-1} will not be exceeded and a 75 % chance that a yield of 702 kg ha^{-1} will not be exceeded. It is also simulated that the *BbBr*, *ObBr*, *SbOr*, *ObOr*, *SbSr* and *ObSr* treatments have a 25 % chance that yields of 690 kg ha^{-1}, 695 kg ha^{-1}, 708 kg ha^{-1}, 711 kg ha^{-1}, 727 kg ha^{-1} and 730 kg ha^{-1}, respectively, will not be exceeded. The *BbBr*, *ObBr*, *SbOr*, *ObOr*, *SbSr* and *ObSr* treatments have a 75 % chance that yields of 828 kg ha^{-1}, 835 kg ha^{-1}, 867 kg ha^{-1}, 870 kg ha^{-1}, 888 kg ha^{-1} and 892 kg ha^{-1}, respectively, will not be exceeded. The closer the graph is to the righthand bottom corner of the figure, the higher is the potential of the production strategy.

All the IRWH treatments are shown to be highly significantly better (significance level: P = 0.01) than the *CON* treatment. This means first-degree stochastic dominance. The *ObSr* and *SbSr* treatments are shown to be significantly better (P = 0.05) than the *BbBr* and *ObBr* treatments. This implies second-degree stochastic dominance. Simulated results of the IRWH treatments indicate little benefit of mulching when starting with a half-full profile. The simulated results indicated a large benefit of IRWH compared to *CON* tillage and little benefit to yield by mulching. This result may be due to the difficulty in modelling the benefit of mulching in the basins and on the runoff area. The *ObSr* treatment is shown to be the best treatment in terms of dry bean yield, followed by the *SbSr*, *ObOr*, *SbOr*, *ObBr*, *BbBr* and *CON* treatments. All the treatments with a mulch (organic or stone) on the runoff area performed better than the treatments with a bare runoff area.

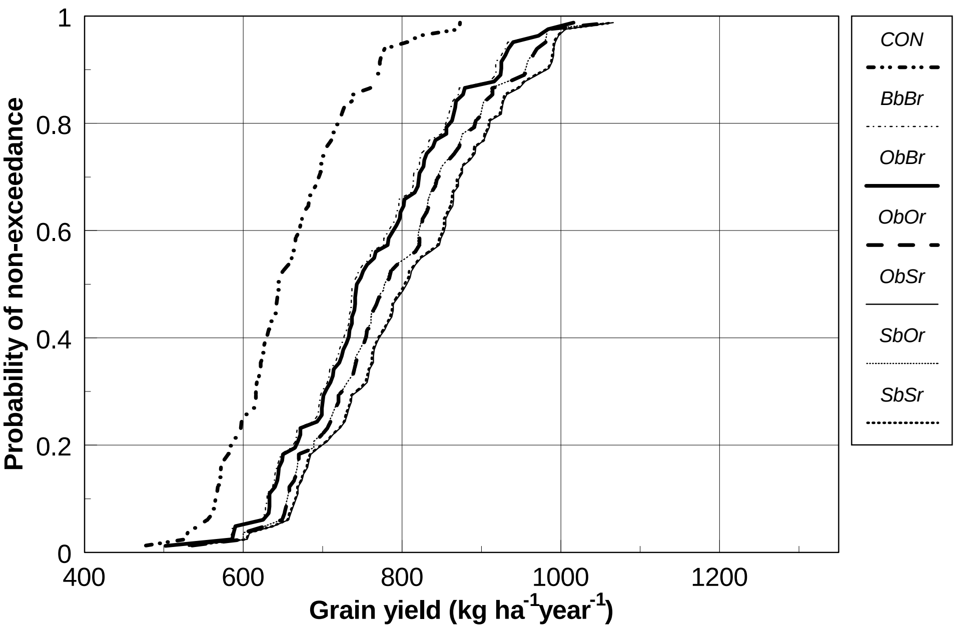


Figure 8.4 CPF graphs of long-term dry bean yields on the Glen/Bonheim - Onrus ecotope planted in the middle of December (half-full profile). The climate data used are for the 81-year period, 1922 – 2003.

The results of a simulation study to try to identify the best planting date for dry beans on the Glen/Bonheim ecotope are presented in Figure 8.5. The best water conservation treatment, *ObSr*, was used with three planting dates, *viz*., early (5th October), intermediate (17th December) and late (5th January).

CYP-SA indicated that late planting was highly significantly better (P = 0.01) than early planting, and that the intermediate date also gave significantly better (P = 0.05) results than early planting. The simulations indicated that a farmer would have an 80 % probability of harvesting 660 kg ha^{-1}, 700 kg ha^{-1} and 750 kg ha^{-1} with early, intermediate and late plantings respectively. In principle it means that a farmer would harvest on average around 100 kg ha^{-1} more if he/she planted beans late instead of early on this specific ecotope. Further interpretation shows that to harvest 800 kg ha^{-1} dry beans per year a farmer would have a 34 %, 51 % and 64 % probability of succeeding by planting early, intermediate and late, respectively. That means that a farmer would have a 30 % better chance of harvesting 800 kg ha^{-1} with the late planting compared to early planting. These differences could easily make the difference between economic success and failure. The reason for the better yields with late planting is probably the more favourable conditions at flowering provided by the March climate (Table 3.1). An additional advantage, not reflected by these results, is that the root zone water content would most probably almost be higher in January than in October due to the runoff water stored in the basins after 3 months of the rain season.

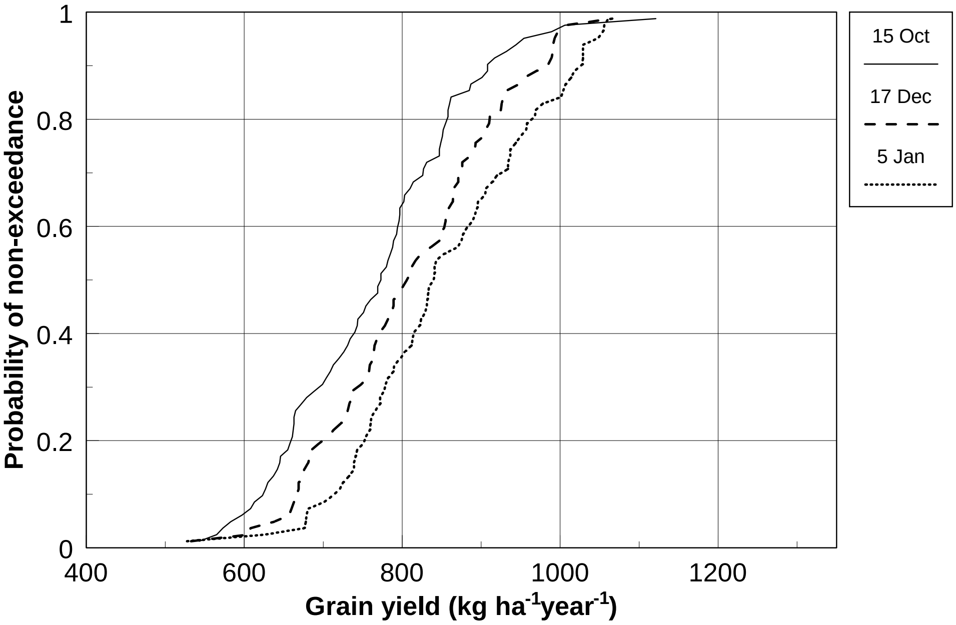


Figure 8.5 CPF graphs of long-term dry bean yields on the Glen/Bonheim - Onrus ecotope using the *ObSr* technique planted in a half-full profile with different planting dates. The climate data used are for the 81-year period, 1922 – 2003.

In Figure 8.6 the results of a simulation study with CYP-SA (dry beans) to show the influence of increasing θ_p values are presented. The planting date was 5 January and five θ_p values were used, *viz*. empty, ¼, ½, ¾ and full. Results are summarised in Table 8.1.

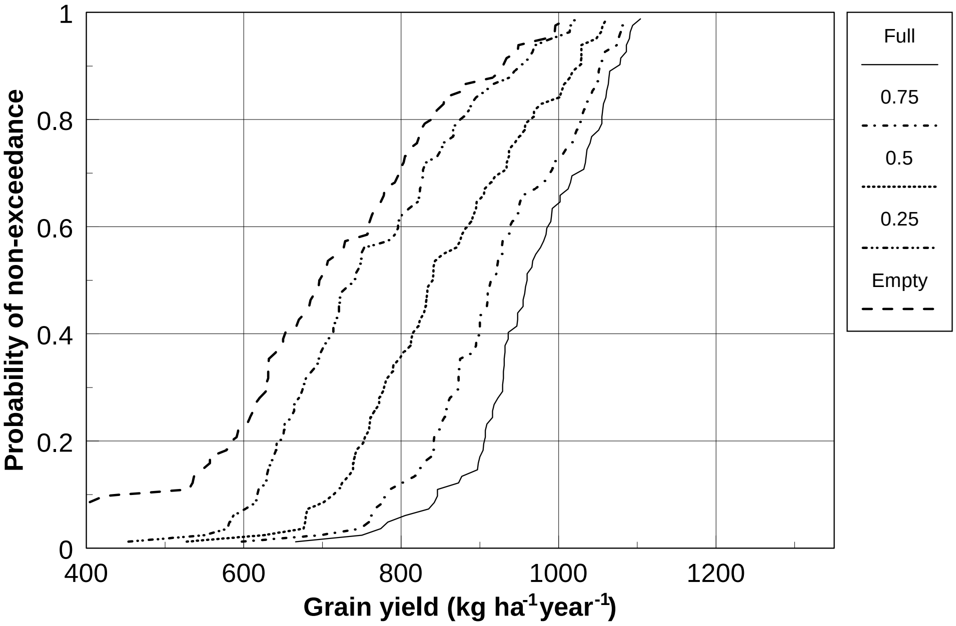


Figure 8.6 CPF graphs of long-term dry bean yields on the Glen/Bonheim - Onrus ecotope planted early in January using the *ObSr* technique and with different water contents at planting. The climate data used are for the 81-year period, 1922 – 2003.

Table 8.1 Summary of long-term dry bean yield results with *ObSr* technique planting on 5 January with 5 different θ_p values.

θ_p	Estimated 80 % chance of achieving the following yields (kg ha^{-1})	Statistics	
		Comparison	P - level
Full	907	> ¾, ½, ¼, empty	0.01
¾	840	> ½, ¼, empty	0.01
½	750	> ¼, empty	0.01
¼	645	> empty	0.05
Empty	587		

In practice the results indicate that a farmer would generally harvest 55 % more dry beans per hectare by planting on a full profile compared to an empty one. The benefits on this ecotope of a soil water content of at least half-full at planting are also clearly demonstrated.

CPF graphs of simulated long-term dry bean yields simulated with CYP-SA on the Glen/Bonheim ecotope indicate that the *ObSr* treatment is the best, that it would be advisable to plant early in January, and that particularly good results can be expected when θ_p is between ¾ full and full. This information could help a farmer on this ecotope to reduce the risks of crop and financial failure. Although it was shown that CYP-SA (beans) is not yet reliable, the usefulness of the model has been adequately demonstrated and motivation to improve the model has therefore been generated.

8.4.1.2 Maize

CPFs simulated long-term maize yields with CYP-SA (maize) on the Glen/Bonheim-Onrus ecotope using different production techniques are presented in Figure 8.7(a), (b) and (c). The production techniques tested in each case are described on the figures. The results in Figure 8.7(a) show that all the IRWH treatments are significantly better (P = 0.01) than the *CON* treatment. *ObSr* and *SbSr* are significantly better (P = 0.01) than *BbBr*. *ObBr* is significantly (P = 0.05) lower than *SbSr* and *ObSr*. The graphs predict that the mean long-term yield (80 % chance of exceedance, i.e. very low level of risk) starting with a half-full profile for the *CON*, *BbBr*, *ObBr*, *SbOr*, *ObOr*, *SbSr* and *ObSr* treatments are 770, 1600, 1650, 1850, 1875, 2000 and 2020 kg ha^{-1} respectively. At this low level of risk the *BbBr* treatment, which will be the departure point for any farmer, yielded 830 kg ha^{-1} higher than the *CON* treatment. Also all the treatments with mulch (organic or stone) on the runoff area (second letter M or S) produced on average 286 kg ha^{-1} higher yields than the *ObBr* treatment with a bare runoff area.

Steyn (2003) has found in the Eastern Cape Province of South Africa that a household of between 6 and 10 members needed as staple food between 1000 kg and 1500 kg maize per annum. De Lange (2003) and Groenewald (2003) estimate that a household consisting of 5 members would need about 960 kg of maize per year. The households in the area east of Bloemfontein consist on average of 5 members. Using the results on a typical ecotope in the Thaba Nchu area similar to the Glen/Bonheim in Figure 8.7(a), CYP-SA predicts that the risk involved for a farmer to harvest 960 kg ha^{-1} maize with *CON* tillage would be 28 %. If one assumes that the farmer has 1 ha of arable land from which to produce his staple food, this result means that in about one out of four years he would have too little food for his family. For the small scale-farmer who cannot afford to fail, where it could mean life or death, this probability of failure is too high. With the *BbBr*, *ObBr*, *SbOr*, *ObOr*, *SbSr* and *ObSr* treatments the risk of failing (not harvesting 960 kg ha^{-1}) is only 12 %, 10.5 %, 8 %, 7.8 %, 6 % and 5.7 % respectively. With these techniques a household would have between an 88 % and 96 % probability of realizing a yield of 960 kg ha^{-1}, which is a very low risk. The risk of failing with the *BbBr* treatment compared to the *CON* treatment is more than halved. It is clear that the IRWH techniques decrease the risk of crop failure tremendously. Assuming an 80 % probability of success of reaping 960 kg of maize to be acceptable, the areas that would be needed using different tillage techniques would be 1.25 ha, 0.6 ha and 0.48 ha using the *CON*, *BbBr* and *ObSr* treatments, respectively. Using the better techniques would, relative to *CON*, therefore allow the farmer to plant other crops on the “spare” land to improve the balance of his family’s diet or to sell.

Figure 8.7(b) shows that the January planting is best. The predicted mean long-term yields (80 % probability) for early, intermediate and late planting are 1100 kg ha^{-1}, 2000 kg ha^{-1} and 2150 kg ha^{-1} respectively. CYP-SA further predicts that a farmer has an 83 % probability to obtaining a yield of 2000 kg ha^{-1} with a late planting date, 80 % with intermediate, and only a 56 % probability with an early planting date. The results indicate that late and intermediate planting are significantly better (P = 0.01) than early planting, and that there is no significant difference between intermediate and late planting on this ecotope.

The results in Figure 8.7(c) are summarised in Table 8.2.

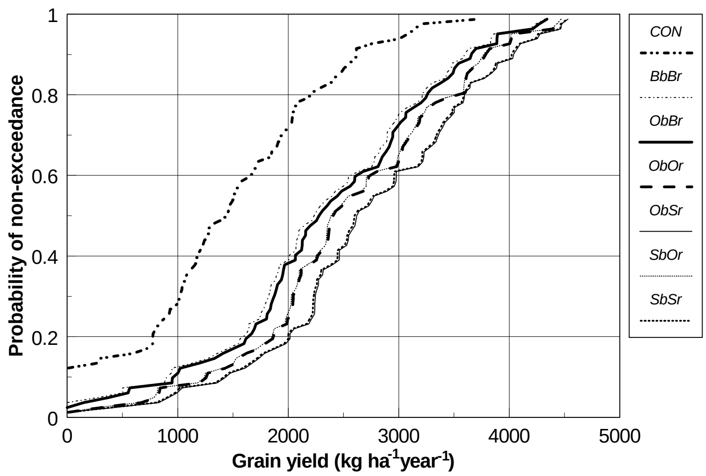
Table 8.2 Summary of long-term maize yield results with *ObSr* technique planting on 5 January with 5 different θ_p values.

θ_p	Predicted yield obtained with 80 % probability (kg ha^{-1})	Statistics of CPFs	
		Comparison	P- level
Full	2775	> ½, ¼, Empty	0.01
¾	2500	> ¼, Empty	0.01
½	2150	> ¼	0.05
		> Empty	0.01
¼	1700	Empty	0.01
Empty	850		

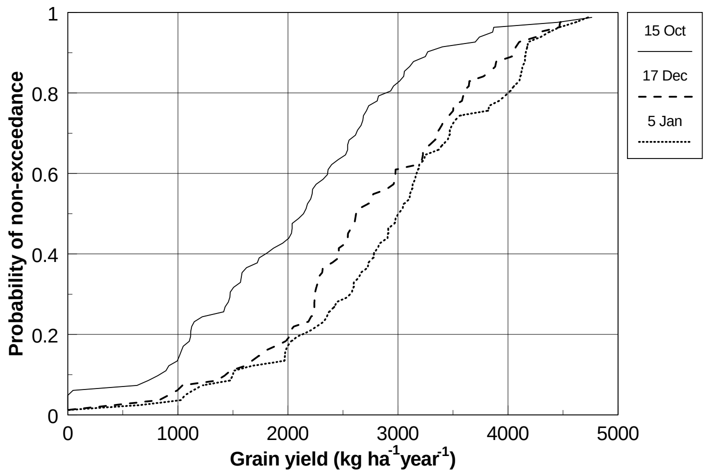
The value of planting with a root zone that is at least ¾ full is clearly demonstrated, the predicted long-term yield (80 % probability) being almost three times that with θ_p at empty.

All the above mentioned results indicate that for farmers to reduce the risk of crop failure it is more advantageous to use the IRWH technique instead of the *CON* treatment. By simply changing from *CON* to *BbBr* a farmer's probability to fail by not being able to harvest 960 kg ha^{-1} will be decreased by 43 %. This will help the farmer to have an 88 % probability to realize a maize yield of 960 kg ha^{-1}. This benefit can be attributed to the fact that IRWH has the ability to conserve more rainwater in the soil profile due to the total prevention of R. CYP-SA also indicates that a farmer, when using the *ObSr* treatment and planting early in January in full profile, has a 98.2 % probability (i.e. almost 100 % certainty) of realizing a maize yield of 960 kg ha^{-1}. This is probably due to the fact that the mulch reduces Es.

(a)



(b)



(c)

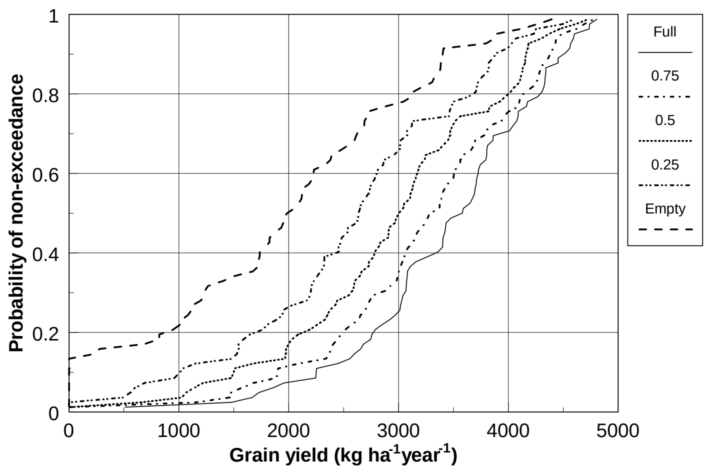


Figure 8.7 CPF graphs of long-term maize yields simulated with CYP-SA (maize) on the Glen/Bonheim - Onrus ecotope: (a) different tillage techniques, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using three planting dates; (c) *ObSr* tillage technique, planting 5 January with 5 different θ_p values. Climate data used are for the 81-year period 1922-2003.

8.4.1.3 Sunflower

CPFs of long-term sunflower yields simulated with CYP-SA (sunflower) using different production techniques are presented in Figure 8.8(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

The results in Figure 8.8(a) are summarised in Table 8.3.

Table 8.3 Summary of long-term sunflower yield results with different tillage techniques, θ_p ½ full, planted on 17 December.

Production technique	Predicted mean long-term yield (kg ha^{-1})			Statistics of CPFs	
	Chance of success			Comparison	P - level
	80 %	50 %	20 %		
ObSr	1120	1840	3075	> *CON, BbBr*	0.01
				>*ObBr*	0.05
SbSr	1100	1810	3060	> *CON, BbBr*	0.01
				>*ObBr*	0.05
ObOr	1015	1700	2830	>*CON*	0.01
SbOr	990	1670	2720	>*CON*	0.01
ObBr	785	1475	2550	>*CON*	0.01
BbBr	742	1425	2500	>*CON*	0.01
CON	315	800	1500		

The superiority of all the IRWH treatments over the *CON* treatment for all risk levels is clearly shown, with the best IRWH treatments yielding 3.5 times as much as *CON* at a low risk level. Even at the low level of risk, i.e. 80 % chance of success, the *BbBr* (first step of IRWH) yielded more than twice that of the *CON* treatment. *ObBr* produced a slightly higher yield than *BbBr,* presumably due to the suppressing effect of the organic mulch in the basins on Es, especially during the vegetative stage. All the treatments with a mulch (organic or stones) on the runoff area (second letter M or S) yielded (80 % chance) on average 271 kg ha^{-1} more than the *ObBr* treatment. This result draws the attention to the importance of water conservation on the runoff area, in addition to that which takes place in the basins.

In Figure 8.8(b) it is predicted that the best planting date for sunflower on the Glen/Bonheim ecotope is around 5 January, and that the intermediate planting date around 17 December is slightly better than the early planting date around 15 October. Late planting is significantly better ($P = 0.01$) than early and intermediate planting. The reason for this might be that sunflower will experience a more favourable climate (especially temperature and rain) during the flowering period, which would be during March, when planted in January. The graphs also indicate that a farmer would have an 80 % probability of harvesting 675 kg ha^{-1}, 1000 kg ha^{-1} and 1580 kg ha^{-1} with early, intermediate and late plantings respectively. In principle this means that a farmer would generally harvest 905 kg ha^{-1} more if he planted sunflower late instead of early on this specific ecotope. The model also simulated that to harvest 2000 kg ha^{-1} a farmer would have a 33 %, 38 % and 61 % chance of succeeding by planting late, intermediate and early, respectively. These differences could easily make the difference between economic success and failure.

(a)

(b)

(c)

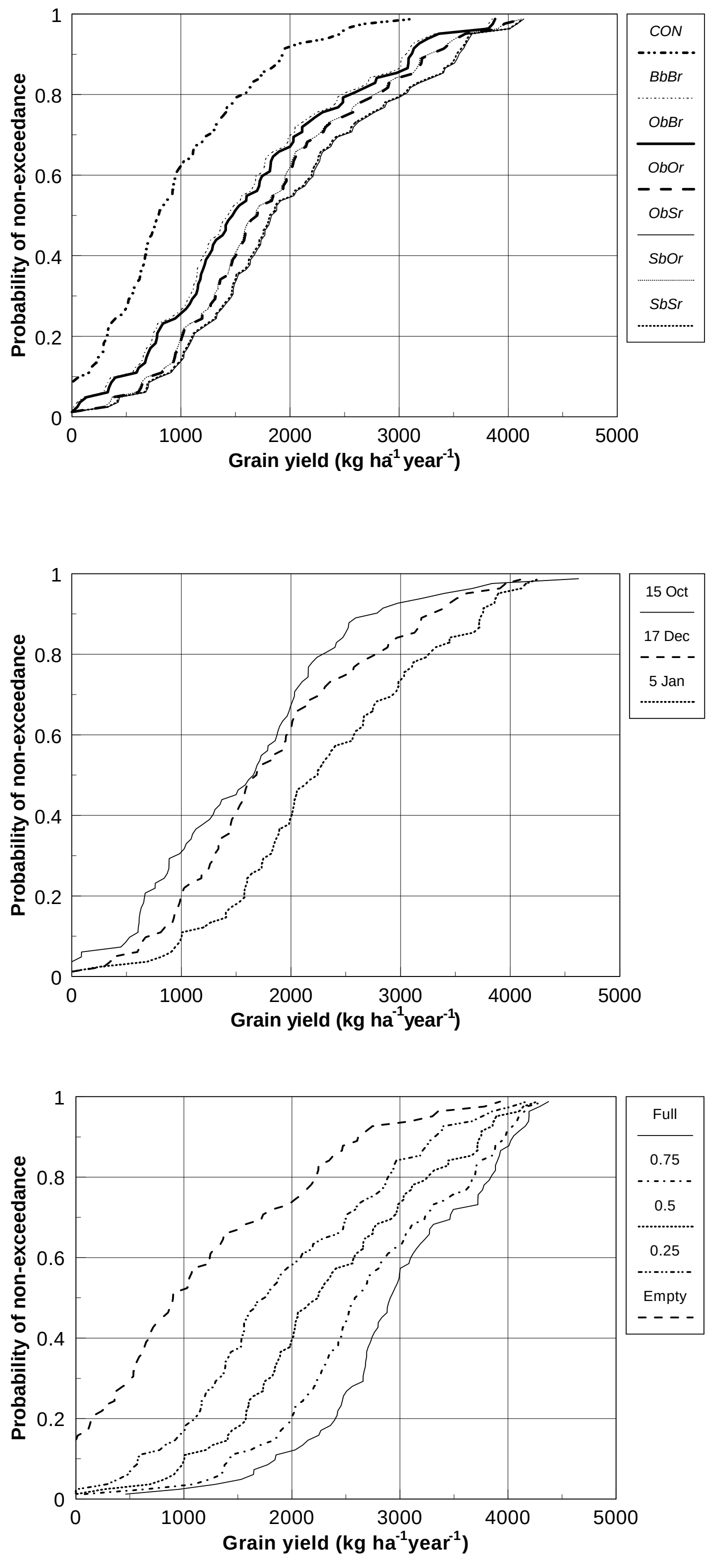


Figure 8.8 CPF graphs of long-term sunflower yields simulated with CYP-SA (sunflower) on the Glen/Bonheim – Onrus ecotope: (a) different tillage techniques, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique θ_p = ½ full, using three planting dates; (c) *ObSr* tillage technique, planting 5 January and with 5 different θ_p values. Climate data used are for the 81-year period 1922 – 2003.

The results presented in Figure 8.7(c) are summarised in Table 8.4.

Table 8.4 Summary of long-term sunflower yield results with *ObSr* technique planting on 5 January with 5 different θ_p values.

θ_p	Predicted mean long-term yield (kg ha^{-1}) Chance of success		Statistics of CPFs	
	80 %	20 %	Comparison	P - level
Full	2650	3850	> ¾	0.05
			> ½, ¼, Empty	0.01
¾	2000	3690	> ½	0.05
			> ¼, Empty	0.01
½	1580	3270	> ¼, Empty	0.01
¼	1075	2895	Empty	0.01
Empty	150	2220		

The benefits of having a root zone as full as possible at planting are clearly demonstrated. It needs to be kept in mind that these results were obtained using the best tillage technique (Figure 8.8(a)) and the best planting date (Figure 8.8(b)). The poor results with θ_p values of half-full and less are also clearly exposed. It is, for example, predicted that a farmer would be able to harvest 1850 kg ha^{-1} and 2500 kg ha^{-1} more sunflower by planting on a ¾ full and full soil water profile, respectively, instead of an empty profile, and 1070 kg ha^{-1} and 420 kg ha^{-1} more, respectively, compared to planting on a half-full profile. Based on this information one could advise farmers on this ecotope that it may be economically advantageous to only plant when θ_p is at least ¾ full. A possible management strategy indicated is therefore to delay planting until the root zone is close to full - even if it means sometimes not planting during a particular season. This strategy could lead to economic gains in the long-term. A detailed economic study would be needed to test the validity of such a strategy, however.

The overall conclusions from this study are that on the Glen/Bonheim ecotope the *ObSr* treatment is the best, and it is advisable to plant dry beans, maize or sunflower early in January, especially when the soil water profile is between ¾ full and full. This strategy could help a farmer on this ecotope to reduce the risks of crop and financial failure, and in so doing promote food security.

8.4.2 Khumo/Swartland - Amandel

One of the advantages of crop models is that they facilitate the pedo-transfer process. They enable predictions to be made for properly characterized ecotopes where experiments with a particular production technique have not been carried out. Although dry beans and maize were not grown on the Khumo/Swartland and Vlakspruit/Arcadia ecotopes during the project period, with a crop model it is possible to simulate what could be expected there. Daily rainfall for a nearby farm “North Bend” at latitude 29^{0}04’30” and longitude 26^{0}05’ is available from 1913 to 1984. It is situated about 2 km north of Vlakspruit and about 5 km west of Khumo. The rainfall of North Bend for the period 1922 to 1984 was used for the long-term simulations on the Khumo and Vlakspruit ecotopes. Since the rainfall pattern of Glen is similar to that experienced in the Thaba Nchu area it was decided to use the Glen rainfall data for the period 1985 to 1996. For the period 1997 to 2002 the rainfall measured at Khumo and Vlakspruit was used. Since no Eo values were available for the Thaba Nchu area it was decided to use the Glen Eo values of the Glen meteorological station. The

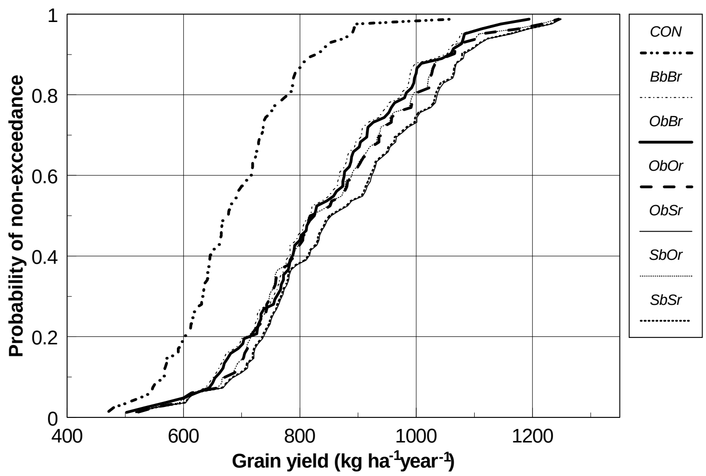
Khumo/Swartland – Amandel ecotope is characterized in detail in Section 3.2. Long-term yield predictions were done using this newly constructed weather data set.

8.4.2.1 Dry beans

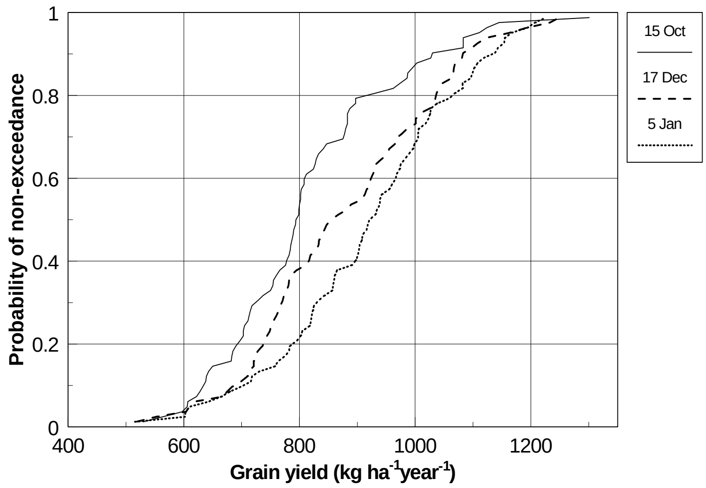
CPFs of long-term dry bean yields simulated with CYP-SA (beans) on the Khumo/Swartland ecotope using different production techniques are presented in Figure 8.9(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

The results on this ecotope are similar to those on Glen/Bonheim, and confirm the result that the *ObSr* treatment is the best treatment and the *CON* treatment the most risky treatment in terms of crop failure. The CPF graphs also indicated that for a farmer to reduce the risk of crop failure it would be advisable to use the IRWH technique instead of *CON*, to plant later rather than early, and preferably to plant when the soil water content of the root zone is more than half-full.

(a)



(b)



(c)

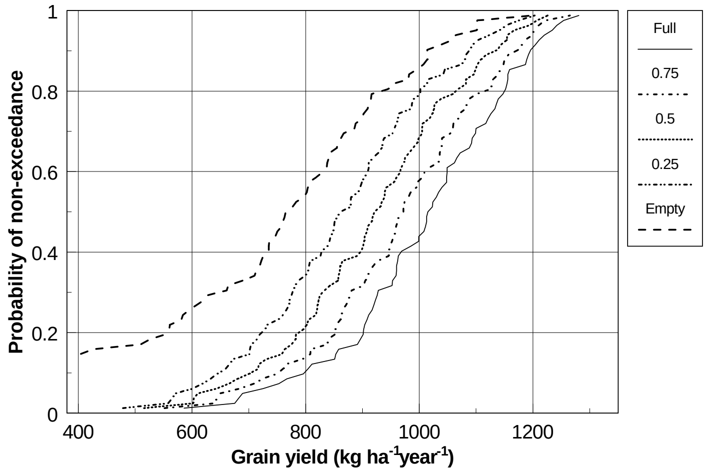


Figure 8.9 CPF graphs of long-term dry bean yields simulated with CYP-SA on the Khumo/Swartland - Amandel ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

8.4.2.2 Maize

CPFs of long-term maize yields simulated with CYP-SA (maize) on the Khumo/Swartland ecotope using different production techniques are presented in Figure 8.10(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

Exactly the same trends as on the Glen/Bonheim ecotope for maize can be seen here, although the yields realized there are higher. Considering low risk, the *CON* treatment has an 80 % chance of producing a maize yield of 400 kg ha^{-1}, indicating that a household would need at least 2.4 ha to realize the needed 960 kg of maize for own consumption. Using the *BbBr* or *ObSr* treatments, for which the comparable predicted yields are 1500 and 1850 kg ha^{-1} respectively, a household would need only 0.64 and 0.52 ha respectively to produce the maize needed for home consumption. These more efficient strategies would allow the household to use more land to plant other crops to improve the balance of their diet, or to plant more maize to sell. The results indicate that it would be beneficial for a farmer, in terms of reducing risk and realizing higher sustainable yields, to use IRWH instead of *CON*, plant late rather than early, and preferably only plant when the soil water profile is more than half-full.

(a)

(b)

(c)

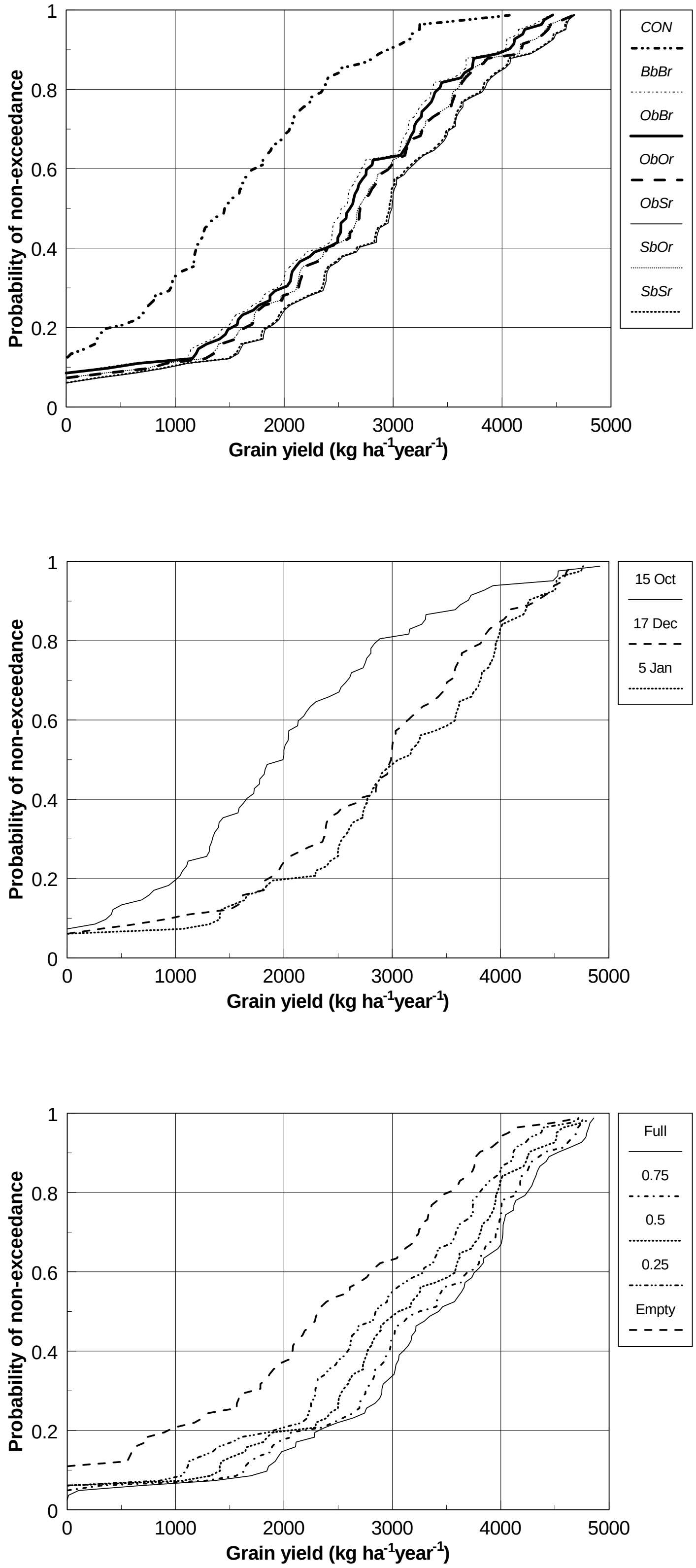


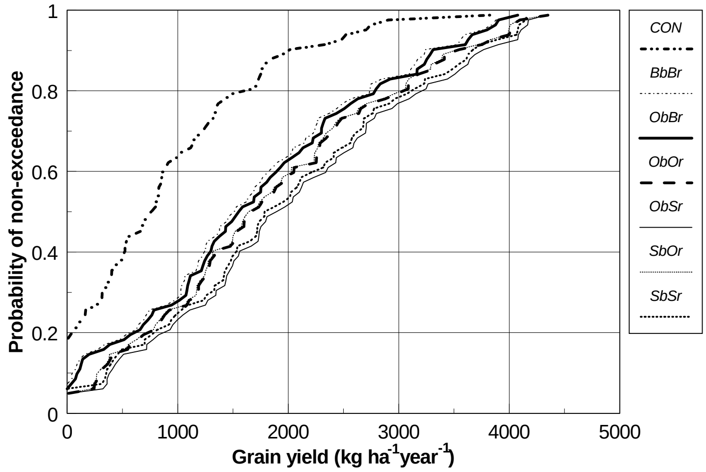
Figure 8.10 CPF graphs of long-term maize yields simulated with CYP-SA on the Khumo/Swartland - Amandel ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

8.4.2.3 Sunflower

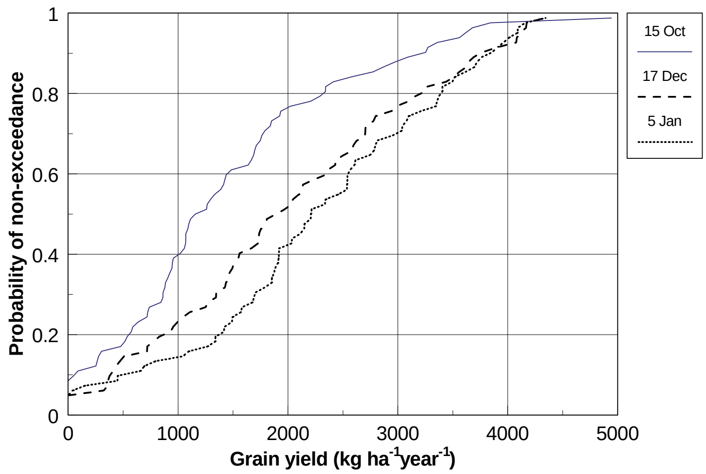
CPFs of long-term sunflower yields simulated with CYP-SA (sunflower) on the Khumo/Swartland ecotope using different production techniques are presented in Figure 8.11(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

CPF graphs follow the same trends as for the sunflower CPF graphs on the Glen/Bonheim ecotope. This again confirms the superiority of the IRWH techniques above *CON*. It also confirms the superiority of late planting above early and intermediate planting. The CPF graphs indicate that a pre-plant water advantage plays an important role in decreasing the level of risk, but that at a high risk level the role of pre-plant water advantage decreases. This clearly indicates the superiority of planting when θ_p is above half-full to reduce the risk of crop failure.

(a)



(b)



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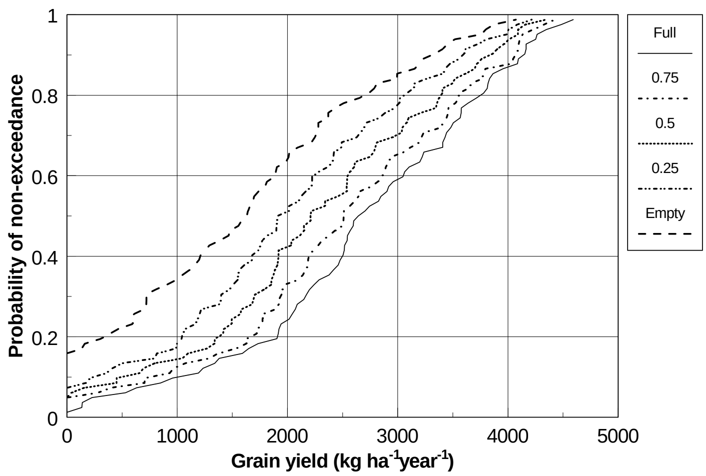


Figure 8.11 CPF graphs of long-term sunflower yields simulated with CYP-SA on the Khumo/Swartland - Amandel ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

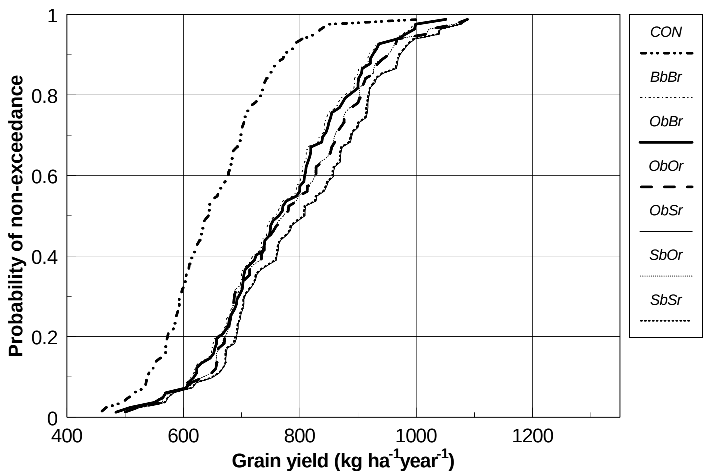
8.4.3 Vlakspruit/Arcadia

8.4.3.1 Dry beans

CPFs of long-term dry bean yields simulated with CYP-SA (beans) on the Vlakspruit/Arcadia ecotope using different production techniques are presented in Figure 8.12(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

Exactly the same trends can be seen here as on the Khumo/Swartland ecotope for dry beans. The only difference is that the yields are slightly lower here. In general these results confirm that the IRWH techniques out-perform *CON* at all probability levels, and that the treatments with mulches on the runoff area yield slightly more than the *ObBr* treatment with a bare runoff area. The CPF graphs also indicate that for a farmer to reduce the risk of crop failure it would be advisable to use the IRWH technique instead of *CON*, to plant later rather than early, and preferably to plant when the soil water content of the root zone is more than half-full.

(a)



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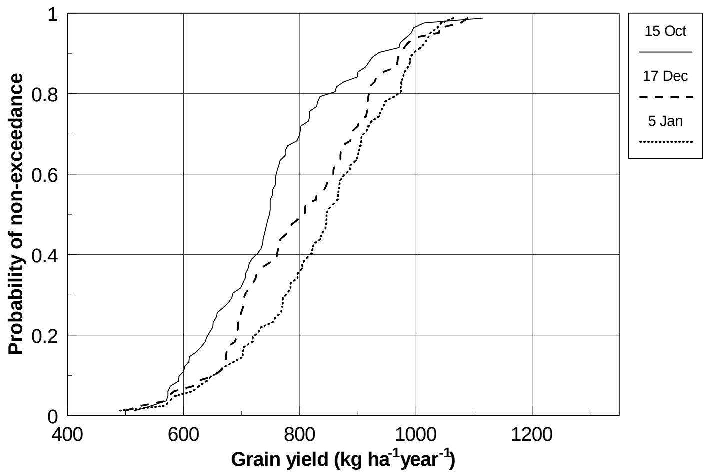


(c)

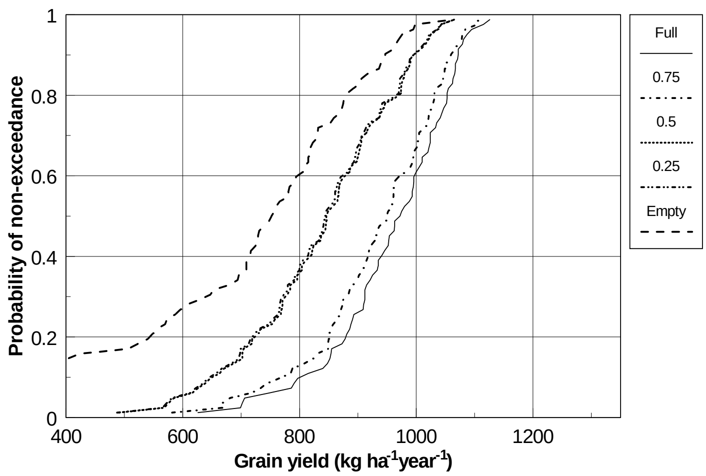


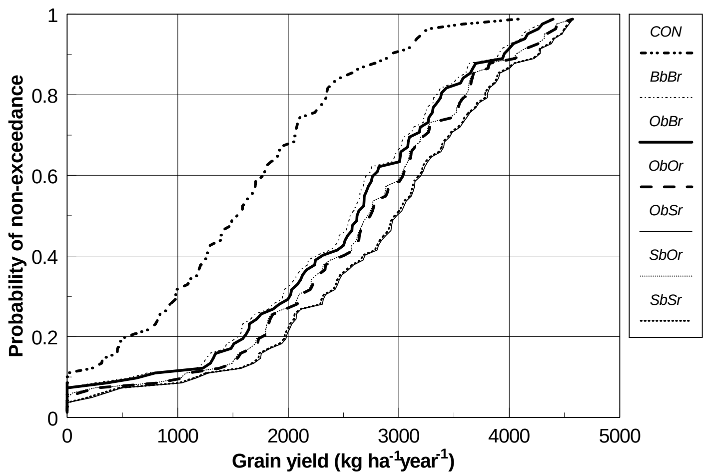
Figure 8.12 CPF graphs of long-term dry bean yields simulated with CYP-SA (beans) on the Vlakspruit/Arcadia - Lonehill ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

8.4.3.2 Maize

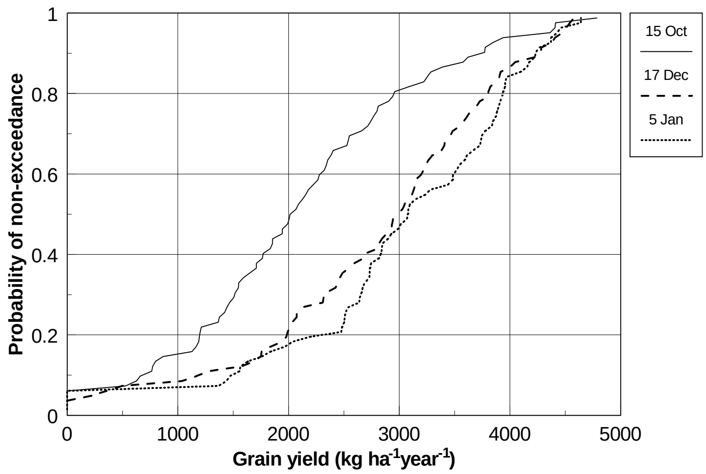
CPFs of long-term maize yields simulated with CYP-SA (maize) on the Vlakspruit/Arcadia ecotope using different production techniques are presented in Figure 8.13(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

Exactly the same trends can be seen here as on the Khumo/Swartland ecotope for maize. The only difference is that the maize yields are slightly higher here. In general the long-term CPF graphs of simulated maize yields indicate that it would be beneficial for a farmer, in terms of risk reduction and realizing higher sustainable yields on this ecotope, to use the IRWH production technique instead of *CON*, to plant rather late than early, and preferably only plant when θ_p is more than half-full.

(a)



(b)



(c)

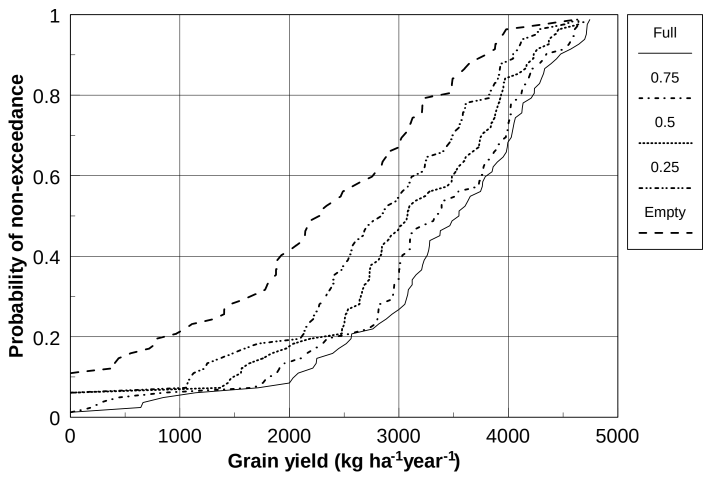


Figure 8.13 CPF graphs of long-term maize yields simulated with the CYP-SA (maize) on the Vlakspruit/Arcadia - Lonehill ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

8.4.3.3 Sunflower

CPFs of long-term sunflower yields simulated with CYP-SA (sunflower) on the Vlakspruit/Arcadia ecotope using different production techniques are presented in Figure 8.14(a), (b) and (c). The production techniques tested in each case are recorded on the figures.

Exactly the same trends can be seen here as on the Khumo/Swartland ecotope for sunflower. The only difference is that the yields are slightly higher here. In general the long-term CPF graphs indicate that it would be beneficial for a farmer on this ecotope to use the IRWH production technique, to plant late, and to only plant when the soil water profile is more than half-full.

(a)

(b)

(c)

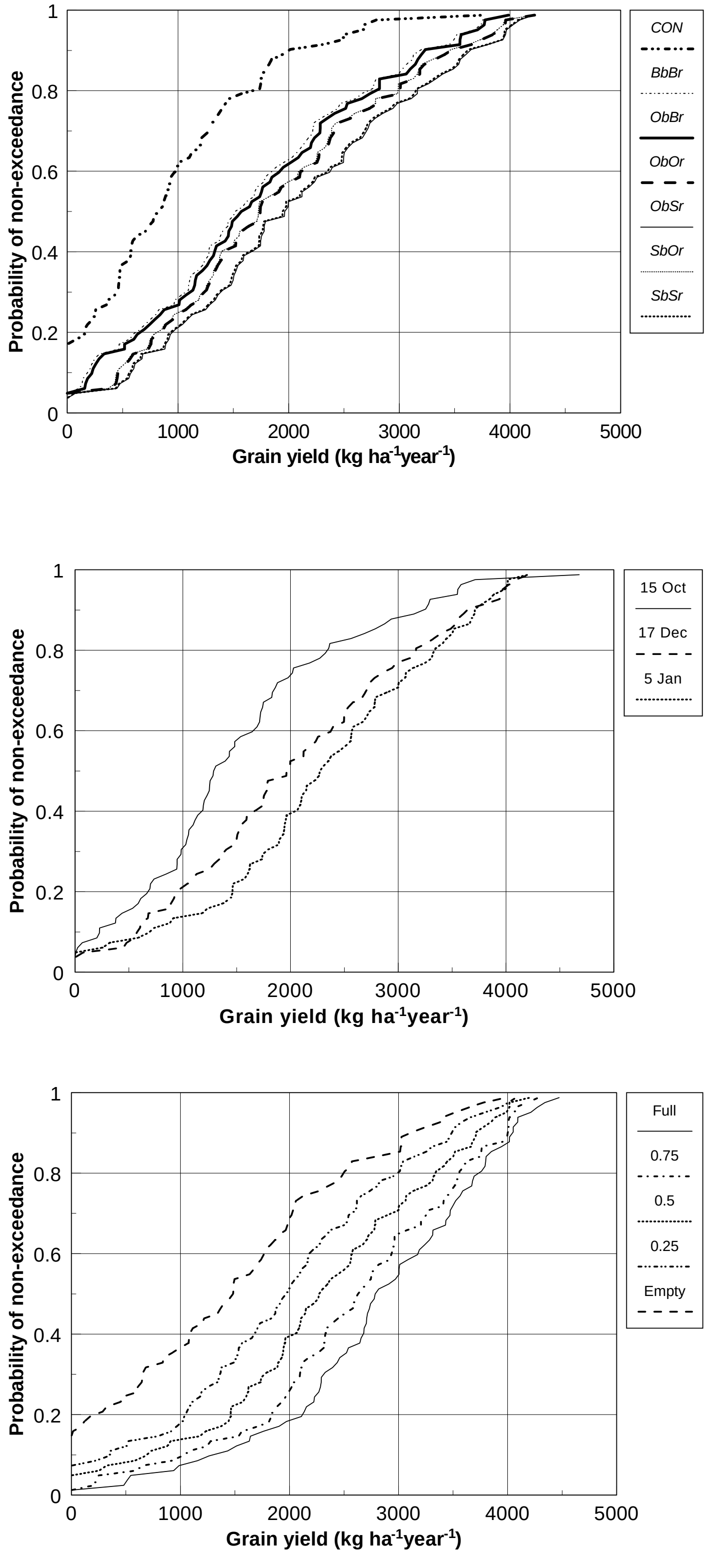


Figure 8.14 CPF graphs of long-term sunflower yields on the Vlakspruit/Arcadia - Lonehill ecotope: (a) different tillage treatments, θ_p = ½ full, planted on 17 December; (b) *ObSr* tillage technique, θ_p = ½ full, using 3 planting dates; (c) *ObSr* tillage technique, planting on 5 January, and with 5 different θ_p values. Climate data used are for the 81-year period, 1922 – 2003.

8.4.4 Conclusions

The main aim with long-term weather data and the model CYP-SA was to differentiate between different tillage treatments on different ecotopes. Out of these results a few management recommendations could be made. The Kolmogorov-Smirnov test has indicated, out of the CFP graphs of dry beans, maize and sunflower, that all the IRWH techniques statistically (P = 0.01) out-performed the *CON* tillage. Furthermore that the *ObSr* and *SbSr* treatments performed statistically better than the *BbBr* treatment, with dry beans (P = 0.05), maize and sunflower (P = 0.01). It has also indicated that with maize and sunflower crops the *ObSr* and *SbSr* treatments performed statistically better (P = 0.05) than the *ObBr* treatment.

CYP-SA indicates that dry bean yields will increase by 19 % through changing from *CON* to *BbBr*, by another 1 % when changing to *ObBr* and by a further 7 % when changing to *ObSr* (Appendix 8.3). For maize it is simulated that yields will increase by 71 % through changing from *CON* to *BbBr*, by another 3 % when changing from *BbBr* to *ObBr* and by a further 17 % when changing from *ObBr* to *ObSr*. CYP-SA simulates that sunflower yield will increase by 93 % when changing from *CON* to *BbBr*, by another 7 % when changing from *BbBr* to *ObBr* and by a further 47 % when changing from *ObBr* to *ObSr* (Appendix 8.3). It is simulated that a farmer will increase crop yield on average by 60 % when changing from *CON* to *BbBr*, another 4 % when changing from *BbBr* to *ObBr* and by a further 27 % when changing from *ObBr* to *ObSr* (Appendix 8.3).

Certain management practices are more important for certain crops. CYP-SA simulated that it would be more advantageous for a farmer to plant dry beans on similar ecotopes late or otherwise between 17 December and early January in a soil with a water content of between ¾ full and full. In the case of maize it would be better for a farmer to plant maize on similar ecotopes between mid-December and early January in a profile between ¾ full and full. The same strategy can be followed for sunflower, except that it would be much more of an advantage to plant late.

When comparing the different ecotopes in terms of risk (80 % probability of succeeding) the Khumo/Swartland would be the best ecotope to plant dry beans on, while for maize it would be the Glen/Bonheim and Vlakspruit/Arcadia ecotopes, and in the case of sunflower the Glen/Bonheim ecotope, although higher yields are possible on the other ecotopes. When comparing the ecotopes in terms of crop yields at all levels, the Khumo/Swartland is the best for dry beans while higher maize and sunflower yields are possible on the Vlakspruit/Arcadia ecotope (Appendix 8.3).

8.5 LONG-TERM ECONOMIC FEASIBILITY

Enterprise budgets for three crops (dry beans, maize and sunflower) under *CON* and different IRWH techniques on the Glen/Bonheim ecotope were linked to yield data obtained with CYP-SA for an 81-year period and gross margins (R ha^{-1}) were calculated. All the prices are based on base year prices obtained in "Combut enterprise budgets" (Department of Agriculture - conservation and environment - North West Province). Prices for the 1999/2000 growing season were used as the base year. The prices for dry beans, maize and sunflower were R 2900 ha^{-1}, R 570 ha^{-1} and R 1040 ha^{-1}, respectively. The gross margins are presented in tabular and cumulative probability function format for each crop. The results are aimed at drawing comparison between the *CON* and IRWH techniques in order to make some recommendations on crop production practices in the study area. To get a complete perspective on the enterprise budgets used in this study the report of Kundhlande *et al*. (2003) should be read.

8.5.1 Dry beans

Gross margins (R ha^{-1}) for beans over the 81-year period are presented in tabular format in Appendix 8.4. *CON* distinctly gives lower gross margins compared to all the IRWH techniques.

Figure 8.15 presents the CPFs for the production techniques. CPF trends of gross margins for dry beans (Figure 8.15) are very similar to that of yield (Figure 8.4). *CON* lies to the left of all the IRWH techniques followed by that of dry bean *BbBr*. This implies that all the IRWH techniques are dominant and hence superior to *CON*. However, dry beans show a lower risk than is the case with sunflower and maize (Figures 8.16 and 8.17 respectively), due to the higher price of dry beans. There is only a 4 % chance of getting a negative gross margin as opposed to the higher risk level associated with the production of maize and sunflower. Another observation peculiar to Figure 8.15 is that all the IRWH techniques do not have any parts of them in the negative gross margin region, implying that there is no chance of yielding a negative gross margin. Even though this might be important and acceptable, the magnitudes of the returns will then play an important role in determining their desirability. The highest possible gross margin for the conventional technique is R 929 ha^{-1} compared to R 1393 ha^{-1} for *BbBr*, which is the lowest of all the water harvesting techniques. The results presented in Figure 8.15 are summarised in Table 8.5. At a very low risk, a farmer has an 80 % probability of realizing a gross margin of R 146 ha^{-1} with *CON*, compared to R 520 ha^{-1}, R 531 ha^{-1} and R 647 ha^{-1} with *BbBr*, *ObBr* and *ObSr*, respectively. This implies that the farmer could increase his gross margin by 256 % simply by changing from *CON* to *BbBr*, and could even increase the gross margin by a further 8 % to 87 % with *ObBr* and *ObSr*, respectively.

Late (5 January) and intermediate (17 December) planting have been shown to be superior to early (15 October) planting (Appendix 8.5(a)). A farmer could increase his/her gross margin by 17 % and 22 % by planting on 17 December and 5 January, respectively. The advantages of planting on a full or ¾ full soil water content above empty, ¼ and ½ full are presented in Appendix 8.5(b). A farmer could increase the gross margin by 28 % and 48 % by planting on a full or ¾ full profile instead of a ½ full one.

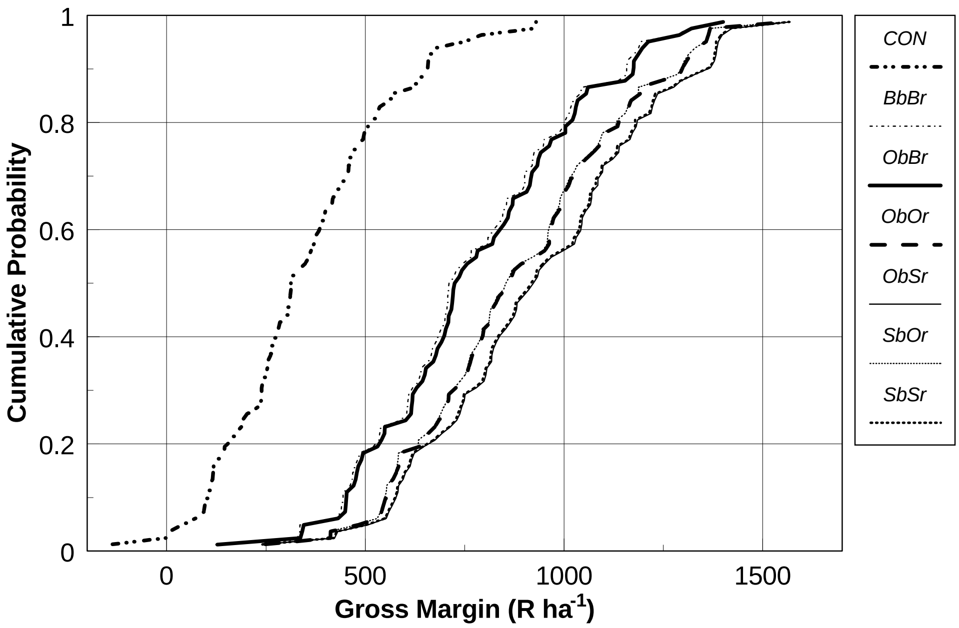


Figure 8.15 Cumulative probability distribution functions based on gross margins for dry beans for the past 81 years (1922-2003) on the Glen/Bonheim ecotope.

Table 8.5 Summary of long-term results of gross margins for dry beans with different tillage techniques, θ_p ½ full, planted on 17 December on the Glen/Bonheim ecotope.

Production technique	Predicted mean long-term gross margins (R ha^{-1})		Statistics of CPFs	
	Chance of success		Comparison	P - level
	80 %	20 %		
ObSr	647	1182	> *CON*	0.01
			> *BbBr*	0.05
SbSr	644	1179	> *CON*	0.01
			> *BbBr*	0.05
ObOr	636	1135	> *CON*	0.01
SbOr	633	1129	> *CON*	0.01
ObBr	531	1003	> *CON*	0.01
BbBr	520	998	> *CON*	0.01
CON	146	507		

8.5.2 Maize

Appendix 8.4 tabulates the calculated gross margins for maize for each year over the 81-year period (1923-2003), for the various production techniques. The table shows that all the IRWH techniques are superior to *CON* as shown by the higher calculated gross margins. *ObSr* is the most superior of the IRWH techniques.

CPFs based on gross margins (R ha^{-1}) for maize for the past 81-year period are reported in Figure 8.16. *CON* lies to the left of all the IRWH techniques and hence is stochastically dominated by the IRWH techniques in the first order. The *CON* function shows that about 80 % of the time the technique will yield gross margins less than or equal to zero. This is higher than that of 68 % from sunflower (Figure 8.17) due to the difference in price. This implies that there is higher risk associated with *CON* production of maize in the study area as opposed to the use of IRWH techniques. The least productive IRWH technique, *BbBr*, has about a 36 % chance of yielding a gross margin of zero or less. This is considerably different from the *CON*, a reduction in risk of about 44 %. This implies, therefore, that major gains are made by moving from *CON* to IRWH. This is further shown by the differences in improvement between *BbBr* and *ObBr*, *ObOr* and *SbOr*, and finally *ObSr* and *SbSr*. The differences between these pairs of IRWH techniques are not as large as that between *CON* and *BbBr*. *CON* carries the highest risk and may not be acceptable in terms of maximizing profits with minimum risk from production.

BbBr is the least productive of the IRWH techniques as it lies to the left of the other functions whilst *ObSr* lies to the right of all the functions and is hence the most productive. This implies that *ObSr* is first order stochastically dominant to all the other techniques. The IRWH techniques also have lower risks associated with them as opposed to *CON*. *BbBr* has about a 36 % chance of a gross margin less than or equal to zero, and *ObSr* has a less than 12 % chance of the above occurring, as opposed to about 80 % when *CON* is used. When using *ObSr*, there is an 88 % chance (no risk) of getting a gross margin above zero, whereas for *BbBr* it is 64 %.

The same trend seems to persist between *ObOr* and *SbOr*, and *ObSr* and *SbSr* for maize. There are very slight differences between the techniques, but large enough to show which one stochastically dominates the other using first order stochastic dominance.

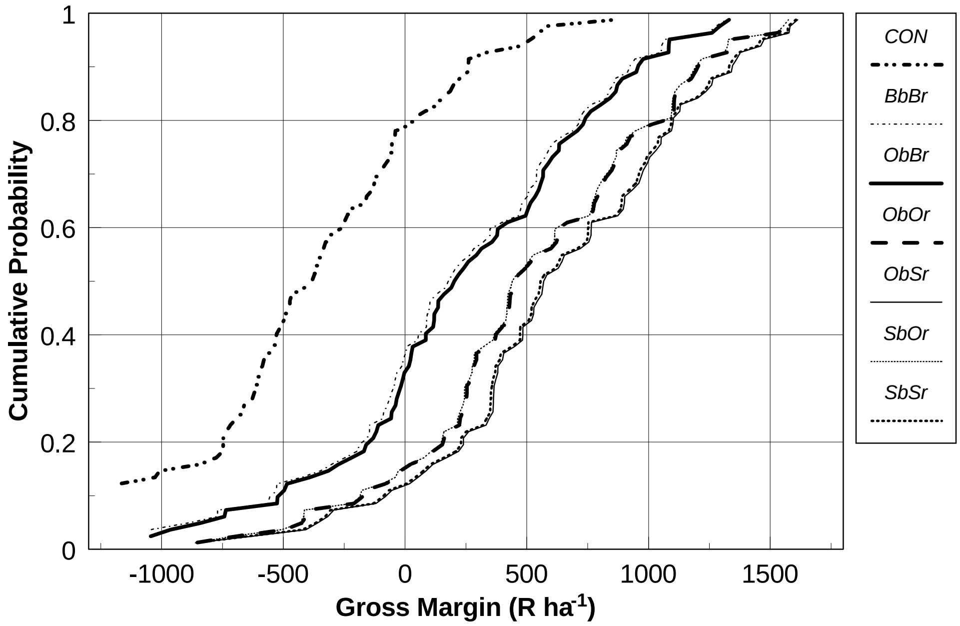


Figure 8.16 Cumulative probability distribution functions based on gross margins for maize for the past 81 years (1922-2003) on the Glen/Bonheim ecotope.

Based on the comparison of IRWH, *ObSr* was shown to be the most productive technique and was used to test the effect of planting date and then determine the best planting date (Appendix 8.6(a)). The determined planting date was then used in determining the effect of soil water content at the time of planting on the returns (Appendix 8.6(b)). A summary of the results of planting date and water content on gross margins of maize are presented in Tables 8.6 and 8.7 respectively.

Table 8.6 Summary of long-term results of gross margins for maize with different planting dates, θ_p ½ full on the Glen/Bonheim ecotope.

Planting date	Predicted mean long-term gross margins at 80 % chance of success	Chance of getting positive returns	Statistics	
			Comparison	P - level
15 October	R -252 ha^{-1}	64 %		
17 December	R 240 ha^{-1}	88 %	> 15 October	0.01
5 January	R 279 ha^{-1}	88 %	> 15 October	0.01

The CPF graph of planting on 15 October lies to the left of the other two planting dates while that for 5 January lies to their right. Planting on 15 October has a 36 % chance of achieving a gross margin less than or equal to zero, as opposed to 17 December with a probability of about 12 % of making negative returns. Planting on 5 January has a slightly lower probability of that occurring. The functions for 5 January and 17 December are almost touching at the point where they get into positive gross margin region. By implication these dates have an almost similar chance of negative returns; however, when planting maize on this ecotope on the 5 January, at a very low risk level (80 % probability of success), a farmer could get a gross margin of 16 % more compared to planting on the 17 December.

From this graph (Appendix 8.6(a)) it can be concluded that planting on 5 January will have the highest benefits for farmers and reduce the risk of crop failure considerably. For this date the farmer has an over 88 % chance of getting positive returns, as opposed to 65 % when planting on 15 October. This implies that 5 January will be the best planting date. The second most preferred date will be 17 December and the least preferred 15 October.

Table 8.7 Summary of long-term results of gross margins for maize with *ObSr*, planting 5 January with 5 different θ_p values on the Glen/Bonheim ecotope.

θ_p	Estimated 80 % chance of achieving the following gross margins	Chance of getting positive returns	Statistics	
			Comparison	P - level
Full	R 645 ha^{-1}	96 %	> ½, ¼, empty	0.01
¾	R 490 ha^{-1}	93 %	> ¼, empty	0.01
½	R 279 ha^{-1}	88 %	> empty	0.01
			> ¼	0.05
¼	R 39 ha^{-1}	81 %	> empty	0.01
Empty	R -412 ha^{-1}	64 %		

As expected, Appendix 8.6(b) points out that planting maize on 5 January with a full soil profile is first order stochastically dominant to all the other soil water levels. The least productive will be planting on an empty profile which has a 36 % probability of getting negative returns. However, the farmer still has a 64 % chance of getting positive returns with IRWH even with a relatively dry season before planting. Planting with a ¼ full profile has a 19 % chance of negative returns. This is a considerable improvement (17 %) from the previous case. The ½ full profile further reduces the risk to 12 %, followed by the ¾ full profile to 7 % and finally the full profile to 4 %.

The results imply that the use of *ObSr* and hence any of the water harvesting techniques, independent of the quantity of rainfall during the season (fallow and growing) before planting, enables farmers to make positive returns from their production at least 64 % of the time. This is very important in the study area since farmers are incurring serious losses mainly due to inadequate rainfall during the fallow period, but IRWH gives them a more than 50 % probability of getting positive returns. With good rains during the fallow period the farmers have a 96 % chance of success and with an average rainfall during the fallow period the farmers will have an 88 % chance of positive returns from their production.

One thing that must be taken into consideration is the price of maize, which in this case was taken as R 570 ton^{-1}. The negotiation ability of the farmers in the study area differs and the price depends on the negotiation abilities and also the request for certain produce. The price negotiated by the different farmers from the village Yoxford during the 2002/03 growing season varied between R 3200 ha^{-1} to R 10000 ha^{-1}. If prices like these were taken to construct enterprise budgets then very good gross margins would be realized.

8.5.3 Sunflower

From the table in Appendix 8.4 it can be seen that all the IRWH techniques are superior to the *CON* technique and *ObSr* is superior to all other IRWH techniques as shown by the higher gross margins calculated.

CPFs of simulated long-term sunflower gross margins on the Glen/Bonheim ecotope starting with a ½ full root zone water content at planting for different treatments are presented in Figure 8.17. The figure compares the production techniques but also shows what has been observed (dry beans and maize). *CON* is inferior to all the IRWH techniques. The graphs also show that there is a high risk of getting a negative gross margin when a farmer is using *CON*. The *CON* technique has a 68 % chance of yielding a gross margin of zero or less, which implies there is only a 32 % chance of yielding a positive gross margin from production. In contrast, the least performing IRWH technique (*BbBr*) exposes the farmer to a 27 % chance of achieving a gross margin equal to or less than zero, while the highest performing (*ObSr*) only has a 11 % chance of a gross margin of zero or less. This implies that *CON* exposes the farmer to a lot of risk and may not be acceptable in line with maximizing profit from production.

Comparing the IRWH techniques, *BbBr* is the least productive technique as it lies to the left of all the IRWH functions whereas *ObSr* is the most productive as it lies to their right. By implication, *ObSr* is stochastically dominant, in the first order, to all IRWH techniques and *CON*. Secondly, IRWH techniques show low levels of risk, as shown by the case of *BbBr* as was earlier discussed. *ObBr,* which lies to the immediate right of the *BbBr* graph, indicates that there is a 23 % probability of getting a gross margin of zero or less as opposed to 27 % in the case of *BbBr*. The risk reduces considerably as we move from *BbBr* to *ObSr*. This means that when using *BbBr*, a farmer has a 77 % probability of getting a positive gross margin. *ObSr*, as might be expected, shows the lowest risk level of an 11 % chance of getting a gross margin of zero or less. This implies that a farmer using *ObSr* has an 89 % chance of getting a positive gross margin.

ObOr is slightly superior to *SbOr,* as shown by the closeness of the two functions to each other. However, *ObOr* is distinctly to the right of *SbOr* and therefore stochastically dominates

SbOr in the first order. Almost the same trend is shown between *SbSr* and *ObSr,* but is more distinguishable than the case of *ObOr* and *SbOr*.

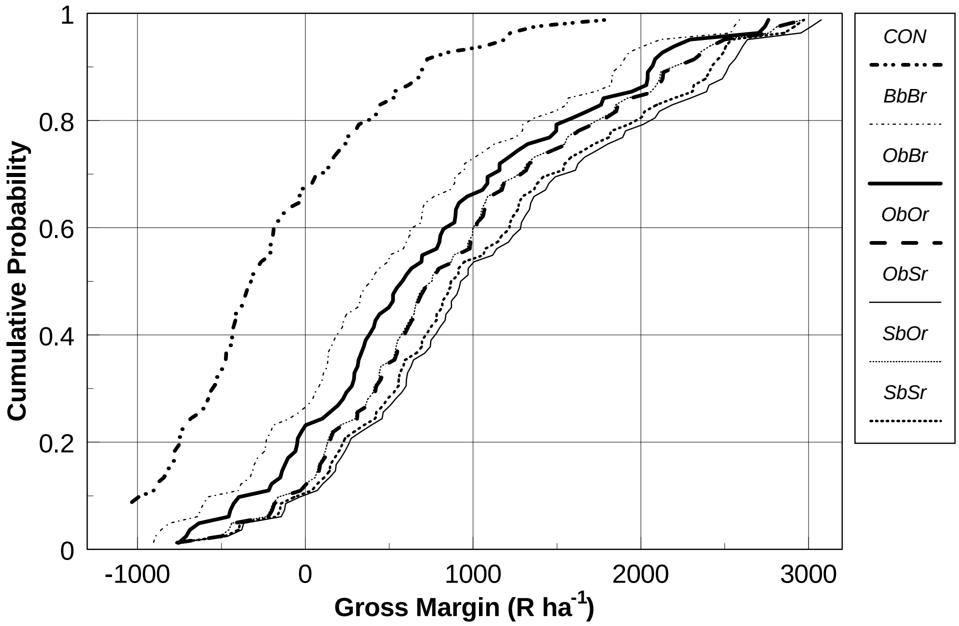


Figure 8.17 Cumulative probability distribution functions based on gross margins for sunflower for the past 81 years (1922-2003) on the Glen/Bonheim ecotope.

The results of a simulation study to try to identify the best planting date for sunflower on the Glen/Bonheim ecotope are presented in Appendix 8.7(a). The best treatment, *ObSr*, was used with three planting dates, *viz*., early (5th October), intermediate (17th December) and late (5th January). Results indicate that a farmer could have a 22 %, 11 % and 5 % chance of getting a gross margin of zero or less with early, intermediate and late planting dates, respectively. This implies that a farmer's risk could be halved by using the intermediate planting date instead of early and halved again by planting late rather than intermediate.

In Appendix 8.7(b) the results to show the influence of increasing θ_p values are presented. The planting date was 5 January and five θ_p values were used, *viz*. empty, ¼, ½, ¾ and full. A summary of the results of water content on gross margins of maize is presented in Table 8.8.

Table 8.8 Summary of long-term results of gross margins for with *ObSr,* planting 5 January with 5 different θ_p values on the Glen/Bonheim ecotope.

θ_p	Estimated 80 % chance of achieving the following gross margins	Chance of getting positive returns	Statistics	
			Comparison	P - level
Full	R 878 ha^{-1}	98 %	> ½, ¼, empty	0.01
			> ¾	0.05
¾	R 664 ha^{-1}	97 %	> ¼, empty	0.01
			> ½	0.05
½	R 442 ha^{-1}	95 %	> ¼, empty	0.01
¼	R 180 ha^{-1}	88 %	> empty	0.01
Empty	R -317 ha^{-1}	56 %		

Once again the superiority of a full and ¾ full profile above empty, ¼ and ½ full, is shown in Table 8.7. This implies that if a farmer plants when θ_p is ½, ¾ full or full he/she will have a 95 %, 97 % and 98 % chance of positive returns. This means that with the *ObSr* treatment when planting occurs on the 5 January with a θ_p of more than ½ full, a farmer has almost no risk of failure.

In general the long-term CPF graphs indicate that it would be beneficial for a farmer on this ecotope to use the IRWH production technique, plant late, and only plant when the soil water profile is more than ½ full. In conclusion, the discussion of the results is not conclusive and should not be seen as prescriptive, but rather as indicative, since there are a lot of other factors that need to be taken into consideration before a more definite conclusion can be reached. These include such factors as the minimum expected gross margin, the risk attitude of the decision-maker and the period over which the enterprise budgets are validated.

8.5.4 Conclusions

Based on the above results, it can be concluded that greater gains are made in dry bean production than with the other two crops (due to the higher price); however, IRWH increases returns considerably for all the crops. *ObSr* is the most productive of the techniques for all the crops followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and *BbBr*. Where *CON* exposes farmers to a lot of risk, most of the cases, especially with maize, not even worthwhile with *CON* (80 % probability of realizing a negative gross margin), IRWH techniques reduced risk considerably for maize and sunflower production, whereas in the case of dry beans production risk was even reduced to zero. It should be noted that it is not easy to determine which crop or production technique will be desirable, considering the varied objectives and circumstances of different farmers. However, one can conclude that greater returns are possible by moving from *CON* to IRWH techniques. The results indicate that it would be beneficial for a farmer, in terms of reducing risk and realizing higher sustainable incomes, to use IRWH instead of *CON*, plant late rather than early, and preferably only plant when the soil water profile is more than half-full. Generally speaking, IRWH techniques, just like *CON*, are dependent on other factors like rainfall which the farmer has no control over, but offer an opportunity for a farmer to be able to limit risk as they perform much better than the *CON* practices.

Secondly, the results are based on 1999/2000 producer prices and, due to the price volatility in crop markets in the past few years, the price relations are changing considerably from year to year, making it difficult to make recommendations about what crops to grow. Also of importance is that circumstances differ amongst farmers and farming regions, contributing further to making recommendations for specific farmers. However, the results of this investigation will give guidelines, especially to extension officers and farm advisors, regarding the relative profitability of different IRWH techniques.

Finally, even though the analysis was based on long-term yield predictions, the crop enterprise budgets used were based on a relatively short period of experience with farmers still moving up the learning curve. This makes it necessary to expand the research to cover a longer period in order to obtain more applicable and validated results.

8.6 SUMMARY

Various crop models were used for the prediction of crop yields as affected by mulch combinations in the in-field water harvesting and micro-basin tillage (IRWH) systems. Unfortunately, none of the models that have been used during the course of the project were able to make satisfactory yield predictions. As a last resort the empirical Crop Yield Predictor for Semi-Arid areas (CYP-SA) model for sunflower was upgraded to predict seed yield as affected by mulches. Two new versions to cater for maize and dry bean production were developed. Results for the short-term yield predictions were reasonable and consequently used to make long-term yield predictions with long-term climate data (81-year period).

Long-term yields were used to quantify risk. Cumulative probability functions (CPFs) of simulated long-term yields for the three crops on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes using different production techniques were drawn.

Enterprise budgets for the three crops under conventional tillage (*CON*) and the different IRWH techniques on the Glen/Bonheim ecotope were linked to yield data obtained with CYP-SA for an 81-year period and gross margins (R ha^{-1}) were calculated. CPFs of long-term gross margins for the three crops on the Glen/Bonheim ecotope using different production techniques were drawn.

From the CFP graphs (yield and gross margin) for dry beans, maize and sunflower, the Kolmogorov-Smirnov test has indicated that all the IRWH techniques statistically ($P = 0.01$) out-performed the *CON* tillage. The organic mulch in the basin and stone on the runoff area (*ObSr*), and stones in the basins and stones on the runoff area (*SbSr*) treatments performed statistically better than the bare basins with a bare runoff area (*BbBr*) treatment. *ObSr* proved to be the most productive technique for the crops tested followed by *SbSr*, organic mulch in the basin and on the runoff area (*ObOr*), stones in the basin and organic mulch on the runoff area (*SbOr*), organic mulch in the basin and a bare runoff area (*ObBr*) and *BbBr*. Where *CON* exposes farmers to production risk, IRWH techniques reduced risk considerably. Greater returns are possible by moving from *CON* to IRWH techniques. Results indicated that a farmer would increase his/her crop yield on average by 60 % when changing from *CON* to *BbBr*, by another 4 % when changing from *BbBr* to *ObBr* and by a further 27 % when changing from *ObBr* to *ObSr*.

Based on the above results, it can be concluded that greater gains (yield and gross margin) can be made with dry bean production than with the other two crops (due to the higher price). However, IRWH increases returns considerably for all the crops.

The first step for a farmer would be to apply the IRWH (*BbBr*) to obtain higher yields. The second step would be to apply mulch, if available, in the basins of the IRWH technique (*ObBr*) and on the runoff area. If organic and stone mulches are available, the organic mulch should be applied in the basins and the stone mulch on the runoff area (*ObSr*).

The results indicate that it would be beneficial for a farmer, in terms of reducing risk and realizing higher sustainable yields and incomes, to use IRWH instead of *CON*, to plant late rather than early, and preferably only plant when the soil water profile is more than half-full. Generally speaking, IRWH techniques, just like *CON*, are dependent on other factors like rainfall which the farmer has no control over, but offer an opportunity for a farmer to be able to capture the risks as they perform much better than the *CON* practices.

9 SOCIO-ACCEPTABILITY OF IRWH

9.1 INTRODUCTION AND BACKGROUND

Among some of the factors that have been hypothesised to be the cause of low levels of application of water conservation technologies by farmers include the lack of information on the economic viability of the techniques, lack of understanding of the social impacts of applying the techniques, and lack of knowledge amongst agricultural extension officers. Processes such as runoff, infiltration, drainage, evaporation and transpiration are by nature very complex to analyse and understand. These processes play an essential role in any crop production system. Farmers who are able to conceptualise the practical impact of each of these processes on crop yield tend to adopt new sustainable technologies more readily than those who do not understand it. Consequently, the packaging and communication of information to communal farmers in rural areas holds the key to enhancing the acceptance of a particular technique.

According to Rogers & Shoemaker (1971), communication is the process by which messages are transferred from a source (in this case the researchers) to a receiver (the people in communities). Communication factors are vital in many aspects of the decision processes, which together make up social change. Development is a type of social change in which new ideas (e.g. the IRWH technique) are introduced into a social system in order to produce higher per capita incomes and levels of living through more modern production methods and improved social organization. Research alone is not enough to solve problems but the results of the research must be diffused and utilized before their advantages can be realized. Diffusion is the process by which innovations (e.g. the IRWH technique) spread to the members of a social system. An innovation is an idea, practice or object perceived as new by an individual. After the system’s legitimizers have ruled on the innovation, it is up to the members to accept or reject that decision.

According to Rogers & Shoemaker (1971), the rate of acceptance is the relative speed with which an innovation is implemented and used by members of the social system. It is generally measured as the number of receivers who apply a new idea in a specified time period.

The living standards in the villages in and around the two towns of Thaba Nchu and Botshabelo are characterized by extreme poverty, hardship and suffering, hunger, poor housing with water and electricity often being a major problem, illiteracy, and demotivation. The people in these remote resource-poor areas where hunger and poverty prevail are living way below the breadline. Because they are unable to provide for their basic needs (food) they feel that they have failed in life. To address these problems the research team wanted to:

- Help farmers to help themselves
- Assist farmers to better decision making
- “Show the Way”
- Enhance the quality of life of farmers through themselves
- Stimulate higher production, through human development
- Encourage behavioural change for the better.

This chapter gives more background about the target area and discusses the results of a socio-acceptability study of IRWH among smallholder farmers in Thaba Nchu, a semi-arid area in the Free State Province in South Africa. The study employed participatory research techniques and other standard research techniques such as questionnaire surveys and demonstrations to generate the data analysed in the sections that follow. This report is part of a bigger project and to get a complete perspective it is suggested that the report of Kundhlande *et al.* (2003) should be read as well.

9.2 SELECTION OF VILLAGES

After a number of contact sessions were held with the farmers to introduce the new farming technology, through pre- and post-harvest focus group discussions as well as a number of other technology exchange sessions, it was decided that it was time to take the IRWH technique to the people. Discussions with extension officers during a reconnaissance visit to the study area revealed that cattle, horses, sheep, pigs and poultry are the most common livestock kept in Thaba Nchu. Cattle and horses are raised mainly for draft purposes, traction for animal drawn carts used for local transport and for sale, while small stock are raised mainly to supply meat for households' own consumption.

There are 42 villages in the whole of Thaba Nchu. The villages are diverse in economic activity, demographic structure and location. Although mixed farming (livestock and crop production) is practised in all villages, farmers in the southern part of Thaba Nchu were reported to be more successful in livestock production, as indicated by a higher off-take rate for the market. Three of the villages have water reservoirs and some irrigation infrastructure, thus allowing farmers in these areas to practise irrigated agriculture. The amount of land that each farmer can irrigate is limited by the availability of water, which is influenced by reservoir capacity and the amount of rain (since the reservoirs are fed from runoff collection). Irrigators mostly produce vegetable crops such as cabbages, beetroot, carrots, onions and spinach.

The villages in the region also differ in the degree to which villagers are able to organise into groups to pursue collective interests. For example, in some of the villages households have organised themselves into livestock production, horticulture and field crops producer groups, and are pursuing efforts to attract outside financial and material resources (mostly from the Community Projects Fund – Support Programme (CPF-SP) administered by the provincial Department of Agriculture) to boost production. However, some of the villages were described by extension officers as lacking motivation to engage in self-help projects, and others seemed not to be cohesive enough to enable members to come together in pursuit of common goals. The Thaba Nchu agricultural ward is divided into three zones, the northern, central and southern zones, for purposes of assigning agricultural extension officers.

The objective of this chapter is to assess the social acceptability of IRWH by the end users, the local farmers working under wide range of conditions. It is therefore important that the trial and assessment of new agricultural practices and techniques be carried out with a full understanding of the socio-economic and agro-climatic conditions under which the target farmers operate.

Four villages were selected for this study: Talla in the north, Paradys and Feloanè in the central zone and Yoxford in the south. Talla is a relatively poor community, without community development projects taking place at the time of the study. This is attributed to the general lack of initiative among the residents and the lack of cooperation among community members making collective action difficult. Paradys has a group of farmers who have started farming collectively, producing sunflower and wheat for the market. The Yoxford community was identified as being successful at producing livestock. A large proportion of the households in the village are headed by females. Feloanè was inevitably selected as the fourth village and as a second one in the central region, because the residents had already indicated tremendous keenness in implementing the IRWH technique. The youth of Feloanè have grouped themselves to produce crops on the croplands and have invested in an irrigation scheme to improve their produce.

The next phase of the research was to meet the communities and the community leaders and to discuss the constraints and opportunities for increasing agricultural production. The participatory research techniques (Participatory Rural Appraisal - PRA and Participatory Action Research - PAR) were deemed as the most applicable.

9.3 BACKGROUND ON PARTICIPATORY RESEARCH METHODOLOGY

In an attempt to answer the question "What is wrong in development?", Kotze & Kotze (1996) point out, *inter alia,* the gap between the expert and the people. They state that it would seem as though the vast amount of information made available by advisors to developing countries has simply had no effect. Edwards (cited in Kotze & Kotze, 1996) ascribes this state of affairs to the distance between the possessor of the information and those to whom it is supposed to be conveyed. Too often the information is inappropriate, partial and outdated as a result of inappropriate research methods that satisfy nothing else but the expert's notion of science. In contrast to the expert, Kotze & Kotze (1996) state that "the poor people appear incompetent and ignorant, and nobody dares to challenge the superior scientifically acquired knowledge". Data, knowledge and insight that could be obtained from the poor, the illiterate and the far-off, are often ignored by the expert. It is precisely those who have learned to survive with virtually nothing at their disposal who possess valuable knowledge. "Indigenous networks of production, barter and mutual support, which have evolved over centuries and could form the basis for development, are sometimes destroyed by plans for commercial production" warn Kotze & Kotze (1996).

Due to alternative approaches in development and methodology, a growing body of literature within the field of small-scale farming is qualitative by nature. Because of the many advantages of participatory research techniques, PAR and PRA were the research paradigms opted for in this research to investigate the acceptability of the IRWH technique by the people in the targeted communities. PRA, PAR and other participatory approaches in development and related work came about due to the need to merge learning and practice. Participatory approaches aim to involve stakeholders in planning, project implementation and evaluation; and to harness local initiatives as opposed to attempts at corralling support for centrally/externally conceived development plans. PRA should be looked at as a catalysing exercise that lays the foundation for on-going processes of empowerment and development. Coetzee, Graagg, Hendricks & Wood (2001) state that 'PAR could be seen primarily as a methodology for empowering participants and only secondarily as a methodology for producing "research" in the conventional sense'. Babbie (2001) defines PAR as a research paradigm where the researcher's function is to serve as a resource to those being studied - usually, disadvantaged groups - to empower them to act effectively in their own interest. The community should therefore define their problems and remedies and take the lead in research that will help them achieve their aims. PAR gives the community access to information with power. This power has in the past been kept in the hands of the dominant class, gender or group. Once the members of the community see themselves as researchers, they regain power over knowledge (Babbie, 2001). PAR is therefore a participative bottom-up approach in which the investigated become the investigators. True to the characteristics of PAR, all four communities played an active part in the entire research process. As partners in and beneficiaries of this project their participation was of the utmost importance. As the farmers were partners in the process, they were the owners of the research results. They made their own decisions regarding the choice of crop and what to do with it, although they could be assisted in marketing it if they so wished.

Participatory forms of research emerged during the 1970s as a response to the failure of conventional research techniques to address issues in Third World or developing contexts. Participatory research is based on the belief that development should be people-centred. People are central to any kind of development process, and communities should be part of the decision-making process.

Babbie & Mouton (2001) state that "conceptualization is the process through which we specify what we will mean when we use particular terms… The product of this conceptualization process is the specification of one or more *indicators* of what we have in mind, indicating the presence or absence of the concept we are studying". Examination of one's "social acceptability" of a new technique is not easy to measure. What will the indicators be? Are the indicators that you decide on valid ones and are the measuring instruments reliable?

Conceptualization is a continuing process and it needs to be addressed at the beginning of the study design, especially rigorously structured research designs such as surveys and experiments. When measuring the socio-economic status (SES) of a respondent, one may simply specify that he/she is going to treat it as a combination of income and educational attainment, ruling out occupational status, property, lifestyle, and so forth. Conceptualization and operationalization have one essential scientific virtue that it is absolutely specific and unambiguous. Many concepts are subject to varying interpretations – each with several possible indicators.

In less structured research methods (as is the case in this study), it was necessary to begin with an initial set of anticipated meanings that could have been refined during data collection and interpretation. To "measure" the concept "social acceptance", it was necessary spell out what indicators were to be used. There is no existing, standardised "scale" to measure social acceptance.

For the purpose of this part of the project, and within the research design of PAR, the "indicators" of social acceptance are the extent to which the project succeeded in enhancing the levels of "mobilisation, capacity building, empowerment, human well-being, self-reliance and community participation". In other words, the research outcomes were to enhance the levels of mobilising and empowering the communities that were part of the project; to increase its capacity building potential; to uplift the level of overall health, emotional comfort, economic security and confidence in the people's ability to solve life's problems; and to create a condition that is conducive to community participation. These outcomes can only be observed as processes that develop over a long period of time and can therefore not be "measured" within the time limit of this single project.

Besides other characteristics of PAR (see De Vos, Strydom, Fouche & Delport (2002) and Kundlande *et al.* (2003) for a comprehensive list of these), focus was placed on the following characteristics of this model in the research:

- The development of knowledge and the role of knowledge as an instrument of power and control.
- PAR as applied research that is directed at practical problem solving.
- The principle of self-development, where people must organise themselves into action.
- Community forums, nominal groups, workshops, focus groups, in-depth interviewing and participant observation as data collection techniques and research procedures.
- Multidisciplinary framework where all disciplines should be involved.
- Accountability of the community for the progress made with the project and also for management of its own resources.
- Equal partnership in the research process and shared ownership.
- A desire to find useful solutions to the problem.
- An interest in and commitment to change.
- The emancipatory nature of PAR.
- Stamina and patience that was required in PAR projects to deal with the competing demands for immediate action versus meaningful participation.
- Recognition of available resources in the community, such as values, culture, knowledge and experience, and that it must be used to its full potential.
- The shift from a dependency model to an empowerment model, with a participatory approach where communities can do things for themselves in order to enhance community building and eventually improve their quality of life.
- PAR as a process of collective reflection and self-realisation in order to help the disadvantaged to regain their confidence in themselves. In this manner people are encouraged to share their experiences and to fight their way out of their problems.
- Implementation of PAR projects in such a manner that a community gains a sense of ownership of a project so that they can then shape the necessary services as required.
- The ultimate goal of PAR to improve self-esteem, self-reliance and self-determination.

Specific terms that are important in the PAR model and that were focused on include the following: community, mobilisation, capacity building, empowerment, human well-being, self-reliance and community participation. These “indicators” were used to “measure” the socio-economic acceptability of IRWH crop production techniques.

Community – The community is seen by De Vos *et al.* (2002) as a local community, a group of people in a small area, who share physical and social space. The communities in this study included the villages of Yoxford, Feloanè, Paradys and Talla, all located east of Bloemfontein near Thaba Nchu. The awareness and interaction of individual, family and community strengths and mutual needs were recognised in these communities. PAR helps communities to create informal social support networks in cooperation with ‘professional people’, to “prevent or cure” a problem in the community.

Mobilisation - As the economic well-being and emotional stimulation of the community are becoming more important considerations, this research, in following the principles of PAR, strongly focused on the mobilisation of the community participants as active agents in the process of creating knowledge, reaching a collective objective and solving problems. The social action or change (adoption of new farming techniques) was community-initiated and defined – as a shared goal – by the participants themselves, on the basis of their own perception of reality. The researchers who played the role of change agents for this project supported or helped the people concerned to undertake such actions. This also helped to ensure continued adjustments of the actions to people's unique circumstances (Coetzee *et al.*, 2001).

Capacity building - This refers to the potential and capacity of the people of a particular community and to the process of assisting them in developing skills at various levels in order to become the masters of their own development and thus acquire the capability to manage their own future (De Vos *et al.*, 2002). It is therefore a learning process characterised by flexibility, sustainability and a total capacity-building approach.

Empowerment - The process of increasing personal, interpersonal, socio-economic and political power which enables people to improve their circumstances. Participants gained knowledge by being part of an enquiry that created knowledge. Since PAR is action-based, participants benefit from further knowledge and empowerment when actions are being activated. Other forms of empowerment through PAR are conscientization, also termed "consciousness raising", emancipation, learning, strengthening of research capacities and generating autonomy amongst the participants (Babbie & Mouton, 2001). PAR endeavours to empower deprived and disenfranchised people with research capabilities so that they can identify and transform their situation for themselves. This takes place in an ongoing learning process for everyone involved. In this cooperative manner more successful and more sustainable outcomes can be achieved. This means that all stakeholders involved in the study remain, therefore, involved in all stages of the research process.

- **Conscientization -** The term "conscientization" is generally used to refer to raising participants' "self-awareness' and can be achieved through the incorporation of participants' own local knowledge. Self-awareness is raised through collective self-inquiry.

- **Emancipation** - Emancipation refers to the establishment of self-critical communities who create a new system of knowledge, which is considered to be a key element to their empowerment and liberation.

- **Learning -** The research process is a learning strategy aimed at empowering the participants. The central role that adult education plays is highly appreciated. The learning process is ongoing and inseparable from PAR's function.

- **Strengthening of research capacities -** Empowering participants also carries the general meaning of strengthening their research capacity to solve problems and achieve their objectives. Coetzee *et al.* (2001) state that the most important of all capacities to be developed, improved or strengthened is the participants' capacity to conduct their own research. Fundamental to PAR is the commitment that all participants actually do research. For participants to learn how to collect and make sense of their own data, it is necessary for research techniques to be popularised (Coetzee *et al.*, 2001). Popularisation of research techniques means that participants are taught simpler, more economic, and controllable methods of research.

- **Human well-being -** De Vos *et al*. (2002) regard welfare or human well-being as "the efforts of a community to help its people achieve a condition of overall health, emotional comfort and economic security". Human well-being should be the focal point and aim of the total research endeavour and development process and includes well-being on all levels, including the social, economic, technological, political, cultural and spiritual potential of people in their communities (De Vos *et al*., 2002).

- **Self-reliance -** De Vos *et al.* (2002) define self-reliance as "a driving force for creative activity that requires an awareness of one's creative assets, confidence in one's ability to solve life's problems, the courage to take on challenging tasks, and the stamina to make sustained efforts to accomplish them".

- **Community participation -** Community participation was seen as the creation of a democratic system and procedure to enable community members to become actively involved in the institutions and systems that govern their lives and to assume responsibility for their own human development. In the process of community participation, De Vos *et al.* (2002) state that the members will be "economically uplifted, achieve social and economic rights, seek macro-social transformation, which includes social reconstruction, capacity building and sharing in the advantages of community development, and improve their decision-making power". Furthermore it provides a sense of belonging, a commitment to common goals, a willingness to assume responsibility for oneself and others, and a readiness to share and interact.

The process of PAR that was followed in this project includes the stages that are suggested by De Vos *et al*. (2002). Briefly these include the following:

- *Introduction to the community* - According to De Vos *et al*. (2002) the request for an action-research project should, ideally speaking, come from members of a community faced with a problem. Whatever the case may be, contact with the community should be made at grass-roots level and entry into the community must be negotiated.

- *Problem identification and statement* - The point of departure in PAR is that people, especially those who are marginalised and deprived, have their own agenda, and that this should be respected at all costs. A collective sense of clarity with regard to the exact nature of the problem should therefore be developed. Although the researchers may have a time-frame of their own within which the project should be completed, it is important to move at the pace of the community.

- *Goals and objectives* - After a comfortable working relationship has been achieved, the goals and objectives of all groups involved in the project were considered. At that stage it was crucial for the researchers to determine and formulate from various agendas what has to be evaluated, and how. All parties had to be prepared to work together to find a solution to the problem and to achieve all the various goals that were set out at the start of the project. It had to be determined what information was needed and how the relevant data were to be collected. The whole team had to work together to break the project down into manageable tasks and to allocate responsibility for each of these tasks to the various participants.

- *Implementation of data collection techniques* - During this stage the nature and context of the community's impediments had to be determined by way of research. This phase means implementing the data collection techniques, after the total proposed research methodology to be followed in the inquiry has been carefully considered.

Unlike the known formal research procedures, it was decided to make use of community forums, nominal groups, workshops and focus groups as group formats for gathering data. The aim of community forums (as community meetings) was to generate ideas, to gain an impression of the community's perspective of the problem, and to create awareness among the community of the issue. Nominal groups consist of specific people who are interested in, and involved in the problem. These groups were used to prioritise the needs and problems of the community. Their views were required for further action and planning of the research. Participant observation and in-depth interviews were used for the gathering of data. Workshops with specifically targeted interest groups (in this case small-scale farmers) were held to refine the community's preferences. In total, about 12 workshops took place and during these 8 focus groups (as small selected groups of eight to twelve people) were drawn together to share their knowledge, experience and expertise to the problem of farming under circumstances.

- *Analysis of the data* - It was decided that the process of analysis and interpretation of the data that was gathered by means of the different group formats, in-depth interviews and participant observation, could best be represented in a spiral image – a data analysis spiral (see De Vos *et al.,* 2002). The researchers moved in analytical circles rather than using a fixed linear approach. One enters with data made up of a text of images (drawings, recorded audio- and videotapes) and exits with an account or a narrative. This analytical spiral includes the following steps: (1) collecting and recording data, (2) managing data, (3) reading and memoing, (4) describing, classifying and interpreting, and (5) representing and visualising.

- *Negotiation* - This phase in the PAR process ensured that the representatives of the community were truly representative of all sectors and interest groups of the community, and that all facets of the problem were addressed. Was the will of the majority of the people reflected? In PAR group dynamics is important, as this will eventually determine to a large extent the success or failure of the project. To enable everybody to participate and not to leave the whole process to the researcher, is an important aspect of this model. Through negotiation the communities have to assume ownership of the total process. Expansion of the understanding of the dimensions of the problem and the development of relevant strategies for change in a spirit of negotiation had to take place. On various occasions the multi-dimensional nature of the problems of small-scale farmers, as well as strategies for change, have been discussed with the stakeholders. Training the farmers in skills other than applying new technology also took place occasionally. Farmers attended training in, *inter alia,* group dynamics, leadership, motivation, team work, etc. in order to develop strategies that will enhance their opportunities to live a better life.

- *Planning* - During this phase the individual interpretations of the participants were linked to, and integrated into, the broader context of the problem. By means of in-depth interviews with several farmers, the researchers (as change agents) explored and affirmed the inherent strengths, skills as well as weaknesses within the different communities. Valued and held high during the research process, is the inside knowledge or local knowledge of the participants, their expertise, common sense and wisdom. However, this does not mean that the participants are knowledgeable or experts. Their perspectives on their situation and environment are respected, relied upon and incorporated into the research process. It was always kept in mind that PAR is not the end in itself, but a basis for, and a means through which action can be planned and implemented. PAR sometimes emphasises research and sometimes action. It is employed in research projects where a need for change in social conditions is required. The results are therefore converted into actions and the participants are still involved even at this stage. During the interviews, almost all the farmers stated that it became a great pleasure for them to participate in research where they surely knew that it was going to bring about change to the unpleasant social conditions they were living in.

- *Evaluation* - Evaluation as part of the process, refers to the extent to which goals have been achieved, the level of skills development and empowerment of the people, and the benefits to the community through participation in the research process. Although this is part of the ongoing process of PAR, it remains to be investigated and monitored during the next year and even longer, and will therefore not form part of this report.

- *Recommendations and action plan* - In this section we will have to initiate some kind of action to be undertaken jointly by the action-research partners. If the farming practices of the farmers in the communities cannot be changed by persuasion, power strategies or some other kind of action, the only solution to the problem remains self-help programmes for and by the community itself.

- *Evaluation of the action outcomes* - After the action plan has been implemented, the results of the action will have to be assessed and a further period of research is initiated. Depending on these results, it may then be necessary to redesign the original action undertaken. Thus, action and research continue as alternate processes in the solution to the communities' problem. De Vos *et al.* (2002) state that the action part of the process "keeps the research relevant, initiates further research and implements research findings, while the research part guides and evaluates the action".

9.4 PREPARATION FOR PRA AND PAR SURVEYS

Good planning is a prerequisite for undertaking a successful PRA/PAR and for the exercise to achieve its intended objectives. To this end, researchers sought to learn about how the communities were structured, their leadership structures, the presence of various interest groups, etc., before setting out to meet with the farmers. Discussions with the regional extension officer in Thaba Nchu provided some of this information. The team also sought the close cooperation of extension workers in setting up meetings in the selected villages. Since the extension workers are more familiar to local people, their presence can help allay the locals' suspicions regarding the intentions of outsiders who come purporting to be working for the improvement of the communities. Many communities have had bad experiences in the past with external agencies that assured them help to improve the lot of the locals but never reappeared. But, extension workers belong to government departments without a tradition of seeking locals' participation in influencing policies and development programmes, so there is a need to have them sensitised to the new approach before they are invited to be part of the PRA/PAR team. In meetings prior to field visits, discussions were held with the extension workers during which the potential for increasing crop production using IRWH techniques was outlined. The agricultural extension officers were invited to be part of the process, jointly with the communities and researchers, of diagnosing problems in the farming system and the experimentation with IRWH as a technique to increase available soil water in farmers' fields.

Even more importantly, the participatory approach as the philosophy to underpin interactions with communities was also discussed with the extension workers.

Although PRA/PAR consists of largely open-ended interactions with communities, it is still important for researchers to compile a list of questions that could be used to guide the discussion and to ensure that all pertinent issues are discussed, and that the critical information needs are met. For researchers to ask questions is in line with the participatory approach. It is an acknowledgement that farmers have some knowledge which outsiders can gain access to by letting farmers explain how they do things and the reasons for doing them the way they do. However, it is also important that farmers also have the opportunity to question the researchers so that they can also tap into the knowledge of outsiders. Prior to the field visits the researchers met to discuss and compile a list of open-ended questions.

It was decided that one member of the research team will be assigned the responsibility of guiding the discussion to ensure proceedings would not deviate from the central purpose of the PRA/PAR. The main objective of the PRA was to assess people's needs, opportunities, and problems and seek solutions. Also important was the assessment of the economic viability, social and environmental sustainability of the IRWH, which was intended for use by the communities of the four villages that existed under a wide range of conditions.

Two weeks prior to the field visit the Regional Agricultural Extension officer, Mr. Morumo, sent a letter to the village headmen in each of the four villages (Paradys, Talla, Yoxford and Feloanè) requesting a meeting between households and the researchers. The letter specified the date, time and purpose of the meeting.

9.5 RESULTS OF THE PRA

A team of six researchers from the University of the Free State and the Agricultural Research Council participated in the PRA/PAR exercises. Two extension workers from the Provincial Department of Agriculture joined the team at Thaba Nchu. The following sections summarise the results of the meetings held with farmers in the four villages.

9.5.1 Paradys

The village of Paradys covers a total area of 2 109 hectares, divided into three land use niches – 1 795 ha for grazing, 274 ha for crop farming and 40 ha for residential plots. 173 households were found in Paradys. The town is linked to Thaba Nchu, 12 km to the south, by a good road. A regular bus service, 3 times a day, is available between Paradys and Thaba Nchu, and from there travelers can get buses and commuter taxis to other parts of Thaba Nchu, Botshabelo and Bloemfontein.

The soils in the Paradys area have a high clay content (see section 3.4). The vegetation here is dominated by grasslands, and typical of semi-arid regions, rainfall is low (less than 600 mm per annum) and is unevenly distributed. Surface water is generally scarce. All of Thaba Nchu (the villages and the town), Botshabelo and Bloemfontein constitute the Municipality of Mangaung. Bloemwater, a company that supplies water for the city of Bloemfontein is also contracted by the Mangaung Municipality to supply water for domestic use in Paradys and the other villages in Thaba Nchu. Water is not delivered directly to individual households, but to water points that are located at the end of each street. Households have to pre-pay for the units of water that they want to use.

The meeting at Paradys took place in one of the local church buildings. A member of the local youth group, who is also leader of the group of 50 farmers who decided to pool their land so that they could farm collectively, chaired the meeting. The headman, Mr. Moila, provided the opening remarks and did the introductions. About 70 individuals (men, women and youths), a slight majority of whom were male, attended the meeting. In the opening remarks it was emphasised that the team comprised researchers from the university and a research institute (ARC-ISCW), and that the objective was to learn about farming practices in the village, and the constraints and opportunities facing farmers as they go about their business. It was important to state from the onset that the research team did not have material or financial resources to give to the farmers so as not to raise unrealistic expectations about the nature of the benefits that they could derive from interacting with the team. Sometimes, when farmers think that at the end of a meeting with outsiders there may be some money or other forms of support to be given out, they may not provide truthful information, choosing instead to project an image of extreme deprivation and helplessness in the hope that it makes them more likely to receive assistance.

Even though it is probably ideal to have groups of 20 or fewer individuals for group discussions to ensure that all participants have a chance to talk and make contributions, the group discussion was held with one large group. This was because the first meeting was an introductory one, the main purpose being to acquaint the communities with the research, and for gathering general background information about the villages. This information could be used for planning further PRAs/PARs and the survey.

During the group meeting researchers sat among and mixed with the farmers to avoid the "them versus us" appearance. Communication between researchers and farmers was made easy because most farmers could comprehend and speak Afrikaans or English fairly well. The researchers asked a broad range of questions, for example, the type of crops that people grew, how they carried out land preparation, arrangements for accessing farm land, and constraints faced by farmers.

Almost all households in the villages have access to cropland. The average farm size is 1.87 ha (3 morgen), although some farmers "own" up to 3.74 ha (6 morgen) of cropland. In many cases the additional land was acquired through taking over land left behind by former residents who moved out of the village and settled in the new urban area of Botshabelo in the early 1980s. Surprisingly though, very few households are currently working their cropland (many stopped cropping as long as 10 years ago). Only three persons, Mr. Jimlongwe, Mr. Mothibi and Mr. Lemeon, have continuously farmed their land. These three are quite successful and each owns at least one tractor and equipment for land preparation and planting. It emerged during the group discussions that these farmers have considerable farming experience and knowledge. All three produced sunflower on a commercial scale.

Since 2000, a group of about 50 individuals have formed a cooperative so that they can produce crops as a community. They pooled their land and requested permission to use some of the unallocated agricultural land in the village. During the 2000/2001 growing season the group cultivated 18 ha of sunflower. The land on which the group works belongs to individual members who pooled their plots in favour of group farming. The sunflower was marketed in

Tweespruit, which is about 20 km south-east of Paradys. The group hires a truck to take their produce to the market.

For those who have been involved in crop production in recent years, they have used a tractor to prepare the land for planting. Some used their own tractors, while those who do not own one could hire one from the Provincial Department of Agriculture offices in Thaba Nchu. The Department runs a scheme in which it provides tractors, with a driver, for use by farmers if they can provide their own fuel and cover minor maintenance costs during their use of the tractor. Other production practices, such as planting and weeding, are done by hand.

Besides sunflower, other crops grown by villagers (mostly on their homestead lands) include maize, wheat, potatoes, spinach and pumpkin. Crop yields were reported to fluctuate widely because of variations in growing seasons. The other economic activity of significance besides crop production is livestock farming – cattle, goats, sheep, horses, pigs and poultry. Livestock sales were reported to be the main source of income for many households. Some households have members working off-farm, mainly in manufacturing industries in Thaba Nchu and Botshabelo.

When asked about constraints they face in farming, the top of the list was the destruction of the fence around the cropland (stolen by thieves for sale in Thaba Nchu). This was cited as the major disincentive to any attempts to cultivate the cropland, for fear of having crops destroyed by livestock. Because all croplands are in one location, one perimeter fence is required around the whole area so that everyone's cropland is protected. It was reported that any effort by one farmer to fence off his/her individual plot would not be taken to kindly by the rest of the village. Measures such as letting in cattle to destroy the crop at night and theft of either the crop or the fence were said to be the ways through which "individualistic" actions get "punished". Farmers argued that they would need some outside assistance (e.g. Community Projects Fund (CPF-SP) of the Provincial Department of Agriculture) to buy a new fence, because this will require a large financial outlay, yet not having produced crops for many years now, there was no other way they could generate income. When asked how they would make sure that the new fence will not be stolen again, if somehow they could get it rebuilt, farmers said they would need to form a village committee who will guard the fence and to ensure that those caught stealing or damaging the fence will be punished. In addition, farmers stressed the need for better co-operation between the community and the police in the future. Farmers complained that at present the police are not helping because cases of fence theft reported to them are not fully investigated. Some community members alleged that in some cases when the police were presented with the name of a suspect they turned around and gave away the identity of the person who reported the crime to the suspect. Because of fear of reprisal, villagers were afraid to report crimes to the police.

Other constraints faced by farmers include the inadequacy of water for agricultural production, as the rains are generally inadequate and uneven; as well as the lack of financial resources for the purchase of production inputs such as seed and fertilizer. Many farmers also pointed out that it had been a long time since they were involved in crop farming. If they were to successfully grow crops again, they would need support from agricultural extension workers.

Land in the village is controlled by the Tribal Authority (whose offices are at Thaba Nchu), which in turn delegates the authority to allocate land to the village headmen. An application for land has to be submitted to the headman, who in turn takes the application to the Tribal

Authority. If there is still some unallocated land in the village the Tribal Authority can grant permission for the allocation of a residential stand whose site number has a matching plot number for the use of the new household. Every household has the right to graze as many units of livestock as it desires in the village commons. The rights to homestead and agricultural land and to the commons are inheritable. During the meeting some villagers claimed to be without agricultural land even though they were allocated residential land through the normal channels. The headman promised to investigate such cases because each residential stand is supposed to have a corresponding agricultural plot.

9.5.2 Talla

The village of Talla is situated about 30 km north of Thaba Nchu. The village is serviced by a network of all-season gravel roads, and there is a regular bus service linking Talla to Thaba Nchu and other villages. There are 112 households in Talla. The public amentities available in the village include a community hall, which is used for village meetings, and also functions as a pre-school centre. Public water standpipes are located at the end of each street. Here, households can fetch water for domestic consumption by using electronic cards that reflect the units for water that the household has paid for in advance. In Talla, like in the rest of the villages in Thaba Nchu, provision of water for domestic consumption is the responsibility of the Mangaung Municipal Council, who in turn has contracted Bloemwater to deliver this service. Villagers can obtain some of their provisions – foodstuffs, toiletries and non-prescription medicines - from two local shops. There are post boxes at a central location to which the village's mail is delivered and the household has to pay a nominal fee for the use of a mailbox. There is no clinic in the village. A mobile clinic services the village and makes its call once a month. Most households have electricity and many others are on a waiting list to get their houses connected. Households have to pay in advance for electricity.

Talla is situated in a semi-arid region with rainfall of about 500 mm, unevenly distributed over the summer rainfall season. The soils are clayey, which makes them potentially suitable for water harvesting (the other requirement is that the soil depth be at least 750 mm). The vegetation in the area is largely grassland with a few scattered trees and shrubs.

The meeting at Talla was held at the headman's compound. When the team arrived in the village the villagers had not yet assembled for the meeting even though the team arrived at the appointed time. The headman pointed out that in the past, the people had bad experiences with people who promised to come to meet the villagers but never showed up, and as a result villagers have become reluctant to assemble for meetings before the visitors arrived. When they saw the research team's vehicle parked at the headman's homestead some of the villagers started arriving for the meeting while the headman set out to inform more people of the arrival of the researchers. In the end about 30 people (men, women and youths) came to the meeting. The women and the youths (18-30 years) outnumbered the men. The headman introduced the research team and explained the purpose of the team's visit. The team's opening statement outlined the objective as being to learn about agriculture in the area, the constraints and opportunities facing farmers, and to work with locals to explore potential solutions to some of the problems encountered by farmers.

Again the meeting was held with one group. This group being smaller in size than the one at Paradys, there was less concern about some participants not having had the opportunity to make their contributions. However, it was still important to encourage everyone to participate, especially the women. The researchers asked farmers about their agricultural activities and used a checklist of questions to steer the discussions. At first some of the participants, particularly the youth, were quite argumentative, insisting that they would have been much happier if the team had employment creation projects in mind since there was high unemployment among their ranks. They argued that since young people lacked direct access to land, they did not see how agricultural improvement would help them specifically. In the course of the discussion, as it became clear that vibrant agriculture in the area could lead to spin-offs in rural agro-industries and agribusiness, the youths started showing some interest in the proceedings of the meeting.

Farmers in Talla produce livestock – cattle, sheep, goats, pigs and horses, and crops – mostly vegetable crops (spinach, pumpkin, potatoes and cabbage) grown at the homesteads. Crops produced on the croplands in the village stopped several years ago and not a single farmer reported to be currently involved in crop production. Livestock sales, state-provided pension income for the elderly and state-provided child support (child grant) for children under the age of seven years were cited as the major sources of income for village households. Other households receive remittances from members working in off-farm employment.

Like in Paradys, the lack of a fence around the village's agricultural land was said to be the major reason why farmers were not able to engage in crop production. Without a fence a lot of labour would have to be expended to keep livestock from straying into the croplands during the cropping season, and crops would likely be destroyed during the night when there wouldn't be anyone on guard. The lack of natural fencing material (trees and tree branches) means that farmers need to purchase barbed wire and metal poles for the fence and this can be very expensive. Villagers complained that not having produced crops for many years and being without jobs, they lack the financial resources required for the purchase of fencing materials. They would like the government (provincial or national) to assist them in building the fence. The villagers suggested that once a new fence was erected, they would form a committee for guarding the fence and also to come up with measures to deter its destruction.

Lack of water was also said to be hampering crop and animal production in the village. The villagers had a borehole and a windmill constructed at the edge of the village to provide water for a community garden and for watering livestock. Water is pumped into a tank and from there it is channeled to the garden via a small canal, while a pipe channels some of the water to a drinking trough for livestock. The villagers would like to see more effort put into the development of water sources for agricultural purposes.

Inadequate financial resources for the purchase of production inputs (seed, fertilizers and pesticides) was cited a constraint to crop production. There is also the lack of money to buy fuel to allow the farmers to use the government provided tractors. Land preparation is mostly done using tractors, since most households do not possess animal-drawn farm equipment. Farmers are aware of the possibility of obtaining loans from a number of sources (e.g. the Land Bank), but felt that without a fence around their cropland, and lacking the skills to farm at a commercial level, they would not be able to effectively utilize the loans.

Land in the village is controlled by the Tribal Authority, which in turn delegates the authority to allocate land to the village headman. An applicant has to pay a fee of R230, upon which he/she is allocated a residential stand (with an assigned site number) and an agricultural plot with a matching plot number. Every household has the right to graze as many units of livestock as it desires in the village commons. The rights to homestead and agricultural land and to the commons are inheritable.

9.5.3 Yoxford

Yoxford is located 30 km south of Thaba Nchu. It is linked to Thaba Nchu by an all-season gravel road and a regular bus service provides the locals with transport to town where they can catch buses and commuter taxis to various destinations around the Province. There are 86 households in the village. Public amenities in the village include a primary school, a tuck shop and a small community hall. For health services, the village depends on a mobile clinic that comes around once a month.

The meeting at Yoxford was held in the local community hall. A group of about 40 people (women, men and youths) attended the meeting, with the men commanding a slight majority. In introductory remarks, the researchers pointed out that they are not from a funding or donor agency and as such they did not have financial or material resources to give to them. The researchers expressed their interest in exploring with farmers the nature of the agri-system in the area, and the constraints and opportunities faced by farmers. The researchers also expressed their interest in how the community and the ARC can engage in the search for solutions to some of the problems facing them.

The meeting was held in one group with a member of the village (a representative of the headman) acting as chairman. A member of the research team facilitated the discussions with the aid of a checklist of questions to guide the discussion and to ensure that at the end of the meeting the information requirements for the study were met. The meeting lasted over two and half hours. Many of those present had a chance to put across their opinions on the various issues that were discussed and seemed to do so without any hesitation. Throughout the course of the discussion, participation by women attending the meeting was encouraged. Although they appeared hesitant at first, as the meeting progressed the women realised that they will be listened to and needed no further encouragement to voice their opinions. The youth were also actively involved during the discussion. The representative of the headman who “chaired” the meeting is a member of the local youth group.

The soils in the area are clayey (see section 3.4), and the vegetation is mainly grassland with scattered shrubs. The rainfall is low (about 500 mm per annum) and unevenly distributed. At present, livestock rearing is the main agricultural activity in the village because crop production stopped several years ago. Livestock raised in the area include cattle, sheep, goats, pigs, horses and poultry. For many households in the village, cattle sales are a very important source of income, although there were complaints about prices received for stock. Farmers also complained that the buyer does not necessarily pay them promptly.

When farmers used to grow crops they grew maize, wheat, sunflower, beans and sorghum. At present, crop production is limited to homestead gardens and mainly to vegetable crops. There is a community garden where some members of the village have been assigned some individual plots. Here plot owners grow vegetables – cabbages, carrots and beetroot – under irrigation. Before the area came under the jurisdiction of the Mangaung Municipal Council, irrigation water was supplied from a borehole powered by a windmill. When Bloemwater started providing water for the village under contract from the Mangaung Municipal Council, they dismantled the windmill and now the same system that supplies water for domestic use supplies water for irrigation. Plot holders are not happy because they have to pay for the water at the same rate as for domestic consumption. Some of the villagers who cannot afford to pay for irrigation water have left their plots idle. Villagers were unhappy because they were not consulted when the decision to close down their borehole was made. The borehole had also been used as a source of water for livestock. Bloemwater refused to construct a water pipe to deliver water to drinking troughs for animals, arguing that their responsibility is to provide water for domestic use only and not for agricultural purposes.

At the moment there are limited opportunities for income generation in the village outside agriculture, yet agriculture is not exactly thriving. For most households the most reliable source of income are the pensions of elderly members of the household. The lack of fences around the agricultural land was reported to be the main reason why many farmers had stopped growing crops.

Other constraints faced by farmers include the inadequacy of water for agricultural production, as the rains are generally inadequate and uneven, as well as the lack of financial resources for the purchase of production requirements such as seed and fertilizer. Many farmers also pointed out that it had been a long time since they were involved in crop farming. If they were to successfully produce crops again, they would need support from agricultural extension workers.

Land in the village is controlled by the Tribal Authority, which in turn delegates the authority to allocate land to the village headman. An applicant for land submits his/her application to the headman who in turn takes it to the chief (Chief Moroka). If there is still some unallocated land in the village the chief will give his permission for the applicant to be granted land for the establishment of a homestead and for farming as well as the right to use the village commons. The rights to homestead and agricultural land and to the commons are inheritable.

9.5.4 Feloanè

The village of Feloanè is in the central part of Thaba Nchu, about 15 km north of Thaba Nchu. There are 180 households in the village. The majority of the households in the village have access to electricity and piped water. Mangaung Local Municipality is the authority responsible for providing social services for Feloanè and all the other villages in the area. Households have to pay for water and electricity in advance and receive electronic cards on which the units/quantity of water or electricity they have paid for is credited.

In Feloanè, community members were strangely hostile during the first meeting considering that it bettered the other villages in terms of crop production. There appeared to be two opposing groups; one comprising the younger members and the other the older members of the community. It was later learned that the older members felt intimidated by the younger members who had full control of the irrigation scheme and had already established a strong relationship with the ARC-ISCW team prior to the meeting. They feared that the team would pay more attention to the youth and ignore their needs, especially because the team already knew some of the youth through the technology exchange actions. Needless to say, the youth were very active in their wishes to improve production and in implementing the technique both in the croplands and in their homesteads. The older members also showed some interest but reluctantly attended subsequent meetings.

As in all the other villages, each household in the village has access to land on which to build a homestead, and also has access to the commonage on which they can graze livestock. In addition households have access to cropland. The average farm size in Feloanè is 2.8 hectares. The land allocation process follows the same pattern as in the other villages: if a person wishes to establish his/her homestead in Feloanè, he/she has to seek permission from the village headman. The headman will take the request to the Tribal Authority and, depending upon the availability of land and upon the payment of the necessary fees, a residential stand and arable land are allocated to the applicant.

In Feloanè there is a dam built across a seasonal stream. Some irrigation infrastructure (open concrete canals) is available, allowing the community to take advantage of the water to produce irrigated crops. Only a very small portion of the arable land is under irrigation, as the water supply is very limited. The bulk of the cropland is utilized for dryland cultivation. On the irrigated land farmers grow lucerne (for supplementary feed for livestock) and vegetables. The farm households in Feloanè have organised themselves into livestock production and vegetable production interest groups. With these structures they hope this will enable them to better pursue common interests and to help solicit outside assistance (financial and production inputs) for their production inputs. The community, however, expressed a willingness to work together as one group (those belonging to the two groups identified above and those belonging to neither group) for the purposes of working on the IRWH trials.

9.6 PREPARATION AND IMPLEMENTATION OF THE FORMAL SURVEY

Although some valuable information about the households and the agri-systems in the study villages was gained from the PRA exercises, it is important to understand how decisions are made at the household level and the factors that are likely to influence those decisions. Detailed and household specific information are best acquired through household surveys. Formal household interviews with the use of questionnaires are commonly used to elicit and record information about households.

To gain an in-depth understanding of the agricultural households in the Thaba Nchu area, and for a better insight of how the adoption of IRWH will affect the participating households and the factors that might influence its success, detailed household level data was gathered in a socio-economic survey using a structured questionnaire. 124 households from the three villages of Paradys, Talla and Yoxford were interviewed.

The survey gathered information on household characteristics (e.g., household size, educational level of the head of the household, household wealth and income), farming practices, household food intake and expenditure, use of agricultural support services and the households' opinions on production and support services constraints.

In designing the questionnaire particular attention was given to simplify the questions and the style in which the questions were formulated. In the questionnaire, the order of the questions was such that simpler questions such as the age of the household head (respondent), family size and other information pertaining to the household were asked first. Such questions can be answered without much effort on the part of the farmer and this can serve to relax the respondent who otherwise may feel intimidated by an interviewer carrying pen and paper when probably the respondent has not had much formal education.

The survey type was a single visit and relied upon farmer recall on most of the items in the questionnaire. The questionnaire was tested on a sample of households in a village other than the three selected villages interviewed. This test provided an opportunity to make adjustments to the questionnaire, for example, the rephrasing of some questions that the informants found difficult to understand; and it also provided the opportunity for the interviewers to practise their interviewing skills before the actual interviews.

Although an English version of the questionnaire was used in the field, the interviewers were provided with a Sesotho translation so that they could study it and ensure a consistency in the interviewers' translations of the questions during the surveys.

9.7 RESULTS OF THE FORMAL SURVEY

This section provides a summary of the results from the formal survey. 124 households, about 40 from each village, were interviewed. A summary of household characteristics is presented in Table 9.1.

Of the total of 124 households surveyed, 77 (62 %) of the respondents are female. Of the female respondents, 32 (26 %) are heads of households. The average household size for sample was 5. There is a fair amount of variability in the household size in the sample as suggested by the standard deviation. Most households have more adult female members than adult male members. On average, households have only 3 adults (male and female). Small-holder agriculture is generally highly intensive, and with 3 adult members households may not have sufficient labour particularly during critical periods of weeding and harvesting. About 54 % of the respondents have at least a primary level of education (7 years of formal schooling). The majority (60 %) of the households have lived in the current villages for more than 26 years, with 78 % reporting to have arrived in the current village about 40 - 50 years ago, when most of the villages were established.

Table 9.1 Socio-economic characteristics of households in the villages of Talla, Paradys and Yoxford, 2001.

	Mean & standard deviation
Labour Supply	
Household size	4.96 (2.20)
Number of male adults	1.35 (1.47)
Number of female adults	1.66 (1.08)
Stay in current village (years)	26
Age of head of household (years)	50
Educational level of head of household (years)	7
Assets	
Land (hectares)	1.87 (1.04)
Number of cattle	4.08 (5.92)
Income by month (Rand)	
Pension (and other government transfers)	327.50 (0.75)
Remittances from household members	236.45 (579.76)
Expenditure of food	277.87 (164.77)
Number of Observations	124

The average farm size of the sample households is 1.87 hectares (3 morgen), while some households have up to 3.73 hectares (6 morgen) of farmland. Although all households are guaranteed access to agricultural land in principle, only 70 (56 %) of sample households reported having access to land. There is a need for an investigation into the reason why as many as 30 % of the households do not have access to agricultural land. There is a possibility that a significant number of these households do have assigned agricultural plots but since there is no cropping currently taking place in the villages, these households have never bothered to ask the headman to show them their assigned plots. However, the headmen of the villages also concede that most agricultural land has already been allocated and that it is no longer possible to find land for new households.

Without crop production, and with few employment opportunities, most households rely on livestock sales, state-provided pension for the elderly and on remittances for cash income. Thirty-four (27 %) households in the sample have at least one member involved in off-farm employment, mostly as factory workers in Thaba Nchu and Botshabelo. On average, the member engaged in off-farm employment sent home on average R 236 per month. Pension income is also a significant source of income for households in the region. Sixty (48 %) of the households had a member receiving old age pension (R 570 per month), and 20 households had more than one member eligible for the pension. On average, pensions contribute R 327 to household income in the region, about 65 % of reported cash income. This figure is comparable to the estimate by Carter & May (2001) for all rural households in South Africa.

About 77 % of the households own some livestock, mostly cattle. The average herd size is 4 head per household. Among the cattle owners, 37 households had sold at least one beast in the previous year. The reasons for selling cattle varied, but most households reported to have sold cattle so that they could pay for their children's school fees, to enable them to pay for funeral expenses and to enable the purchase of food, clothing and other household commodities.

Households in this region do not own many other production assets. Only 11 households owned an animal drawn cart, while only 16 households owned an animal-drawn plough. Seven households in the sample owned a tractor and some tractor-drawn farming equipment. A 1993 survey found that 50 % of black South Africans live in poverty, suffering material deprivation and human insecurity (Carter & May, 2001). Mechanisms by which people can escape poverty include asset accumulation, which provide a structural escape from poverty. It has been estimated that about 60 % of poor people are caught in chronic poverty. Characteristics of such people are that they have similar endowments and face similar constraints to use the endowment. Poverty then may be best measured in terms of asset ownership and entitlement combinations that map to an expected livelihood.

Risk and vulnerability play an important role in the inability of poor households to escape from poverty. When households have low resilience to shocks such as droughts they end up being forced to sell off assets or their circumstances make them neglect accumulation of productive assets (accumulation failure) as they struggle to survive. Over time, such households spiral down to a situation where they are trapped in poverty.

Some rather crude expenditure estimates show that households spend on average R 278 (about 50 % of cash income) on food per month. Of the sampled households, 49 % (61 households) relied exclusively on the market to source all their food requirements. Food supplies are purchased mainly at Thaba Nchu, but some items can also be purchased at the local shop.

The land tenure systems, under which many small-holder farmers operate, is frequently cited in the literature as a major disincentive to the adoption of sound land practices. It is argued that communal and allocated lands are frequently abused because farmers and graziers do not feel any responsibility for conservation of the land and the veld. In the arable lands farmers do not have an incentive to apply conservation measures if they are to be trampled by another's cattle when fields are open to communal grazing after harvest. In the communal grazing lands, it pays for the farmer to over-use the pastures because if he does not, someone else will, and he will be the loser. With this in mind farmers were asked about the rights they currently enjoy with respect to the cropland and the homestead land. The results are reported in Table 9.2.

Although the type of rights conferred to land users under a communal tenure system are fairly well understood to be only *usufruct* rights, such an understanding of the land rights may differ from what farmers actually do on the ground. The law prohibits any sale of communal land, but 71 households (57 %) reported that they could sell their homestead land. This was corroborated by the headmen, who explained that because households often make substantial improvements on homestead land (through the construction of house, fences, etc.), if the household has to leave the area and needs to recover the value of its investment it has to be able to sell the homestead. Purportedly, what is being sold is the value of the improvements, but it is not entirely clear how one can separate the value of the improvements from the value of the land in such situations. Of those households that reported having access to agricultural land, 60 % said they could sell their cropland if they wanted to (particularly if they had to relocate away from the village).

The other rights enjoyed by a significant number of the households are the right to rent out land, and the right to bequeath land to offspring or other relatives.

The significance of the type of analysis and the results presented in Table 9.2 is that it seeks to understand land tenures in terms of those characteristics that may be of importance for farm-household decision-making. Moreover, examining land tenures in terms of their specific characteristics can allow the detection of changes that may be taking place in the system which may not be noticeable if tenures are described in broad terms as either communal, state or private. In the case of Thaba Nchu, practices that are contrary to the common understanding of communal tenure (the system in effect in the area), such as the sale of land, were reported to be taking place in different guises. The presence of improvements on the land are cited as presenting a strong case why transfers of land involving monetary payments may be justified.

Water conservation measures are a type of land improvement for which a farmer can demand compensation if he decides to move out of farming. It can thus be concluded that investments in the water conservation works will not be negatively affected by the land tenure regime, since farmers can transfer land and recover the value of their investments.

Table 9.2 Land rights enjoyed by farmers on arable and homestead land in Talla, Paradys and Yoxford, 2001.

Right	Number of households reporting to enjoy rights	
	Arable Land	Homestead Land
Sell		
Sell without approval	24 (38.6)	49 (39.5)
Sell with approval	18 (25.7)	22 (17.7)
Do not possess right	28 (40.0)	53 (42.7)
Rent		
Rent without approval	19 (27.1)	37 (29.8)
Rent with approval	31 (44.3)	40 (32.3)
Do not possess right	20 (28.6)	47 (37.9)
Bequeath		
Bequeath without approval	22 (31.4)	34 (27.4)
Bequeath with approval	14 (20.0)	17 (13.7)
Do not possess right	34 (48.6)	73 (58.9)
Gift		
Gift without approval	12 (17.1)	25 (20.2)
Gift with approval	8 (11.4)	9 (7.3)
Do not possess right	50 (71.4)	90 (72.6)
Pledge		
Pledge without approval	16 (22.9)	37 (29.8)
Pledge with approval	4 (5.7)	6 (4.8)
Do not possess right	50 (71.4)	81 (65.3)
Exclude		
Exclude all times	46 (65.7)	124 (100)
Exclude during growing season	1 (1.4)	
Do not possess right	23 (32.9)	
Number of observations	70 (100)	124 (100)

9.8 SELECTION OF FARMERS FOR FIELD TRIALS

Following the first group meetings in villages and the questionnaire survey, another round of PRA meetings were held with farmers in the villages of Paradys, Talla, Yoxford and Feloanè to determine the level of interest amongst farmers to participate in field trials of the IRWH technique during the 2001/2002 cropping season.

The objective was to set up demonstration plots in each village on which the effect of applying IRWH can be compared with the *CON* practice, if there was sufficient interest amongst farmers to participate in the exercise. The IRWH plot would be divided into two plots, one managed by the farmers themselves with guidance from the research team, with the researchers and farmers managing the other plot (training/demonstration plot). It was clearly stated that the process would be carried out over a period of two years as restricted by the requirements of the project (financial limitations and predetermined project duration). In the first year/growing season of the process, only demonstration plots (cropland or homesteads) and training of villagers would be made. In the second year, interested people would expand the technique and the ARC-ISCW team would still be available to assist with knowledge. The villagers were also made to realize that during the duration of the project, the plots constructed would be communally owned and maintained. The produce thereof would be for all who participated in bringing the IRWH technique to life in their village. A little confusion and discomfort regarding this issue was picked up during the sessions. The researchers did their best to make the owners realize that whatever was done during the duration of the project should be regarded as a training process aimed at empowering the community at large, and not for the individual benefit for those who owned suitable land.

The aims of the meetings were for researchers and the farmers to plan for the carrying out of the training/demonstration trials – selection of plots where the trials would be located, the selection of a team of farmers to act as a project committee for purposes of the trial, the choice of crop for each village for the first season of the trials and the supply of inputs. In each village 10 members volunteered for the management committee, and the volunteers selected a chairperson and a deputy. During the meeting, the role and function of the committee was discussed, namely that they would act as a link between the farmers and the researchers, make decisions regarding the timing for carrying out production practices (such as weeding, application of pesticides, etc.) on the trial plots, and to mobilise all interested farmers to come and work on the training plots. In all villages, some farmers expressed interest in applying the IRWH technique on their homesteads.

Following the meetings, arrangements were made for conducting soil surveys to determine soil depth and other soil properties at the sites selected for the trials to make sure that the soils were suitable for IRWH. Most households in all the villages have suitable soils in the homesteads. In Talla the soils in the croplands were found to be generally shallow (less than 500 mm deep). There is a risk of flooding and waterlogging during unusually wet seasons when IRWH is applied on shallow clayey soils. It was decided that for Talla, application of the technique would be limited to homesteads and vegetable crops for the time being. In the future, adaptations of the technique to suit soils such as those found in Talla would be sought. The farmers from Talla chose dry beans, those in Yoxford chose to start with maize, those in Paradys chose sunflower and those in Feloanè chose sunflower and maize. The farmers in Yoxford chose maize because of the need to produce food for household consumption. The farmers in Paradys chose sunflower because of its potential to generate cash income. The same reasons were cited by farmers in Feloanè for choosing sunflower and maize and they were also interested in planting dry beans.

9.9 ACTIVITIES OVER THE 2001/2002 SEASON

9.9.1 Yoxford

Members of the committee and some villagers were involved in the demarcation and construction of the plots. Maize was planted on a *CON* plot and on two IRWH plots on the cropland. These were used to demonstrate the advantage of IRWH over *CON* and also as training plots. Maize was also planted in two homesteads.

9.9.1.1 Cropland

Maize was planted on 7 December 2001 but was replanted on 22 December 2001 because of bird damage. The crop germinated well but had to be replanted over and over again because birds had eaten the seedlings and the villagers never bothered to chase them away. It was suggested that the villagers make scarecrows for the birds and they complained that they did not have sticks for that because there were no trees in the village. The villagers were not at all active in the maintenance of plots. The committee leader and two other people tried to put a small effort into taking responsibility for these plots.

Although the crop had an unequal plant height and population due to bird damage, it grew well. Differences between the *CON* and IRWH treatments were clearly visible. The plants on the IRWH plots were higher and bigger as compared to the *CON* plots. Maize yields obtained on the cropland are presented in Table 9.3. On average the IRWH technique induced higher maize yields (61 %) compared to *CON* tillage. Both IRWH plots yielded significantly higher than the *CON* plot.

Table 9.3 Maize yields obtained at the cropland of Yoxford during the 2001/2002 growing season.

Treatment	*CON*	IRWH - farmers	IRWH - training
Yield (kg ha^{-1})	1741 a	2643 b	2970 b

Row values followed by the same letter do not differ significantly at P = 0.05.

9.9.1.2 Homesteads

Maize was planted on 22 December 2001 on two homesteads of which one belongs to the committee leader and the other to a young volunteer. Maize in both homesteads germinated and grew very well. Maize in the homestead of the committee leader looked very good. The plot was free of weeds and he was very committed and excited about the whole process. Although he made a few basic errors here and there he was the only person putting in an effort to succeed in the beginning. The supposed lady owner of the plot was only renting the house and she was not actively involved in the process. Although the maize on her homestead grew well a lot of weeds were present. After a pre-harvest group discussion in Yoxford the attitudes of the people started to change. They saw the differences between the two techniques. Maize yields obtained from the two homesteads with IRWH and normal *CON* are presented in Table 9.4. The *CON* plots were managed by the farmers in the way they were used to doing it. In this case on average the IRWH induced a mean maize yield advantage of 3179 kg ha^{-1} or 777 % above the *CON* yield of 409 kg ha^{-1}.

At harvest quite a number of people were gathered to assist in the harvesting, both in the homesteads and in the cropland. It cannot be said for certain whether the interest was out of grabbing a cob or two or because finally some interest in the project had been initiated. Whatever the case, shortly after harvest, the villagers summoned the team to go and see the progress they had made regarding the IRWH technique and to correct them should there be any mistakes. They had gone on to group themselves and assist each other to construct basins in their respective homesteads. This was quite impressive, especially considering it was done on their own initiative. The team encouraged them to continue doing so and promised to help them for as long as they could. At 46 out of the 86 homesteads of the residents of Yoxford they constructed basins. After the application of the IRWH technique the villagers were ready for planting time. The team agreed to provide seed, fertilizer and support for the next year should the need arise.

Table 9.4 Maize yields obtained at two homesteads in Yoxford with different tillage techniques during the 2001/2002 growing season.

Homestead owners	Yield (kg ha^{-1})	
	CON	IRWH
Laserus	522	4371
Gloria	295	2805

9.9.2 Talla

Dry beans were planted in one homestead. It was imperative to satisfy the one and only member who showed interest in the technique. It was hoped that even though the technique could be implemented on a very small scale, the attitude of the people of Talla would change for the better when they saw the results.

9.9.2.1 Homesteads

Members of the committee and some villagers were involved in all the actions. Dry beans were planted on 29 November 2001. The beans grew well and looked very good. Some of the people from Talla were involved in weeding on their own initiative. Should the need arise, the committee leader gathered people to do weeding.

The harvest in Talla was very poor. Dry bean yields are presented in Table 9.5. A lot of rain was received towards harvesting and the beans became waterlogged. This was not surprising considering the shallow depth of the soil. Despite this, IRWH resulted in a mean dry bean yield advantage of 145 kg ha^{-1} or 55 % above the 262 kg ha^{-1} harvested on the *CON* treatment. From then on, the villagers showed very little interest in pursuing the technique and given the poor conditions of the soil, it was decided that the implementation of the technique would be discontinued in Talla.

Table 9.5 Dry bean yields obtained on a homestead in Talla with different tillage techniques during the 2001/2002 growing season

Homestead owner	Yield (kg ha^{-1})	
	CON	IRWH
Lawrence	262	407

9.9.3 Paradys

Sunflower was planted on a *CON* plot and on two IRWH plots on the cropland. Members of the committee and the villagers were involved in all the activities.

9.9.3.1 Cropland

Sunflower was planted on 10 January 2002. The soil was too wet to plant in December 2001 due to good rains during the November to December 2001 period. This is one of the problems of shallow soil (water retention and no deep drainage). Sunflower germinated well but birds damaged the seedlings. The crop grew very well and there were visible differences between the *CON* and the IRWH treatments. Sunflower on the IRWH plots was bigger and higher than sunflower on the *CON* plots. The people from Paradys were not at all actively involved. One of the reasons might be that a lot of people in Paradys are elderly people and the cropland is at a distance from the village.

Sunflower yields obtained from different treatments on the cropland are presented in Table 9.6. On average the IRWH technique induced higher sunflower yields (16 %) compared to *CON* tillage. The differences in yield between the *CON* and IRWH techniques were not so big because of all the good rains received just before planting. Although the difference was not that big both IRWH plots yielded significantly higher than the *CON* plot.

Table 9.6 Sunflower yields obtained at the cropland of Paradys during the 2001/2002 growing season.

Treatment	*CON*	IRWH - farmers	IRWH - train
Yield (kg ha^{-1})	1834 a	2143 b	2126 b

Row values followed by the same letter do not differ significantly at P = 0.05.

The villagers did not show any interest in pursuing the technique and, as already mentioned, that the majority are elderly, it was decided that implementation of the technique would be discontinued.

9.9.4 Feloanè

The people of Feloanè were interested in all three crops and therefore chose maize, sunflower and dry beans. Maize and sunflower were planted on the cropland with three plots (one *CON* and the other two IRWH). Maize was planted in one homestead and maize and dry beans in another. Members of the committee and the villagers were involved in all the actions.

9.9.4.1 Cropland

The cropland where sunflower and maize were planted is a considerable distance from the village. Maize and sunflower were planted on the 29 November 2001. Both crops grew well and considerable differences between the different treatments were visible. Both crops on the IRWH plots grew more vigorously than those of the *CON* plots. The people from Feloanè were involved on these plots. They kept the plots free of weeds and basically took responsibility and ownership of the plots.

Maize and sunflower yields obtained from the cropland with different treatments are presented in Table 9.7.

Table 9.7 Maize and sunflower yields obtained at the cropland of Feloanè during the 2001/2002 growing season.

Treatment	Maize yield (kg ha^{-1})	Sunflower yield (kg ha^{-1})
CON	1987 a	1680 a
IRWH - farmers	3268 b	2137 b
IRWH - train	3642 b	2243 b

Column values followed by the same letter do not differ significantly at P = 0.05

On average the IRWH technique induced higher maize yields by as much as 74 % (1468 kg ha^{-1}) and sunflower yields by as much as 30 % (510 kg ha^{-1}) compared to the *CON*. Both IRWH plots with maize and sunflower yielded significantly higher than the *CON* plots.

9.9.4.2 Homesteads

Maize was planted on 11 December 2001 on the homestead of an old man (Daniël Motaung) who seemed very interested and active at the beginning. Maize grew very well especially when compared to the maize planted at the same time by the same owner on a small portion of his homestead, using normal cropping practices. The owner of this plot was very actively involved and did most of the weeding himself. Close to this homestead, maize and beans were planted on the same day in another homestead of a middle-aged couple (Gladson). Both crops grew well and looked strong and healthy. Unfortunately it seemed that due to lack of help from the community he decided that he was not going to work on his own. This was evident from the fact that he waited for the team to help him with the weeding.

A few villagers were gathered at harvesting. They expressed their interest in expanding the technique to their respective homesteads. Despite their talk and enthusiasm, it took ages for these people to start doing anything. On the one day they would complain they do not have money, on another it would be that there is a funeral in the villages and they must avail themselves for the preparations and so the excuses went on.

Crop yields obtained from the homesteads are presented in Table 9.8. Very good yields (maize and dry beans) were obtained on all the IRWH plots. Maize on the homestead of Daniël from the IRWH technique yielded 4665 kg ha^{-1} or 3240 % higher than the *CON* treatment.

After the good yields obtained especially in the two homesteads, people got excited and applied the IRWH technique in 11 homesteads. From the ARC-ISCW team's point of view, the biggest problem was that the people in Feloanè did not want to work together in the beginning. To exacerbate the problem, it rained a lot and the soil was too wet to work on.

Table 9.8 Maize and dry bean yields obtained at two homesteads of Feloanè with different tillage techniques during the 2001/2002 growing season.

Homestead owners	Crop	Yield (kg ha^{-1})	
		CON	IRWH
Daniël	Maize	144	4809
Gladson	Maize	not planted	4025
	Dry beans	not planted	1806

9.9.5 General

By and large, the communities of the respective villages focused more of their efforts on the homesteads compared to the croplands. All in all, there was a general feeling that the croplands were too far away from where the people stay. As a result, they were a problem to maintain, and the villagers were in fear of theft and malicious damage to their crops that would be exacerbated by the absence of fences. Another plus from a homestead point of view is that the people feel that they have complete control.

It looks like the different committees do not function very well at present. The general feeling was that people elected on the committee were in it for status, with no regard whatsoever for the interests of the village. The committee leaders, with the exception of Paradys, were very active and trying their best. Some people expressed their lack of interest in agriculture, hence the negligence, and some just disappeared without good reason. The mishaps quoted above are expected during the first year of researcher-community interactions. This is a long-term process and high yields from the IRWH technique compared to *CON* will speak volumes.

The enthusiasm and determination of the people of Yoxford to make the technique a success is definitely something to reckon with. At present they are in the process of applying for funds from CPF-SP programme to extend the technique further. People from neighbouring villages already asked the team to introduce the technique to their respective villages.

By and large, the first growing season was a success and the farmers from Feloanè and Yoxford worked so hard at it that the following growing season attracted neighbouring villages to implement the technique. The villages of Balaclava, Tweefontein, Woodbridge 1 and Grootdam expressed their interest in IRWH.

9.10 ACTIVITIES ON HOMESTEADS OVER THE GROWING SEASON 2002/2003

9.10.1 Yoxford

The IRWH technique has been implemented at 46 out of 86 homesteads in the entire Yoxford village. Planting was started on 30 October 2002. The community started with maize and beans with the assistance of technicians from ARC-ISCW. The villagers were so committed that they successfully completed planting at a few homesteads in one day. Planting was delayed a short while later due to drought but in January they started again with the rest of the crops that included pumpkins, watermelons, spinach, etc. after a few showers had occurred.

The community members have formed an association called "MAHATA-MMOHO" (meaning people working together) since the beginning of the 2001/2002 growing season, as a strategy to encourage team spirit amongst the people that have adopted this technique. Out of the 46 plots, 45 were planted. The one that was not planted belonged to one of the three members who resigned from the association. The members grouped themselves according to the blocks that they resided at. They believed that this kind of grouping would instill a sense of ownership and cooperation amongst the members. The individual interests of respective blocks determined selection of crops per block, and it was decided that after harvest, all members would get a share of the harvest. In this manner, they ensured that they would encourage each other to work hard in looking after the plots and looking forward to a shared harvest. Maize, however, was agreed upon as their staple food and was planted in every garden in addition to other selected crops. Whatever was decided upon per block was considered compulsory for that block.

Block A marked the lowest lying area of the village and beans were selected which were planted at seven homesteads. Block B is located further up and basins were constructed at nine homesteads but watermelons were planted in only seven. Of the other two, one was not planted because it belonged to a person who had quit the association and the other to a person who had decided to pursue the technique on his own. Pumpkin was planted at eight homesteads of Block C. Beans were planted at eight homesteads of Block D. Dry beans were once more selected for Blocks E and F and were planted in nine and three (out of six) homesteads, respectively.

Appendix 9.1 is an example of the minutes of a meeting that took place at Yoxford regarding IRWH. The following are several things mentioned in the minutes. Over the growing season, the people of Yoxford noticed that the growth of white maize was comparatively poorer than that of yellow maize. They believed that the reasons were that yellow maize tolerated weeds better than white maize, but the reason might be because of cultivar differences as well as poor weed control by the people who planted white maize. Regardless of how small the population of weeds, the latter seemed to struggle a lot. Secondly, they noticed that white maize attracted insects as was seen by their cluster on the cobs. The villagers also noticed that wherever there were eucalyptus trees in the vicinity of crops, growth was impaired. This problem intensified the closer they were to the trees. The members of the association raised concerns about the homesteads that belonged to the lady members. They said that the ladies were not properly maintaining their plots and therefore their crops were not growing very well. They also noticed that where the soil had been loosened prior to construction of basins and planting, the crops looked much better than those that were planted where the soil had not been tilled before. This phenomenon was very pronounced with white maize. They noticed that crops that were grown on recently prepared basins were not growing as well as crops that were grown on old basins and they said the reason is that there is not enough water. All the crops along the centre of the village grow better than crops on the peripheries. The association intends to put strong rules in place to control vandalism on their plots that is encouraged by their poor fencing. They also feel that some members still need to instill within themselves a strong sense of commitment that is lacking at the moment.

Harvesting was carried out on various dates during May 2003. Some of the yields obtained per homestead were recorded and presented in Table 9.9 and the rest in Appendix 9.2.

Table 9.9 Crop incomes obtained at some of the homesteads in Yoxford during the 2002/2003 growing season.

OWNER	CROP	AREA (m^2)	INCOME (R)	R m^{-2}	TOTAL INCOME (R)	R ha^{-1}
S. Esau	Watermelon	150	1024	6.83	1597	13708
	Maize	1015	573	0.56		
L. Phale	Watermelon	270	1130	4.19	1538	14648
	Maize	780	408	0.52		
E. Motlalile	Maize	600	576	0.96	576	9600
B. Seloka	Maize	500	284	0.57	359	5645
	Beans	136	75	0.55		
E. Khati	Pumpkin	218	320	1.47	612	10588
	Maize	360	292	0.81		
J. Dikgaatlha	Beans	174	312	1.79	986	10239
	Maize	789	656	0.83		
S. Phala	Maize	275	934	3.40	934	3400
B. Molatudi	Maize	294	296	1.01	671	16859
	Beans	104	375	3.61		
J. Khumisi	Maize	466	150	0.32	225	3940
	Beans	105	75	0.71		

The price negotiated by the different farmers determined the income of a specific farmer. This shows the negotiation abilities of the farmers, for example they sold their maize (converted to R ha^{-1}) for between R 3200 ha^{-1} and R 10000 ha^{-1}. The farmers did much better than the current available price for yellow maize, which is R 850 ton^{-1} (21/07/03). Large watermelons were sold for between R 15 to R 22 per watermelon. Table 9.9 clearly indicates that the farmers or members of Yoxford are not only producing food for own consumption, but some of them already produced more and sold it. Some of the members supplied family members in other communities or in townships with produce to help them to overcome food shortages. This also indicates that the homesteads production can make a significant impact on food security through: (i) the ability of the people to buy food with the money obtained through selling of their produce; and (ii) the cultivation of a variety of crops for own consumption. Most of the "MAHATA-MMOHO" members mentioned that they had never harvested so much previously. They are excited about the IRWH technique and are planning to take the IRWH technique to their croplands where they will continue to work in groups.

9.10.2 Feloanè

Maize and dry beans were planted on 5 November 2002 with 10 members of the community. Eleven people were elected to form a committee and there were three more people who expressed interest in constructing basins. The soils were wet for the first few days but became too dry to allow planting by 8 November. Pumpkin and watermelons were planted on 22 November. Those who attended did a good job of constructing basins, planting, replanting, thinning and weed control. On 10 January, Jacob Mathews and another member of the community planted potatoes at their homesteads adjacent to the maize rows.

Yields obtained from some of the homesteads in Feloanè are presented in Table 9.10.

Table 9.10 Crop yields obtained at homesteads in the village of Feloanè during the 2002/2003 growing season.

OWNER	CROP	AREA (m^2)	HARVEST (kg)	YIELD (kg ha^{-1})
Lethabile project	maize	500	50	1000
	beans	450	25	556
	potatoes	39	30	7692
Mr. D. Motaung	maize	750	75	1000
Ms. Salman	maize	180	30	1667
	beans	135	10	741
Mr. N Moholo	maize	750	50	666
Mr. F. Kgathole	maize	120	10	833
	beans	90	10	1111

The yields mentioned in Table 9.10 were only what the members harvested at the end of the growing season since they had already eaten most of the crops or used them for own consumption during the season. On average the people harvested 1033 kg ha^{-1} maize at the end of the growing season after own consumption during the season, and 803 kg ha^{-1} in the case of dry beans. The Lethabile project consisted of 7 members and they divided the potatoes between them and everyone got a 5 litre container full of potatoes. This was a good achievement, especially when keeping in mind that it was the first season where the people managed everything on their own, only with the help and support of the team. The people from Feloanè who implemented the IRWH technique during the 2002/2003 growing season are very excited and they are expanding in other homesteads and are already applying the IRWH technique on two large areas on their croplands, working together as a group.

The community's plans for the future are to expand the IRWH technique at their homesteads and also on croplands closer to the village because they have realized that it really works.

They say that with the IRWH technique they feel in a position to store water for the next generation. They feel courageous enough to plan a good future and assist neighbouring villages to implement the technique. They already helped people from a neighbouring community (Potsanè) to apply the IRWH technique.

9.10.3 Woodbridge 1

People from Woodbridge 1, not very far from Yoxford, also expressed their interest after attending a technology exchange action at Yoxford and after they saw the IRWH plots that have been constructed at Yoxford. They invited the ARC-ISCW team via extension personnel to enlighten them about the technique. Interested people were mostly women but the biggest problem was that everybody preferred to work independently and not as a group. They constructed basins with their respective families and by 2 December planting was commenced at the first garden. By 17 December, planting had been completed at 11 homesteads and at one public school. They planted crops like maize, dry beans, pumpkins, potatoes and peas. By early February, the plants looked quite good and the community was so impressed they swore to plant more in the next growing season. Some of the maize yields obtained at the end of the season and recorded from homesteads in the village of Woodbridge 1 are presented in Table 9.11. Also included in Table 9.11 is the income that the people could have earned if they had sold their maize cobs for R 2 a cob like Yoxford. The yields presented in Table 9.11 do not include what the people consumed as "green mealies" during the season, it is only what was left at the end. The people from Woodbridge 1 formed a group called "REAHOLA". The people used all their produce for own consumption.

Table 9.11 Crop yields and income obtained at homesteads in the village of Woodbridge 1 during the 2002/2003 growing season.

OWNER	AREA (m^2)	MAIZE		INCOME FROM COBS (R) [*1]
		Cobs (kg bags)	Kernels (kg)	
Moses Bob	675	4*50 kg	4.5	448
Lebogang Kwadibane	540	5*25 kg		280
Paulina Khoalane	693	3*50 kg	8.5	336
Motlalepula Moneso	432	1*80 kg	4.5	180
Peter Mazwane	720	4*50 kg	4.5	448
Adelina Sekonyela	861	2*50 kg		224

[*1] Income if cobs had been sold for R 2 a cob.

9.10.4 Tweefontein

Demonstration trials on the farm Willow Park belonging to the Lekhule trust funded by the National Department of Agriculture (NDA) have been conducted during 2000 - 2003. Some of the people belonging to the Lekhule trust live in the village Tweefontein. The people from the village Tweefontein showed interest in the IRWH technique and the team went on to hold a public gathering at Tweefontein during May 2002. A committee comprising 12 members of the community was elected and the technicians from the ARC-ISCW taught them how to construct the basins. They constructed their own and taught the rest of the community to do the same. The clinic was selected to represent a homestead for training and demonstration purposes.

Basins were constructed in 15 homesteads from 1 October until 30 October 2002. With time, the number increased to 23 as they realised how important the technique is and that the team had nothing to gain by assisting them in implementing the technique. The people expressed concern at the fact that planting was started soon after they had completed constructing basins and were quite happy when they started on 30 October with maize and dry beans. On 26 November, watermelons and pumpkin were planted on one homestead. On 19 December, the representative technician demonstrated how to plant carrots, spinach and beetroot in one of the homesteads. The plants in the homesteads had all germinated and the maize did exceptionally well. Plants like dry beans, spinach, carrots and beetroot were not as good but that did not discourage the people because they understood that they had not received enough rain. Towards the end of February, the people started to harvest and some of the plots were covered with weeds. Maize seemed to grow very well.

On 6 March, the committee members informed the technicians of their intention to hold a mass meeting in order to teach more people about the technique. This was done on 26 March and at that time four more homesteads were added to the existing 23. The people from Tweefontein learned fast and did all of the work on their own. What they learned at the training plots at the clinic they applied at their homesteads and even taught other farmers.

Some of the yields that were obtained from homesteads in Tweefontein during the 2002/2003 growing season are presented in Table 9.12.

Most of the yields mentioned in Table 9.12 were only what the members harvested at the end of the growing season and do not include what had been eaten or used for own consumption during the season. The negotiation abilities from the different people to sell their produce are highlighted in Table 9.12. Most of the people who sold maize and dry beans sold them in small packages and by doing that they obtained a very good price. Mr. Lekhule did very well with his spinach and earned R 600 on an area of 108 m^2. He sold his spinach for R4/bunch, and he sold 150 bunches. Mr. Letshasa did so well that he bought himself a fridge with the money that he made by selling his produce! He earned R 1 100 on an area of 693 m^2. Mr. Kopa produced maize on an area of 720 m^2. He sold 390 maize cobs (R2/cob) and earned R 780. He also harvested 320 kg of maize. If he sold the 320 kg maize for an average price of R 4.81 kg^{-1}, he would have earned an additional R1 539. That would have given him an income of R 2 319 from a 720 m^2 area with maize, which is remarkable. This indicated that members of Tweefontein produced enough food for own consumption and sold the rest. This also indicates that the homesteads' production can make a significant impact on the total well-being and empowerment of people.

The people in Tweefontein set themselves a goal to implement the IRWH technique in more than 40 homesteads before the end of 2003, and also plan to start on a small scale on the croplands.

Table 9.12 Crop yields and income obtained at homesteads in the village of Tweefontein during the 2002/2003 growing season.

OWNER	AREA (m^2)	CROP	YIELD (kg)	CONSUMED (kg)	SOLD (kg)	INCOME (R)	Total (R)	Total[*1] (R)
Phandlewe	630	Maize	300		300	750	775	850
	840	Beans	20	15	5	25		
Ntsepe	120	Maize	10	2	2	50	65	287
	180	Beans	5	3	2	15		
F. Choane	384	Maize	25	15	10	50	50	163
	288	Beans	5	5				
Lesimola	720	Maize	15	10	5	30	30	165
	270	Beans	10	10				
Kopa	720	Maize	320 390[*2]	320 390[*2]	390[*2]	780	780	2319
E. Phandlewe	480	Maize	25	10	15	90	90	188
	360	Beans	5	5				
R. Mototo	108	Maize	25	25				120
Clinic	432	Maize	168[*2]	168[*2]				411
	216	Beans	10	10				
Letshasa	396	Maize	150 28[*2]	28[*2]	150	500	1100	1586
	297	Beans	100	40	60	600		
	18	Pumpkin	3	3				
Moroka	240	Maize	50	50				279
	180	Beans	5	5				
Lekhula	18	Maize	50	50			600	879
	24	Beans	5	5				
	108	Spinach	150[*3]		150[*3]	600		
R. Choane	720	Maize	100	40	60	360	360	675
	360	Beans	10	10				

*1 Total income if all produce would have been sold (at price negotiated by the farmer; if farmer did not sell anything the average price obtained by the farmers in Tweefontein were used)
*2 Maize cobs - green mealies"
*3 Spinach in bunches

9.10.5 Balaclava

Since the owner of the tractor that has been used to prepare soil in Tweefontein was from Balaclava and after some members of Balaclava attended an information day at Tweefontein, interest amongst the Balaclava people mounted and the ARC-ISCW team visited their village. The people of Balaclava were introduced to the concepts of the IRWH on 26 September 2002. They quickly understood how to construct basins and assured the ARC-ISCW technicians that they would be able to construct them on their own. Planting commenced on 5 November with maize and dry beans as the main crops. There were only 10 members of the community with 6 of them women. They were quite active but did not seem to understand much. By the next day they were fairly conversant with the process and started asking questions enthusiastically. By 7 November, people started disappearing claiming they had other things to do. There was also a general feeling of discontent because the headman was not assisting in the planting even though his garden was also included in the process. At that time, planting at 5 homesteads had been completed. Pumpkin and watermelons were planted on 3 homesteads on 29 November after 8 mm of rain was received. A few more rainfall events occurred in December and the people continued to plant maize, pumpkin and watermelons. Generally speaking, schoolchildren were more enthusiastic and willing to work than adults were. By mid-December 8 more homesteads were prepared and vegetables like carrots, spinach and beetroot were also planted. The people were encouraged to plant before January, but by 7 January planting had been completed on only 11 homesteads. On this same day it rained 18 mm. Maize, beans, carrots, spinach, beetroot, pumpkin, tomatoes and watermelons were planted in 6 homesteads and maize, beans, watermelons and pumpkin were planted in the other five homesteads.

On 12 January, potatoes were planted at 8 more homesteads. On 13 January, basins were constructed at four more homesteads. They planted maize, beans, spinach and beetroot. It continued to rain for a few subsequent days and by 3 February, the plots were full of weeds. Only the chairperson's plot was clean. After training and technology exchange actions during the growing season and very good work done by the technicians the people started to understand the value of weeding. They got more and more involved and managed their own homestead activities.

Crop yields obtained at some of the homesteads in Balaclava are presented in Table 9.13.

Table 9.13 Crop yields and income obtained at homesteads in the village Balaclava during the 2002/2003 growing season.

OWNER	AREA (m^2)	CROP						INCOME (R)
		Maize (kg)	Beans (kg)	Spinach (bunches)	Beetroot (kg)	Pumpkin	Watermelon	
Borman	567	100	25	15		30	3	846
Zakaria	1095	12.5	2	10	25	5	8	340
Rosaliah	864	100 200[*1]	1.25			5		887
Josiah	270	25	2					130
Cristinah	387	50	4.5	6				286
Magdelena	270	25	4.5					142
Sebatoe	540	17	2					92
Matshweu	378	272 cobs	2			15	6	689
Piet	81		4.5					22
Lenah	450	10	2			6		88
Matokelo	966	25	8.5			7		198
Average price ($R\ kg^{-1}$)		4.81	5.00	4.00/bunch	5.00/kg	5.00/ pumpkin	10.00/ watermelon	

[*1] Cobs eaten during season as "green mealies"

The yields mentioned in Table 9.13 are only what the people harvested and do not included what had been eaten or used for own consumption during the season. The people from Balaclava used all that they had produced for their own consumption. The income mentioned in Table 9.13 is an indication of what the people could have earned if they had sold their produce. Average prices obtained in Tweefontein were used to determine income and are presented in the last row of Table 9.13. Farmers sold maize cobs for R 2 per cob. Prices might be a little too high but it will depend on the negotiation abilities of the seller and also the demand for a specific product. The farmers were also prepared to test vegetables on the IRWH system and the crop diversity used in this village is another positive point. The committee leader Zakaria planted maize, dry beans, spinach, beetroot, pumpkin and watermelon; he also planted tomatoes and carrots but the yields were not recorded. Apart from maize and dry beans it looks as though watermelon, spinach beetroot and carrots did well on the IRWH system. The crop diversity will supply people with a more balanced diet and increases the opportunity of delivering a wide range of crops to the market in future.

9.10.6 Grootdam

A farmer from Grootdam attended a technology exchange session at the village Tweefontein and decided that he was going to apply the technique at his homestead. He contacted the team and showed them his IRWH plots. The technicians taught him to plant maize and dry beans on 31 October. Only the owner of the garden seemed to be really eager to implement the IRWH in Grootdam. Carrots and beetroot were planted on 10 December 2002 and spinach on 18 December. Two weeks later, pumpkin was planted and at that time all the planted crops had started germinating. On 3 January, the owner of the garden planted spinach. The owner started to weed from the second week of January and was really excited and proud of his homestead.

Crop yields obtained by the owner of the homestead during the2002/2003 growing season are presented in Table 9.14.

Table 9.14 Crop yields and income obtained by Mr. Lonake from his homestead in the village Grootdam during the 2002/2003 growing season.

CROP	AREA (m^2)	CONSUMED	SOLD	INCOME (R)	INCOME if all sold (R)
Maize	414	132 cobs	126 cobs	82	168
Tomatoes	81	6 Packets	207 packets	414	426
Beans	138	4.5 kg	44 packets*1	88	111
Beetroot	54		43 bunches	129	129
Spinach	54	3 bunches			12
Pumpkin	54	6 pumpkins			30
TOTAL				713	876

*1 Sold as green beans

Mr. Lonake sold some of his produce, keeping the rest of his harvest for his own consumption. He sold 207 packets of tomatoes (8 tomatoes/packet) for R414, 126 maize cobs for R82 (R0.65 per cob), 44 packets of dry beans for R88 (R2 per packet) and 35 bunches of beetroot for R105 (R 3/bunch - ± 4 beetroots/bunch), giving him a total of R 713 only from the produce that he sold from an area of 687 m^2. It is really a remarkable achievement especially during the first growing season for a person who had lost all hope to produce food for his own consumption. Mr. Lonake also planted carrots, potatoes and watermelons but did not record the yields. He bought himself a welding machine with the money he made from his sales and is repairing his homestead's fence in order to make it more animal-proof. Taking into consideration what Mr. Lonake consumed and what he saved by making it part of the income and using the price that he sold his produce for, he would have earned in total ± R 876 on an area of 795 m^2. This once again indicates that homestead production can make a significant impact on food security, total well-being and empowerment of people.

9.10.7 General

The residents of villages who applied the IRWH technique at their homesteads during the 2002/03 season varied between 1 and 46 families per community. From the first season

(2001/2002) the homesteads in which IRWH was applied expanded from 6 in four villages to 108 homesteads in six villages (Figure 9.1). Four new communities implemented the IRWH technique at their own request. The villages are Balaclava, Woodbridge 1, Grootdam and Tweefontein.

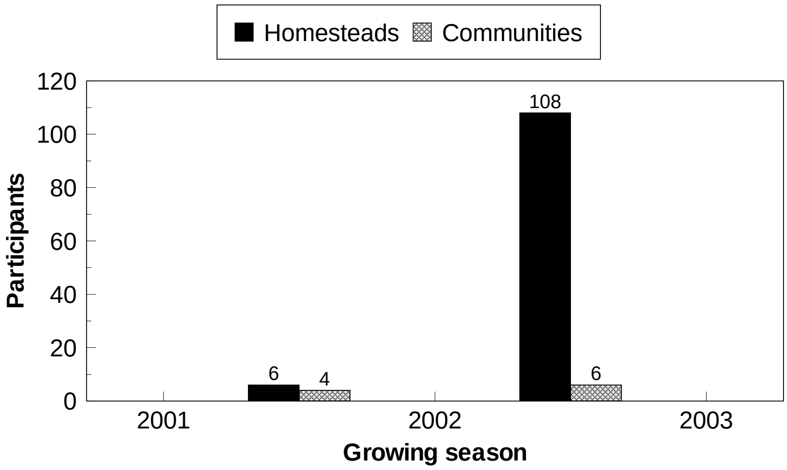


Figure 9.1 A graphical description of the expansion of IRWH in different rural villages and homesteads during the 2001/02 and 2002/03 growing seasons

The residents of the different villages planted a variety of crops, some of which were never demonstrated to them, as part of their IRWH strategy to combat food insecurity. They planted maize, dry beans, watermelons, pumpkins, peas, carrots, beetroot, spinach, tomatoes and potatoes (Figure 9.2).

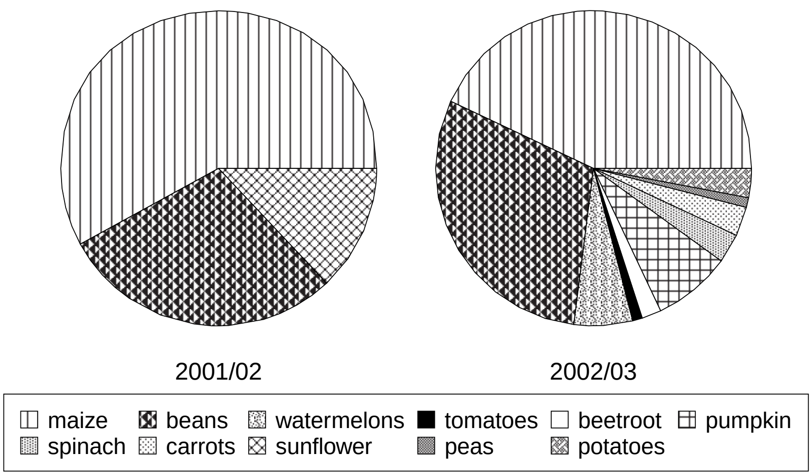


Figure 9.2 A graphical description of the expansion of different crops planted on the IRWH plots at homesteads in different rural villages during the 2001/02 and 2002/03 growing seasons

Case studies from a number of residents indicated that crop production in the homesteads can make a significant impact on food security through: (i) their ability to buy food with the money obtained through selling of their produce; and (ii) the cultivation of a variety of crops for own consumption. Additionally, the homesteads provide a simple environment for promoting the IRWH technique through training. However, converting the croplands into a sustainable enterprise remains the biggest challenge because at the moment they do not use the cropland productively. The attitudes, confidence and hope of people changed through these two years. All of a sudden, people started to believe in themselves and they now have hope of a better future.

9.11 RESULTS ON SOCIO-ACCEPTABILITY

The selected indicators for each of the goals, objectives and outcomes, were subsequently grouped into indicators for social acceptability and economic viability. Results on economic feasibility are discussed in Section 8.5.

Results of social acceptability indicators obtained through evaluation and monitoring in the selected villages, in line with the true characteristics of PAR, are briefly discussed in the list that follows:

- *Development of knowledge and the role of knowledge as an instrument of power and control* **-** Members of the communities actively took part in the research and became researchers on their own sites. Scientifically it was proven that maize, sunflower, sorghum and dry beans can be successfully produced on the IRWH system. They wanted to know about vegetables and it was explained to them and they agreed to test (research) vegetables on small areas. In interviews with the farmers during February 2003 almost all of them indicated that they see themselves now as researchers who can use their knowledge to their own benefit. Over the period the farmers (people) became proud of what they'd achieved and started to share their knowledge with other members and farmers.

- *Practical problem solving* - During the interviews the farmers also emphasised the benefit of the project in the sense that it addresses the problem of food security. All of a sudden the people started to produce food for themselves, something that they lost hope of doing a long time ago. In most cases they produced more than what they could consume at that stage and sold some of their produce. Some of them generated good incomes and used the money to buy various items and food. Some people supplied some of their family members in other communities and townships with produce. They also planted a large variety of different crops (diversity).

- *Self-development, where people must organise themselves into action* - The farmers credited the process for allowing them the opportunity to organise themselves into groups without prescribing them how to do it. They regarded the process as one of mobilising the members of the communities, of them becoming self-reliant in solving the problem of "food shortage" as they put it. The people also formed groups, for example members from Yoxford formed a group called Mahata-Mmoho with their own constitution and rules.

- *Community forums, nominal groups, workshops, focus groups, in-depth interviewing and participant observation as data collection techniques and research procedures* **-** Farmers reported the mobilisation of the community members in the different data collection activities as something that they "enjoyed". People developed skills and increased their knowledge during the project period in such a way that they got more confidence in themselves and started to share their experiences with others. A comprehensive list of all the technology exchange actions with the farmers in the different villages is provided and discussed in Chapter 10.

- *Multidisciplinary collaboration* - From the initial stage of the project it was decided that this research would be approached multidisciplinarily, including researchers from the ARC and the University of the Free State (agricultural economists and sociologists). To get all the information and to see the bigger picture of the whole project it is suggested that the report of Kundhlande *et al.* (2003) should be read as well.

- *Accountability and management of own resources* - The fact that the project was to be one of partnership was strongly emphasised and discussed with the communities already in the planning phases. They entered into this partnership project realising that they would have to use and manage their own resources. Even now the farmers are willing to accept this principle as they indicated during the interviews of February 2003 their willingness to accept the responsibility for the further course of the process.

- *Equal partnership shared ownership* - Through the entire research process this aspect was continuously emphasised and accepted by all the partners and those who are implementing the IRWH technique are already referring to it as their own "property" and no longer to something that belongs to the "people of the ARC".

- *Desire to find useful solutions to problem* - All the farmers expressed their frank desire to find a useful solution to the problem of food shortage as they regard it as "a matter of survival" and stated that "we have no option".

- *Interest in and commitment to change* - Although community members may all have a common interest in the problem, it could not be assumed that they have a homogeneous view of the problem or of the ways in which it should be addressed. During the first meetings with the members of the communities it became clear that almost all of them realised the necessity to change their circumstances. Those farmers who accepted the invitation to become partners in the research project are those who were interested in bringing about a change in their lives and who committed themselves to do something about it. There are, however, also those who did not accept the invitation. This might be for a number of reasons. Again, it cannot be assumed that all the members of the communities have a homogeneous view of the problem or of the ways in which it should be addressed.

- *Emancipation* - The point of departure was that the people should be assisted to recover and to release themselves from the constraints of irrational, unproductive and unsatisfying social structures that limit their self-development and self-determination.

- *Patience for immediate action* - It was realised from the start of the research (and the partners still realise) that results (in this case acceptance of the IRWH technique) will take some time to materialise. Acceptance of anything that is new is a long-term process that first has to take place in one's mind (a change on the value level) before it will concretely materialise. IRWH started during the 2001/2002 season in four villages. To date, 30 villages in the target area have already started to implement the IRWH technique in their homesteads.

- *Recognition of resources in the community* - As acceptance is first of all a process of a mindset change, no attempt to bring about acceptance will succeed without taking into consideration the values, beliefs, culture, indigenous knowledge and experience of the people involved. These aspects were continuously born in mind, especially when the farmers were invited to share their knowledge and farming experience with each other - which they enjoyed doing.

- *Empowerment* - The empowerment of the communities was a high priority for the researchers. A list of the activities that were executed to empower the communities is discussed in detail in Chapter 10.

- *Self-realisation to regain confidence* - People were encouraged to share their experiences and to fight their way out of their problems. The sharing of their experience helped the farmers to have confidence in themselves. They were excited in accepting the challenge to solve the problem of "food shortage" and all of them saw themselves as "prosperous farmers in the next year or two". People who totally lost hope of producing or growing their own food suddenly started to believe in themselves and have hope for a better future.

- *Ownership* - Ownership of the project was one of the most important aspects of the project and was one of the outcomes stated from the beginning of the research. The farmers accepted this responsibility with great enthusiasm.

Community, mobilization, capacity building, empowerment, human well-being, self-reliance and community were used as "indicators" to measure the socio-acceptability of the IRWH crop production technique. The "test results" of the indicators are briefly discussed.

- **Community –** Social support networks (organisations such as the Community-based Water Harvesting Interest Group or the so-called CB:WHIG) were indeed established in the communities. Yoxford is another example that formed a group called Mahata-Mmoho to work together. They wrote their own constitution with rules and things to do and they are quite well organized.

- **Mobilisation** - As there were no suitable organisations in place in the communities, the researchers encouraged the participants to form new ones by means of "self-mobilisation". As a result of the research project, organisations such as the CB:WHIG were established. The diffusion of the IRWH research results to the participants was of the utmost importance. These participants had to be exposed to the results, familiarised with them and sensitised to the possibility that changing their farming techniques could result in a better crop yield. They eventually had to become owners of the results. The diffusion of the "knowledge" was done at various occasions, *inter alia*, by means of demonstrations of the IRWH technique at farmers days held at Glen and in the different villages. People started to keep records of their yields.

- **Capacity building** - As the research process unfolded, capacity building also became one of the important intended outcomes of the project. Farmers, residents and extension officers who were interested in learning more about the IRWH technique and in applying it in their own homesteads or on their croplands, were visited by the researchers at regular intervals during the 2001/02 and 2002/2003 growing seasons. They were assisted to master the technical aspects of land preparation, planting, weeding, marketing, etc. Apart from the day to day activities, various formal technology exchange activities such as pre- and post-harvesting focus group discussions, information days, formal training workshops and an IRWH festival were held. Training in teamwork, motivation, leadership, group dynamics, etc. also formed part of the research outcomes. Observations have shown that certain individuals in the communities have the ability to influence other people's behaviour in a desired way. This is leadership. Rogers & Shoemaker (1971) used the term "opinion leader" for these individuals who lead in influencing other's opinions in informal ways.

- **Empowerment** - Participants were empowered by gaining knowledge, consciousness raising, emancipation, learning, strengthening of research capacities and generating autonomy amongst them. At various occasions, the farmers indicated that they are now equipped with the potential to understand their position in society better than in the past. Now that they understand the underlying socio-economic, political, cultural, environmental and natural causes of the problem, and learned the very basic principles of research, they realize that they can change their circumstances. People in the different communities, for example Yoxford, took on a challenge to fight poverty, divided into a few groups working together as a community and implemented the IRWH technique in 46 homesteads. Before they applied the IRWH technique in their homesteads during the 2002/03 season they drew a map of their homesteads and planned where they were going apply the technique and plant what crops. Scientifically it was proven that maize, sunflower, sorghum and dry beans can be successfully produced on the IRWH system. The wanted to know about vegetables and it was explained to them and they agreed to test (research) vegetables on small areas. Farmers also planted tomatoes and peas on their own initiative. In interviews with the farmers during February 2003 almost all of them indicated that they see themselves now as researchers who can use their knowledge to their own benefit. What is very inspiring is the fact that the farmers developed in such a way that they are able to talk about technical aspects of the technique. The people from Feloanè went to a neighbouring village Putsanè and helped the people there to apply the IRWH technique for remuneration. This is a good indication of understanding of the technique. During focus group sessions held in Yoxford and Feloanè in January and February 2003, all the farmers present indicated that they are confident of becoming successful small-scale farmers within the next two years as a result of them being partners in the present research project. Some of the people/farmers sold their produce for a very good price. One farmer from Tweefontein, for instance, bought himself a fridge while another from Grootdam brought himself a welding machine.

During the second year of the project, demonstration plots were laid out in some croplands and homestead gardens in the villages that were selected to implement the IRWH technique. After the villagers had seen the dramatic yield increases in the homestead gardens of the villagers in whose backyards IRWH was demonstrated, they spontaneously started to implement IRWH at their homesteads as well.

The values of most indicators at the initiation of the project were relatively low. After one year, most indicators showed a slight improvement but after two years, some indicators showed relatively strong improvements (e.g. number of farmer-managed trials, crop yield, gross margin).

An indication that a strong social platform (of human activities) has been created (i.e. institutional development), which is critical for capacity building, learning and sustainability, is seen in the number of farmer group (forum) activities and participation. Another indication that the basis has been laid to launch intensive training and learning activities, was seen in the number of farmer-managed trials, which showed a drastic upward trend over two years. The increase in the number of best practice components indicates that farmers have higher level skills, knowledge and ability to manage new or improved technology and practices introduced through the project. It also indicates increased diversification of farming systems.

In general, crop yields and gross margin values improved markedly after the introduction of IRWH technology. The factors that influenced yields the most appeared to be storage of runoff water, improved fertilizer practices and proper weeding. The reduction of mechanisation costs, as well as increased yields, appeared to have the greatest impact on the profitability of the new or improved 'best practices'.

9.12 CONCLUSIONS

Thaba Nchu is a semi-arid area and receives about 500 mm of rainfall annually, most of it during high intensity storms, and usually unevenly distributed over the cropping season. This makes crop production in the area very risky as crops are likely to experience moisture stress during the critical growth phase. The soils in the area have a high clay content and are subject to surface crusting, which promotes high runoff. Under these circumstances agricultural production is severely constrained and farmers are generally discouraged from engaging in crop production.

Without agricultural production and lacking alternative economic opportunities, farm households in Thaba Nchu are generally quite poor. Results from a household survey conducted in the area showed household income to be substantially below the poverty line, and food intake to be low and lacking variety. Government transfers in the form of old age pensions and child support grants comprised the largest portion of cash income (65 % of total household cash income).

From the group discussions held by the researchers and communities following participatory research principles, most community members indicated that their present circumstances (food insecurity, lack of employment opportunities, etc.) were not satisfactory and that improving agricultural production provided a potential means for more secure livelihoods. It is then that suggestions to try IRWH as a new production technique were discussed with the farmers. These water conservation techniques had undergone several years of agronomic trials on-station at the Glen Agricultural Research Station under agro-climatic conditions similar to those in the study area. The on-station trials showed that by collecting runoff, available moisture for crop production was increased, crop yield could increase by up to 50 % and soil erosion minimized.

Although results from on-station trials proved the benefits of applying water conservation techniques, the widespread use of these techniques by farmers requires that they themselves be involved in diagnosing problems in their farming system and in the identification of potential solutions to the problems. The ultimate goal of the project was that the community becomes independent and empowered and to help its members to overcome the shortcomings in the community. The IRWH technique was seen as a vehicle in mobilizing the community to the simultaneous involvement and engagement of all the members, in order to attain the agreed collective objective of the project. In an ongoing process of encouraging the farmers to take on the challenging tasks of maintaining their farming activities and motivating other members of the communities to join them in adopting new farming techniques, self-reliance became an aim that the communities should strive for. But it is also necessary to demonstrate to farmers that the new innovations result in increased returns.

Demonstration/training plots started during the 2001/2002 season on 6 homesteads in four villages and expanded during the 2002/2003 season to 108 homesteads in six villages. The residents of villages who applied the IRWH technique in their homesteads during the 2002/03 season varied between 1 and 46 families per community. Four new communities implemented the IRWH technique on their request. The residents of the different villages planted a variety of crops, some of which were never demonstrated to them, as part of their IRWH strategy to combat food insecurity. They planted maize, dry beans, watermelons, pumpkins, peas, carrots, beetroot, spinach, tomatoes and potatoes. Case studies from a number of residents indicated that the homesteads' production can make a significant impact on food security through: (i) their ability to buy food with the money obtained through selling of their produce; and (ii) the cultivation of a variety of crops for own consumption. Additionally, the homesteads provide a simple environment for promoting the IRWH technique through training. However, converting the croplands into a sustainable enterprise remains the biggest challenge because at the moment they do not use the cropland productively. The attitudes, confidence and hope of people changed through these two years. All of a sudden, people started to believe in themselves and they have hope of a better future.

By viewing the indicators crop yield and gross margin, the IRWH practice seems to be economically viable (Kundhlande *et al.*, 2003). The average crop yields in the Thaba Nchu and Botshabelo area, for example, improved markedly due to the introduction of new or improved land management practices. The increases in yield, as well as a reduction in mechanisation costs, were the main contributing factors in the sharp increases in gross margin or profitability.

The indicators for social acceptability show that there is a strong movement towards building an active learning process in farmer groups and individual farmers lower down the hierarchy. When taking account of the large study areas and huge number of end-users, much time and effort is invested in empowering the end-users, which is essential for long-term sustainability. The large number of farmer-managed trials and the 'training of trainers' form a solid basis from where further training and learning could be launched.

In general, the evaluation of the different sustainability dimensions being impacted upon by the project need to be viewed over the long-term. Only then could it be judged whether the project has succeeded in implementing sustainable land management practices (or best practice components thereof) among an acceptable percentage of the farmers. However, there are sufficient indications that they are moving towards the goals, objectives and outcomes of sustainable agriculture. If the ARC-ISCW perseveres with the approach or process of 'true participation' for a critical period of at least 5 to 10 years, there should be no doubt that sustainability can be achieved.

The ARC-ISCW research team at Glen will know that their task is accomplished and their work is done once the people of the communities remark: "We have done it ourselves!"

10 TECHNOLOGY EXCHANGE

On various occasions technology has been exchanged with:

(a) Department of Agriculture officials of the Free State Province (especially those of the FSRE and Extension section);

(b) Owners of small areas of land; and

(c) People who have access to arable land.

Three procedures were adopted to achieve this aim. The first consisted of maintaining on-station and on-farm demonstration plots. The second procedure employed was holding information days and working with identified focus groups by means of regularly attended focus group discussions. The third procedure was by taking the IRWH technique to the farmers, and helping, supporting and training them in the principles of IRWH. The guidance and involvement of the socio-economic team from the University of the Free State (Departments of Sociology and Agricultural Economics) was very valuable and made a large contribution towards the technology exchange actions, and especially in bringing the IRWH technique to the farmers.

A complete list of all the technology exchange actions that occurred during the course of the project is listed in Appendix 10.1. Some of the highlights are briefly discussed in this section.

10.1 PRE-HARVEST FOCUS GROUP DISCUSSIONS

A pre-harvest focus group discussion was held on 15 March 2001 at the DoA offices in Glen, with the farmers from both Botshabelo and Thaba Nchu as the two main focus groups. The main purpose of the day was to explain the benefits of IRWH as compared to *CON*. The new technology was introduced and explained in both English and Sesotho. Prof. Groenewald from the Department of Sociology (UFS) was also present to emphasize the financial incentives of the technique. The farmers were taken on an excursion to the on-station demonstration plots at Glen and the on-farm demonstration plots at Khumo. The farmers enjoyed the day and praised the ARC-ISCW team for their efforts and the simple method of knowledge exchange. The farmers also expressed their hope that there would be good relations and communication between them, the extension officers and the research team.

10.2 POST-HARVEST FOCUS GROUP DISCUSSIONS

After the crops had been harvested and the results were known, they were presented at gatherings organized at Thaba Nchu and Botshabelo by officers of the Free State Department of Agriculture. Close cooperation was maintained throughout with the Farming Systems Research and Extension section at Glen and the relevant branch of the FSDA Extension Service in connection with these technology exchange actions.

A combined pre-harvest and post-harvest focus group discussion was held at the DoA offices in Botshabelo on 4 July 2000. This meeting was attended by more than 80 farmers from the Thaba Nchu and Botshabelo areas, eager to learn more about the promising new IRWH technique. The technique was explained by means of slides, pictures and an interactive physical three-dimensional scale model. Pictures of the models are presented in Appendix 10.2. Yields of the 1999/2000 growing season obtained at the experimental site at Glen and the demonstration plots at Khumo and Vlakspruit were also communicated to the farmers. For most of the farmers who attended the gathering this was the first time that they were formally introduced to the IRWH technique. Most of them seemed to be very enthusiastic about the new technique and indicated that they intended to start constructing basins at their homesteads immediately.

An information day was held on 23 August 2001 at the DoA offices in Thaba Nchu for the Thaba Nchu focus group, and on 30 August 2001 a post-harvest focus group discussion was held with the farmers of the Botshabelo area at the DoA offices in Botshabelo. At both gatherings the ARC-ISCW team presented the IRWH technique bt means of posters and pictures. Yields from the previous growing season were also graphically presented. The mission of the farmers' days was to compare the 1999/2000 yields of the *CON* method versus the IRWH technique. The water harvesting technique was explained by means of slides via an overhead projector. The slides included pictures of the crops on the plots with the different treatments, throughout the growing season. In these pictures, simple tools were used to emphasize the comparison. Also shown in the slides was the labour needed to constructing the IRWH layout. A physical interactive three-dimensional scale model was also used to further explain IRWH versus *CON*. This model was used to emphasize the effect of slope and erratic rainfall events on the marginal soils of the Free State and how the IRWH technique could be used to counteract these negative effects. The socio-economic team from the UFS was also present to explain the economic implications of the IRWH technique. They stressed that opting for the IRWH technique would mean financial benefits in the long run although a lot of physical labour input was required during establishment.

On 17 October 2002, the ARC-ISCW team visited Tweefontein to formally introduce IRWH. Approximately 70 people attended, including farmers from neighbouring villages such as Balaclava, Grootdam and Yoxford. By this time, some of the farmers were fairly conversant with the technique and seemed to understand the concepts very well. They wanted to implement the technique but said that they would prefer vegetables to the conventional cereal crops that were tried and tested. They were worried that they would have to pay for the seed, fertilizer, etc provided by the ARC-ISCW. Their other main concern was a lack of co-operation as well as animosity amongst themselves.

10.3 FARMERS' DAYS AND INFORMATION DAYS

The ARC-ISCW team stayed in constant contact with the farmers in the Thaba Nchu and Botshabelo areas who had implemented IRWH. Numerous farmers' days and information days were held to provide the farmers with information and advice. Farmers were given the opportunity to share their experiences and problems with IRWH. During some of these days farmers visited the experimental site at Glen, the demonstration plots at Khumo and Vlakspruit, and homestead gardens and croplands in the villages where IRWH had been implemented. During each of these gatherings the principles of IRWH were once again explained and demonstrated. The whole process of storing water for crop production with IRWH was explained as visual as possible by means of pictures, photos and a 3-D scale model to make understanding the technique as easy as possible. After the farmers had seen the practical demonstration of the IRWH technique, most of them indicated that they fully understood the technique and were convinced that it could be used to improve crop yields dramatically. Farmers' days and information days for the farmers in the Thaba Nchu and Botshabelo areas were held on 22 March 2000, 18 April 2000, 10 & 18 May 2000, 13 & 14

March 2002, 11 July 2002 and 24 & 25 February 2003. On average approximately 120 people attended each event.

10.4 ON-FARM APPLICATIONS OF THE TECHNIQUE

Four villages in the Thaba Nchu area were selected as the main focus groups. These were Talla, Feloanè, Yoxford and Paradys. Soil surveys were carried out at the villages and suitable soils for IRWH identified. A PRA was conducted at each village and a satisfactory level of acceptance amongst the people was established. Demonstration/training plots were made at suitable sites, and in each community one plot was assigned the full responsibility of the ARC-ISCW team, and the other the full responsibility of the respective communities. The ARC-ISCW team regularly visited the villages and kept in touch with the committee members to monitor the progress and growth of the trials. Community members were given the opportunity to ask for assistance for construction of the basins if they wanted to make them in their backyard gardens. A few made them, and the team frequently visited them in order to be a part of the progress all the way. A comprehensive list of all the activities surrounding the implementation of IRWH in the selected villages during the 2001/02 and 2002/03 seasons was discussed in Sections 9.9 and 9.10.

10.5 EXTENSION INFORMATION DAY

On 3 April 2002, Ms. M. Macheli visited the Delta office at Thaba Nchu to brief the extension personnel on IRWH and to propose an information day for them to be held at Glen. Mr. G. Madiba introduced Ms. Macheli to the extension officers and gave her the platform to explain the purpose of her visit. Ms. Macheli first introduced Mr. Esau Motladile and explained that he was a farmer from Yoxford (one of the villages selected for the implementation of IRWH) who was present to represent the current views of the rest of the community on IRWH. She then proceeded to discuss IRWH and how it could be used to improve crop production on the marginal soils of this part of the Free State that are also characterized by a climate unfavourable for crop production. She also pointed out that only certain soils are suitable for the technique and therefore selection of implementation areas will be determined by soil suitability, in addition to upliftment needs.

The importance of support from extension personnel was raised because the Chairman of the WRC Steering Committee’s concern with the fact that the selected villages did not have resident extension officers. It was emphasized that the duration of ARC-ISCW involvement in the project is determined by available funds. Sustainability of the projects can therefore only be maintained by extension officers. The extension officers were made to realize that strong relationships with farmers could only be established with their assistance. To farmers, the people from the ARC-ISCW are a group of strangers who may come and go with unfulfilled promises.

One of the extension officers suggested that the boundaries of their support to the ARC-ISCW team should be clearly defined. They need to know exactly what is expected of them. The definition of sufficient support may vary from one person to the next. The leader of the extension officers suggested that a proper information day be held by ARC-ISCW for the extension officers to clearly place IRWH in perspective, and to clearly define the expectations of ARC-ISCW from extension personnel. The rest of the group agreed with this suggestion as the current meeting was not really arranged for this purpose. The ARC-ISCW team had only been given a slot within the general agenda of the departmental meeting. The date set for the proposed meeting was 16 April 2002.

Mr. E. Motladile was then given an opportunity to express the views of the farmers. He first introduced himself as not only a farmer but also a member of the administrative ward under which Yoxford falls. He explained that the farmers were at first reluctant to implement IRWH, but were now very excited that its results versus conventional methods of cultivation were becoming clearly visible as harvest time approached. At this point, pictures taken from the plots of different villages representing both IRWH and *CON* were passed around for the extension officers to see the results for themselves.

Mr. Motladile made no secret of the fact that since Mr. Madiba had been removed from the extension office, support was almost non-existent, and crop production in his village had collapsed. He therefore made an earnest plea to the extension officers to assist as much as possible with regard to poverty alleviation in the rural communities.

10.6 TRAINING OF EXTENSION OFFICERS AND YOUTH WORKERS

On 16 April 2002, an information day was held for extension officers and youth workers responsible for the respective places. The main aim was to improve their knowledge and understanding of the basic concepts of the IRWH technique, and to establish their role in this particular project. Optimum participation from all individuals was ensured by grouping in such a way that in each group there was a representative from ARC-ISCW, an extension officer and a few youth workers.

The following are a few of the topics discussed: the aims of extension officers, youth workers and researchers regarding the IRWH technique; the benefits and problems of IRWH; the role of extension officers, youth leaders and researchers in the implementation of the IRWH technique; etc. A whole range of views were expressed in this regard and in the final analysis it can be said that there was general enthusiasm amongst the youth workers who were mostly unfamiliar with the IRWH technique. They expressed their interest in introducing the technique in their respective schools but stressed the point that it was not going to be easy, given their transport limitations. Extension officers, on the other hand, were quite familiar with the technique and applauded the ARC-ISCW team on breaking the monotony of the way their information days are conducted. They also said that the technique was beneficial. They also felt the researchers were doing their job (i.e. technology transfer) and hence they felt intimidated. They further mentioned that they had absolutely no objections to being a part of the IRWH team as long as it did not take up too much of their time relative to the Department of Agriculture's priority programmes.

10.7 WORKSHOPS ON IRWH

From 16–18 July 2002, a three-day workshop was held at Glen for the extension officers and the leader farmers of the respective villages where the IRWH is practised. The aim of this workshop was to train the participants on the basic concepts of climate, pedology, teamwork, leadership and the IRWH technique, using field excursions as an integral part of the exercise.

From 6–8 August 2002 another workshop on IRWH was held at Glen. Three representatives from each village where the IRWH technique was already implemented, and two representatives from the villages where it would be implemented during the 2002/03 season, attended the workshop. A total of twenty farmers were present. They were given training on the basic principles of IRWH and each of the participants received a manual on “10 Steps to convert land into an effective IRWH system”. A copy of the 10 steps is presented in Appendix 10.3.

10.8 COMMUNITY WATER HARVESTING FESTIVAL

The festival was scheduled for four days in March (17–20) 2003. The aims were as follows: Bringing farmers, extension, researchers, politicians and the municipal body together in exchanging knowledge on the IRWH techniques; exposure and promotion of IRWH, as well as empowering farmers to fight poverty and food insecurity. Community members of the villages in which the technique has already been implemented and neighbouring villages that had not yet heard or seen IRWH were invited to the festival. Veteran villages included: Feloanè, Yoxford, Tweefontein, Sepanè 7, Woodbridge I, Grootdam and Balaclava. Newly invited villages included: Potsane, Middledeel, Tiger River, Merino, Modutung, Kgalala, Paradys, Mokwena, Excelsior, Ratlou, Woodbridge II, Gladstone, Nogas Post, Springfontein, Klipfontein and Rietfontein. All in all 23 villages were represented. From the “veteran” villages all the people who participated in implementing the technique were invited, while only five people from each new village were invited to represent their respective communities. In accordance with expectations, approximately 400 farmers attended the festival each day.

The festival commenced at the IPJ Hall at Glen on 17 March. The head of extension, Mr. Tseliso Ramanamane, was the programme director and the translator as the need arose. The keynote address was by the MEC of the Free State Department of Agriculture, Mr. Mann Oelrich. He started off by stating the mission of his department and giving their aims, and he then highlighted the importance of agriculture for the alleviation of poverty. He emphasised the importance of IRWH for this part of the Free State and went on to congratulate the ARC-ISCW Glen team for a job well done in organising the festival and in the transfer of technology to the farmers. He encouraged the farmers who had not yet implemented the technique to do so as soon as possible and went on to assure them that they will certainly be assisted by state grants and the expertise of the ARC-ISCW team.

Dr. L.D. van Rensburg of ARC-ISCW explained the long process to improved crop production at grassroots level. He explained the importance of making optimal use of the little available water and the progress of the ARC-ISCW team from IRWH research to technology exchange. Ms. M. Macheli explained the principles of the IRWH technique. She outlined the problems and limitations of crop production in the residential areas of the attending farmers, and explained how these can be overcome by adopting IRWH. Mr. J.J. Botha explained the application of in-field rainwater harvesting in rural villages and also the programme and purpose of the festival. The people were divided into different groups for discussion purposes during the festival.

An excursion was taken to the experimental site at Glen and there Mr. Sebolai and Mr. Thamae explained the various treatments. They showed and explained the differences between the *CON* and the IRWH plots. The farmers were quite impressed to see the differences in plant heights and vigour. The neutron probe pipes and the different types of mulch fascinated them. They wanted to know who and how many people had constructed the basins and the time needed for the task. They wanted to know where the stone mulch came from and were generally impressed that so few people had done such a lot of work.

After lunch, the party departed to Sepanè 7 to hear from the members of the Itumeleng Trust. At the farm, it was learned that all the farmers are struggling to contribute to the success of the farm because they reside very far from it. However, the team spirit amongst them is remarkable and they all seemed to be very courageous and hard working people. Mr. S Rannyama, one of the trustees, explained that implementation of IRWH is quite simple for determined people. It could be seen that they have succeeded in constructing basins on a very large piece of land even though only six of them are actively participating. He went on to tell the other farmers that they intend to go further with the construction of the basins. He showed the farmers the different plots where they have grown maize, beans, pumpkin, watermelons, sunflower and potatoes. The farmers were also shown the importance of weed control on the IRWH plots. This was demonstrated via the water stress induced by weeds.

The farmers then split into four groups to discuss what they had learned at Glen and Sepanè. The main points of the discussion were the evaluation of *CON* versus IRWH, what they had learned from the morning session at the IPJ Hall, and what they needed to do to improve their current situation. They stated that from the morning session they had learned that people should be determined to work hard in order to combat poverty. They realise that they can gain from implementing IRWH in the sense that they will not have to spend as much as they would have with the implementation of *CON*. On evaluation of *CON* versus IRWH, they agreed that IRWH will increase yields and hence income for those that intend to sell. From Sepanè they learned that hard work pays off, weed and pest control is important, and that too much heat and the surrounding trees have impaired the growth of crops. The farmers admire the determination of the trust members in making a success of IRWH even though they have to travel such long distances. They feel that the Free State Department of Agriculture should assist the trustees in one way or another. They thanked the ARC-ISCW team and expressed their wish to be with them as they take on the implementation of IRWH.

The second day of the festival commenced with a visit to Grootdam. There is only one IRWH plot in this village which is owned by an elderly gentleman, Mr. Lonake. He learned about the technique from a neighbouring village (Tweefontein) and asked one of the committee members from that village to teach him how to construct the basins. He went on to construct the basins and waited for a representative from ARC-ISCW to come and help him plant. Thereafter, he single-handedly grew maize, beans, tomatoes and beetroot in his very small garden and was occasionally assisted by visiting friends. At the time of this visit, he had already sold some of his maize, beans and tomatoes. He has collectively made more than R640 from the sales both locally and in town. The sound of that amount of money made the farmers very excited. The local headman, who was initially not interested in knowing about the technique, was so impressed to see the results that he promised to call a public gathering in order to encourage his community to adopt the technique. The interest within the community was reflected by the number of villagers who were present, as well as school children who entertained the crowd with songs. The farmers learnt that they could earn a lot if they are determined to work hard. They felt that the fact that Mr. Lonake worked single-handedly was an inspiration.

From Grootdam, the farmers travelled to Balaclava, where two backyard gardens were visited. The leader farmer, Mr. Tshweu, pointed out that only nine people, mostly women, had implemented the technique because their village was the last in which the IRWH technique was introduced. The nine were working together as a team, he said, and their plots were clean and quite impressive. He said that they have learnt how important it is to harvest water due to its scarcity in their village. He mentioned that he first planted seed in pots and later transplanted them in the garden when it had started raining. He explained that they had constructed the basins in October 2002 and started planting in December after having received a little rain. He and his peers learnt how to plant different vegetables at different planting spaces. At that stage it seemed likely that the best harvest would be obtained from maize. He stressed that *CON* is a waste of time and energy. He believes that their perseverance has paid off. They obtained a large harvest from the vegetables and said they would preserve them to prevent spoilage. The invited farmers learnt that the vegetables were good because they were regularly irrigated. They learnt the importance of the development of a soil crust on the 2 m runoff strip. Some expressed concern about the small spacing on the beetroot plot. They felt that the small space would lead to competition for water amongst the individual plants. The farmers also wanted to know if they could grow winter crops as they presumed that the water already stored in the soil would boost growth during the very dry winter. They also wanted to know if ARC-ISCW would provide fertilizer and seed for the next growing season. The farmers said they intend to expand construction of the IRWH plots and will work in groups to minimise the labour requirements. They said that if they work in groups, they would be able to plant on fairly large pieces of land.

From Balaclava the farmers travelled to Tweefontein. One of the first things that they noticed there is that the soils are different from those they had seen in all the villages that they had already visited. The difference was that the Tweefontein farmers fertilise their soils with kraal manure. Their plots were very clean and very well looked after. However, the crops did not look as good as those in Balaclava and Grootdam because they had been planted later. They also said that the surrounding trees were detrimental and caused increased stress to their crops. The farmers of this village pledged to continue with the IRWH technique annually. They will use mulch to minimise evaporation, and some people have already used stone and straw mulch. It was suggested that they should make fairly big basin walls because their plots are situated on a foothill and hence the effect of runoff is more pronounced. The recruitment of women and the youth in the implementation of the IRWH technique was also encouraged.

Leadership qualities were also discussed at Tweefontein. Dr. G. Kundhlande led the discussion and it was unanimously agreed that leadership entails commitment to work and co-operation. They believe a leader must lead by example and interact with his people. A leader must also take into consideration people’s rights and their suggestions. A leader must respect his people in order to earn respect. A leader must be a responsible person with a vision for a prosperous future. A leader should also be able to motivate and mobilise the youth and women to join in the projects. A leader must be an active person, always willing to learn and bring new ideas to his people. Finally a leader must be reliable, trustworthy and never selfish with information. The community too, must support the leader to promote and encourage good relations amongst groups.

The third day of the festival commenced with a visit to a trust farm, Willow Park. At this farm, the farmers learned the importance of weed control. This was demonstrated by comparing a weeded plot with a non-weeded plot. The use of fertiliser is less effective if weeds are not controlled. This is evident from the fact that crops grown on a weed-free plot thrive better than those on a plot in which weeds were not controlled, despite the fact that both areas received equal fertiliser and planting was done on the same day. It is important to control weeds throughout the growing season, or at least until the crops have developed seed and the need for water has become less crucial. This reasoning stems from the fact that plants compete with weeds for water, air and nutrients. Maintenance of the IRWH plots is also very important. When they become filled with silt they need to be reconstructed. The farmers once again saw the importance of mulch in the basins at Willow Park.

From Willow Park, the farmers proceeded to Woodbridge 1. Here the farmers have also used mulch in the basins. They stated that construction of the basins was very easy because they had loosened the soil by ploughing and they only needed spades and rakes to do the job. They produced seedlings that were transplanted to the IRWH plots. Their pumpkins and watermelons looked very good. They owe their success to working together as a group of parents and children alike, even though they had to work individually in their backyard gardens in order to be able to plant on time. Their soils are very clayey, but their crops looked very good because they were well looked after. Where there were some ashes from firewood, the crops were dying and hence the farmers realised that their plots should not be anywhere near large deposits of ash. They intend to use the straw from the harvest of that season for mulch in the basins. Those with a fairly large piece of land were encouraged to expand their basins in the coming winter. They were advised to follow the correct procedure in implementing the technique, *viz.* planting, thinning out seedlings and weeding. Those that were not well informed about constructing basins were encouraged to ask those who knew, in order to obtain good results. The farmers of Woodbridge believe in teamwork, especially if people want to plant at the correct time. By and large, the farmers there are hard workers.

From Woodbridge, the group proceeded to Yoxford. The farmers there had arranged a grand display of half their harvest of vegetables to show off to the other farmers. They had also cooked a variety of traditional dishes using their produce. A lady from the Free State Department of Agriculture gave a lecture on marketing strategies. She stressed the importance of acquiring markets before planting, if one intends to go commercial, as well as choosing the crop based on demand. From the discussion that followed, the farmers in one group revealed that they had learned to work as a team; that they can go to the extension office for advice on how to market their produce; and that they would like some more training and information dissemination through the use of the media as well as the establishment of regional extension offices. In another group, farmers said they would like the extension officers to assist them to establish markets. They also called for more training and further support from ARC-ISCW and the extension office. In another group the farmers said they had learned that in addition to establishing markets before planting, they must always make sure they plant the right crop. They learnt that they must keep a record of their sales and that packaging is crucial for safety reasons as well as to make the crop look good. They wanted the ARC-ISCW to clarify how long they would be available for assistance. In yet another group, the farmers said they had learned that they must grow crops of a good quality. They should be prepared to lose in order to earn. The FSDA provides free training on marketing, which should be properly managed through such aspects as record keeping. They should consult the markets for pricing before they price their own produce, and realise that delivery of their produce to the markets is their responsibility.

The last day of the festival was held at the municipal hall in Thaba Nchu. On this day exhibitions were held and the items on display were an oil press, a maize grinder, and a solar plate. The uses of these were explained and demonstrated to the farmers. The exhibition was followed by a presentation from Ms. D.B.J. Keikelame from the Free State Rural Development Association on land acquisition and restitution. Prof. Groenewald also addressed the farmers on the social aspects of the IRWH technique and invited them to express their feelings. By and large, the farmers indicated their excitement about the technique, and pledged to take ownership of the project. They also promised to take responsibility for organizing the festival in the future.

10.9 DISSEMINATION OF THE IRWH TECHNIQUE OUTSIDE THE TARGET AREA

The IRWH technique was introduced and demonstrated at various events beyond the boundaries of the target area. By giving the IRWH technique more exposure the team cherished the hope that the technique might eventually spread to other areas with suitable soils. However, the target audience was not always only rural small-scale farmers with limited access to natural resources. Many of these events were attended mostly by school children.

On 23 March 2001 an Expo was held at Glen where IRWH was explained and demonstrated to approximately 800 commercial and developing farmers within the Free State Province. During the National Agricultural Week, at an event held at Cedara near Pietermaritzburg from 21–22 May 2001, the IRWH technique was demonstrated to more than 2000 national and international people in the Agricultural sector. Other national events where the IRWH technique was introduced and demonstrated included the Water Week (23 March 2002; Bethulie), SET Week (6–10 May 2002; UFS, Bloemfontein), and the World Summit for Sustainable Development (26–28 August 2002; Pretoria).

The role that IRWH can play in the elevation of poverty and malnutrition was also communicated to DoA officials, extension officers and farmers on various other occasions. Some of these events included the Integrated Food Security workshop that was held in Bloemfontein on 11 October 2001 and the Research Open Day held at Glen on 23 November 2001.

11 CAPACITY BUILDING AND RESEARCH OUTPUTS

11.1 CAPACITY BUILDING

With the previous Water Research Commission project (1997-1999) three previously disadvantaged young men were selected for training as Technical Assistants (TAs) (Hensley *et al.*, 2000). Two aspects of their training received attention. Firstly, in-service training to carry out the many necessary tasks associated with field experimentation. The in-service training process over a number of years has proceeded well and the TAs are now able to carry out the following tasks effectively: prepare water harvesting/basin tillage plots; plant maize, sunflower, sorghum, wheat, dry beans, watermelons, pumpkin, spinach, carrots, beetroot, peas, tomatoes and potatoes by hand on experimental plots and demonstration/training plots in the villages, maintaining correct row spacing, seeding rate and fertilizer application; thin out the crops after germination to get the correct plant density; spray the crops with the correct insecticides and apply chemical weed control procedures; take soil samples for NWM calibration and determine gravimetric water content on these samples; insert NWM access tubes; make soil water content readings with a NWM; measure leaf area indices; reap crops and record yields; obtain oven dry values for biomass yields; take samples for bulk density determinations and carry out the necessary calculations; assist with a variety of calculations using a hand calculator; tasks on the computer. They also play a very important role regarding technology exchange actions. They assisted and conducted a number of technology exchange actions in the form of farmers' days with the identified groups, information days with extension officers and farmers and information days with colleges, held a water harvesting festival and led focus group discussions. They are responsible for the success of the IRWH technique in the rural villages. They have developed in such a way that they are able to train and teach people in the villages how to construct IRWH plots correctly, plant different crops mentioned above, identify problems like insects and problem weeds, teach people about management practices during the growing and fallow period and motivate the people interested in IRWH. They have also acquired the skills to work with people (improved communication skills), and conduct and lead meetings with committee members and people in the villages. Their leadership qualities have come to the fore and improved tremendously. An example of minutes that they took during a meeting is presented in Appendix 11.1.

The second part of their training was to obtain some sort of academic training. Hensley *et al.* (2000) decided that to enable the TAs to be accepted as registered students at Technikon SA it was necessary to improve their school leaving results. They needed a pass mark in Std. 10 Biology. They were thus registered with Damelin Correspondence College for this purpose during 1998, and were also given additional tuition. Although their marks for the end of the year examination were not good, they were accepted as students for a Diploma in Agricultural Management at Technikon SA on the basis of these marks, their previous Std 10 records, and their mature age. They elected to start off during 1999 with three of the 16 courses needed for the Diploma. During 1999 they also attended a one-week practical training course at Cedara. Mr. Sebolai passed two subjects and failed one. Mr. Thuthani passed one and failed two. Mr. Thamae failed all three. During 2000 all three of them registered for three courses. Mr. Sebolai and Mr. Thuthani passed one and failed two while Mr. Thamae failed all three. During 2001 all three of them were registered for two courses but they failed both. Mr. Thuthani obtained his driving licence during 2001. Mr. Sebolai was registered for two computer courses during 2002 at CCS IT solutions and he passed both of them. Mr. Sebolai did a lot of computer work for this final report.

De Vos *et al*. (2002) describe capacity building as the process of assisting people with the potential and capacity to develop skills at various levels to manage their own future. Although the TAs did not perform well with their academic training they definitely developed a lot of skills to manage their futures better and they are going to play a vital role in water harvesting in the future. They have already touched the lives of a lot of people in the rural areas not only with the IRWH technique but have helped to develop people's good qualities.

Quite a number of capacity building actions took place during the duration of the project with farmers, extension officers, youth workers and members of rural villages who were interested in learning about the IRWH technique and applying it in their homesteads or croplands. They were assisted in mastering the technical aspects of IRWH like land preparation, planting, weeding, marketing etc. Apart from day to day activities, various formal technology exchange activities such as pre- and post-harvesting focus group discussions, information days and formal training workshops were held. Training in teamwork, motivation, leadership, group dynamics, etc. also formed part of the research outcomes. All these were described in detail in Chapter 10.

- Mr. P.P. van Staden received his M.Sc. Agric. degree with distinction from the UFS during 2000. His study was based on water harvesting results obtained from the previous project funded by the WRC. The title of his thesis is: "The effect of runoff-storage relations on rainwater utilization by maize on clay soils with high drought risk". [Afr.]
- Two students from the University of the Free State obtained their M.Sc. Agric. degrees on work done on the water-harvesting project:
  - Ms. M.C. Hlena received her M.Sc. Agric. degree from the UFS during 2001. Her study was based on results obtained from the demonstration plots on the Vlakspruit/Arcadia ecotope. The title of her thesis is: "Water harvesting and basin tillage technique - its effects in the microbial ecology of the soil".
  - Mr. N.M. Reda received his M.Sc. Agric. degree from the UFS during 2001. His study was based on results obtained from the on-station trials on the Glen/Bonheim ecotope. The title of his thesis is: "Effect of in-field water harvesting with different mulching practices in crop response".
- Mr. van Staden and Ms. Macheli attended a LandCare workshop on Participatory Rural Appraisal in the Drakensberg during October 1999.
- Mr. Anderson attended a LandCare workshop in the Limpopo Province from 4–7 April 2000.
- Dr. L.D. van Rensburg attended the 12th International World Fertilizer Congress in Beijing, China from 3-9 August 2001. The congress focused on Fertilization in the Third Millennium – fertilizer, food security and environmental protection. Valuable lessons on plant nutrition were learned that can be used to improve crop production using IRWH. More than 800 people attended the congress.
- Messrs. Anderson and Botha attended a workshop on "Exploring linkages between farmer participatory research and computer-based simulation modeling to increase crop productivity at the Small-holder Level" from 14-20 October 2001, presented by ICRISAT, in Zimbabwe to obtain hands-on experience in the use of the APSIM model. This workshop was a joint venture between SWNM, ICRISAT and CIMYT.The first two days of the workshop focussed on experiences in participatory research approaches. This was followed up with three days of fieldwork with smallholder communities in the Tsholotsho and Zimuto communal areas, Zimbabwe. The APSIM crop growth model was used to run different management scenarios for individual farmers in the communities. The APSIM might be used as a decision support tool for improved soil, water and

nutrient management to stabilize and increase crop production in the highly populated scattered villages and towns of Thaba Nchu and Botshabelo, east of Bloemfontein.

- Messrs. Botha, Anderson and van Staden and Ms. Macheli attended a workshop from 22–23 January 2002 on: “A reflection on LandCare in the ARC-ISCW”. The workshop was arranged to bring together the ARC-ISCW LandCare and management project teams to review their activities during the past two years, to refocus their strategic plans and to determine what lessons were learnt during project implementation and execution. A total of 21 participants attended the workshop, representing all the ARC-ISCW LandCare projects. Dr. Zenda Ofir, Executive Director of Scientech Evaluation (Pty) Ltd, a company focusing on strategic planning and evaluation activities, was asked to facilitate the workshop.
- Messrs. Botha, Anderson and van Staden and Ms. Macheli attended a workshop from 10–11 June 2002 on: “Evaluation and monitoring of Land Care projects”.
- Mr. Anderson will use some of the data from this project as well as data from another WRC project entitled: "Estimation of rainfall intensity for potential crop production on clay soil with in-field water harvesting practices in a semi-arid area" by Walker & Tsubo (2003) for his Ph.D. thesis.
- Mr. Botha will use some of the data from this project as well as data from other WRC projects entitled: "Optimizing rainfall use efficiency for developing farmers with limited access to irrigation water" by Hensley *et al.* (2003) and "On-farm application of in-field water harvesting techniques on small plots in the central region of South Africa", on which the project team is presently working, for his Ph.D. thesis.

11.2 RESEARCH OUTPUTS

11.2.1 Presentations

- Two papers were delivered at the National Congress of the South African Society of Crop Production (SASCP) in January 2000 in Bloemfontein. The titles of the presentations were:
    - Crop production on high drought risk clay soils using an in-field water harvesting production technique – J.J. Botha, J.J. Anderson, M. Hensley, L.D. van Rensburg & P.P. van Staden (Oral presentation).
    - An empirical model (CYP-SA) to predict sunflower yields: developing, calibration and application - J.J. Botha, M. Hensley & L.D. van Rensburg (Poster presentation).
- A poster presentation was presented at the Joint Congress of the Soil Science Society of South Africa (SSSSA), SASCP and South African Weed Science Society held in Pretoria during January 2001. Mr. Botha received the medal for the best poster presentation from the SSSSA. The title of the presentation was:
    - Water conservation techniques on small plots in semi-arid areas to increase sunflower yields – J.J. Botha, J.J. Anderson, P.P. van Staden & L.D. van Rensburg.
- Mr. J.J. Botha attended the 10th International Conference on Rainwater Catchment Systems in Manheim, Germany from 10-14 September 2001 and presented a paper and a poster. More than 600 people attended the congress. The titles of the presentations were:
    - Water conservation techniques on small plots in semi- arid areas to increase sunflower yields – J.J. Botha, J.J. Anderson, P.P. van Staden & L.D. van Rensburg.
    - Converting rainwater into food efficiently – J.J. Botha, M Hensley, J.J. Anderson P.P. van Staden & L.D. van Rensburg (Oral presentation).

- Dr. D.J. Beukes, the Programme Manager, attended a thematic workshop in April 2002 in Turkey where he made a presentation on: "Assessment and modeling of water harvesting techniques to optimize water use in a semi-arid crop production area in South Africa" by J.J. Botha, J.J. Anderson, L.D. van Rensburg, D.J. Beukes, N.N. Nhlabathi, M.S. Macheli & P.P. van Staden.
- Three presentations were made at the SASAS conference held in Pretoria from 26–28 August 2002. The titles of the presentations were: Characterizing soil temperature during the summer for the Glen/Swartland-Rouxville ecotope – L.D. van Rensburg, J.J. Botha, D.J. Beukes, P.P. van Staden & J.J. Anderson (Poster).Temperature and Humidity profiles for the Glen/Bonheim-Onrus ecotope as affected by mulching treatments – N.N. Nhlabathi, L.D. van Rensburg, J.J. Anderson, J.J. Botha & R. Kuschke.Quantify evaporation for the Glen/Swartland-Rouxville ecotope under various mulching strategies – J.J. Botha, J.J. Anderson, L.D. van Rensburg, D.J. Beukes, M. Hensley & P.P. van Staden (Poster).
- Dr. L.D. van Rensburg attended a workshop in Nairobi, Kenya from 28-30 October 2002 on: The use of databases and simulation models. He delivered an oral presentation on "Soil and Water Management: Irrigation and dry land crop production in the Republic of South Africa". The authors of the presentation were L.D. van Rensburg, J.J. Botha & P.P. van Staden.
- Seven papers were delivered at the National Combined Congress of the SSSSA, SASCP and Southern African Society for Horticultural Sciences in January 2003 in Stellenbosch. Mr. J.J. Botha received a medal from the SSSSA for the best poster presentation. The titles of the presentations were:
  - Diurnal fluctuation of temperature, humidity and water content as affected by mulching – L.D. van Rensburg, N.N. Nhlabathi, J.J. Botha, J.J. Anderson, P.P. van Staden & M.S. Macheli (Oral presentation).
  - Water conservation techniques on small plots in semi-arid areas to increase crop yields – J.J. Botha, J.J. Anderson, L.D. van Rensburg, M.S. Macheli & P.P. van Staden (Oral presentation).
  - Evaluation of evaporation subroutines of various models as affected by mulching – N.N. Nhlabathi, L.D. van Rensburg, J.J. Botha, J.J. Anderson, P.P. van Staden & M.S. Macheli.
  - The application of crop modeling technology to quantify risk for marginal crop production areas – J.J. Anderson, J.J. Botha, L.D. van Rensburg, M. Hensley & P.P. van Staden (poster).
  - Quantifying evaporation under various mulching strategies – J.J. Botha, J.J. Anderson, L.D. van Rensburg, D.J. Beukes, P.P. van Staden & M. Hensley (poster).
  - Small-scalefarmers response to in-field water harvesting technology using visual models – L.D. van Rensburg, J.J. Botha, J.J. Botha, D.G. Groenewald, M.S. Macheli & P.P. van Staden (poster).
  - Characterization of the Glen/Bonheim-Onrus ecotope – P.P. van Staden, L.D. van Rensburg, M. Hensley, J.J. Botha & J.J. Anderson (poster).
- On 17 March 2003 three presentations were delivered at the Water Harvesting Festival held at Glen. The titles of the presentations were:
  - The long walk to improve crop production at grass root level – L.D. van Rensburg, J.J. Botha, J.J. Anderson, M.S. Macheli & P.P. van Staden.
  - In-field rainwater harvesting: Principles & Crops – M.S. Macheli, L.D. van Rensburg, J.J. Botha, J.J. Anderson & P.P. van Staden.

- Application of in-field rainwater harvesting in rural villages in semi-arid areas of South Africa – J.J. Botha, L.D. van Rensburg, J.J. Anderson, G. Kundhlande & M.S. Macheli.

- Five oral and one poster presentation were delivered at the Water Conservation Technologies (WCT) symposium held in Bloemfontein from 8–11 April 2003. The titles of the presentations were:
  - Application of in-field rainwater harvesting to stabilize crop yields in rural villages in semi-arid areas of South Africa – J.J. Botha, L.D. van Rensburg, J.J. Anderson, G. Kundhlande, M. Hensley & M.S. Macheli.
  - Water conservation techniques on small plot plots in semi-arid areas to increase crop yield – J.J. Botha, J.J. Anderson, L.D. van Rensburg, M.S. Macheli & P.P. van Staden.
  - Development and evaluation of a physical model to exchange technology on crop production techniques – L.D. van Rensburg, D.G. Groenewald, J.J. Botha, J.J. Anderson & P.P. van Staden.
  - Socio-economic considerations for successful water harvesting for improved agricultural production in semi-arid areas – G. Kundhlande, J.J. Botha & L.D. van Rensburg.
  - A preliminary analysis of the economic viability of a water conservation technique in semi-arid areas in South Africa: A case study from Thaba Nchu in the Free State Province – M.N. Baiphethi, G. Kundhlande, M.F. Viljoen, J.J. Botha & L.D. van Rensburg.
  - The use of crop modeling to compare different tillage techniques – J.J. Anderson, J.J. Botha & L.D. van Rensburg (Poster).
- On 25 April 2003 a presentation on: "The role of the Water Harvesting Group in the War against malnutrition and poverty through agriculture" by L.D. van Rensburg, J.J. Botha, J.J. Anderson, P.P. van Staden, M.S. Macheli & N.N. Nhlabathi was presented in at an Imbiso of the Free State Department of Agriculture in Verkeerdevlei.

11.2.2 Reports and publications

- Anderson, J.J., Botha, J.J. & Van Rensburg, L.D., 2003. The use of crop modeling to compare different tillage techniques Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).
- Baiphethi, M.N., Kundhlande, G., Viljoen, M.F., Botha J.J. & Van Rensburg, L.D., 2003. A preliminary analysis of the economic viability of a water conservation technique in semi-arid areas in South Africa: A case study from Thaba Nchu in the Free State Province. Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).
- Botha, J.J., Anderson, J.J., Van Rensburg, L.D., Macheli, M.S. & Van Staden, P.P., 2003. Water conservation techniques on small plot plots in semi-arid areas to increase crop yields. Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).
- Botha, J.J., Anderson, J.J., Van Staden, P.P. & Van Rensburg, L.D., 2001. Water conservation techniques on small plots in semi-arid areas to increase sunflower yields. Proceedings of 10th International Conference on Rainwater Catchment Systems, Manheim, Germany, 10-14 September, 2001.
- Botha, J.J., Hensley, M., Anderson J.J., Van Staden, P.P. & Van Rensburg, L.D., 2001. Converting rainwater into food efficiently. Proceedings of 10th International Conference on Rainwater Catchment Systems, Manheim, Germany, 10-14 September, 2001.

- Botha, J.J., Van Rensburg, L.D., Anderson, J.J., Groenewald, D.G., Kundhlande, G., Hensley, M. & Macheli, M.S., 2003. Application of in-field rainwater harvesting to stabilize crop yields in rural villages in semi-arid areas of South Africa. Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).
- Kundhlande, G., Botha, J.J. & Van Rensburg, L.D., 2003. Socio-economic considerations for successful water harvesting for improve agricultural production in semi-arid areas. Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).
- Van Rensburg, L.D., Groenewald, D.G., Botha, J.J., Anderson J.J. & Van Staden, P.P., 2003. Development and evaluation of a physical model to exchange technology on crop production techniques. Proceedings of WCT Symposium, Bloemfontein, South Africa, 8-11 April, 2003. (In Press).

11.2.3 Media

- On 23 May 2003 Dr. L.D. van Rensburg gave a radio interview with Radio Oranje. The talk was about the implementation of water harvesting in Thaba Nchu.
- Three video productions on IRWH were produced. The titles of the videos are:
  - In-field rain water harvesting (1) "Basic concepts to insure agronomic and conservation sustainability in small scale farming".
  - In-field rainwater harvesting to promote sustainable rural livelihoods (June 2003).
  - IRWH technology exchange using physical models.
- A manual with 10 steps on how to implement the IRWH technique was published and is handed out at information days and farmers' day to people who show interest in the technique.
- Two physical interactive three-dimensional models that represent a *CON* and IRWH treatment were built to visually demonstrate the advantages of the IRWH technique at information and farmers' days. The models are also used to explain complicated processes such as runoff, infiltration drainage and evaporation.

11.2.4 Press releases made

- Landbou Weekblad, 15 October 1999, No. 1118. Benutting van afloop-reënwater verhoog produksie (Article – Utilization of runoff rainwater increase production).
- Volksblad, 05 April 2003. Navorsers van UV wen medaljes op kongres (Article – Researchers of the University of the Free State obtain medals at National SSSSA Congress).
- Farmer's Weekly, 19 July 2002. Water harvesting: a solution to the food crisis.
- Volksblad, 09 April 2003. Stelsel besorg kleinboere landerye om van te droom [Afr.] (Article – Application of in-field rainwater harvesting in the Thaba Nchu area).
- AgriNews (Official newsletter of the Department of Agriculture), April 2003. Rainwater harvesting boosts crops in Free State.
- The Water Wheel, May -June 2003, Volume 2 nr 3. Water harvesting: A key to food security for Africa?

11.2.5 Visitors

- On 30 May 2001 Dr. J. Skerritt and Ms. I. van Rensburg from the Australian Centre for International Agricultural Research (ACIAR) visited Glen in connection with projects for small-scale farmers. This was seen as an ideal marketing opportunity and a video on rainwater harvesting was shown to them.

- On 6 June 2001 Mr. L. Ncukana, Director Operations of the Free State Department of Agriculture, visited Dr. van Rensburg to promote cooperation between the Department and ARC-ISCW on water harvesting projects.
- On 29 August 2001 H. Sally, H. Levite, L. Magingxa & A. Kamara from the International Water Management Institute (IWMI) visited Glen to discuss possible cooperation and funding of water conservation projects.
- On 6 September 2002 a delegation from IWMI (Ms. Marna de Lange & Mr. Crosby) as well as other representatives from Australia visited the community of Yoxford where the IRWH technique is already successfully implemented. Afterwards, discussions were held at Glen on further development and implementation of other water conservation technologies.
- On 17 September 2002 an information day on IRWH was held for an Australian delegation that is actively involved in LandCare projects.
- A delegation of the Angolan Department of Agriculture, accompanied by the MEC of Agriculture in the Free State province, visited the Glen experimental site during April 2003. They were accompanied by Mr. J.J.Botha.
- Approximately sixty delegates from the Water Conservation Technology Symposium visited the Glen experimental site where the IRWH technique is investigated and also some demonstration trials and farmers' plots located in the Thaba Nchu area on 10 April 2003.
- On 13 May 2003 six farmers and two agricultural technicians from the Rustenburg area visited Glen. They were accompanied by three researchers from ARC-ISCW – Pretoria and the Programme Manager Dr. D.J. Beukes. The farmers who attended were mainly commercial farmers, farming with sunflower and cotton. During the last growing season the IRWH technique was demonstrated in one of the visiting farmer's fields. However, the demonstration trial was not very successful due to late land preparation, late planting and unfavourable climatic conditions. Therefore it was decided to bring the people to Glen where this technique has been successfully employed for the past 6 years.
- On 2 June 2003 the Soil Classification Working Group classified the soil profile pits at Glen where the IRWH was implemented. They were accompanied by Dr. L.D. van Rensburg.
- On 3 June 2003 a student from Germany, Sibylle Hassler, visited the IRWH trials at Glen.

11.2.6 Models

- An empirical maize and dry bean stress model (CYP-SA) has made a valuable contribution to this study, and the sunflower version has been updated and adapted to cater for mulches on the runoff area within an IRWH system.

12 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

12.1 GENERAL DISCUSSION

Water scarcity affects rainfed agriculture and directly threatens the livelihood of billions of people, particularly in developing countries. Agriculture is the largest user of freshwater; 70 % of it is used to provide food, natural fibres and to employ billions of rural dwellers. Where water is scarce, the need for rainwater management skills and efficiency increases. Due to constant population growth, there is a necessity for an increased food supply, requiring the use of marginal land for food production. To combat this problem, water harvesting can be used to maximize crop available water for increased yields.

This project had three objectives. The extent to which each of these has been achieved will form the basis of the discussion in this chapter.

(A) Evaluate different water conservation techniques, which will enhance rainfall/precipitation use efficiency (PUE), promote food security, and ensure sustainable productivity.

- **Enhance PUE:** PUE was measured over three growing seasons in the on-station statistical trials for maize and sunflower on blocks A and B. A common trend of organic mulch in the basin and stones on the runoff area (*ObSr*) > organic mulch in basin and organic mulch on the runoff area (*ObOr*) > stone mulch in basin and organic mulch on the runoff area (*SbOr*) > organic mulch in basin and a bare runoff area (*ObBr*) was observed during the experimental period. The mean PUE for maize indicated that *ObSr*, *ObOr* and *SbOr* are 14, 3 and 2 %, respectively, more efficient in converting rainwater into staple food than the *ObBr* treatment. *ObSr* was for most of the seasons significantly better than the *ObBr*. The same trend was observed for sunflower except that *SbOr* is slightly better than *ObOr*. *ObSr* was significantly better than *ObBr* during the 00/01 and 01/02 seasons. A common trend for the various precipitation use efficiencies (PUE_a, PUE_{ET} and PUE_{pg}) was obtained for maize, *viz. ObSr* > *ObOr* > *SbOr* > *ObBr*, and similarly for sunflower, excepting that *ObOr* and *SbOr* changed positions. The PUE of the *ObSr* treatment was in most seasons significantly higher than *ObBr* for both crops. In all these cases all the treatments with a mulch on the runoff area increased PUE.

  PUE was also measured in the semi-statistical demonstration plots on blocks C and D (on-station) with maize, sunflower and dry beans, as well as in the two demonstration plots with sunflower on the farms Khumo and Vlakspruit. On blocks C and D it was proved with all the crops that PUE was the highest on the stone mulch in the basin and stone mulch on the runoff area (*SbSr*) treatment, followed by *ObBr*, with conventional tillage (*CON*) the least productive treatment. On the two demonstration plots, results showed that *ObSr* was the best, followed by *SbOr*, *ObBr* and *CON*. On all the demonstration plots with all the crops, PUE on the IRWH techniques was significantly higher than with *CON*. The PUE of both *ObSr* and *SbSr* was significantly higher than for *ObBr*.

  Results have indicated clearly that the IRWH techniques are far more efficient than *CON* at converting rainwater into food. Results have also indicated that all the IRWH techniques with a mulch on the runoff area produced higher PUEs. In terms of PUE, *ObSr* was the best treatment followed by *SbSr*, *ObOr*, *SbOr ObBr* and *CON*.

- **Promote food security:** According to Brown (2000), food security is access by all people at all times to sufficient food, in terms of quality, quantity and diversity, for an active and healthy life without risk of loss of such access. During the three growing seasons with on-station as well as with on-farm trials it was proved that all the IRWH techniques contributed to much higher crop yields, compared to *CON*. It was also proved with cumulative probability functions (CPFs) of crop yields and gross margins that the IRWH techniques are far superior to the *CON* technique, and that the risk of failure (crop yield and gross margins) is very low with the IRWH techniques. The risk becomes even lower when moving from the IRWH treatment that was the least productive, *viz*. the bare basin and a bare runoff area (*BbBr*), to the IRWH technique that was the most productive of them all (*ObSr*). People in rural communities have also proved that very good yields were obtained with the IRWH (*BbBr*) technique compared to the people who used *CON* and harvested very little or nothing at all, and that only in the homesteads. The residents of the different villages also planted a variety of crops, some of which was never demonstrated to them, as part of their IRWH strategy to combat food insecurity. They planted maize, dry beans, watermelons, pumpkins, peas, carrots, beetroot, spinach, tomatoes and potatoes. Case studies from a number of residents indicated that the crop production in the homesteads can make a significant impact on food security through: (i) the cultivation of a variety of crops for own consumption; and (ii) their ability to buy food with the money obtained through selling of their produce. Additionally, the homesteads provide a simple environment for promoting the IRWH technique, and therefore food security, through training. However, converting the croplands into a sustainable enterprise remains the biggest challenge because at the moment they do not use the cropland productively.

- **Ensure sustainable productivity:** Sustainability describes the appropriate use of crop systems and agricultural inputs supporting those activities that maintain economic and social viability while preserving the high productivity quality of land. The requirements for sustainable crop production according to Smyth & Dumanski (1993) are described in the following five points:

  ➥ *Agronomic productivity (improved production)*: The results already presented show that IRWH significantly increased crop yields compared to *CON* (on-station, on-farm demonstrations and in rural villages), and that the IRWH treatments with stone or organic mulch on the runoff area give the best yields of maize, sunflower and dry beans. The most productive IRWH treatment is *ObSr*, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and *BbBr*.

  ➥ *Risk - security (reduction in the level of risk)*: The crop model CYP-SA and long-term climate data were used to provide long-term yield simulations to quantify risk. CPFs were drawn of simulated long-term yields for the three crops on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes using different production techniques. Results obtained from simulations done with CYP-SA indicate that dry bean yields could be increased by 19 % by changing from *CON* to *BbBr*, by another 1 % by changing to *ObBr*, and by a further 7 % by changing to *ObSr*. For maize it is simulated that yields will increase by 71 % by changing from *CON* to *BbBr*, by another 3 % when changing from *BbBr* to *ObBr* and by a further 17 % by changing from *ObBr* to *ObSr*. CYP-SA also simulates that sunflower yield will increase by 93 % when changing from *CON* to *BbBr*, by another 7 % when changing from *BbBr* to

ObBr and by a further 47 % when changing from *ObBr* to *ObSr*. It was simulated that a farmer will increase crop yields (beans, maize and sunflower) by 60 % on average when changing from *CON* to *BbBr*, by another 4 % when changing from *BbBr* to *ObBr* and by a further 27 % when changing from *ObBr* to *ObSr*. Results indicate that *ObSr* was the best treatment in terms of risk reduction, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr*, *BbBr*, and the treatment with the highest risk probability, *CON*.

Enterprise budgets for the three crops under *CON* and the different IRWH techniques on the Glen/Bonheim ecotope were linked to yield data obtained with CYP-SA for an 81-year period and gross margins (R ha^{-1}) were calculated. CPFs were drawn of long-term gross margins for the three crops on the Glen/Bonheim ecotope using different production techniques. From the yield and gross margin CPF graphs of dry beans, maize and sunflower, the Kolmogorov-Smirnov test has indicated that all the IRWH techniques statistically ($P = 0.01$) out-performed the *CON* tillage. Furthermore that the *ObSr* and *SbSr* treatments performed statistically better than the *BbBr* treatment. *ObSr* proved to be the most productive technique for the crops tested, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and *BbBr*. Where *CON* exposes farmers to production risk, IRWH techniques reduced risk considerably. Greater returns are possible by changing from *CON* to IRWH. The results indicated that it would be beneficial for a farmer, in terms of reducing risk and realizing higher sustainable incomes, to use IRWH techniques instead of *CON*, to plant late rather than early, and preferably to plant when the soil water content is more than half its capacity. Generally, IRWH techniques, just like *CON*, are dependent on rainfall over which the farmer has no control; nevertheless the former techniques offer an opportunity for a farmer to reduce risks considerably.

➥ *Conservation techniques (conservation of natural resources)*: Results of long-term in-field runoff predictions within the IRWH system indicated that organic mulch, stone and bare treatments have an 80 % probability of harvesting 22 mm, 90 mm and 156 mm every year, respectively, compared to the *CON* tillage, which has a very high probability (80 %) of losing 40 mm of rainwater every year through runoff. This implies that the organic mulch, stone and bare treatments conserve 62 mm, 130 mm and 196 mm more rainwater, respectively, than *CON*, due to their total stoppage of ex-field runoff.

Ex-field runoff was completely stopped by the IRWH system and hence also soil erosion. An area of concern that influences the sustainability of the IRWH system is the siltation of the basins through the in-field runoff process. Sediment measurements and estimates have revealed that the basins will take between 12 and 81 years to become filled if no sediment is removed. The period depends on the type of mulch on the runoff area and also in the basins. Mulch on the runoff area restricts sediment movement, depending on mulch type, while mulch type in the basin influences the capacity of the basin to absorb sediment. However, it is also necessary to realize that all the IRWH techniques need maintenance, especially because of the need to prevent the basins overflowing during heavy rainstorms.

The carbon cycle processes in the soil are drastically influenced by ploughing (*CON*), and the system responds accordingly, with the carbon content tending towards a lower equilibrium with long-term cultivation. Carbon measurements at the start and end of the project revealed that the no-till IRWH treatments showed similar trends in C content over time, but appear to have stabilized at a relatively higher C % compared to the *CON* treatments. Carbon declined by 19 % over the period 1998 - 2002 for the *CON* treatments and by 10 % for the IRWH treatments. It seems that the C % in the IRWH system with organic mulches might recover or improve, while in the case of *CON* it will probably decline every year with continuous ploughing. It seems that there is a potential for the IRWH systems to be more beneficial for carbon conservation than *CON*, and also that C % is not sensitive over the short-term, and needs to be tested over a long-term period.

The N-budget study reveals that a large amount of nitrogen was released by mineralization when the veld was transformed into a crop production system by ploughing (*CON*). The N-budget for the IRWH system indicates that the Nrec level of 15 kg N ha^{-1} needs to be slightly increased, depending on the mulch combinations and crop rotation systems, if agronomic and conservation sustainability is to be maintained in the long run.

➥ *Economic viability*: Enterprise budgets for the three crops under *CON* and the different IRWH techniques on the Glen/Bonheim ecotope were linked to yield data obtained with CYP-SA for an 81-year period and gross margins (R ha^{-1}) were calculated. CPFs, of long-term gross margins for the three crops on the Glen/Bonheim ecotope using different production techniques were developed. Based on the results, it can be concluded that greater profits are made with the IRWH techniques compared to *CON*. *ObSr* is the most productive of the IRWH techniques for all the crops, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and *BbBr*. Where *CON* exposes farmers to production risk, (80 % probability of a negative gross margin), the IRWH techniques reduce risk considerably. Greater returns are possible by changing from *CON* to IRWH techniques, with even more benefits by changing from *BbBr* to the best technique, *ObSr*. The results indicate that it would be beneficial financially for a farmer to use IRWH instead of *CON*, to plant late rather than early in the season, and preferably to only plant when the soil water content is more than half of the profile available water.

Farmers from a number of rural communities have shown improved economic viability with even the least productive IRWH technique (*BbBr*), compared to *CON*.

➥ *Social acceptability*: Specific “indicators” used to monitor socio-acceptability of the IRWH technique included the following: community, mobilisation, capacity building, empowerment, human well-being, self-reliance and community participation. These indicators show that there is a strong movement towards building an active learning process in farmer groups and individual farmers lower down the hierarchy. When taking account of the large study area and huge number of end-users, much time and effort was invested for empowering the end-users, which is essential for long-term sustainability. The large number of farmer-managed trials (108 homesteads in 6 villages), and the ‘training of trainers’ programme, form a solid basis from where further training and learning could be launched. The residents of villages who applied the IRWH technique at their homesteads during the 2002/03 season, varied between 1 and 46 families per community. From the first season (2001/2002) the homesteads in which IRWH were applied expanded from 6 in four villages to 108 homesteads in six villages. Four new communities implemented the IRWH technique at their own request, *viz.* Balaclava, Woodbridge 1, Grootdam and Tweefontein. The residents of the different villages planted a variety of crops, some of which were never demonstrated to them, as part of their IRWH strategy to combat food insecurity. They planted maize, dry beans, watermelons, pumpkins, peas, carrots, beetroot, spinach, tomatoes and potatoes.

Short-term data indicate that the IRWH technique is far more sustainable that *CON* for this specific study area. Of all the IRWH techniques tested, *ObSr* has been shown to be the best, followed by the *SbSr*, *ObOr*, *SbOr* and *ObBr*. In general, evaluation of the project in terms of the different sustainability criteria really needs to be done in the long-term. Only then could it be properly judged whether or not the project has succeeded in implementing sustainable land management practices (or best practice components thereof) among an acceptable percentage of the farmers. However, there are sufficient indications that they are moving towards the goals, objectives and outcomes of sustainable agriculture. If the ARC-ISCW perseveres with the approach of 'true participation' for a critical period of at least 5 to 10 years, there is no doubt that sustainability can be achieved.

Taking all the above-mentioned results into consideration it can be concluded that IRWH will enhance PUE, promote food security and ensure sustainability. The *ObSr* treatment was overall the best treatment, followed by *SbSr*, *ObOr*, *SbOr*, *ObBr* and *BbBr*. The people should have the option to choose which technique will suit their situation the best. The first step will be to apply the simple *BbBr* IRWH on plots to obtain higher yields. The second step could be to apply mulch, if available, in the basins of the IRWH technique. If enough mulch is available, then it should be applied in the basins and on the runoff area. If organic and stone mulches are available, the organic mulch should be applied in the basins and the stone mulch on the runoff area (*ObSr*).

(B) Develop the capacity, as technical assistants in this research field, of three previously disadvantaged young people.

With the previous Water Research Commission project (1997-1999) Messrs. Daniël Thuthani, Elias Sebolai and David Thamae were selected for training as Technical Assistants (TAs) (Hensley *et al.*, 2000). Two aspects of their training receive attention. Firstly, in-service training to carry-out the many necessary tasks associated with field experimentation and crop production within an IRWH system; and secondly, some sort of academic training which would eventually provided them with a qualification. The in-service aspect of their training proceeded very well. At the end of two WRC projects they are able to carry out most of the experimental work, are able to introduce IRWH to new communities, mobilise communities in terms of IRWH, assist and conduct technology exchange actions (farmers' days, conduct and lead group discussions and meetings, conduct a water harvesting festival and train farmers and extension personnel in IRWH practices). Messrs. Thuthani, Sebolai and Thamae are responsible to a considerable extent for the success of the IRWH programme in the rural villages. During the course of the project the TAs were registered for a few of the courses required for a Diploma in Agricultural Management at Technikon SA. However, their results were not good. Mr. Thuthani received his driving licence and Mr. Sebolai was registered for two computer courses during 2002 at CCS IT Solutions. He passed both of them. Although the TAs did not perform well with their academic training they have definitely developed a lot of useful skills. They are going to play a vital role in water harvesting in the future. They have already touched the lives of a lot of people in the rural areas, not only with the IRWH technique, but have helped to develop people's good qualities.

During the course of the project three people received their M.Sc. Agric. degrees. Mr. P.P. van Staden, a member of the research team, received his M.Sc. on data obtained from the previous WRC project of Hensley *at al.* (2000). The other two students (Ms. M.C. Hlena and Mr. N.M. Reda) received their M.Sc.s from data obtained from this project.

Five workshops, of which one was international, were attended by members of the project team in order to strengthen their skills in communicating and interacting with the people in the rural villages. Ten poster presentations were delivered, four of them internationally. Two of the national poster presentations received medals for the best poster. Seventeen oral presentations were delivered of which nine were at international gatherings. A total of eight publications were published. One radio interview regarding IRWH took place. Three videos on IRWH have been produced. A manual with 10 steps on how to implement the IRWH technique has been compiled. Two physical interactive three-dimensional models that represent a *CON* and IRWH treatments were built. Six press releases were made about IRWH and the research team, and a number of people (national and international) visited the research team and IRWH research plots.

(C) Transfer technology as effectively as possible by means of demonstration plots and information days to Department of Agricultural officials (FSRE and Extension section) and owners of small areas of land or those who have access to communal land.

Two procedures were adopted to achieve this aim. The first consisted of maintaining demonstration plots at the on-station trials (blocks C & D), on-farm demonstrations at the two farms Khumo and Vlakspruit, and also at the rural villages (2001/02) Talla, Feloanè, Yoxford and Paradys. The second procedure employed was by means of information days, workshops and group discussions. IRWH has been communicated to extension officers of the FSDA and small-scale farmers in the Thaba Nchu and Botshabelo areas on various occasions. During the lifespan of the project numerous information days and farmers' days have been held at which IRWH was explained and demonstrated by means of pictures, photos, videos and 3D-scale models representing IRWH and *CON*. The visual presentations made it easy for those present to understand the basic principles of the new conservation tillage practice. During the information days and farmers' days, farmers visited the on-station and on-farm demonstration plots to get a full appreciation of the new promising cultivation method. At these gatherings farmers had the opportunity to share their experiences, address problems and seek more knowledge on IRWH, and the research team was always more than willing to provide information and support. Group discussions were also held with specific target groups to communicate the crop yields obtained with *CON* and IRWH at the on-station and on-farm plots. A total of 17 information days and farmers' days were held over a period of three years.

The research team not only hosted information days but also provided formal training in the form of workshops to farmers and extension officers to improve their knowledge and understanding of the basic principles of IRWH. Participants also had lectures on climate, pedology, teamwork, marketing and leadership. Hands-on practical exercises formed an integral part of the training sessions.

During the course of the project the research team regularly visited the villages and stayed in close contact with all the farmers who had implemented IRWH, or intended to. This provided them with the necessary support and advice on how to make optimal use of the new crop production technique. Events, like the Water Harvesting Festival, were also organized to give farmers the opportunity to visit and interact with people in other villages who also produce crops with IRWH.

IRWH was not only introduced and demonstrated to resource-poor small-scale farmers in the Thaba Nchu and Botshabelo areas, but was also given exposure at various events beyond the borders of the target area with the hope that it might eventually spread to other areas with suitable soils. These events were not only attended by small-scale farmers, but drew the attention of various interest groups in the agricultural sector on national and international levels.

In the planning of the project it was hypothesised that mulch (organic or stone mulch) on the runoff area will depress evaporation and soil movement and therefore promote sustainability and higher yields. Two questions were answered in the project:

(1) Can the IRWH technique decrease Es to a reasonable level through mulch combinations on the runoff area and in the basin area?
(2) Will the farmers in rural villages use the IRWH technique?

Results indicate that stone and organic mulch on the runoff area generally conserved more water by suppression of Es for both maize and sunflower compared to the bare runoff treatment. Stones on the runoff area, compared to bare, reduced evaporation by 12 % and 10 % for maize and sunflower, respectively, whereas organic mulch reduced evaporation by 16 % and 12 %, respectively, compared to bare. Water conserved this way contributed towards higher transpiration values, and hence higher seed yield for both crops. Sediment measurements and estimates have revealed that the basins will take between 12 and 81 years to become filled if no sediment is removed. It can be concluded that mulches on the runoff area restrict sediment movement, decrease Es and therefore increase crop yield in a sustainable system. From the first season (2001/2002) the homesteads in which IRWH was applied expanded from six in four villages, to 108 homesteads in six villages. Four new communities implemented the IRWH technique on their request. This is already short-term proof that farmers in rural villages are using IRWH with very good results.

12.2 CONCLUSIONS

The overall main conclusions are that IRWH techniques are superior to *CON*; that mulches on the runoff area of the IRWH technique minimize Es and siltation of the basins, and therefore increase PUE; and that the technique produces sustainable higher crop yields at a very low probability of crop failure. The *ObSr* treatment is the best, followed by *SbSr*, *ObOr*, *ObSr*, *ObBr* and *BbBr*. IRWH is a tool to empower people in rural villages to enable them to fight food insecurity. The following are important details concerning the findings:

(a) A major advantage of the IRWH system is that ex-field runoff can be stopped completely if the system is correctly designed. No erosion from the field as a whole will therefore occur. In contrast, topsoil losses of around 0.6 mm per year were measured on conventionally tilled plots on long-term runoff experiments at Glen and Pretoria.

(b) The results of this project reveal the importance of surface redistribution of water with regard to crop yield.

(c) Runoff measurements on the Glen/Bonheim ecotope, converted to long-term predictions by appropriate equations, indicated that where the runoff strip in the IRWH system was left bare or covered by stones or organic mulch, the amount of water harvested annually in the basins was predicted to be 196, 130 and 62 mm more, respectively, than with *CON*.

(d) Sediment measurements and estimates have revealed that the basins will take between 12 and 81 years to become filled if no sediment is removed. The period depends on the type of mulch on the runoff area and also in the basins. Mulch on the runoff area restricts sediment movement.

(e) Measurements on the experimental plots showed that water losses through deep drainage were negligible, and since runoff losses were also zero on all the IRWH plots, the only cause of water loss was evaporation from the soil surface (Es).

(f) Calculated infiltration ratios for the basins versus the runoff area with data from all the IRWH treatments were plotted against relative yields. A parabolic curve fitted to the data showed that the optimum infiltration ratio, associated with stones on the runoff area, was found to be between 1.6 and 1.9.

(g) The soil fertility study, which focused on nitrogen, showed that where available crop water was > 470 mm, sunflower responded positively to high N levels while maize did not respond to the high N level, probably due to: (i) the lower available water levels (376 – 404 mm), and (ii) the relatively high nitrogen supply capacity for the crop-soil system of 58 kg N ha^{-1}. The study also revealed that the recommended N application of 15 kg N ha^{-1} needs to be slightly increased, depending on the mulch combinations and crop rotation systems, if agronomic and conservation sustainability is to be maintained in the long run.

(h) CPFs of long-term crop yields obtained with CYP-SA indicate a yield advantage with early January planting of the crops, compared to mid-December and mid-October planting dates.

(i) Demonstration plots and many pre- and post-harvest information days, workshops and educational sessions helped the rapid expansion of the IRWH technique.

(j) Homesteads provide a simple environment for promoting the IRWH technique through training.

12.3 RECOMMENDATIONS, INCLUDING ADDITIONAL RESEARCH NEEDS

(a) Farmers

- Firstly, apply the IRWH technique to obtain higher yields.
- Secondly, apply any mulch that is available in the basins of the IRWH technique. If enough mulch is available, apply it in the basins and on the runoff area. If organic and stone mulches are available, apply the organic mulch in the basins and the stone mulch on the runoff area (*ObSr*).
- Plant later in the season rather than early, on a profile with a soil water content that is more than half full whenever possible.

(b) Administrators and Policy makers

- A very good foundation has been laid for people in rural villages around Thaba Nchu to become self sufficient and produce more, and to earn a good income with the IRWH technique. It is a long-term process that should be continued in the future.
- When a new crop production technique is to be introduced into rural villages, one should first start with the homesteads. These provide a simple environment for promoting a new technique through training. The starting point of a new technique should first focus on food security, and later expanded to larger scale operations.
- For a total improvement in rural villages in dry areas, IRWH and other water harvesting techniques should be applied. But the first step should be IRWH, since it is easy, simple and reproducable. Later, other rainwater harvesting techniques such as water collection from roads, roofs etc., can be implemented to complement the system.

- Technology exchange and training concerning the results of this report should take place in future.
- A future focus should be the development of the croplands of rural villagers into sustainable enterprises.
- On-farm demonstration of IRWH techniques assessing the impact of investment in weeding.
- On-farm demonstration of IRWH techniques assessing the impact of investment in fertilizer.
- The development of formal education material for primary, secondary and tertiary institutions needs to be addressed urgently.

(c) Researchers

- Investigate other ways to reduce Es. It is clear that in order to further improve PUE it will be necessary to find ways of suppressing Es still further. Options could be to investigate the percentage cover, and also different types of mulches. Evaporation from the soil surface especially with a crop present is a complex process. It would be of great value if this process could be modelled.
- Although the correlations between rainfall amounts and in-field runoff with different mulches are very useful as first approximations, they expose by default the important influence which rainfall intensity has on runoff and sediment load. A fruitful avenue for future research is revealed here – especially for model building purposes.
- The parabolic curve of optimum infiltration ratio associated with the mulch type in the basins and on the runoff area is valuable, and more research with different kinds of mulch (e.g. gravels) could lead to further improvements in PUE.
- Improvements in the CYP-SA model for maize, sunflower and dry beans, and other crops are necessary. An efficient IRWH adapted crop model would make a valuable contribution towards the "NEPAD" expressed aim of improving rainfed crop production in Africa by means of water harvesting. The model would make it possible to extrapolate results to a wide range of ecotopes in Africa.
- Ways of combining crops and animals in an integrated IRWH system need to be investigated.
- Future research is needed with regard to introducing a permanent crop into the IRWH system.
- As a first approximation, nitrogen fertilizer application can be adjusted for mulch practices within the IRWH system. Preliminary results showed that the N_{rec} should be adjusted to rates of 20, 30, 32 and 50 kg N ha^{-1} for *ObOr*, *ObSr*, *ObBr* and *SbOr* respectively.
- One of the major constraints restricting the extrapolation and hence the application of the IRWH techniques, is the modeling of the water and soil nitrogen balance components.
- In depth study to determine the economic viability and socio-acceptability of the different treatments used in this study.

In general, evaluation of the different sustainability criteria in relation to the project needs to be considered in the long-term. Only then can it be judged whether or not the project has succeeded in implementing sustainable land management practices (or best practice components thereof) among an acceptable percentage of the farmers. However, there are sufficient indications that the farmers are moving towards the goals, objectives and outcomes of sustainable agriculture, which were derived through a participatory monitoring and evaluation process. If the ARC-ISCW perseveres with the approach of ‘true participation’ for a critical period of at least 5 to 10 years, there is no doubt that sustainability can be achieved.

13 REFERENCES

AGASSI, M., 1990. Effects of water quality on soil erosion. A report on soil management for improving rain and irrigation water intake and preventing runoff and erosion. Emeq-Hefer, Israel.

BABBIE, E., 2001. The practice of social research. 9th ed. Belmont: Wadsworth.

BABBIE, E. & MOUTON, J., 2001. The practice of social research. South African edition. Cape Town: Oxford University Press.

BAUMHARDT, R.L., WENDT, C.W. & MOORE, J., 1988. The effect of water quality on infiltration of simulated rainfall. In Challenges in dryland agriculture – a global perspective. Proceedings of the International Conference on dryland farming. Amarillo, Texas, USA.

BEMBRIDGE, T.J., 1991. Contributions to the science of agricultural extension. DSc Agric Thesis. University Stellenbosch

BENNIE, A.T.P., 1984. Doeltreffende wateropgaring in grond in hoë droogte risiko gebiede. In: Verslag en aanbevelings van werksessies oor die benutting van gronde in hoë droogte risiko gebiede. GVSA Kongres, Bloemfontein.

BENNIE, A.T.P., COETZEE, M.J., VAN ANTWERPEN, R., VAN RENSBURG, L.D., & BURGER, R. Du T., 1988. ‘n Waterbalansmodel vir besproeiing gebaseer op profile watervoorsieningstempo en gewas waterbehoeftes. WNK verslag no 144/1/88, Pretoria.

BENNIE, A.T.P.,STRYDOM, J.E. & VERY, H.S.,1994. Opgaring en benutting van reënwater in grond vir die stabilisering van plantproduksie in halfdroë gebiede. Waternavorsingskommisie verslag no. 227/1/94, Pretoria.

BENNIE, A.T.P., STRYDOM, M.G. & VREY, H.S., 1998. [The use of computer models or agricultural water management on ecotope level] [Afr] Water Research Commission of South Africa, Pretoria, Report No. TT 102/98.

BERRY, W.A.J. & MALLETT, J.B., 1988. The effect of the tillage: maize residue interactions upon soil water storage. *S. Afr. J. Plant Soil* 5, 57-64.

BOCK, B.R., 1984. Efficient use of nitrogen in cropping systems. In R.D. Hauck (ed.) Nitrogen in crop production. *Am. Soc. of Agron.*, Madison, Wisconsin.

BOOTE, K.J., JONES, J.W. & PICKERING, N.B., 1996. Potential Uses and Limitations of Crop Models. *Agron. J.*, 88, 704-716.

BOTHA, J.J., ANDERSON, J.J., VAN STADEN, P.P., VAN RENSBURG, L.D., BEUKES, D.J. & HENSLEY, M., 2001. Quantifying and modelling the influence of different mulches on evaporation from the soil surface. OSWU. ARC-ISCW Report No. GW/A/2001/5, 43 pp.

BLOEM, A.A. & BARNARD, R.O., 2001. Effect of annual legumes on soil nitrogen and on the subsequent yield of maize and grain sorghum. *S. Afr. J. Plant Soil* 18, 56-61.

BROWN, L.R., 2000. Personal communication.

CAMERON, D.R., DE JONG, R. & CHANG, C., 1978. Nitrogen inputs and losses in tobacco, bean and potato fields in a sandy loam watershed. *J. Environ. Qual*. 10, 545-550.

CARTER, M.R. & MAY, J., 2001. One Kind of Freedom: Poverty Dynamics in Post-Apartheid South Africa. *World Development*. 29(12), 1987-2006.

CHAPMAN, S.C., HAMMER, G.L. & MEINKE, H., 1993. A sunflower simulation model: I. Model development. *Agron. J*. 85, 725-735.

COETZEE, J.J., GRAAGG, J.J., HENDRICKS, F. & WOOD, G., 2001. Development. Theory, Policy, and Practice. Cape Town: Oxford University Press.

CRASWELL, E.T. & STRONG, W.M., 1976. Isotopic studies of the nitrogen balance in a cracking clay. III. Nitrogen recovery in plant and soil in relation to the depth of fertilizer addition and rainfall. *Aust. J. Soil. Res*. 14, 75-83.

DANSO, S.K.A. & POPASTYLIANOU, I., 1992. Evaluation of the nitrogen contribution of legumes to subsequent cereals. *J. of Agric. Sci*. 119, 13-18.

DE JAGER, J.M. & SINGELS, A., 1990. Economic quantification of climatic risk in maize production using a crop model. Pp 68-69. *In:* R.C.Muchow and J.A. Bellamy (Eds.), Proceedings of the International Symposium on Climatic Risk in Crop Production, Brisbane, Australia.

DE LANGE, M., 2003. Personal communication.

DEPARTMENT OF AGRICULTURE - FREE STATE, 1996. From entitlement to self reliance. Business Plan 1996-1999. Dept. Agricuture - Free State, Glen.

DE VOS, A.S., STRYDOM, H., FOUCHè, H. & DELPORT, C.S.L., 2002. Research at grass roots for the social science and human service professions. 2nd ed. Pretoria. Van Schaik Publishers.

DU TOIT, M.E. & DU PREEZ, C.C., 1995. Effect of cultivation on the nitrogen fertility of selected dryland soil in South Africa. *S. Afr. J. Plant Soil* 12, 73-81.

DU TOIT, M.E., DU PREEZ, C.C., HENSLEY, M. & BENNIE, A.T.P., 1984. Effek van bewerking op die organiese materiaalinhoud van geselekteerde droëland-gronde in Suid-Afrika. *S. Afr. J. Plant Soil* 11, 71-79.

DU PLESSIS, M.C.F. & MOSTERT, J.W.C., 1965. [Runoff and soil loss at the Agricultural Research Centre Glen] [Afr.]. *S. Afr. J. Agric. Sci.* 8, 1051-1060.

ECK, H.V., 1984. Irrigated corn yield response to nitrogen and water. *Agron. J.* 76, 421–428.

ELOFF, J.F., 1984. Die gronghuplbronne van die Vrystaatstreek. Ph.D profskrif, Universiteit van Stellenbosch.

FAO REPORT, 1993. Water harvesting for improved agricultural production.

FIRESTONE, M.K., 1982. Biological denitrification. In F.J. Stevenson (ed.). Nitrogen in agricultural soils. Am. Soc. Of Agron., Madison, Wisconsim.

FISHER, 2000. Personal communication.

FRIED, M., TANJI, K.K. & VAN DER PLO, R.M., 1976. Simplified long term concept for evaluating leaching of nitrogen from agricultural land. *J. Environ. Qual.* 5, 197–200.

GREGORY, P.J., 1989. Concepts of water use efficiency. Pp 9-19. (Eds.) Proceedings of an international Workshop, ICARDA, Turkey.

GROENEWALD, D.G., 2003. Personal communication.

HATTINGH, H.W., 1993. [The estimation of evaporation from the soil surface under dryland wheat and maize production] [Afr] M.Sc. Agric. Dissertation, University of the Orange Free State, Bloemfontein.

HATIBU, N. 2002. Rainwater Management: Strategies for Improving Water Availability and Productivity in Semi-arid and Arid Areas. www.iwmi.cgiar.org/home/rainwater.htm#

HAYLETT, D.G., 1960. Runoff and soil erosion studies at Pretoria. South African Journal of Agricultural Science. Vol. 3, No. 3. Government Printer, Pretoria.

HENSLEY, M., BOTHA, J.J., ANDERSON, J.J., VAN STADEN, P.P. & DU TOIT, A., 2000. Optimising rainfall use efficiency for developing farmers with limited access to irrigation water. Water Research Commission of South Africa, Pretoria, Report No. 878/1/00, 96pp.

HENSLEY, M., HATTINGH, H.W. & BENNIE, A.T.P., 1993. A water balance modelling problem and a proposed solution. 4th Annual Conference of the SADC-Land and Water Management Research Program, Windhoek.

HENSLEY, M. & SNYMAN, P.J., 1991. Wheat yields probabilities on the Glen/Shorrocks ecotope with different soil water contents at planting. *S. Afr. J. Plant Soil*, 8(4), 194-199.

HENSLEY, M., SNYMAN, P.J. & POTGIETER, H.L.J., 1990. A parameter for describing the efficiency of water use in rainfed cropping. Poster paper presented at International Symposium held in Brisbane, Australia. July 1990.

HILLEL, D., 1972. The field water balance and water use efficiency. Pp 79 – 100. *In:* D. Hillel (Ed). Optimising the soil physical environment towards greater crop yields. Academic Press, London.

HOFFMAN, J.E., 1997. Kwantifisering en voorspelling van grondwaterverdamping by droëlandgewasproduksie. Ph.D, Uinversity of the Free State, Bloemfontein.

HOUSTON , B.J. & BERRY, W.A.J., 1996. MODEVAL - Evaluation of model performance. ARC-Grain Crops Research Institute, Potchefstroom, South Africa.

ISFAN, D., 1984. Corn yield variation as related to soil water fluctuation and nitrogen fertilizer. Soil water-yield relationships. *Commun. In Soil Sci. Plant Anal.* 15, 1147-1161.

KOLMOGOROV-SMIRNOV. The KS-test to determine if two datasets differ significantly. http//www.physics.csbsju.edu/stats/KS-test.hlml

KOTZE, D.A. & KOTZE, P.M.J., 1996. What is wrong in development? Focus Forum, HSRC, May/June: 4-8.

KRONEN, M., 1994. Water harvesting and conservation techniques for smallholder crop production systems. *Soil and Tillage Research* 32, 71-86.

KUNDHLANDE, G., GROENEWALD, D.G., BAIPHETHI, M.N., VILJOEN, G, BOTHA, J.J., VAN RENSBURG, L.D. & ANDERSON, J.J., 2003. Socio-economic study on water conservation techniques in semi-arid areas. Water Research Commission of South Africa, Pretoria.

LAKER, M.C., CEULEMANS, R.J.M. & VANASSCHE, F.M.G., 1991. Effects of soil water stress on stomatal diffusion conductance and leaf water potential in maize (*Zea mays* L.) at flowering stage. *Water S.A.* 17(4), 255-262.

LEGG, J.O. & MEISINGER, J.J., 1982. Soil nitrogen budgets. In F.J. Stevenson (ed.). Nitrogen in agricultural soils. Am. Soc. of Agron., Madison, Wisconsin.

MACVICAR, C.N., SCOTNEY, D.M., SKINNER, T.E., NIEHAUS, H.S. & LOUBSER, J.H., 1974. A classification of land (climate, terrain form, soil) primarily for rain fed agriculture. *S. Afr. J. Agric. Ext.* 3, 21-24.

MATHEWS, O.R. & ARMY, T.J., 1960. Moisture storage on followed wheat land in the Great Plains. *Proc. Soil. Sci. Soc. Am.* 24, 414-418.

MCPHEE, P., 1988. The rainfall simulator and soil erodibility. Agring No. 4, Jan. 1988.

MEISINGER, J.J. & RANDALL, G.W., 1991. Estimating nitrogen budgets for soil-crop systems. In R.F. Follet, D.R. Keeney & R.M. Cruse (Eds.). Managing nitrogen for groundwater quality and farm profitability Am. Soc. of Agron., Madison, Wisconsin.

MORIN, J. & BENYAMINI, Y., 1990. Tillage method selection based on runoff modeling. In Challenges in dryland agriculture – a global perspective. Proceedings of the International Conference on dryland farming. Amarillo, Texas, USA.

MONTEITH, J.L., 1996.The Quest for Balance in Crop Modelling. *Agron .J.* 88, 695-697.

MUCHOW, G.L., HAMMER, P.S. & CARBERRY, P.S., 1990. Optimising crop and cultivar selection in response to climatic risk. Pp 235-262. *In:* R.C. Muchow and J.A. Bellamy (Eds.), Proceedings of the International Symposium on Climatic Risk in Crop Production, Brisbane, Australia.

NEL, A.A., LOUBSER, H.L. & HAMMES, P.S., 2000. The yield and processing quality of sunflower seed as affected by the amount and timing of nitrogen tolerance. *S. Afr. J. Plant Soil* 17, 155-159.

OBERLê, S.L. & KEENEY, D.R., 1990. Factors influencing corn fertilizer N requirements in the northern U.S. Corn Belt. *J. A. Prod. Agric.* 3, 527-534.

OWEIS, T., HACHUM, A. & KIJNE, J., 1999. Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. IWMI contribution (no. 7) to System-Wide Initiative on Water Management (SWIM).

PASSIOURA, J.B., 1983. Roots and drought resistance. A*gric Water Management* 7, 265-280.

PRINSLOO, M.A., WILTSHIRE, G.H. & DU PREEZ, C.C., 1990. Loss of nitrogen fertility and its restoration in some Orange Free State soils. *S. Afr. J. Plant Soil* 7, 15-61.

RASMUSSEN, V.P. & HANKS, R.J., 1978. Spring wheat yield model for limited moisture conditions. *Agron. J.* 70, 940-944.

RATLIFF, L.F., RITCHIE, J.T. & CASSEL, D.K., 1983. Field-measured limits of soil water availability as related to laboratory-measured properties. *Soil Sci. Soc. Amer. J.* 47, 770-775.

RHOADS, F.M., 1984. Nitrogen or water stress: their interrelationships. In R.D. Hauck (ed.) Nitrogen in crop production. Am. Soc. of Agron., Madison, Wisconsin.

RITCHIE, J.T., 1997. Personal communication.

ROBINSON, J.M. & HUBBARD, K.G., 1990. Soil water assessment model for several crops in the High Plains. *Agron. J*. 82, 1141-1148.

ROGERS, E.M. & SHOEMAKER, F.F., 1971. Communication of Innovations. 2nd ed. Macmillan Publishers, New York.

SCHULZE, R.E., 1995. Soil water budgeting and total evaporation. pp. AT 7-1 to AT 7-21. Water Research Commission of South Africa, Pretoria. Report No. TT 69/95.

SHAW, R.H. & LAING, D.R., 1962. Moisture stress and plant response. In W.H. Pierre (ed.) Plant environment and efficient water use. Am. Soc. of Agron., Madison, Wisconsin.

SHARMA, B.D., KAR, S. & CHEEMA, S.S., 1990. Yield, water use and nitrogen uptake for different water and N levels in winter wheat. *Fert. Res*. 22, 119-127.

SIEGERT, K., 1993. Introduction to water harvesting: some basic principles for planning, design and monitoring. In: Water harvesting for improved agricultural production. FAO report.

SINCLAIR, T.R. & SELIGMAN, N.O., 1996. Crop Modelling: From Infancy to Maturity. *Agron. J*. 88, 698-704.

SMYTH, A.J. & DUMANSKI, J., 1993. FESLM: An International Framework for Evaluating Sustainable Land Management. World Soil Resources Report No 73. FAO Rome.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil Classification - A taxonomic System for South Africa. Soil and Irrigation Research Institute, Department of Agricultural Development, Pretoria, 257 pp.

SPIERTZ, J.H.J & DE VOS, N.M., 1983. Agronomical and physiological aspects of the role of nitrogen in yield formation of cereals. *Plant Soil* 75, 379-391.

STEYN, C.E., 2003. Personal communication.

STROOSNIJDER, L., 2003. Technologies for improving rainwater use efficiency in semi-arid Africa. Symposium/workshop: 8-11 April 2003, Bloemfontein, South Africa water conservation technologies for sustainable dryland agriculture in sub-Saharan Africa (WCT). In press.

STUTLER, R.K., JAMES, D.W., FULLERTON, T.M., WELLS, R.F. & SHIPE, E.R., 1981. Corn yield functions of irrigation and nitrogen in central America. *Irrig. Sci.* 2, 79-81.

TANNER, C.B. & SINCLAIR, T.R., 1983. Efficient water use in crop production. In: T.R. Jordan & H.M. Taylor (Eds). Efficient water use in crop production. Am. Soc. of Agron. Inc, Madison, Wisconsin, USA.

TURNER, N.C., 1986. Crop water deficits: a decade of progress. *Adv. Agron.*, 39, 1-51.

VAN DER WATT, H.V.H. & VAN ROOYEN, T.H., 1990. [An explanatory dictionary for Soil Science] [Afr] Soil Science Society of South Africa, Pretoria 356 pp.

VAN RENSBURG, L.D., 1996. Interasksie tussen stikstof- en wateropname deur koring en mielies. Ph.D. thesis. Universiteit van die Oranje Vystaat, Bloemfontein.

VAN RENSBURG, L.D., DU PREEZ, C.C. & BENNIE, A.T.P., 1997. Efficiency of nitrogen and water uptake by irrigated winter wheat. In O. van Gleemput, S. Haneklaus, G. Hofman, Dr. E Schnug, A, Vermoesen (Eds.). Fertilization for sustainable plant production and soil fertility. Proceedings Vol. I. CIEC, Germany. pp 595–602.

VAN RENSBURG, L.D., DU PREEZ, C.C. & BENNIE, A.T.P., 2001. Nitrogen and water application management toward sustainable cropping of irrigated maize in South Africa. In JI Lanzhu, G. Chen, E. Schnug, C. Hera, S. Haneklaus (Eds.). Fertilizer in the third millennium fertilizer, food security and environment protection. Proceedings Vol. I. CIEC, China.

VAN RENSBURG, L.D., NHLABATHI, N.N., ANDERSON, J.J., BOTHA, J.J., VAN STADEN, P.P. & KUSCHKE, R., 2003. Modelling evaporation from the soil surface as affected by mulching and soil factors. Final Report to OSWU.

WALKER, S., OGINDO, H.O. & HENSLEY, M., 2001. Measurement of a transpiration coefficient for common bean using a lysimeter. Paper presented to ASA-CSSA_SSSA Annual Conference, Charlotte, North Carolina, USA.

WALKER, S. & TSUBO, M., 2003. Estimation of rainfall intensity for potential crop production on clay soil with in-field water harvesting practices in a semi-arid area. Water Research Commission of South Africa, Pretoria, Report No. 1049/1/02.

WIEBE, 2000. Personal communication.

WILLMOTT, C.J., 1981 On the validation of models. *Physical Geography* 2, 184-194.

WILLMOTT, C.J., 1982. Some comments on the evaluation of model performance. *Bul. Am. Meteorol. Soc.* 63, 1309-1313.

WILTSHIRE, G.H. & DU PREEZ, C.C., 1993. Long-term effects of conservation practices on the nitrogen fertility of a soil cropped annually to wheat. *S. Afr. J. Plant Soil* 10, 70-76.

ZERE, T.B., 2003. Evaluating maize production potential of selected semi-arid ecotopes using a water balance model. M.Sc. Agric. Dissertation, University of the Free State, Bloemfontein.

APPENDICES

Appendix 3.1

SOIL PROFILE DESCRIPTION

Map / photo: 2826CD Glen
Latitude & Longitude: 28°55´13´´ / 26°21´12´´
Land type No: Ea39c
Climate zone: 45S
Altitude: 1330 m
Terrain unit: Upper Foot slope
Slope: 1%
Slope shape: Straight
Aspect: West
Micro relief: None
Parent material solum: Origin binary, local colluvium, solid rock
Underlying material: Sandstone (feldspatic)

Soil Form: Bonheim
Soil Family: Onrus
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet slight, partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: 0 mm
Described by: M. Hensley & P.P. van Staden
Date described: 1998 - 02
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Calcified

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 400	Dry; dry dark brown 7.5YR3/2, moist dark brown 7.5YR3/2; disturbed; clay; coarse angular blocky; very hard; few normal fine pores; fine cracks; many clay cutans; very few fine pedotubules; water absorption: 1 second(s); few roots; gradual smooth transition.	Melanic
B1	400 - 550	Dry; dry dark brown 7.5YR3/4, moist dark brown 7.5YR3/4; undisturbed; clay; strong coarse angular; blocky; very hard; few normal fine pores; fine cracks; many slickensides; many clay cutans; very few fine pedotubules; water absorption: 10 second(s); few roots; gradual smooth transition.	Pedocutanic
B1	550 - 800	Moist; dry brown to dark brown 7.5YR4/4, moist dark brown 7.5YR3/4; undisturbed; clay loam; common medium distinct black illuvial humus mottles; common medium distinct white oxidized iron oxide mottles; moderate medium subangular blocky; friable; few normal fine pores; non-hardened free lime, slight effervescence; few clay cutans; very few fine biocasts; water absorption: 8 second(s); few roots; gradual smooth transition.	Pedocutanic
C	800 - 1300	Moist; undisturbed; clay loam; many coarse distinct white lime mottles; many medium distinct many coloured geogenic mottles; non-hardened free lime, strong effervescence; few roots; not observed transition.	Saprolite

Remarks: The saprolite is favourable for roots.
Survey name: BEP - BO1220
NATIONAL SOIL PROFILE NO: 6222

Appendix 3.2

SOIL ANALYTICAL DATA

ECOTOPE: Glen/Bonhein - Onrus

Horizon		**A**(veld)	**A** (profile)	**B1**	**B2**	**C**
Depth (mm)		0 - 300	0 - 400	400 - 550	550 - 800	800 – 1300
PARTICLE SIZE DISTRIBUTION (%)						
>2 mm						
c sand	2 - 0.5 mm	0.5	0.1	0.6	0.3	1.3
m sand	0.5 - 0.25 mm	2.7	1.7	1.8	1.9	2.1
f sand	0.25 - 0.106 mm	23.7	23.1	21.9	22.6	20.4
vf sand	0.106 - 0.05 mm	16.6	19.5	20	19.4	17.1
c silt	0.05 - 0.02 mm	4.9	5.1	7.3	6.8	5.7
f silt	0.02 - 0.002 mm	4.8	4.4	4.5	7.1	14.3
clay	> 0.002 mm	45.1	43.5	43	39.6	37.7
Texture		Cl	Cl	Cl	ClLm	ClLm
CHEMICAL ANALYSIS						
C (%)		0.85	0.57			
Plasticity index		33	21	33	29	28
Resistance (ohm)		340	340	320	240	240
pH H_20		7.78	7.56	8.23	8.27	8.49
pH KCl		6.5	6.11	7.06	7.36	7.6
EXCHANGEABLE / EXTRACTABLE CATIONS (c mol+/kg soil)						
Na		0.71	0.56	0.85	1.24	1.19
K		0.8	0.65	0.55	0.62	0.58
Ca		10.78	8.33	7.98	7.98	13.77
Mg		11.24	12.22	11.53	11.94	8.86
S value		23.53	21.76	20.91	21.78	24.4
T value (CEC)		25.77	24.3	23.12	24.04	26.21

Appendix 3.3

SOIL PROFILE DESCRIPTION: KHUMO

NATIONAL SOIL PROFILE NO: 6224
Map / photo: 2926BB Thaba Nchu
Latitude & Longitude: 29°04´00´´ / 26°56´39´´
Land type No: Db37
Climate zone: 46S
Altitude: 1520 m
Terrain unit: Upper Foot slope
Slope: 2%
Slope shape: Straight
Aspect: North-West
Micro relief: ***None***
Parent material solum: Origin binary, local colluvium, solid rock
Underlying material: Sandstone (feldspatic)

Soil Form: Swartland
Soil Family: Amandel
Surface rockiness: None
Surface stoniness: <2% exposed surface, angular, stones
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet slight, stabilized
Vegetation / Land use: Agronomic cash crops
Water table: 0 mm
Described by: M. Hensley, P.A.L. le Roux, L.D. van Rensburg & J.J. Botha
Date described: ***1999 - 05***
Weathering of underlying material: Moderate physical, moderate chemical
Alteration of underlying material: Ferruginised

Horizon	Depth(mm)	Description	Diagnostic horizons
A	0 - 300	Moist; dry brown 7.5YR5/4, moist reddish brown 5YR4/3; disturded; fine sandy loam; apedal massive; few normal fine pores; few coarse pores; water absorption: 1 second(s); common roots; gradual smooth transition.	Orthic
AB	300 - 400	moist; moist dark reddish brown 5YR3/4; undisturbed; clay; strong fine angular blocky; slightly firm; common normal fine pores; few coarse pores; common clay cutans; very few fine sesquioxide concretions: water absorption: 3 second(s); common roots; clear smooth transition.	Pedocutanic
B1	400 - 550	Moist; moist brown to dark brown 7.5YR4/4; undisturbed; clay; many coarse distinct grey and yellow illuvial humus mootles; few fine distinct black oxidized iron oxide mottles; strong coarse angular blocky; firm; few normal fine pores; many clay cutans; very few fine sesquioxides concretions; water absorption: 3 second(s);few roots; gradual smooth transition.	Pedocutanic
B2	550 - 700	Moist; moist brown to dark brown 10Yr4/3; undisturbed; clay; many coarse distinct grey and yellow illuvial humus mottles; few fine distinct black oxidized iron oxide mottles; strong coarse angular blocky; firm; few normal fine pores; many slickensides; many clay cutans; very fine sesquioxide concretions; water absorption: 5 second(s); few roots; gradual smooth transition.	Pedocutanic
C1	700 - 1200	Moist; moist dark yellowish brown 10YR4/4; undisturbed; clay; fine distinct black oxidized iron oxide mottles; common medium faint grey, yellow and olive illuvial humus mottles; strong coarse angular blocky; very firm; few normal fine pores; many slickensides; very few fine sesquioxide concretions; very few fine lime concretions; waterabsorption: 5 second(s); few roots; gradual transition.	Saprolite

Survey name: BEP - SW1122

Appendix 3.4

SOIL ANALYTICAL DATA

Khumo/Swartland-Amandel

Horizon	A1	AB	B1	B2	C1
Depth (mm)	0-300	300-400	400-550	550-700	700-1200
Lab No	M3552	M3553	M3554	M3555	M3556
PARTICLE SIZE DISTRIBUTION (%)					
>2 mm					
c sand 2-0.5 mm	2.1	0.7	0.6	0.5	0.5
m sand 0.5-0.25 mm	3	1.5	0.9	0.7	0.7
f sand 0.25-0.106 mm	27.1	15.1	10.4	11.3	10.9
vf sand 0.106-0.05 mm	29.4	18.1	14.5	17.4	19.8
c silt 0.05-0.02 mm	11.9	8.3	8.1	10.8	12.4
f silt 0.02-0.002 mm	6.8	4.9	4.8	6.8	10.1
clay > 0.002 mm	17.5	18.7	58.5	50.1	42.8
Texture	FiSaLm	Cl	Cl	Cl	Cl
CHEMICAL ANALYSIS					
C (%)	0.37				
Resistance (ohm)	2800	1800	1600	1400	1400
pH H_20	6.03	6.1	6.9	7.84	8.83
pH KCl	4.5	4.61	5.17	6.06	7.26
EXCHANGEABLE / EXTRACTABLE CATIONS (c mol+/kg soil)					
Na	0.07	0.5	0.72	0.9	1.5
K	0.56	0.73	0.98	0.87	0.96
Ca	2.3	5.32	7.24	6.84	10.63
Mg	1.21	4.34	6.94	7.29	9.35
S value	4.14	10.89	15.88	15.9	22.44
T value (CEC)	8.01	14.66	16.92	16.48	19

APPENDIX 3.5

SOIL PROFILE DESCRIPTION:VLAKSPRUIT

NATIONAL SOIL PROFILE NO: 6225
Map / photo: 2926BB Thaba Nchu
Latitude & Longitude: 29°05´37´´ / 26°54´33´´
Land type No: Db37
Climate zone: 46S
Altitude: 1500 m
Terrain unit: Upper Foot slope
Slope: 3%
Slope shape: Straight
Aspect: North-West
Micro relief: None
Parent material solum: Origin single
Underlying material: Basic extrusive rocks

Soil Form: Arcadia
Soil Family: Lonehill
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation / Land use: Agronomic cash crops
Water table: 0 mm
Described by: M. Hensley, P.A.L. le Roux, L.D. van Rensburg & J.J. Botha
Date described: 1999 - 05
Weathering of underlying material: Moderate physical, moderate chemical
Alteration of underlying material: Calcified

Horizon	Depth(mm)	Description	Diagnostic horizons
AP	0 - 150	Wet; disturbed; clay loam; strong fine blocky; slightly sticky, plastic; few normal fine pores; few clay cutans; few roots; gradual smooth transition.	Vertic
A	150 - 540	Wet; undisturbed; clay; strong fine angular blocky; sticky, very plastic; few normal pores; many clay cutans; very few mixed-shape gravel; very few fine sesquioxide concretions; few roots.	Vertic
B1	540 - 1000	Wet; undisturbed; clay; common meduim faint white mottles; strong coarse angular blocky; sticky, very plastic; few normal pores; non-harded free lime, moderate effervescence; many slickensides; many clay cutans; few fine sesquioxide concretions; few roots.	Pedocutanic

Survey name: BEP - VLAKSPRUIT / ARCADIA

Appendix 3.6

SOIL ANALYTICAL DATA

ECOTOPE: Vlakspruit/Arcadia-Lonehill

Horizon	Ap	A1	B1
Depth (mm)	0-150	150-540	540-1000
Lab No	D1421	D1422	D1423
PARTICLE SIZE DISTRIBUTION (%)			
>2 mm			
c sand 2-0.5 mm	1.1	0.6	0.3
m sand 0.5-0.25 mm	1.5	0.9	0.7
f sand 0.25-0.106 mm	20.4	14.7	12.1
vf sand 0.106-0.05 mm	21.1	14.6	14.4
c silt 0.05-0.02 mm	9.6	8	8.3
f silt 0.02-0.002 mm	7.3	7.1	7.9
clay > 0.002 mm	37	52.4	54.1
Texture	ClLm	Cl	Cl
CHEMICAL ANALYSIS			
C (%)	0.82	0.69	
Resistance (ohm)	1600	1400	460
pH H_20	8.07	8.83	9.03
pH KCl	6.41	6.71	7.36
EXCHANGEABLE / EXTRACTABLE CATIONS (c mol+/kg soil)			
Na	0.31	1.02	1.7
K	0.5	0.63	0.43
Ca	9.38	10.13	17.71
Mg	7.11	10	14.82
S value	17.3	21.78	34.66
T value (CEC)	21.77	27.5	34.77

APPENDIX 3.7

SOIL PROFILE DESCRIPTION: FELOANè (BACKYARD) (MOTAUNG)

NATIONAL SOIL PROFILE NO: 14932 – Profile no. 1
Map / photo: 2926BA Sannaspos
Latitude & Longitude: 29°07´00´´ / 26°44´20´´
Land type No: Dc17
Climate zone: 46S
Altitude: 1420 m
Terrain unit: Upper Midslope
Slope: 3 %
Slope shape: Straight
Aspect: North east
Micro relief: None
Parent material solum: Origin binary; dolerite colluvium & sandstone
Underlying material: Felspathic sandstone

Soil Form: Sepane
Family: Ramabesa
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: None
Described by: M. Hensley & P.P. van Staden
Date described: 6/2003
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Calcified

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 150	dry colour: brown to dark brown 10YR4/3; moist colour: very dark brown 10YR2/2; sandy clay; structure: weak coarse subangular blocky; consistence: hard; many roots; clear smooth transition.	Orthic
B1	150 - 500	dry colour: brown to dark brown 10YR4/3; moist colour: dark brown 10YR3/3; clay; structure: strong coarse angular blocky; consistence: very hard; many cutans; common roots; gradual smooth transition.	Peducutanic
B2	500 – 900	dry colour: dark yellowish brown 10YR4/6; moist colour: dark yellowish brown 10YR3/6; clay; fine distinct grey, yellow and olive reduced iron oxide mottles; structure: strong coarse angular blocky; consistence: very firm; non-hardened free lime, slight effervescence; many slickensides; very many cutans; few roots; gradual smooth transition.	Pedocutanic
C	900 -1100	non-hardened free lime, slight effervescence	Saprolite

REMARKS: Vertic properties in the B2-horizon; signs of wetness in C-horizon; at 1100 hard, impenetrable sandstone
Parent material is dolerite colluvium on felspathic sandstone.

APPENDIX 3.8

PROFILE DESCRIPTION: FELOANè (FIELD)

NATIONAL SOIL PROFILE NO: 14312 - Profile no. 2
Map / photo: 2926BA Sannaspos
Latitude & Longitude: 29°06´13´´ / 26°43´03´´
Land type No: Dc17
Climate zone: 46S
Altitude: 1400 m
Terrain unit: Lower Footslope
Slope: level
Slope shape: Straight
Aspect: Level
Micro relief:
Parent material solum: Origin binary; alluvium, local colluvium
Underlying material: Sandstone (feldspathic)

Soil Form: Valsrivier
Soil Family: Aliwal
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet slight, partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: None
Described by: P.P. van Staden
Date described: 09/2001
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Normal weathering

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 450	horizon disturbed; dry colour: dark yellowish brown 10YR4/4; moist colour: dark yellowish brown 10YR3/4; structure: apedal; common fine normal pores; many roots; clear smooth transition.	Orthic
B1	450 - 750	horizon undisturbed; dry colour: dark yellowish brown 10YR4/6; moist colour: dark yellowish brown 10YR3/6; few fine distinct yellow and brown illuvial iron and humus mottles; few fine distinct white salt mottles; structure: moderate medium subangular blocky; consistence: hard; common fine pores, fine cracks; non-hardened free lime, strong effervescence; few slickensides; common cutans; very few mixed-shaped gravel 2-6mm; very few fine <2-6mm biocasts; common roots; clear smooth transition.	Peducutanic
C	750 – 1200+	horizon undisturbed; dry colour: yellowish brown 10YR5/6, moist colour: dark yellowish brown 10YR3/6; few medium distinct geogenic mottles; few fine distinct white salt mottles; structure: moderate medium subangular blocky; consistence: slightly hard; common fine normal pores, fine cracks; non-hardened free lime; strong effervescence; few mixed-shaped coarse gravel 6-25mm, very fine <2-6mm lime concretions; common roots; transition not reached.	Unconsolidated, material, without signs of wetness

APPENDIX 3.9

SOIL PROFILE DESCRIPTION: TALLA (BACKYARD)

NATIONAL SOIL PROFILE NO: 14928 – Profile no. 3
Map / photo: 2826DD Verkeerdevlei
Latitude & Longitude: 28°58´45´´ / 26°54´35´´
Land type No: Db37
Climate zone: 46S
Altitude: 1460 m
Terrain unit: Upper Foot slope
Slope: 2%
Slope shape: straight
Aspect: South-east
Micro relief: None
Parent material solum: Dolerite
Underlying material:

Soil Form: Sterkspruit
Soil Family: Smithfield
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet moderate
Vegetation / Land use: Agronomic cash crops
Water table: None
Described by: M. Hensley & P.P. van Staden
Date described: 06/2003
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Calcified

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 200	dry colour: brown 10YR5/3; moist colour: brown to dark brown 10YR4/3; sandy clay loam; structure: apedal massive; consistence: hard; many roots; abrupt transition.	Orthic
B1	200 - 600	dry colour: dark yellowish brown 10YR4/4; moist colour: dark brown 10YR3/3; clay; fine distinct many coloured reduced iron oxide mottles; structure: strong coarse prismatic; consistence: very hard; many cutans; common roots; gradual transition.	Prismacutanic
B2	600 – 1150	dry colour: light yellowish brown 10YR6/4; moist colour: grey 10YR5/1; clay; medium distinct many coloured iron oxide mottles; structure: strong coarse angular blocky; consistence: very hard; non-hardened free lime; strong effervescence; many slickensides; very many cutans; few fine <2-6mm sesquioxide concretions; few roots.	Pedocutanic

REMARKS: Vertic properties in the B2-horizon; Dry colour of the B2 qualifies as "grey" indicating hydromorphy, which is non-diagnostic in the case of Sterkspruit Form.

APPENDIX 3.10

SOIL PROFILE DESCRIPTION: PARADYS (FIELD)

NATIONAL SOIL PROFILE NO: 14931- Profile no. 4
Map / photo: 2926BB Thaba Nchu
Latitude & Longitude: 29°05´16´´ / 26°51´08´´
Land type No: Db37
Climate zone: 46S
Altitude: 1505 m
Terrain unit: Upper Midslope
Slope: 2 %
Slope shape: straight
Aspect: South
Micro relief: None
Parent material solum: Local collovium, possibly some wind blown sand
Underlying material: Sandstone (unspecified)

Soil Form: Sepane
Soil Family: Ramabesa
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet slight, partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: None
Discribed by: M. Hensley & P.P. van Staden
Date described: 6/2003
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Ferruginised

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 200	dry colour: yellowish brown 10YR5/4; moist colour: dark yellowish brown 10YR3/4; sandy clay loam; structure: apedal massive; consistence: slightly hard; many roots; gradual smooth transition	Orthic
B1	200 - 350	dry colour: brown 7.5YR5/4; moist colour: brown to dark brown 7.5YR4/4; sandy clay loam; structure: moderate coarse subangular blocky; consistence: very hard; common fine <2-6mm sesquioxide concretions; common roots; gradual smooth transition.	Pedocutanic
B2	350 - 700	dry colour: brown to dark brown 10YR4/3; moist colour: dark brown 10YR3/3; structure: strong coarse prismatic; consistence: very hard; few slickensides; common clay cutans; common roots; gradual transition.	Pedotanic
B3	700 – 1000	dry colour: olive yellow 2.5Y6/6; moist colour: light olive brown 2.5Y5/6; clay; common fine distinct many coloured reduced iron oxide mottles; structure: strong coarse angular blocky; consistence: very hard; non-hardened free lime; moderate effervescence; many slickensides; many clay cutans; very few fine <2-6mm sesquioxide concretions; few roots; gradual transition.	Unconsolidated material with signs of wetness
C	1000 – 1150+	slightly weathered sandstone.	Saprolite

REMARKS: At the one end of the pit the B1 consists almost entirely of Fe concretions; The structure of the B1 generally is transitional between weak and moderate blocky designated as neocutanic, and the Form becomes Tukulu; Vertic properties in the B3-horizon.

APPENDIX 3.11

SOIL PROFILE DESCRIPTION: YOXFORD (BACKYARD) (GLORIA)

NATIONAL SOIL PROFILE NO: 14929 – Profile no. 5
Map / photo: 2926BD Eureka
Latitude & Longitude: 29°24´48´´ / 26°50´54´´
Land type No: Dc17
Climate zone: 46S
Altitude: 1522 m
Terrain unit: Upper Midslope
Slope: 2 %
Slope shape: Convex
Aspect: South
Micro relief: None
Parent material solum: Origin binary; dolerite colluvium on sandstone/ mudstone
Underlying material: Mudstone/sandstone

Soil Form: Sepane
Soil Family: Ramabesa
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Sheet slight, partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: None
Described by: M. Hensley & P.P. van Staden
Date described: 6/2003
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Calcified

Horizon	Depth(mm)	Description	Diagnostic horizons
A	0 - 200	dry colour: brown to dark brown 7.5YR4/2; moist colour: dark brown 7.5YR3/2; sandy clay loam; structure: moderate medium subangular blocky; consistence: hard; common roots; clear smooth transition.	Orthic
B1	200 - 500	dry colour: dark greyish brown 10YR4/2; moist colour: very dark greyish brown 10YR3/2; clay; structure: strong coarse angular blocky; consistence: very hard; very many cutans; common fine <2-6mm sesquioxide concretions; common roots; gradual smooth transition.	Peducutanic
B2	500 - 750	dry colour: yellowish brown 10YR5/4; moist colour: dark yellowish brown 10YR3/4; clay; grey, yellow and olive reduced iron oxide mottles; structure: strong coarse angular blocky; non-hardened free lime, moderate effervescence; very firm; many slickensides; very many cutans; few roots; gradual transition.	Pedocutanic
C	750 - 950	slightly weathered sandstone/mudstone.	Saprolite

REMARKS: Signs of wetness in B2-horizon; vertic properties in B2-horizon.

APPENDIX 3.12

SOIL PROFILE DESCRIPTION: YOXFORD (BACKYARD) (LAZARUS)

NATIONAL SOIL PROFILE NO: 14930 – Profile no. 6
Map / photo: 2926BD Eureka
Latitude & Longitude: 29°24´54´´ / 26°50´54´´
Land type No: Dc17
Climate zone: 46S
Altitude: 1520 m
Terrain unit: Upper Midslope
Slope: 2 %
Slope shape: Straight
Aspect: South
Micro relief: None
Parent material solum: binary; dolerite colluvium on mudstone
Underlying material: Mudstone

Soil Form: Sepane
Soil Family: Ramabesa
Surface rockiness: None
Surface stoniness: None
Occurrence of flooding:
Wind erosion: None
Water erosion: Sheet slight, partially stabilized
Vegetation / Land use: Agronomic cash crops
Water table: None
Described by: M. Hensley & P.P. van Staden
Date described: 6/2003
Weathering of underlying material: Moderate physical & chemical
Alteration of underlying material: Calcified

Horizon	**Depth(mm)**	**Description**	**Diagnostic horizons**
A	0 - 200	dry colour: brown to dark brown 7.5YR4/2; moist colour: dark brown 7.5YR3/2; sandy clay loam; structure: moderate medium subangular blocky; consistence: hard; common roots; clear smooth transition.	Orthic
B1	200 - 650	dry colour: dark greyish brown 10YR4/2; moist colour: very dark greyish brown 10YR3/2; clay; structure: strong coarse angular blocky; consistence: very hard; many clay cutans; gradual smooth transition.	Pedocutanic
B2	650 – 1300	dry colour: yellowish brown 10YR5/4; moist colour: dark yellowish brown 10YR3/4; clay; grey, yellow and olive reduced iron oxide mottles; structure: strong coarse angular blocky; consistence: very firm; non-hardened free lime, moderate effervescence; many slickensides; many clay cutans; common fine <2-6mm sesquioxide concretions; few roots; gradual transition.	Pedocutanic
C	1300+	slightly weathered mudstone	Saprolite

REMARKS: Signs of wetness in B2-horizon; Vertic proterties in B2; Structure of the B1 transitional

Appendix 5.1

Infiltration in the runoff area (RA) and basin area (BA) for the various periods

Crop	Year	Treatment	Area	F_p	V_p	R_p	G_p	P_p
Maize	99/00	*ObBr*	IR	58	31	42	73	131
			RA	98	64	92	155	254
			BA	274	157	217	374	648
			Rain	157	95	133	228	385
			n	23	19	34	53	76
			RA:n	4.28	3.36	2.69	2.93	3.34
			BA:n	11.90	8.28	6.38	7.06	8.53
			BA:RA	2.78	2.47	2.37	2.41	2.55
		ObOr	IR	8	4	6	10	18
			RA	149	91	128	218	367
			BA	173	103	145	248	422
			Rain	157	95	133	228	385
			n	23	19	34	53	76
			RA:n	6.46	4.78	3.75	4.12	4.83
			BA:n	7.54	5.44	4.26	4.68	5.55
			BA:RA	1.17	1.14	1.13	1.14	1.15
		ObSr	IR	34	17	24	41	75
			RA	123	78	110	187	311
			BA	224	130	180	310	534
			Rain	157	95	133	228	385
			n	23	19	34	53	76
			RA:n	5.36	4.08	3.23	3.54	4.09
			BA:n	9.74	6.83	5.30	5.85	7.03
			BA:RA	1.82	1.67	1.64	1.65	1.72
		SbOr	IR	8	4	6	10	18
			RA	149	91	128	218	367
			BA	173	103	145	248	422
			Rain	157	95	133	228	385
			n	23	19	34	53	76
			RA:n	6.46	4.78	3.75	4.12	4.83
			BA:n	7.54	5.44	4.26	4.68	5.55
			BA:RA	1.17	1.14	1.13	1.14	1.15
	00/01	*ObBr*	IR	85	30	79	110	194
			RA	149	51	119	171	319
			BA	403	142	358	499	902
			Rain	234	81	199	280	514
			n	47	16	22	38	85
			RA:n	3.17	3.19	5.43	4.49	3.76
			BA:n	8.57	8.86	16.25	13.14	10.61
			BA:RA	2.71	2.77	2.99	2.93	2.83
		ObOr	IR	12	4	12	16	29
			RA	221	77	187	263	485
			BA	258	90	222	312	570
			Rain	234	81	199	280	514
			n	47	16	22	38	85
			RA:n	4.71	4.81	8.48	6.93	5.70
			BA:n	5.49	5.63	10.09	8.21	6.71
			BA:RA	1.17	1.17	1.19	1.18	1.18
		ObSr	IR	49	18	47	64	113
			RA	185	64	152	216	400
			BA	331	116	292	408	739
			Rain	234	81	199	280	514

			n	47	16	22	38	85
			RA:n	3.93	3.99	6.90	5.67	4.71
			BA:n	7.05	7.27	13.25	10.73	8.70
			BA:RA	1.79	1.82	1.92	1.89	1.85
		SbOr	IR	12	4	12	16	29
			RA	221	77	187	263	485
			BA	258	90	222	312	570
			Rain	234	81	199	280	514
			n	47	16	22	38	85
			RA:n	4.71	4.81	8.48	6.93	5.70
			BA:n	5.49	5.63	10.09	8.21	6.71
			BA:RA	1.17	1.17	1.19	1.18	1.18
	01/02	*ObBr*	IR	135	57	31	88	223
			RA	225	105	55	159	384
			BA	630	275	149	424	1054
			Rain	360	161	86	247	607
			n	59	31	15	46	105
			RA:n	3.81	3.38	3.64	3.46	3.66
			BA:n	10.68	8.86	9.92	9.21	10.03
			BA:RA	2.80	2.62	2.73	2.66	2.74
		ObOr	IR	20	8	5	13	33
			RA	340	153	81	235	575
			BA	399	178	95	273	672
			Rain	360	161	86	247	607
			n	59	31	15	46	105
			RA:n	5.76	4.95	5.43	5.10	5.47
			BA:n	6.77	5.73	6.35	5.93	6.40
			BA:RA	1.17	1.16	1.17	1.16	1.17
		ObSr	IR	79	33	18	51	129
			RA	281	129	68	197	478
			BA	517	227	122	349	866
			Rain	360	161	86	247	607
			n	59	31	15	46	105
			RA:n	4.77	4.15	4.52	4.27	4.55
			BA:n	8.76	7.31	8.16	7.59	8.25
			BA:RA	1.84	1.76	1.81	1.78	1.81
		SbOr	IR	20	8	5	13	33
			RA	340	153	81	235	575
			BA	399	178	95	273	672
			Rain	360	161	86	247	607
			n	59	31	15	46	105
			RA:n	5.76	4.95	5.43	5.10	5.47
			BA:n	6.77	5.73	6.35	5.93	6.40
			BA:RA	1.17	1.16	1.17	1.16	1.17
Crop	Year	Treatment	Area	Fp	Vp	Rp	Gp	Pp
Sunflower	99/00	*ObBr*	IR	76	32	23	55	131
			RA	129	78	47	125	254
			BA	357	174	117	291	648
			Rain	205	109	70	179	384
			n	31	27	17	44	75
			RA:n	4.15	2.89	2.76	2.84	3.38
			BA:n	11.50	6.45	6.88	6.62	8.64
			BA:RA	2.77	2.24	2.49	2.33	2.56
		ObOr	IR	11	4	3	7	18
			RA	194	105	67	172	366
			BA	226	118	77	194	420
			Rain	205	109	70	179	384

			n	31	27	17	44	75
			RA:n	6.25	3.89	3.96	3.91	4.88
			BA:n	7.30	4.35	4.51	4.41	5.60
				1.17	1.12	1.14	1.13	1.15
		ObSr	IR	44	18	13	31	75
			RA	161	91	57	149	309
			BA	292	145	97	241	533
			Rain	205	109	70	179	384
			n	31	27	17	44	75
			RA:n	5.19	3.39	3.36	3.38	4.13
			BA:n	9.43	5.35	5.68	5.48	7.11
			BA:RA	1.82	1.58	1.69	1.62	1.72
		SbOr	IR	11	4	3	7	18
			RA	194	105	67	172	366
			BA	226	118	77	194	420
			Rain	205	109	70	179	384
			n	31	27	17	44	75
			RA:n	6.25	3.89	3.96	3.91	4.88
			BA:n	7.30	4.35	4.51	4.41	5.60
			BA:RA	1.17	1.12	1.14	1.13	1.15
	00/01	*ObBr*	IR	85	30	79	110	194
			RA	148	52	119	171	318
			BA	402	142	357	499	901
			Rain	232	82	198	280	513
			n	46	19	19	38	84
			RA:n	3.21	2.72	6.26	4.49	3.79
			BA:n	8.73	7.48	18.79	13.14	10.73
			BA:RA	2.72	2.76	3.00	2.93	2.83
		ObOr	IR	12	4	12	16	28
			RA	220	77	187	264	484
			BA	257	91	222	313	569
			Rain	232	82	198	280	513
			n	46	19	19	38	84
			RA:n	4.79	4.07	9.82	6.94	5.76
			BA:n	5.58	4.77	11.68	8.22	6.78
			BA:RA	1.17	1.17	1.19	1.18	1.18
		ObSr	IR	49	18	47	64	113
			RA	184	64	152	216	400
			BA	330	117	292	408	739
			Rain	232	82	198	280	513
			n	46	19	19	38	84
			RA:n	3.99	3.38	7.98	5.68	4.76
			BA:n	7.18	6.15	15.34	10.74	8.79
			BA:RA	1.80	1.82	1.92	1.89	1.85
		SbOr	IR	12	4	12	16	28
			RA	220	77	187	264	484
			BA	257	91	222	313	569
			Rain	232	82	198	280	513
			n	46	19	19	38	84
			RA:n	4.79	4.07	9.82	6.94	5.76
			BA:n	5.58	4.77	11.68	8.22	6.78
			BA:RA	1.17	1.17	1.19	1.18	1.18
	01/02	*ObBr*	IR	135	57	31	88	223
			RA	225	105	56	160	385
			BA	630	275	150	425	1055
			Rain	360	161	87	248	608
			n	59	31	16	47	106
			RA:n	3.81	3.38	3.47	3.41	3.63

			BA:n	10.68	8.86	9.36	9.03	9.95
			BA:RA	2.80	2.62	2.70	2.65	2.74
		ObOr	IR	20	8	5	13	33
			RA	340	153	82	236	576
			BA	399	178	96	274	673
			Rain	360	161	87	248	608
			n	59	31	16	47	106
			RA:n	5.76	4.95	5.14	5.01	5.43
			BA:n	6.77	5.73	6.01	5.82	6.35
			BA:RA	1.17	1.16	1.17	1.16	1.17
		ObSr	IR	79	33	18	51	129
			RA	281	129	69	198	479
			BA	517	227	123	350	867
			Rain	360	161	87	248	608
			n	59	31	16	47	106
			RA:n	4.77	4.15	4.29	4.20	4.52
			BA:n	8.76	7.31	7.71	7.44	8.18
			BA:RA	1.84	1.76	1.79	1.77	1.81
		SbOr	IR	20	8	5	13	33
			RA	340	153	82	236	576
			BA	399	178	96	274	673
			Rain	360	161	87	248	608
			n	59	31	16	47	106
			RA:n	5.76	4.95	5.14	5.01	5.43
			BA:n	6.77	5.73	6.01	5.82	6.35
			BA:RA	1.17	1.16	1.17	1.16	1.17

Appendix 5.2

Rainfall events within specified classes

Crop	Season	Parameter	Period	Total	<9 mm	>=9	>=10	>=12	>=16	>=22
Maize	99/00	Rain (mm)	Fp	156.8	52.2	104.6	104.6	94.3	64.6	48.5
			Vp	95.0	36.1	58.9	40.7	30.1	17.3	0.0
			Rp	133.3	76.4	56.9	47.3	35.7	20.8	0.0
			Gp	228.3	112.5	115.8	88.0	65.8	38.1	0.0
			Pp	385.1	164.7	220.4	192.6	160.1	102.7	48.5
		% of total	Fp	100	33.3	66.7	66.7	60.1	41.2	30.9
			Vp	100	38.0	62.0	42.8	31.7	18.2	0.0
			Rp	100	57.3	42.7	35.5	26.8	15.6	0.0
			Gp	100	49.3	50.7	38.5	28.8	16.7	0.0
			Pp	100	42.8	57.2	50.0	41.6	26.7	12.6
		Number Events	Fp	23	17	6	6	5	3	2
			Vp	19	14	5	3	2	1	0
			Rp	34	30	4	3	2	1	0
			Gp	53	44	9	6	4	2	0
			Pp	76	61	15	12	9	5	2
		% of total	Fp	100	73.9	26.1	26.1	21.7	13.0	8.7
			Vp	100	73.7	26.3	15.8	10.5	5.3	0.0
			Rp	100	88.2	11.8	8.8	5.9	2.9	0.0
			Gp	100	83.0	17.0	11.3	7.5	3.8	0.0
			Pp	100	80.3	19.7	15.8	11.8	6.6	2.6
Maize	00/01	Rain (mm)	Fp	233.5	60.8	172.7	153.5	142.9	114.2	58.4
			Vp	81.3	27.5	53.8	53.8	42.1	29.6	29.6
			Rp	198.8	45.7	153.1	143.8	132.0	132.0	96.0
			Gp	280.1	73.2	206.9	197.6	174.1	161.6	125.6
			Pp	513.6	134.0	379.6	351.1	317.0	275.8	184.0
		% of total	Fp	100	26.0	74.0	65.7	61.2	48.9	25.0
			Vp	100	33.8	66.2	66.2	51.8	36.4	36.4
			Rp	100	23.0	77.0	72.3	66.4	66.4	48.3
			Gp	100	26.1	73.9	70.5	62.2	57.7	44.8
			Pp	100	26.1	73.9	68.4	61.7	53.7	35.8
		Number Events	Fp	47	37	10	8	7	5	2
			Vp	16	13	3	3	2	1	1
			Rp	22	15	7	6	5	5	3
			Gp	38	28	10	9	7	6	4
			Pp	85	65	20	17	14	11	6
		% of total	Fp	100	78.7	21.3	17.0	14.9	10.6	4.3
			Vp	100	81.3	18.8	18.8	12.5	6.3	6.3
			Rp	100	68.2	31.8	27.3	22.7	22.7	13.6
			Gp	100	73.7	26.3	23.7	18.4	15.8	10.5
			Pp	100	76.5	23.5	20.0	16.5	12.9	7.1
Maize	01/02	Rain (mm)	Fp	359.8	82.6	277.2	267.6	201.2	156.4	84.6
			Vp	161.4	60.9	100.5	100.5	90.1	47.3	28.9
			Rp	86.0	22.2	63.8	63.8	63.8	50.0	30.0
			Gp	247.4	83.1	164.3	164.3	153.9	97.3	58.9

			Pp	607.2	165.7	441.5	431.9	355.1	253.7	143.5
		% of total	Fp	100	23.0	77.0	74.4	55.9	43.5	23.5
			Vp	100	37.7	62.3	62.3	55.8	29.3	17.9
			Rp	100	25.8	74.2	74.2	74.2	58.1	34.9
			Gp	100	33.6	66.4	66.4	62.2	39.3	23.8
			Pp	100	27.3	72.7	71.1	58.5	41.8	23.6
		Nunber Events	Fp	59	43	16	15	9	6	2
			Vp	31	25	6	6	5	2	1
			Rp	15	12	3	3	3	2	1
			Gp	46	37	9	9	8	4	2
			Pp	105	80	25	24	17	10	4
		% of total	Fp	100	72.9	27.1	25.4	15.3	10.2	3.4
			Vp	100	80.6	19.4	19.4	16.1	6.5	3.2
			Rp	100	80.0	20.0	20.0	20.0	13.3	6.7
			Gp	100	80.4	19.6	19.6	17.4	8.7	4.3
			Pp	100	76.2	23.8	22.9	16.2	9.5	3.8

Crop	Season	Parameter	Period	Total	<9 mm	>=9	>=10	>=12	>=16	>=22
Sunflower	99/00	Rain (mm)	Fp	204.6	59.3	145.3	145.3	124.4	81.9	48.5
			Vp	109.1	70.1	39.0	20.8	20.8	20.8	0.0
			Rp	70.3	34.2	36.1	26.5	14.9	0.0	0.0
			Gp	179.4	104.3	75.1	47.3	35.7	20.8	0.0
			Pp	384.0	163.6	220.4	192.6	160.1	102.7	48.5
		% of total	Fp	100	29.0	71.0	71.0	60.8	40.0	23.7
			Vp	100	64.3	35.7	19.1	19.1	19.1	0.0
			Rp	100	48.6	51.4	37.7	21.2	0.0	0.0
			Gp	100	58.1	41.9	26.4	19.9	11.6	0.0
			Pp	100	42.6	57.4	50.2	41.7	26.7	12.6
		Number Events	Fp	31	22	9	9	7	4	2
			Vp	27	24	3	1	1	1	0
			Rp	17	14	3	2	1	0	0
			Gp	44	38	6	3	2	1	0
			Pp	75	60	15	12	9	5	2
		% of total	Fp	100	71.0	29.0	29.0	22.6	12.9	6.5
			Vp	100	88.9	11.1	3.7	3.7	3.7	0.0
			Rp	100	82.4	17.6	11.8	5.9	0.0	0.0
			Gp	100	86.4	13.6	6.8	4.5	2.3	0.0
			Pp	100	80.0	20.0	16.0	12.0	6.7	2.7
Sunflower	00/01	Rain (mm)	Fp	232.4	59.7	172.7	153.3	142.9	114.2	58.4
			Vp	81.8	28.0	53.8	53.8	42.1	29.6	29.6
			Rp	198.3	45.2	153.1	143.8	132.0	132.0	96.0
			Gp	280.1	73.2	206.9	197.6	174.1	161.6	125.6
			Pp	512.5	132.9	379.6	350.9	317.0	275.8	184.0
		% of total	Fp	100	25.7	74.3	66.0	61.5	49.1	25.1
			Vp	100	34.2	65.8	65.8	51.5	36.2	36.2
			Rp	100	22.8	77.2	72.5	66.6	66.6	48.4
			Gp	100	26.1	73.9	70.5	62.2	57.7	44.8
			Pp	100	25.9	74.1	68.5	61.9	53.8	35.9
		Number Events	Fp	46	36	10	6	7	5	2
			Vp	19	16	3	3	2	1	1

			Rp	19	12	7	6	5	5	3
			Gp	38	28	10	9	7	6	4
			Pp	84	64	20	15	14	11	6
		% of total	Fp	100	78.3	21.7	13.0	15.2	10.9	4.3
			Vp	100	84.2	15.8	15.8	10.5	5.3	5.3
			Rp	100	63.2	36.8	31.6	26.3	26.3	15.8
			Gp	100	73.7	26.3	23.7	18.4	15.8	10.5
			Pp	100	76.2	23.8	17.9	16.7	13.1	7.1
Sunflower	01/02	Rain (mm)	Fp	359.8	82.6	277.2	267.6	201.2	156.4	84.6
			Vp	161.4	60.9	100.5	100.5	90.1	47.3	28.9
			Rp	86.9	23.1	63.8	63.8	63.8	50.0	30.0
			Gp	248.3	84.0	164.3	164.3	153.9	97.3	58.9
			Pp	608.1	166.6	441.5	431.9	355.1	253.7	143.5
		% of total	Fp	100	23.0	77.0	74.4	55.9	43.5	23.5
			Vp	100	37.7	62.3	62.3	55.8	29.3	17.9
			Rp	100	26.6	73.4	73.4	73.4	57.5	34.5
			Gp	100	33.8	66.2	66.2	62.0	39.2	23.7
			Pp	100	27.4	72.6	71.0	58.4	41.7	23.6
		Number Events	Fp	59	43	16	15	9	6	2
			Vp	31	25	6	6	5	2	1
			Rp	16	13	3	3	3	2	1
			Gp	47	38	9	9	8	4	2
			Pp	106	81	25	24	17	10	4
		% of total	Fp	100	72.9	27.1	25.4	15.3	10.2	3.4
			Vp	100	80.6	19.4	19.4	16.1	6.5	3.2
			Rp	100	81.3	18.8	18.8	18.8	12.5	6.3
			Gp	100	80.9	19.1	19.1	17.0	8.5	4.3
			Pp	100	76.4	23.6	22.6	16.0	9.4	3.8

Appendix 5.3

Soil water contents (mm) for the different soil layers within the root zone of block A and block B on the Glen/Bonheim ecotope during the experimental period.

Block A

Date	DOY	Depth	*ObBr* Me	*ObSr* Me	*ObOr* Me	*SbOr* Me	*ObBr* Hi	*ObSr* Hi	*ObOr* Hi	*SbOr* Hi	*BbBr* N0
29-10-99	302	0-300	91.7	93.6	69.7	98.1	80.8	84.1	104.9	76.4	
		300-600	85.8	99.3	100.5	115.1	84.7	97.0	111.3	99.4	
		600-900	78.1	75.8	94.5	115.3	80.1	80.5	102.7	84.0	
		900-1200	79.8	80.6	79.7	96.6	82.2	77.8	99.3	83.7	
		0-1200	335.4	349.3	344.4	425.0	327.8	339.4	418.2	343.5	
02-11-99	306	0-300	76.5	85.7	68.5	87.8	76.3	78.9	91.5	72.0	
		300-600	86.1	90.2	95.1	111.7	83.1	89.7	96.1	83.9	
		600-900	78.1	74.8	84.0	108.2	79.6	78.3	100.0	81.7	
		900-1200	80.4	80.9	78.2	95.2	84.9	78.0	95.6	83.1	
		0-1200	321.2	331.6	325.9	403.0	323.9	325.0	383.2	320.7	
05-11-99	309	0-300	71.1	83.1	64.5	87.5	77.5	75.1	85.0	68.5	
		300-600	85.1	89.7	94.7	108.8	82.9	90.4	96.1	83.7	
		600-900	78.9	74.4	82.8	108.5	80.1	77.8	98.5	82.7	
		900-1200	79.4	81.0	79.3	95.4	83.7	78.2	92.7	82.8	
		0-1200	314.4	328.2	321.4	400.2	324.1	321.4	372.3	317.7	
10-11-99	314	0-300	70.7	72.1	67.6	76.8	68.3	68.0	79.2	71.3	
		300-600	90.6	92.3	92.3	100.3	83.1	88.7	90.3	87.8	
		600-900	79.6	76.9	96.0	97.9	80.5	80.8	86.9	85.8	
		900-1200	79.5	81.2	95.5	91.2	86.9	81.5	89.2	89.1	
		0-1200	320.3	322.4	351.3	366.3	318.8	319.0	345.5	334.1	
18-11-99	322	0-300	59.4	70.8	60.0	70.7	59.6	70.3	64.9	67.3	
		300-600	92.5	89.4	89.2	93.8	82.8	94.5	86.0	87.1	
		600-900	82.9	78.1	91.0	91.3	79.9	84.9	86.0	86.2	
		900-1200	85.9	80.1	92.7	88.3	83.6	92.0	85.0	91.5	
		0-1200	320.8	318.4	333.0	344.2	305.9	341.7	322.0	332.1	
06-01-00	6	0-300	95.2	112.9	104.5	113.2	102.8	116.6	98.2	119.6	
		300-600	107.3	111.5	116.5	118.8	109.5	118.4	111.8	113.9	
		600-900	107.4	109.3	111.6	99.3	100.8	102.4	94.3	109.7	
		900-1200	102.1	93.7	101.2	94.8	82.0	102.4	84.1	111.9	
		0-1200	411.9	427.4	433.9	426.1	407.9	439.8	388.5	455.1	
07-01-00	7	0-300	98.8	111.1	103.9	104.5	98.7	112.7	104.4	107.8	
		300-600	109.2	116.4	115.6	118.3	107.5	120.5	115.8	116.7	
		600-900	107.7	106.8	113.8	103.6	94.0	96.9	108.5	109.0	
		900-1200	103.0	94.6	107.8	94.7	94.4	100.9	93.5	104.6	
		0-1200	421.4	428.9	441.1	421.1	394.6	431.0	422.1	438.1	
02-02-00	33	0-300	86.9	96.4	86.3	94.1	88.3	96.9	89.7	97.6	
		300-600	97.3	97.4	100.1	100.0	98.1	102.6	99.7	100.8	
		600-900	96.0	100.0	100.4	97.7	96.3	96.4	99.7	101.5	
		900-1200	94.1	96.8	98.4	97.0	96.6	94.8	94.1	99.4	
		0-1200	374.3	390.6	385.1	388.8	379.3	390.7	383.2	399.3	
07-02-00	38	0-300	59.3	65.8	62.4	65.0	61.9	73.4	64.5	71.3	
		300-600	93.5	96.0	99.0	96.3	95.5	104.0	96.1	101.7	
		600-900	100.0	102.4	108.3	105.0	102.2	99.0	102.9	106.5	
		900-1200	97.7	100.2	104.9	102.7	103.9	102.3	99.4	107.1	
		0-1200	350.4	364.4	374.6	369.0	363.6	378.7	362.9	386.6	

21-02-00	52	0-300	78.0	84.1	71.9	83.5	77.5	88.8	78.0	89.4	
		300-600	105.7	104.2	107.0	108.3	104.0	110.8	105.6	109.2	
		600-900	102.9	105.8	111.1	106.6	103.1	102.8	104.7	110.5	
		900-1200	99.4	101.7	106.2	102.9	106.4	101.7	99.8	107.7	
		0-1200	386.0	395.9	396.2	400.7	390.9	404.0	388.1	416.8	
23-03-00	83	0-300	63.8	72.5	66.3	70.2	67.2	73.9	63.9	77.4	
		300-600	85.4	85.9	87.0	84.5	85.3	86.0	86.2	88.5	
		600-900	87.6	88.7	94.1	94.6	92.3	89.4	93.0	96.6	
		900-1200	93.9	98.2	102.1	101.5	102.6	97.9	97.7	103.5	
		0-1200	330.7	345.2	349.5	350.8	347.3	347.1	340.7	366.1	
06-04-00	97	0-300	55.5	61.6	57.1	60.4	58.8	60.5	56.5	63.1	
		300-600	81.7	80.4	81.1	81.3	81.6	82.2	81.4	82.9	
		600-900	79.7	82.3	84.8	83.2	83.4	79.8	83.3	84.6	
		900-1200	82.9	85.8	89.8	86.3	88.8	86.9	86.0	91.5	
		0-1200	299.9	310.0	312.7	311.1	312.6	309.5	307.3	322.2	
26-04-00	117	0-300	52.9	54.7	52.5	55.4	54.3	55.6	51.5	54.8	
		300-600	79.1	77.5	78.4	87.4	79.8	78.6	77.7	79.2	
		600-900	76.9	77.1	79.9	78.3	80.3	76.4	77.9	84.6	
		900-1200	77.9	77.5	80.2	78.6	81.6	79.5	79.7	81.6	
		0-1200	286.7	286.8	291.1	299.7	296.0	290.1	286.8	300.2	
11-05-00	132	0-300	56.0	59.2	58.3	59.7	58.2	56.7	54.6	59.6	
		300-600	79.6	79.3	82.0	80.1	82.4	80.6	80.3	81.5	
		600-900	78.6	79.1	82.8	79.5	81.7	78.5	79.2	82.1	
		900-1200	78.2	78.4	81.3	78.9	81.5	79.9	80.9	82.0	
		0-1200	292.4	296.0	304.3	298.2	303.9	295.6	294.9	305.3	
23-05-00	144	0-300	49.8	51.2	49.6	52.8	51.1	51.0	49.1	52.8	
		300-600	76.8	75.6	76.7	77.4	77.4	81.3	76.2	78.5	
		600-900	76.0	76.0	79.9	77.7	78.8	75.6	76.2	79.2	
		900-1200	76.3	75.5	79.0	77.0	79.3	79.6	78.5	79.9	
		0-1200	278.9	278.3	285.2	284.9	286.7	287.4	280.0	290.4	
20-06-00	172	0-300	49.3	50.7	49.9	52.9	50.9	51.5	49.0	52.9	
		300-600	79.3	77.4	78.7	78.4	79.8	78.3	78.1	80.2	
		600-900	77.9	78.7	81.5	78.4	80.7	76.8	79.2	82.0	
		900-1200	77.1	77.6	80.6	78.2	81.7	80.1	79.7	81.8	
		0-1200	283.6	284.4	290.7	287.9	293.2	286.7	286.0	296.9	
30-11-00	335	0-300	84.3	101.7	84.8	96.8	81.6	96.7	86.2	98.6	
		300-600	91.5	97.6	96.8	99.3	95.4	96.8	95.5	95.4	
		600-900	79.7	83.4	85.3	82.4	85.0	80.2	80.4	82.7	
		900-1200	77.2	78.1	80.4	80.1	81.6	78.7	79.3	81.1	
		0-1200	332.7	360.8	347.3	358.6	343.6	352.5	341.5	357.8	
08-01-01	8	0-300	87.9	103.7	85.6	93.0	88.6	96.1	80.6	91.9	
		300-600	106.7	107.3	101.4	106.8	102.2	105.8	101.9	103.7	
		600-900	87.8	89.4	95.0	95.1	91.8	87.5	89.0	90.0	
		900-1200	81.4	78.0	82.9	84.3	82.1	85.1	80.9	85.5	
		0-1200	363.7	378.4	365.0	379.2	364.6	374.5	352.4	371.2	
06-02-01	38	0-300	69.0	76.9	65.3	74.7	69.3	80.8	70.6	79.6	66.6
		300-600	94.7	96.1	96.4	95.0	95.7	99.9	92.8	98.2	83.4
		600-900	84.5	91.5	93.2	94.7	89.9	88.2	88.7	91.7	74.3
		900-1200	79.8	82.4	84.4	85.7	85.7	83.7	83.8	85.9	69.0
		0-1200	328.1	346.9	339.3	350.2	340.5	352.6	335.9	355.4	293.2
20-02-01	51	0-300	88.7	106.6	83.0	97.5	90.7	103.9	86.2	98.0	89.4
		300-600	91.1	92.3	91.4	90.0	93.2	94.7	94.3	92.8	86.8
		600-900	87.0	93.0	94.3	92.6	92.0	90.9	92.3	93.7	76.7

		900-1200	79.8	85.5	87.9	87.4	87.0	86.4	86.3	88.3	68.0
		0-1200	346.6	377.3	356.7	367.4	362.8	376.0	359.0	372.7	320.9
28-02-01	59	0-300	84.0	107.2	83.4	95.0	81.4	108.0	88.2	87.0	93.3
		300-600	90.0	88.1	87.4	90.1	89.2	91.6	89.9	91.3	85.2
		600-900	84.3	89.6	92.7	90.1	89.3	88.0	91.3	93.0	74.0
		900-1200	83.4	85.3	87.5	85.6	85.5	84.9	83.4	90.1	69.4
		0-1200	341.6	370.3	351.0	360.7	345.5	372.5	352.7	361.3	321.9
08-03-01	67	0-300	54.7	60.8	66.8	65.9	55.5	63.6	59.4	61.3	60.0
		300-600	82.5	82.3	85.7	84.0	84.3	86.0	85.5	84.3	82.1
		600-900	81.6	87.3	88.5	86.7	86.6	85.4	87.8	88.3	75.1
		900-1200	79.5	82.9	84.4	84.9	84.7	84.2	82.5	85.1	68.6
		0-1200	298.3	313.4	325.3	321.6	311.2	319.1	315.2	319.0	285.7
14-03-01	73	0-300	50.2	54.0	53.7	55.1	51.8	54.7	53.1	54.1	56.5
		300-600	79.3	80.1	83.8	80.6	83.7	81.7	82.5	81.7	82.0
		600-900	80.2	85.3	89.2	86.5	84.9	83.7	86.8	87.3	76.1
		900-1200	78.7	82.4	86.2	84.2	85.1	82.9	84.8	86.6	68.9
		0-1200	288.5	301.8	312.9	306.4	305.5	303.0	307.2	309.6	283.4
27-03-01	86	0-300	92.3	114.2	107.9	111.2	89.5	110.3	102.2	111.0	105.1
		300-600	88.3	89.8	104.4	96.1	85.0	92.2	98.3	94.9	94.1
		600-900	82.6	85.3	90.8	87.7	85.8	82.9	87.3	86.5	79.4
		900-1200	79.7	85.2	86.9	85.0	84.4	83.6	85.7	86.5	70.3
		0-1200	342.9	374.5	390.0	379.9	344.7	369.0	373.5	378.9	348.9
02-04-01	92	0-300	70.0	91.8	84.9	91.0	72.1	87.0	84.6	89.3	87.4
		300-600	85.4	86.4	99.9	93.1	83.8	90.8	96.4	92.4	94.6
		600-900	81.5	86.1	91.0	89.6	85.5	82.0	88.8	86.2	76.3
		900-1200	81.4	81.9	86.8	84.8	85.2	83.4	87.7	87.4	69.0
		0-1200	318.3	346.2	362.6	358.5	326.6	343.2	357.5	355.3	327.3
03-04-01	93	0-300	89.5	108.4	107.7	114.5	81.0	106.6	94.8	105.4	94.0
		300-600	86.3	86.8	92.4	92.0	83.2	88.0	93.1	88.0	88.2
		600-900	80.4	87.0	91.6	87.0	86.0	82.4	86.6	85.0	76.7
		900-1200	83.3	83.9	84.6	83.3	85.4	83.3	84.1	84.4	69.9
		0-1200	339.4	366.1	376.4	376.9	335.6	360.3	358.6	362.8	328.8
04-04-01	94	0-300	103.0	118.6	114.4	124.0	90.0	123.6	114.4	126.9	112.1
		300-600	87.3	90.8	103.4	102.9	86.1	90.4	97.9	95.7	91.4
		600-900	80.3	85.3	92.4	85.2	84.6	84.2	91.7	89.1	77.7
		900-1200	80.1	82.4	91.5	84.7	82.9	75.8	87.5	85.8	70.2
		0-1200	350.7	377.0	401.7	396.8	343.7	374.0	391.6	397.6	351.4
09-04-01	99	0-300	103.4	127.9	126.0	132.7	104.9	123.9	116.7	126.0	117.8
		300-600	93.9	95.0	109.5	99.2	87.6	91.0	99.6	98.1	100.2
		600-900	81.0	84.0	97.6	85.3	86.4	80.2	93.7	89.9	79.1
		900-1200	79.3	84.9	85.9	82.2	85.9	81.0	85.2	86.0	69.6
		0-1200	357.6	391.7	419.0	399.4	364.8	376.1	395.2	400.1	366.7
17-04-01	107	0-300	115.2	130.8	120.2	128.6	108.7	123.2	115.1	126.5	123.2
		300-600	104.1	99.8	109.9	103.8	96.8	100.8	104.4	108.2	102.3
		600-900	86.1	85.3	100.3	92.2	83.5	83.6	95.6	90.7	87.8
		900-1200	81.9	83.7	89.2	75.4	84.0	81.9	86.8	85.7	69.2
		0-1200	387.4	399.5	419.7	400.0	372.9	389.4	401.8	411.1	382.6
23-04-01	113	0-300	117.0	132.7	125.8	127.9	105.5	123.2	115.6	128.7	114.9
		300-600	103.0	99.7	112.0	102.3	100.8	98.0	103.8	111.8	102.1
		600-900	83.6	89.4	103.7	98.5	86.8	88.2	97.3	94.3	87.2
		900-1200	76.8	84.0	94.9	86.0	82.3	85.1	91.9	92.8	71.3
		0-1200	380.4	405.9	436.4	414.8	375.3	394.6	408.6	427.7	375.5
25-04-01	115	0-300	116.6	129.5	126.8	131.3	105.9	131.8	124.2	123.6	120.9

		300-600	103.0	98.9	119.7	110.2	100.5	93.3	101.5	111.3	102.5
		600-900	87.3	89.5	105.0	96.5	88.4	89.9	103.6	96.7	88.4
		900-1200	82.8	86.7	94.9	89.5	87.3	82.6	89.7	90.6	73.2
		0-1200	389.7	404.6	446.4	427.4	382.1	397.7	419.0	422.2	385.0
03-05-01	123	0-300	124.7	128.2	127.9	129.7	107.5	132.9	115.9	121.2	111.8
		300-600	103.3	102.1	108.5	104.9	88.2	100.5	101.7	108.4	100.1
		600-900	88.1	91.7	107.1	93.3	93.2	91.3	100.4	101.2	86.0
		900-1200	83.6	83.7	100.2	92.9	83.1	88.9	90.3	95.7	74.5
		0-1200	399.8	405.7	443.6	420.7	371.9	413.7	408.4	426.5	372.5
08-05-01	128	0-300	101.8	116.7	109.2	115.6	99.3	107.5	99.3	103.9	107.1
		300-600	94.5	100.2	110.4	103.4	91.9	102.5	100.1	106.0	101.0
		600-900	85.7	93.8	100.7	91.9	87.7	89.8	97.2	97.2	87.2
		900-1200	82.1	83.5	93.6	86.1	85.4	86.0	89.1	94.4	71.9
		0-1200	364.1	394.3	413.9	397.0	364.3	385.7	385.8	401.5	367.2
25-05-01	145	0-300	96.0	113.4	101.2	107.0	92.8	106.9	99.5	104.3	102.7
		300-600	96.4	103.7	108.8	105.0	98.2	107.8	104.7	108.7	100.6
		600-900	91.6	99.1	107.3	103.0	94.9	98.2	106.7	106.1	92.5
		900-1200	87.0	90.5	100.3	90.8	90.8	92.5	97.3	99.9	77.5
		0-1200	371.0	406.8	417.6	405.8	376.7	405.4	408.2	418.9	373.3
24-08-01	236	0-300	87.6	107.9	85.5	93.8	85.2	101.0	90.9	96.7	104.2
		300-600	99.4	105.3	107.7	107.4	98.6	111.9	104.6	109.6	106.2
		600-900	92.3	103.8	111.5	105.5	99.7	102.2	106.9	108.8	88.7
		900-1200	90.7	96.6	105.4	100.9	98.4	98.3	104.1	105.5	79.8
		0-1200	370.0	413.7	410.2	407.7	381.9	413.5	406.5	420.7	378.9
13-09-01	256	0-300	96.8	116.5	104.3	111.2					
		300-600	96.1	99.1	110.1	106.8					
		600-900	90.1	110.0	110.2	107.3					
		900-1200	84.6	102.4	101.6	102.2					
		0-1200	367.6	428.1	426.1	427.5					
08-10-01	281	0-300	71.0	92.7	67.9	80.5	72.1	87.3	73.3	80.0	86.1
		300-600	95.6	99.4	100.1	99.2	94.6	104.0	100.2	101.8	98.2
		600-900	89.2	96.2	102.2	98.7	91.9	94.6	96.7	99.8	86.0
		900-1200	87.2	91.3	96.6	93.4	92.6	94.8	97.0	95.5	77.3
		0-1200	343.1	379.6	366.9	371.8	351.2	380.7	367.2	377.1	347.6
31-10-01	304	0-300	99.2	116.9	104.5	114.7	99.5	114.8	102.9	110.2	109.8
		300-600	115.0	112.3	118.7	119.2	115.6	119.7	116.8	119.2	113.3
		600-900	107.6	113.2	117.6	112.3	106.8	112.8	116.3	115.0	97.9
		900-1200	93.0	106.5	111.0	106.8	104.4	112.1	112.2	106.9	80.8
		0-1200	414.9	449.0	451.8	453.0	426.3	459.4	448.3	451.3	401.8
14-11-01	318	0-300	100.4	123.3	108.6	118.6	105.9	118.0	105.6	117.7	106.3
		300-600	114.0	112.4	112.4	116.6	112.7	120.2	110.8	114.0	115.9
		600-900	108.0	112.7	116.8	111.4	111.7	107.5	117.9	114.6	102.5
		900-1200	97.1	108.1	109.7	108.1	106.3	111.9	113.1	108.9	84.4
		0-1200	419.5	456.4	447.5	454.7	436.5	457.6	447.5	455.1	409.0
21-12-01	355	0-300	115.3	130.0	116.4	125.3	104.7	127.0	121.7	123.3	120.4
		300-600	115.0	112.3	119.3	112.4	114.2	119.8	118.1	117.5	118.9
		600-900	116.2	114.7	116.3	112.4	113.3	111.5	112.3	118.2	110.9
		900-1200	106.4	111.8	110.1	106.1	114.9	115.4	114.5	111.2	98.6
		0-1200	452.9	468.9	462.2	456.2	447.1	473.7	466.6	470.2	448.8
08-01-02	8	0-300	101.8	129.1	110.8	119.5	101.9	123.2	112.9	124.4	115.8
		300-600	115.4	114.0	113.9	116.4	115.5	117.2	115.8	116.7	116.0
		600-900	113.5	110.3	116.0	108.8	113.2	110.5	111.9	114.9	107.9
		900-1200	106.8	107.0	108.4	109.5	110.7	111.1	111.2	112.9	96.8

		0-1200	437.5	460.3	449.1	454.2	441.3	461.9	451.7	469.0	436.5
16-01-02	16	0-300	90.4	118.9	109.1	114.9	90.1	112.3	104.4	113.2	108.3
		300-600	112.4	110.7	115.3	116.3	112.8	118.7	114.5	114.6	115.7
		600-900	112.2	110.0	115.2	111.1	111.3	108.6	113.4	111.9	105.4
		900-1200	104.3	108.2	106.5	104.1	109.5	106.0	110.6	110.7	97.5
		0-1200	419.3	447.9	446.1	446.3	423.7	445.6	442.9	450.4	426.9
24-01-02	24	0-300	62.7	84.3	77.1	76.0	61.5	77.3	71.9	78.0	82.5
		300-600	101.3	107.1	110.3	111.1	100.5	109.3	110.9	109.0	110.1
		600-900	108.5	110.2	111.8	108.4	107.3	105.1	111.2	111.6	107.0
		900-1200	105.6	106.4	106.7	105.1	108.9	110.1	110.2	108.6	95.2
		0-1200	378.0	408.0	405.9	400.6	378.3	401.8	404.2	407.2	394.8
30-01-02	30	0-300	98.1	124.1	114.7	121.0	99.6	121.0	110.7	118.4	121.4
		300-600	98.2	105.2	112.9	105.7	98.3	107.7	109.3	108.3	108.5
		600-900	102.5	105.4	110.7	107.1	99.9	104.3	107.2	107.7	105.9
		900-1200	98.6	103.9	105.5	101.0	103.3	106.5	106.3	108.3	93.2
		0-1200	397.4	438.6	443.9	434.7	401.1	439.5	433.6	442.7	429.0
31-01-02	31	0-300	99.5	119.9	111.1	117.3	97.8	117.7	108.6	115.8	114.8
		300-600	96.6	97.7	99.0	98.8	94.8	99.1	100.0	100.1	99.0
		600-900	98.2	99.0	101.5	98.8	97.5	98.9	100.9	100.1	99.4
		900-1200	97.4	98.4	99.7	96.9	99.5	99.8	100.1	100.9	93.4
		0-1200	391.7	415.0	411.2	411.8	389.5	415.5	409.6	416.9	406.6
08-02-02	39	0-300	56.0	65.9	62.0	62.4	54.6	59.9	56.2	59.5	65.0
		300-600	85.4	87.0	89.5	86.1	84.0	86.1	87.7	85.9	87.7
		600-900	89.4	92.9	95.6	92.8	90.7	91.5	94.4	93.9	93.8
		900-1200	93.7	95.8	97.3	94.5	94.9	96.5	97.2	97.2	91.0
		0-1200	324.4	341.5	344.5	335.8	324.2	334.1	335.4	336.6	337.6
20-02-02	51	0-300	58.6	60.4	57.1	59.1	57.7	57.7	57.9	58.7	61.3
		300-600	80.2	77.9	81.6	78.5	78.7	78.9	77.3	78.3	81.2
		600-900	79.1	81.2	84.5	80.9	82.5	79.2	84.2	84.5	82.0
		900-1200	83.3	85.6	89.6	83.4	88.8	84.2	88.4	90.3	79.6
		0-1200	301.2	305.1	312.8	301.8	307.7	300.0	307.8	311.7	304.1
07-03-02	66	0-300	54.5	55.3	51.4	54.4	52.6	55.5	51.0	55.0	59.8
		300-600	79.5	76.7	74.8	75.2	77.8	75.1	74.8	78.4	83.2
		600-900	75.3	77.1	79.3	77.0	78.6	75.9	77.1	79.6	75.6
		900-1200	76.2	77.1	80.4	76.9	78.8	79.3	79.7	81.3	68.7
		0-1200	285.5	286.1	285.9	283.5	287.8	285.7	282.7	294.4	287.3
19-03-02	78	0-300	50.7	51.5	49.3	51.0	50.7	51.1	48.5	52.6	53.4
		300-600	79.0	74.4	74.0	74.9	76.4	77.0	75.5	76.0	75.1
		600-900	74.7	76.0	79.8	76.0	79.1	75.9	76.2	78.5	74.6
		900-1200	75.7	76.4	79.7	75.1	78.1	78.2	76.6	79.1	66.9
		0-1200	280.1	278.3	282.8	277.1	284.3	282.2	276.8	286.2	270.0
02-04-02	92	0-300	46.8	48.8	46.5	46.7	48.8	49.4	46.2	49.0	50.3
		300-600	75.9	72.5	72.8	72.9	75.4	74.3	73.4	74.0	77.1
		600-900	73.3	74.2	77.4	74.1	76.8	73.5	73.8	77.4	72.4
		900-1200	73.9	73.4	77.2	73.3	76.4	77.1	76.2	77.9	66.3
		0-1200	269.9	268.9	274.0	267.0	277.4	274.2	269.6	278.3	266.2
12-04-02	102	0-300	94.9	106.7	88.3	100.4	94.4	102.6	90.1	100.6	118.8
		300-600	88.5	93.9	93.8	93.3	86.2	91.4	93.7	93.1	89.6
		600-900	75.0	80.1	85.7	80.0	81.1	78.1	82.3	80.3	74.5
		900-1200	74.3	76.3	81.1	76.8	78.5	79.4	79.1	80.1	66.1
		0-1200	332.7	357.0	348.9	350.5	340.2	351.4	345.3	354.2	349.1
26-04-02	116	0-300	77.4	89.6	74.0	83.7	77.2	83.3	76.5	83.3	94.7
		300-600	87.4	89.9	91.1	89.8	86.3	90.2	91.5	90.4	86.5

		600-900	75.6	77.8	83.2	78.6	78.8	76.7	79.0	78.7	74.0
		900-1200	74.7	75.0	79.9	75.0	77.0	77.6	77.8	79.5	65.8
		0-1200	315.1	332.3	328.2	327.2	319.3	327.8	324.8	332.0	321.0
24-06-02	175	0-300	78.3	94.3	73.4	88.9	78.3	90.8	77.2	88.8	92.5
		300-600	88.1	94.5	93.5	89.5	89.2	96.1	91.8	91.8	86.8
		600-900	74.2	80.8	82.3	79.1	78.3	77.0	78.8	78.1	74.6
		900-1200	74.1	76.0	78.0	76.0	78.1	77.0	77.1	76.3	71.0
		0-1200	314.7	345.6	327.2	333.5	323.9	341.1	324.9	335.0	324.8

Block B

Date	DOY	Depth	*ObBr* Me	*ObSr* Me	*ObOr* Me	*SbOr* Me	*ObBr* Hi	*ObSr* Hi	*ObOr* Hi	*SbOr* Hi	*BbBr* N0
05-11-99	309	0-300	73.1	79.3	53.7	70.6	71.0	49.7	74.9		
		300-600	89.7	83.0	86.8	84.2	97.9	81.3	87.0		
		600-900	73.3	71.1	74.6	73.5	87.7	74.0	75.9		
		900-1200	68.9	65.7	76.1	74.2	84.3	76.0	72.4		
		0-1200	305.0	299.0	291.2	302.4	340.9	281.0	310.1		
10-11-99	314	0-300	74.4	80.2	53.1	68.9	71.9	49.5	71.6	65.2	
		300-600	88.8	82.2	86.3	84.6	97.6	83.9	87.8	119.5	
		600-900	74.5	71.4	74.9	74.8	89.6	75.5	75.9	106.4	
		900-1200	69.4	65.3	76.5	73.3	83.7	75.6	72.6	110.2	
		0-1200	307.0	299.0	290.9	301.7	342.7	284.4	307.9	401.4	
18-11-99	322	0-300	71.6	63.8	62.0	61.8	64.1	56.8	58.5	63.7	
		300-600	94.7	90.8	89.9	82.6	95.1	84.6	84.7	97.1	
		600-900	81.3	83.5	74.1	73.8	84.5	75.4	73.1	85.0	
		900-1200	76.1	79.7	74.7	71.0	82.1	72.1	71.1	86.3	
		0-1200	323.7	317.8	300.7	289.1	325.8	288.9	287.4	332.1	
29-11-99	333	0-300	91.1	98.3	82.5	86.1	85.1	77.7	82.4	85.8	
		300-600	106.3	100.3	103.8	96.6	108.0	100.6	100.2	105.4	
		600-900	95.6	97.6	90.2	85.7	103.5	91.1	88.1	96.5	
		900-1200	90.3	90.5	86.6	81.4	99.6	87.7	81.7	98.0	
		0-1200	383.3	386.7	363.1	349.8	396.2	357.1	352.4	385.6	
08-01-00	8	0-300	98.1	101.6	95.5	99.6	91.5	97.2	94.8	105.6	
		300-600	114.4	110.8	119.5	118.1	111.1	118.4	113.3	122.8	
		600-900	100.8	96.8	90.5	103.8	102.2	94.6	92.7	100.5	
		900-1200	87.0	86.8	77.4	77.1	93.8	75.7	78.5	88.0	
		0-1200	400.4	396.0	382.9	398.6	398.5	385.9	379.4	417.0	
16-02-00	16	0-300	86.7	89.0	83.4	89.1	83.8	85.3	88.4	91.0	
		300-600	95.5	95.7	95.1	95.3	94.1	95.8	94.4	97.5	
		600-900	93.5	94.2	93.3	93.7	95.1	94.3	89.2	94.9	
		900-1200	90.5	86.8	89.0	89.0	92.2	87.6	86.4	92.3	
		0-1200	366.2	365.6	360.8	367.1	365.3	363.0	358.4	375.7	
07-03-00	67	0-300	56.9	60.7	54.2	58.6	53.3	58.4	57.0	63.4	
		300-600	86.4	84.8	83.0	83.3	82.9	84.8	82.8	88.8	
		600-900	88.8	87.6	85.7	87.6	87.8	87.2	83.9	91.2	
		900-1200	88.6	85.7	85.8	85.5	87.4	82.0	82.4	92.4	
		0-1200	320.6	318.8	308.8	315.0	311.4	312.5	306.1	335.8	
23-03-00	83	0-300	70.0	70.8	61.9	68.9	58.8	66.8	64.3	68.1	
		300-600	87.4	87.7	83.0	84.0	85.8	86.1	81.2	86.5	
		600-900	85.5	83.4	81.6	83.5	84.9	83.3	80.1	85.5	
		900-1200	85.1	82.8	84.6	82.7	85.8	81.8	80.3	87.7	
		0-1200	328.1	324.6	311.1	319.1	315.2	318.0	306.0	327.9	
06-04-00	97	0-300	63.6	69.5	61.1	68.9	55.4	65.9	65.7	76.3	

		300-600	81.5	82.3	80.0	79.4	80.5	82.2	77.5	82.7	
		600-900	82.7	82.2	78.8	80.4	82.0	80.9	77.1	83.5	
		900-1200	83.2	81.1	81.6	79.7	85.3	79.5	78.9	86.3	
		0-1200	311.0	315.1	301.4	308.4	303.2	308.4	299.2	328.7	
26-04-00	117	0-300	67.9	76.3	60.9	73.0	60.7	66.1	63.7	69.3	
		300-600	82.1	82.1	79.7	78.4	80.2	81.3	76.7	81.4	
		600-900	80.8	80.0	76.9	78.5	79.7	78.2	75.0	80.9	
		900-1200	81.1	78.2	80.6	79.1	82.2	77.5	77.3	85.2	
		0-1200	311.9	316.6	298.2	309.0	302.9	303.2	292.7	316.9	
11-05-00	132	0-300	80.3	90.0	80.4	88.3	74.1	83.2	84.9	82.7	
		300-600	83.2	84.7	84.3	84.6	82.7	85.4	86.5	88.7	
		600-900	82.1	79.1	77.1	79.5	84.0	80.5	77.3	82.8	
		900-1200	81.6	79.4	80.3	79.8	82.6	77.4	78.3	86.1	
		0-1200	327.2	333.3	322.2	332.1	323.4	326.4	327.0	340.3	
23-05-00	145	0-300	65.9	73.9	67.6	75.9	59.3	71.1	73.8	73.7	
		300-600	83.6	85.5	85.4	84.8	84.3	85.8	86.4	87.8	
		600-900	81.7	80.7	78.8	80.4	81.2	82.9	77.7	83.7	
		900-1200	81.3	79.9	81.8	80.2	83.9	79.2	78.5	86.7	
		0-1200	312.6	320.1	313.6	321.4	308.8	319.1	316.5	332.0	
01-12-00	336	0-300	90.3	103.7	99.8	103.4	90.9	97.9	100.1	97.9	
		300-600	97.7	101.3	102.4	99.6	97.8	102.5	100.3	101.8	
		600-900	88.4	90.6	89.8	92.7	92.0	91.9	89.0	92.5	
		900-1200	84.8	82.3	83.3	84.9	88.2	81.8	81.9	91.2	
		0-1200	361.3	378.0	375.2	380.7	368.9	374.1	371.3	383.3	
08-01-01	8	0-300	97.1	103.0	92.5	96.2	92.7	100.0	92.7	97.6	
		300-600	100.9	102.5	103.3	102.9	102.0	103.8	99.6	104.4	
		600-900	95.0	97.4	97.2	99.4	97.2	98.6	94.5	97.9	
		900-1200	90.8	91.1	92.1	95.4	93.6	92.1	91.5	95.0	
		0-1200	383.8	394.1	385.1	394.0	385.6	394.4	378.3	394.9	
05-02-01	36	0-300	67.2	77.3	72.6	74.9	60.5	76.5	74.7	78.1	66.4
		300-600	94.8	96.6	98.4	96.3	93.8	99.2	95.4	99.5	84.7
		600-900	94.8	94.8	96.0	96.0	95.4	97.4	91.9	97.4	75.0
		900-1200	91.1	91.8	91.4	92.0	92.5	90.7	90.7	97.1	73.1
		0-1200	347.8	360.4	358.5	359.2	342.2	363.8	352.7	372.0	299.3
20-02-01	51	0-300	72.7	57.3	53.1	57.5	60.5	59.4	53.7	53.8	55.3
		300-600	69.2	67.0	68.2	67.6	69.0	68.6	65.8	68.5	67.5
		600-900	69.7	68.0	70.4	70.4	69.5	69.8	67.0	73.3	63.3
		900-1200	71.8	70.3	73.2	72.4	71.0	71.3	69.4	78.6	62.2
		0-1200	283.4	262.6	265.0	267.9	270.0	269.1	255.9	274.2	248.2
26-02-01	57	0-300	61.2	62.9	56.9	60.3	56.2	61.4	57.3	57.5	57.5
		300-600	81.5	80.4	83.8	81.4	83.6	84.6	79.5	83.6	80.4
		600-900	81.5	79.5	81.8	81.5	81.8	80.9	77.1	83.5	72.8
		900-1200	82.7	80.2	86.5	82.6	83.1	80.9	81.7	89.6	72.0
		0-1200	307.0	303.1	309.1	305.7	304.7	307.8	295.6	314.1	282.8
27-02-01	58	0-300	83.3	84.1	68.7	76.9	80.4	72.8	67.5	67.7	61.4
		300-600	85.1	83.2	82.3	82.5	86.0	82.6	79.9	83.0	80.4
		600-900	82.1	78.5	81.0	82.0	81.5	80.3	76.8	83.1	74.4
		900-1200	81.7	79.9	86.2	81.9	83.5	80.4	80.0	90.8	73.7
		0-1200	332.1	325.6	318.3	323.3	331.5	316.1	304.3	324.7	289.9
28-02-01	59	0-300	81.6	79.6	70.4	74.3	73.6	73.1	65.1	68.9	60.6
		300-600	83.7	84.0	83.8	83.1	82.4	84.9	80.8	83.4	80.3
		600-900	81.6	79.1	80.2	82.3	78.9	81.9	78.3	85.2	73.9
		900-1200	83.2	80.6	85.1	82.5	81.5	81.0	78.7	89.2	73.7

		0-1200	330.1	323.3	319.4	322.2	316.4	321.0	302.8	326.7	288.5
08-03-01	67	0-300	51.9	55.6	51.9	54.9	50.8	52.2	53.3	52.5	52.3
		300-600	79.2	80.4	82.3	79.4	79.3	81.6	77.4	81.2	77.3
		600-900	75.7	74.3	77.7	77.2	76.7	76.5	72.4	81.0	72.5
		900-1200	77.3	74.0	78.6	76.8	75.6	73.1	73.6	80.2	73.0
		0-1200	284.2	284.2	290.5	288.3	282.4	283.4	276.6	294.9	275.1
14-03-01	73	0-300	49.2	50.8	49.6	51.0	49.1	50.9	49.4	50.5	49.9
		300-600	76.2	76.5	77.6	75.9	75.8	78.7	74.8	77.6	76.7
		600-900	73.8	72.4	73.2	73.3	74.9	73.5	70.4	76.4	72.0
		900-1200	72.2	70.9	73.3	71.4	72.8	68.7	70.4	77.3	71.8
		0-1200	271.4	270.6	273.7	271.7	272.5	271.7	265.0	281.7	270.4
27-03-01	86	0-300	94.7	111.5	109.8	112.7	90.7	105.3	113.0	108.0	78.3
		300-600	86.9	90.3	95.1	90.1	86.4	90.9	94.2	92.3	79.5
		600-900	76.2	75.0	79.6	76.4	75.9	74.5	75.6	80.1	70.9
		900-1200	74.1	72.0	74.6	73.0	72.5	68.2	73.0	77.9	71.2
		0-1200	331.9	348.7	359.2	352.3	325.5	339.0	355.9	358.3	300.0
02-04-01	92	0-300	78.3	93.2	89.2	91.9	75.6	87.0	95.1	91.5	72.0
		300-600	84.0	86.3	91.5	86.6	82.6	85.9	87.7	87.1	80.2
		600-900	75.9	73.6	78.1	75.5	76.4	75.2	74.8	77.8	71.1
		900-1200	73.0	72.3	74.3	71.8	72.8	67.6	72.3	77.8	71.9
		0-1200	311.3	325.4	333.1	325.7	307.4	315.6	329.9	334.3	295.2
04-04-01	94	0-300	93.5	122.7	118.5	112.0	102.3	112.7	122.8	115.1	75.5
		300-600	81.9	87.8	94.1	88.8	82.2	86.2	90.3	89.0	77.6
		600-900	74.4	74.3	75.9	73.5	75.9	74.4	70.5	78.6	66.1
		900-1200	71.4	71.3	71.8	71.7	72.3	69.4	72.0	76.6	71.7
		0-1200	321.2	356.0	360.4	345.9	332.6	342.7	355.6	359.3	290.8
09-04-01	99	0-300	101.4	122.6	121.6	123.2	110.3	119.1	119.6	117.8	82.0
		300-600	88.5	97.7	99.8	94.4	89.1	95.1	96.7	93.7	81.0
		600-900	77.2	74.3	77.8	78.2	74.5	75.4	74.6	78.0	71.5
		900-1200	71.7	71.7	72.5	71.4	71.2	70.1	72.0	77.1	70.7
		0-1200	338.7	366.3	371.7	367.3	345.0	359.7	362.9	366.7	305.2
17-04-01	107	0-300	108.5	125.2	111.8	115.9	116.6	123.8	124.1	116.4	96.5
		300-600	92.2	99.8	95.4	97.2	93.1	97.1	98.9	96.0	81.9
		600-900	76.0	75.9	71.4	78.6	76.1	74.4	78.5	80.0	70.7
		900-1200	71.9	71.1	68.5	72.5	71.5	69.2	71.4	74.5	70.7
		0-1200	348.6	372.0	347.1	364.3	357.4	364.4	372.8	366.9	319.9
23-04-01	113	0-300	107.6	126.1	125.1	122.8	112.6	124.1	125.5	121.2	92.2
		300-600	88.5	101.5	104.7	98.1	94.9	99.9	101.3	99.0	82.9
		600-900	78.1	81.9	80.1	79.6	79.5	75.0	80.2	77.3	71.6
		900-1200	72.0	72.1	73.2	71.9	72.0	69.2	71.5	76.5	71.5
		0-1200	346.2	381.6	383.0	372.4	359.0	368.2	378.5	374.0	318.2
25-04-01	115	0-300	110.7	122.6	125.2	120.9	118.7	120.1	126.0	120.4	87.7
		300-600	91.7	102.6	106.1	100.8	99.9	102.4	103.5	101.1	82.8
		600-900	79.1	89.6	88.6	80.5	84.1	80.2	86.3	82.1	69.2
		900-1200	72.2	73.9	73.4	72.3	73.1	68.6	73.4	77.7	70.9
		0-1200	353.6	388.6	393.2	374.4	375.7	371.3	389.2	381.3	310.6
03-05-01	123	0-300	115.4	127.9	125.6	125.8	116.9	125.0	127.0	124.6	105.9
		300-600	95.9	104.4	106.0	102.8	102.1	104.5	104.2	102.5	84.9
		600-900	81.3	95.7	96.1	91.7	92.0	93.8	91.5	90.5	72.2
		900-1200	71.8	77.8	78.1	73.2	75.2	69.4	77.3	77.1	71.0
		0-1200	364.3	405.7	405.9	393.5	386.2	392.7	400.0	394.7	334.0
08-05-01	128	0-300	110.4	123.4	118.8	121.6	111.5	120.4	120.9	124.4	99.1
		300-600	96.6	101.8	105.2	102.7	102.4	104.4	102.5	102.1	88.0

		600-900	84.5	94.6	97.5	96.7	96.1	99.0	93.8	94.7	69.3
		900-1200	73.7	81.7	84.6	77.1	79.4	72.4	79.5	80.3	71.2
		0-1200	365.2	401.4	406.0	398.0	389.5	396.1	396.7	401.5	327.6
14-05-01	134	0-300	32.7	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1
		300-600	29.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3
		600-900	28.6	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3
		900-1200	26.5	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3
		0-1200	117.1	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9
16-05-01	136	0-300	105.1	112.9	113.4	112.4	104.7	115.7	115.3	118.0	96.5
		300-600	97.4	104.0	105.2	102.3	102.6	103.5	103.2	103.0	89.6
		600-900	85.5	96.8	97.3	95.5	96.8	99.0	94.8	94.8	74.5
		900-1200	75.8	85.9	86.4	78.9	82.8	78.6	83.0	83.2	71.9
		0-1200	363.9	399.5	402.3	389.1	387.0	396.8	396.3	399.0	332.5
24-08-01	236	0-300	73.2	81.5	73.1	75.0	68.1	71.8	74.1	71.5	65.7
		300-600	96.1	98.8	102.1	97.4	98.3	94.8	97.1	99.7	88.3
		600-900	85.5	93.2	95.9	93.7	93.9	94.7	91.0	93.7	71.5
		900-1200	78.1	88.2	89.9	85.5	86.4	85.5	85.4	88.7	70.7
		0-1200	332.9	361.6	361.0	351.7	346.6	346.8	347.5	353.6	296.2
13-09-01	256	0-300	73.2	88.9	74.7	86.0					
		300-600	97.8	98.6	101.3	96.4					
		600-900	88.3	91.5	94.3	91.8					
		900-1200	80.4	79.8	90.5	82.5					
		0-1200	339.7	358.9	360.8	356.7					
08-10-01	281	0-300	82.3	96.7	83.2	87.9	74.6	89.6	87.0	78.8	81.1
		300-600	96.4	100.1	101.7	98.1	98.1	101.7	98.2	99.9	89.6
		600-900	87.9	94.3	95.1	94.0	94.9	94.9	90.9	93.7	74.0
		900-1200	78.4	87.9	90.1	85.7	87.6	86.1	86.4	89.7	72.1
		0-1200	345.0	379.0	370.1	365.7	355.2	372.3	362.5	362.1	316.7
31-10-01	304	0-300	112.3	121.4	119.3	119.0	107.9	118.5	119.8	117.5	99.3
		300-600	105.0	105.5	106.3	105.3	105.5	105.7	105.3	106.1	93.0
		600-900	100.1	102.2	103.8	103.8	104.1	103.5	99.5	103.4	77.7
		900-1200	87.4	98.7	100.8	97.8	98.2	97.9	98.1	100.0	72.5
		0-1200	404.7	427.8	430.1	425.9	415.7	425.6	422.6	427.0	342.5
12-11-01	316	0-300	111.9	114.7	114.6	115.4	109.5	118.7	117.4	112.8	95.8
		300-600	105.4	105.3	106.4	106.3	106.0	106.1	105.7	99.5	100.0
		600-900	102.6	103.1	104.6	105.3	105.5	0.0	100.7	104.5	84.3
		900-1200	98.2	99.9	102.5	99.8	101.7	99.4	99.7	104.9	74.8
		0-1200	418.2	423.0	428.1	426.7	422.6	428.9	423.6	421.6	354.9
22-12-01	256	0-300	109.7	113.0	109.2	109.7	97.2	112.2	108.8	109.1	89.8
		300-600	104.5	103.7	106.0	104.7	103.4	104.8	105.2	104.9	100.9
		600-900	100.6	102.6	103.4	102.3	104.3	102.8	99.9	102.3	97.9
		900-1200	99.6	96.5	100.5	99.5	99.5	99.4	96.1	102.8	91.9
		0-1200	414.5	415.7	419.2	416.1	404.4	419.3	410.0	419.2	380.5
08-01-02	8	0-300	105.1	121.3	109.0	116.1	100.9	114.6	112.4	104.7	95.3
		300-600	104.3	105.4	105.5	103.8	104.4	105.4	103.6	104.1	100.9
		600-900	100.0	99.3	101.7	101.7	102.1	101.1	96.6	101.7	96.2
		900-1200	98.7	95.6	99.3	97.5	99.0	96.0	95.2	103.3	92.6
		0-1200	408.1	421.6	415.5	419.1	406.3	417.1	407.8	413.8	385.0
16-01-02	16	0-300	104.6	121.5	115.5	118.1	100.9	117.7	117.1	112.6	96.2
		300-600	102.9	105.5	106.0	104.3	104.1	105.6	103.4	105.1	101.4
		600-900	99.2	100.8	100.3	101.2	101.5	101.3	96.7	102.0	95.7
		900-1200	97.4	96.1	99.0	97.3	98.8	96.5	96.2	102.8	93.4
		0-1200	404.1	423.9	420.9	420.8	405.3	421.1	413.4	422.5	386.7

24-01-02	24	0-300	91.5	102.0	99.7	101.0	83.7	98.4	103.3	99.0	82.6
		300-600	103.3	104.2	105.7	104.1	103.5	105.2	103.7	104.3	100.1
		600-900	99.3	100.2	101.7	101.5	101.8	101.5	96.5	101.9	95.5
		900-1200	96.8	96.5	99.6	98.0	97.7	96.8	95.2	102.8	92.7
		0-1200	390.9	402.9	406.8	404.6	386.7	401.9	398.8	408.1	370.9
30-01-02	30	0-300	113.6	122.4	120.4	124.1	110.3	122.0	121.5	117.4	99.2
		300-600	103.7	105.6	106.4	104.9	105.6	105.8	105.6	106.2	100.4
		600-900	99.1	102.2	103.2	103.4	103.1	103.2	99.1	103.1	95.5
		900-1200	97.3	97.7	100.2	98.0	98.4	97.4	95.4	103.1	92.2
		0-1200	413.6	427.9	430.2	430.4	417.3	428.4	421.6	429.7	387.4
31-01-02	31	0-300	103.6	118.6	113.0	114.7	96.5	113.0	114.3	107.5	86.7
		300-600	117.9	123.0	128.3	123.7	121.1	127.3	123.3	124.8	111.8
		600-900	107.4	112.8	117.0	116.7	115.2	114.2	103.7	112.8	95.8
		900-1200	99.5	104.5	108.3	102.3	103.2	103.4	97.8	112.8	94.2
		0-1200	428.4	458.8	466.6	457.3	436.0	457.9	439.2	457.9	388.4
08-02-02	39	0-300	60.2	69.6	62.3	68.8	55.8	66.2	65.4	60.7	58.3
		300-600	104.5	108.4	112.7	106.8	98.3	108.1	103.0	107.4	99.6
		600-900	102.4	103.6	106.3	106.4	105.8	104.0	98.3	106.8	92.7
		900-1200	97.4	98.1	103.3	100.3	98.8	98.2	93.5	107.9	92.0
		0-1200	364.5	379.7	384.6	382.3	358.8	376.5	360.1	382.9	342.6
20-02-02	51	0-300	57.3	60.7	64.6	60.1	57.6	61.0	56.2	65.1	57.9
		300-600	86.7	86.6	92.9	86.0	81.9	86.7	84.9	102.3	87.4
		600-900	93.2	92.0	98.0	94.7	88.2	93.2	88.8	106.3	88.7
		900-1200	96.8	94.9	103.1	95.9	92.8	96.7	93.2	116.7	96.8
		0-1200	333.9	334.1	358.6	336.7	320.5	337.6	323.2	390.4	330.8
07-03-02	66	0-300	51.9	54.9	50.8	54.2	47.5	50.0	48.6	49.1	54.7
		300-600	81.6	82.4	83.3	81.7	78.5	82.0	77.8	79.5	83.2
		600-900	84.3	82.2	83.1	85.1	81.1	82.8	81.8	85.4	79.4
		900-1200	92.6	88.4	91.5	91.7	88.8	88.0	88.2	98.0	87.1
		0-1200	310.4	307.9	308.7	312.7	295.9	302.8	296.4	311.9	304.5
19-03-02	78	0-300	46.3	49.5	46.3	50.3	41.7	43.6	44.6	45.7	47.3
		300-600	77.4	78.4	78.6	77.5	74.9	76.5	75.1	77.8	77.1
		600-900	79.5	79.6	78.1	79.6	76.5	76.8	74.0	83.8	76.2
		900-1200	84.0	85.0	84.2	84.0	81.9	80.9	83.9	86.2	79.0
		0-1200	287.3	292.5	287.3	291.3	275.0	277.8	277.6	293.3	279.7
02-04-02	92	0-300	40.8	44.2	41.1	44.2	37.3	41.0	40.4	40.6	42.6
		300-600	74.4	75.8	76.5	75.7	72.8	75.3	73.6	74.2	74.2
		600-900	75.5	74.5	76.0	77.4	74.6	74.6	73.0	77.7	75.2
		900-1200	80.4	79.2	84.4	82.3	81.0	79.2	80.1	88.5	78.5
		0-1200	271.1	273.7	278.0	279.5	265.6	270.2	267.0	280.9	270.5
12-04-02)	102	0-300	94.7	97.8	76.7	94.4	78.2	94.9	87.8	84.1	87.8
		300-600	90.4	95.4	96.6	90.1	86.9	100.9	93.1	95.3	90.7
		600-900	77.2	79.1	79.4	77.4	77.5	77.8	73.6	79.4	75.1
		900-1200	79.7	79.2	82.0	80.4	80.4	79.6	79.9	88.3	79.1
		0-1200	342.0	351.6	334.8	342.3	323.0	353.2	334.4	347.1	332.8
23-04-02	114	0-300	75.5	80.5	65.0	79.3	63.5	72.3	69.8	69.5	72.2
		300-600	88.8	91.9	92.0	87.8	85.4	98.3	89.8	90.5	87.2
		600-900	77.0	79.0	78.6	77.4	76.5	76.9	74.7	78.8	74.7
		900-1200	81.4	80.7	83.4	81.8	81.5	73.5	80.0	89.1	78.8
		0-1200	322.7	332.1	319.0	326.3	306.9	321.0	314.3	328.0	313.0
24-06-02	175	0-300	92.7	99.0	85.5	98.3	76.0	88.5	88.9	81.8	78.1
		300-600	91.1	99.6	100.1	95.4	90.6	99.8	93.5	95.5	87.8
		600-900	82.6	86.2	84.4	84.8	77.2	78.0	74.2	80.4	72.8

		900-1200	86.0	83.6	88.4	85.7	82.1	80.3	80.5	89.7	77.3
		0-1200	352.4	368.3	358.5	364.1	325.9	346.5	337.1	347.4	316.1

Appendix 5.4

Climate data for the Glen/Bonheim ecotope during the experimental period

Year	DOY	Rn	T	RH	WS	Rain	Tn	RHx	RHn	Evap
99	300	27.7	15.6	55.1	1.7	0.0	7.2	91.2	21.6	5.5
99	301	28.7	17.4	47.9	1.9	0.0	8.8	84.9	18.9	6.2
99	302	26.6	19.3	44.9	3.3	0.0	8.7	77.1	17.3	7.4
99	303	27.0	19.7	53.8	3.3	0.7	14.2	74.2	25.9	7.2
99	304	26.0	21.3	44.4	1.9	0.0	10.5	86.8	19.7	6.3
99	305	28.4	23.9	32.6	2.0	0.0	14.0	65.7	12.6	7.8
99	306	29.2	23.6	34.2	2.0	0.0	12.9	73.0	12.8	7.8
99	307	28.8	23.6	41.2	2.3	0.0	13.3	83.0	13.7	8.1
99	308	23.4	5.3	30.6	4.1	0.0	0.0	52.8	17.9	
99	309	29.3	15.6	20.2	2.3	0.0	0.0	40.7	10.0	
99	310	25.6	22.0	47.6	4.1	1.8	13.7	85.9	19.1	8.5
99	311	24.8	22.4	47.6	4.5	1.3	14.7	77.4	20.3	8.9
99	312	28.5	22.0	37.3	3.1	0.0	14.9	70.5	13.4	8.4
99	313	24.9	21.6	50.6	5.6	5.9	15.9	73.4	23.5	9.3
99	314	28.0	22.5	49.5	3.5	0.0	15.8	79.9	15.6	8.6
99	315	29.7	24.0	34.7	3.4	0.0	17.6	60.2	13.4	9.3
99	316	29.5	24.6	38.7	3.0	0.0	18.6	62.3	18.6	8.8
99	317	29.1	25.6	26.5	2.6	0.0	15.8	56.6	12.0	8.7
99	318	25.2	25.6	25.9	3.5	0.0	17.9	51.8	13.0	9.4
99	319	22.9	22.9	41.5	3.5	0.3	17.5	65.6	21.8	8.0
99	320	17.4	22.1	49.9	5.1	0.1	16.1	75.2	14.2	8.9
99	321	29.4	22.2	50.0	2.0	0.0	12.4	87.7	21.8	7.1
99	322	30.8	22.2	31.9	3.4	0.0	14.8	66.5	13.0	8.8
99	323	31.4	18.6	30.5	1.8	0.0	8.7	63.9	9.6	7.1
99	324	28.5	21.2	33.4	3.2	0.0	10.3	74.0	11.0	8.5
99	325	28.8	23.7	35.4	3.5	0.0	15.9	71.7	12.9	9.0
99	326	31.6	23.6	28.6	2.7	0.0	15.7	59.9	7.5	9.3
99	327	31.9	25.0	17.4	2.1	0.0	11.2	35.8	7.7	9.0
99	328	27.6	24.8	41.4	4.8	8.0	16.9	82.4	13.4	10.8
99	329	24.4	22.7	52.8	3.8	13.9	14.4	93.4	23.6	7.8
99	330	29.6	22.0	55.2	2.7	3.8	14.9	94.6	14.1	7.9
99	331	29.2	23.9	39.7	3.4	0.0	17.1	72.7	14.3	9.0
99	332	19.9	21.5	58.8	5.2	4.4	16.0	85.9	27.2	8.0
99	333	27.1	21.6	55.0	3.2	0.0	13.7	88.6	25.1	7.4
99	334	25.9	21.0	55.7	5.6	5.7	15.7	79.8	32.5	8.0
99	335	27.3	21.6	54.4	2.8	0.0	15.4	80.3	29.7	7.0
99	336	15.5	18.5	73.7	3.3	23.4	14.7	96.3	44.4	4.5
99	337	11.4	17.6	86.7	2.0	7.9	14.9	95.3	68.7	2.7
99	338	26.0	20.5	71.3	1.0	0.1	14.0	96.5	35.6	5.3
99	339	29.4	23.5	52.4	2.8	0.0	16.3	85.3	21.4	7.9
99	340	30.3	22.1	43.5	2.1	0.0	14.7	86.7	15.6	7.4
99	341	30.5	22.0	45.2	2.8	0.0	13.7	87.5	14.7	8.2
99	342	15.2	20.0	65.3	4.5	2.8	15.9	84.4	39.3	5.9
99	343	11.2	18.4	73.4	1.6	0.0	14.0	90.4	47.0	3.2
99	344	14.1	18.4	75.3	3.8	2.1	15.0	86.8	47.3	4.6
99	345	27.5	19.3	64.7	2.1	0.0	11.7	96.6	26.6	6.4
99	346	28.3	20.3	56.7	2.9	0.0	12.5	87.9	26.4	7.2
99	347	24.6	21.0	52.7	3.0	0.0	13.8	81.5	31.7	6.5

99	348	30.0	22.9	45.9	2.4	0.0	16.4	73.2	22.9	7.8
99	349	20.4	23.5	42.2	3.0	0.0	17.8	60.9	23.5	7.3
99	350	11.3	19.8	64.0	3.8	10.3	15.4	82.0	40.1	4.9
99	351	17.1	19.9	62.9	3.2	0.0	15.7	80.7	43.1	5.1
99	352	28.1	23.4	49.2	3.4	0.0	16.8	80.1	18.4	8.6
99	353	12.1	19.4	73.9	3.1	2.6	15.7	92.7	55.9	3.5
99	354	10.8	18.4	83.5	1.9	1.2	15.8	95.5	60.3	2.9
99	355	14.8	20.3	78.1	2.8	3.6	15.8	96.5	57.9	3.8
99	356	15.5	20.1	78.4	4.0	5.0	17.4	94.4	41.7	5.3
99	357	7.4	17.9	89.0	2.7	15.8	16.5	96.2	80.8	1.9
99	358	20.6	19.4	81.1	3.3	4.2	16.1	91.7	61.5	4.5
99	359	11.2	17.2	83.8	3.3	16.1	14.7	96.3	69.4	2.7
99	360	26.7	21.1	68.6	2.7	0.0	13.9	93.2	41.3	6.2
99	361	14.2	20.6	74.6	2.0	0.0	17.1	92.7	54.8	3.7
99	362	24.4	21.8	69.6	2.6	0.0	17.1	91.4	43.0	5.9
99	363	26.9	21.7	63.3	2.0	0.0	15.0	91.4	36.0	6.1
99	364	24.7	22.3	58.4	2.6	0.0	15.5	88.8	36.0	6.4
99	365	29.4	22.6	54.6	2.4	0.1	15.2	84.6	26.2	7.3
2000	1	25.5	21.7	61.4	3.6	0.4	17.7	87.1	41.3	6.5
2000	2	29.7	21.6	53.8	1.9	0.0	14.7	86.5	22.6	6.9
2000	3	20.7	21.8	61.0	3.9	0.2	16.7	83.7	36.6	6.5
2000	4	19.7	21.3	65.1	3.6	0.1	16.3	86.1	40.0	6.0
2000	5	10.6	18.2	87.9	3.2	25.1	15.0	98.1	72.2	2.6
2000	6	23.9	21.3	79.2	1.4	0.0	16.5	96.6	53.6	5.0
2000	7	24.8	22.7	70.8	2.2	0.0	18.6	95.8	45.9	5.7
2000	8	30.8	22.2	60.9	2.5	0.0	12.8	89.6	26.9	7.4
2000	9	21.8	21.3	65.0	3.3	0.0	15.9	82.8	44.9	5.8
2000	10	26.2	23.6	57.0	2.9	0.2	17.8	81.8	34.4	7.0
2000	11	19.2	22.5	63.5	3.6	12.8	17.1	90.7	37.5	6.3
2000	12	16.8	19.2	84.2	2.6	10.6	15.0	94.9	56.2	4.2
2000	13	9.4	16.7	74.9	3.1	0.0	13.1	92.0	60.4	2.9
2000	14	17.1	15.5	76.3	4.4	17.3	11.1	97.6	66.0	3.3
2000	15	6.3	12.9	87.0	3.2	2.7	10.1	95.2	68.9	1.9
2000	16	30.4	16.5	71.5	1.8	0.0	9.3	95.6	36.7	5.7
2000	17	28.0	18.3	62.0	2.1	0.0	9.9	92.2	33.8	6.0
2000	18	26.9	17.5	62.4	1.2	0.0	9.3	90.5	34.5	5.2
2000	19	30.2	19.1	53.2	2.1	0.0	12.1	72.5	32.5	6.5
2000	20	29.7	21.1	49.4	2.0	0.0	14.2	77.9	26.9	6.9
2000	21	29.6	22.3	50.0	1.2	0.0	12.8	85.7	23.0	6.4
2000	22	21.0	22.3	46.8	1.8	0.0	14.0	74.7	27.8	5.9
2000	23	23.9	23.2	47.6	3.3	0.0	17.1	69.2	20.9	8.0
2000	24	13.2	20.5	59.7	3.0	0.0	16.0	77.9	46.2	4.5
2000	25	20.6	20.5	65.7	1.5	0.0	13.8	90.9	35.7	4.9
2000	26	9.7	19.6	75.7	1.1	1.0	16.6	92.1	51.4	2.7
2000	27	17.7	19.8	75.6	1.9	3.0	14.1	93.3	40.0	4.6
2000	28	27.1	21.1	65.9	2.0	0.2	15.9	96.9	26.1	6.3
2000	29	29.0	18.1	56.5	2.0	0.0	12.0	92.0	23.4	6.2
2000	30	29.4	19.6	42.3	2.0	0.0	7.6	82.8	16.4	7.0
2000	31	29.9	20.5	37.7	1.7	0.0	8.8	68.2	14.6	7.2
2000	32	29.4	22.2	37.9	1.8	0.0	10.8	71.4	17.5	7.3
2000	33	28.6	23.9	33.4	2.1	0.0	11.3	67.3	13.0	8.0
2000	34	26.9	24.8	47.5	4.9	0.0	18.2	72.4	19.7	9.9
2000	35	27.3	23.9	47.0	3.1	0.0	14.9	80.8	21.9	8.1

2000	36	28.0	25.3	39.8	2.8	0.0	17.9	67.1	15.5	8.7
2000	37	23.8	26.0	42.1	3.2	0.0	18.6	74.8	18.6	8.4
2000	38	20.3	24.6	52.4	3.7	0.0	19.3	71.6	33.7	7.0
2000	39	27.1	24.3	53.4	3.0	0.0	16.4	85.0	23.4	7.9
2000	40	23.7	23.3	54.5	3.4	0.0	18.6	77.1	32.5	7.1
2000	41	9.0	19.4	86.1	3.1	9.2	17.0	95.2	62.0	2.9
2000	42	16.7	22.3	72.5	1.6	0.9	17.3	94.9	43.5	4.3
2000	43	22.3	23.3	68.1	2.2	0.0	18.3	94.2	37.0	5.8
2000	44	17.4	22.4	68.2	2.7	4.0	17.5	88.8	46.2	5.0
2000	45	25.2	22.6	64.8	2.9	0.0	16.5	90.0	39.8	6.3
2000	46	22.2	22.7	64.4	2.4	2.9	16.1	93.3	24.5	6.4
2000	47	24.0	22.2	61.4	2.2	0.0	14.4	93.9	24.6	6.3
2000	48	22.7	21.6	53.1	2.7	0.0	15.3	78.4	31.0	6.3
2000	49	21.7	20.0	48.8	4.0	0.0	14.8	70.7	31.2	6.6
2000	50	15.4	21.0	64.3	2.5	2.3	14.8	84.7	39.8	4.8
2000	51	22.0	22.9	63.7	2.0	2.3	16.7	93.2	31.9	5.8
2000	52	13.3	21.4	76.3	2.2	8.5	18.0	94.4	39.0	4.4
2000	53	13.7	22.6	67.4	1.6	0.0	17.8	89.7	42.3	3.9
2000	54	7.1	20.3	72.9	2.2	0.0	17.7	87.1	59.2	2.7
2000	55	24.9	22.3	59.3	2.0	0.0	15.3	91.2	31.1	6.0
2000	56	24.5	22.4	58.9	2.2	0.0	14.4	89.5	29.5	6.2
2000	57	16.8	22.1	63.9	1.6	0.0	16.2	86.3	40.3	4.4
2000	58	20.2	23.0	80.4	1.5	9.0	16.5	99.0	49.4	
2000	59	16.7	21.4	76.6	1.6	0.0	16.5	99.3	49.5	
2000	60	22.8	22.0	74.0	1.2	0.0	15.0	95.7	42.8	
2000	61	18.7	24.8	78.7	0.8	0.0	19.0	99.9	54.4	
2000	62	13.7	23.3	80.2	2.2	0.0	18.5	94.9	56.6	
2000	63	17.4	22.3	73.4	3.5	1.0	18.3	90.0	47.2	5.2
2000	64	12.3	21.0	82.7	1.4	5.2	17.8	95.1	45.2	3.5
2000	65	17.3	21.6	74.6	1.5	1.9	16.7	95.1	45.5	4.2
2000	66	24.6	23.0	59.3	1.8	0.0	16.5	92.6	23.3	6.0
2000	67	20.5	21.4	63.0	1.7	0.0	14.5	92.0	32.1	5.0
2000	68	19.0	22.3	57.5	2.9	0.0	17.1	78.0	34.5	5.8
2000	69	17.8	21.3	58.1	2.1	1.2	16.1	87.7	26.4	5.3
2000	70	18.9	22.1	52.8	1.8	0.0	15.8	83.1	23.9	5.4
2000	71	18.7	22.7	56.2	2.8	1.3	17.3	85.7	28.0	6.1
2000	72	17.4	21.6	60.8	2.5	3.2	16.6	87.8	24.2	5.7
2000	73	17.4	20.7	63.4	2.6	0.1	15.7	88.4	31.4	5.3
2000	74	14.1	20.4	69.0	2.4	2.0	16.7	85.2	40.9	4.5
2000	75	15.2	19.5	76.3	2.6	4.0	15.5	92.3	41.0	4.5
2000	76	13.6	19.7	80.4	2.0	20.8	16.7	95.2	50.2	3.7
2000	77	12.2	19.5	81.8	2.2	6.0	16.1	96.3	55.6	3.2
2000	78	20.1	20.7	73.5	1.3	0.2	14.9	96.7	34.6	4.4
2000	79	19.9	21.6	69.1	1.1	0.0	15.6	92.9	43.3	4.1
2000	80	13.0	20.0	78.1	2.0	4.2	15.0	95.3	48.4	3.6
2000	81	14.8	19.7	75.2	3.5	0.6	16.0	92.4	52.8	4.0
2000	82	19.7	19.8	75.5	1.0	0.0	13.8	97.0	46.0	3.9
2000	83	17.7	21.3	66.1	1.6	0.0	14.7	92.7	32.7	4.5
2000	84	17.3	22.3	55.8	2.4	0.0	16.6	85.2	32.7	5.1
2000	85	14.2	19.5	78.2	1.6	1.1	15.0	94.7	47.8	3.4
2000	86	15.3	18.9	81.5	2.7	1.7	15.4	96.0	49.3	4.0
2000	87	5.4	16.1	91.8	3.6	8.4	14.2	96.5	82.5	1.4
2000	88	11.8	18.6	84.4	0.9	1.8	15.8	96.7	63.3	2.4

2000	89	10.7	17.9	86.5	2.5	5.3	16.2	95.9	63.7	2.6
2000	90	17.6	19.4	73.8	1.7	0.0	15.1	96.3	33.6	4.1
2000	91	19.9	18.9	67.9	1.4	0.0	12.0	95.8	32.2	4.1
2000	92	16.0	18.6	68.6	4.5	0.0	14.8	82.7	50.4	4.6
2000	93	18.2	18.5	64.6	2.0	0.0	11.3	92.6	35.8	4.2
2000	94	10.4	18.1	68.1	1.6	2.1	12.7	91.7	39.1	3.1
2000	95	14.3	14.8	76.2	3.6	2.5	11.2	96.5	51.3	3.2
2000	96	11.3	12.3	73.0	2.4	6.0	8.7	86.9	49.4	2.7
2000	97	11.7	12.9	76.7	0.9	0.0	8.8	92.9	53.7	2.1
2000	98	20.2	13.7	66.8	1.1	0.0	7.1	95.0	29.1	3.5
2000	99	19.8	14.7	62.2	1.1	0.0	6.1	91.7	28.4	3.7
2000	100	19.9	15.8	55.0	1.2	0.0	7.1	88.2	24.3	3.8
2000	101	19.4	17.7	46.5	2.3	0.0	10.7	69.2	25.6	4.9
2000	102	18.8	17.4	55.8	1.3	0.0	7.8	83.8	27.6	3.9
2000	103	18.5	18.3	56.4	1.3	0.2	9.5	86.1	26.0	3.9
2000	104	14.5	17.7	62.0	1.1	0.1	13.4	84.3	33.4	3.2
2000	105	11.7	14.9	75.2	1.2	14.9	9.8	91.4	39.3	2.7
2000	106	18.6	15.1	66.2	1.3	0.1	7.5	95.7	28.3	3.5
2000	107	13.5	15.1	66.4	1.3	0.0	7.0	94.1	36.3	2.8
2000	108	14.5	15.2	67.9	1.5	1.7	8.4	90.6	31.8	3.3
2000	109	17.0	15.2	70.2	1.1	0.0	8.7	94.8	35.3	3.0
2000	110	12.1	15.5	73.2	2.0	0.0	9.4	95.0	48.1	2.8
2000	111	5.4	14.6	84.7	1.9	4.7	12.5	93.5	68.2	1.6
2000	112	11.4	14.2	81.0	3.0	0.3	11.2	91.4	59.0	2.6
2000	113	7.7	13.6	83.9	2.1	6.7	10.0	94.7	68.5	1.8
2000	114	9.5	12.8	82.1	1.6	0.0	8.0	97.5	49.3	2.2
2000	115	15.8	12.4	69.1	1.2	0.0	3.5	98.4	28.3	2.8
2000	116	16.3	13.8	60.5	1.5	0.0	5.5	87.0	26.1	3.5
2000	117	15.3	13.2	66.1	1.4	0.0	6.0	89.9	32.7	3.0
2000	118	15.4	10.3	61.9	1.8	0.0	3.5	92.4	17.9	3.1
2000	119	14.4	11.0	68.1	3.0	0.0	0.7	93.6	38.4	3.5
2000	120	8.9	15.5	73.4	4.5	9.6	12.5	93.1	54.8	2.9
2000	121	5.0	13.5	85.3	2.5	5.2	11.3	96.5	69.7	1.5
2000	122	11.6	15.1	78.6	3.2	4.4	12.0	91.5	47.3	3.2
2000	123									2.4
2000	124	4.9	11.4	87.4	2.3	11.6	6.2	96.4	72.4	1.3
2000	125	14.4	9.2	81.2	1.0	0.1	3.4	97.6	46.8	1.9
2000	126	14.5	9.6	72.6	1.4	0.1	3.7	94.1	31.8	2.5
2000	127	15.5	8.8	74.8	0.9	0.0	1.5	96.1	37.1	2.1
2000	128	15.5	10.9	68.7	1.5	0.0	1.6	95.8	35.8	2.7
2000	129	14.6	12.2	67.5	1.3	0.0	5.7	90.8	33.3	2.6
2000	130	14.8	11.6	66.7	1.1	0.0	3.7	92.9	30.3	2.6
2000	131	14.6	12.1	64.4	1.1	0.0	5.0	87.7	31.1	2.6
2000	132	13.5	12.4	58.8	1.7	0.0	5.1	90.1	19.8	3.2
2000	133	12.2	10.9	68.8	1.3	0.0	3.8	92.1	38.8	2.3
2000	134	14.6	9.0	66.5	0.8	0.0	1.4	91.7	32.9	2.0
2000	135	14.5	9.2	65.1	1.6	0.0	0.9	89.7	33.3	2.6
2000	136	12.2	8.6	63.4	0.9	0.0	2.5	90.7	21.8	2.1
2000	137	14.3	9.6	59.3	1.1	0.0	0.9	89.0	26.3	2.4
2000	138	13.7	12.2	53.9	1.5	0.0	4.1	85.3	25.8	2.8
2000	139	10.6	14.7	49.7	2.5	1.1	8.9	73.1	25.5	3.7
2000	140	11.4	13.0	66.3	2.8	0.0	8.3	87.2	42.2	2.9
2000	141	14.0	13.4	58.1	2.0	0.0	5.5	90.3	26.4	3.2

2000	142	14.0	13.1	54.2	1.7	0.0	2.8	87.9	24.9	3.1
2000	143	14.0	14.5	46.5	1.8	0.0	7.3	70.7	24.3	3.3
2000	144	12.5	13.1	51.9	1.4	0.0	3.7	82.9	28.8	2.6
2000	145	10.2	15.0	57.2	4.3	0.0	11.2	79.2	34.5	4.0
2000	146	13.2	14.3	54.3	3.4	0.0	9.4	79.0	24.2	4.2
2000	147	14.1	9.0	54.7	2.0	0.0	2.8	80.7	26.1	2.8
2000	148	14.1	6.9	60.2	1.1	0.0	-1.1	89.4	27.0	2.0
2000	149	13.9	7.0	56.4	1.4	0.0	-1.9	87.9	22.4	2.4
2000	150	14.0	6.4	54.0	1.4	0.0	-2.1	86.5	21.1	2.4
2000	151	13.9	6.9	47.6	1.4	0.0	-2.1	78.8	17.4	2.6
2000	152	13.8	6.8	44.4	1.1	0.0	-3.1	80.7	12.7	2.4
2000	153	13.9	8.4	36.4	1.5	0.0	-2.4	66.8	12.0	3.0
2000	154	13.4	11.3	32.5	2.1	0.0	1.0	53.1	15.2	3.8
2000	155	13.4	8.7	48.3	1.5	0.0	-0.7	80.4	18.0	2.6
2000	156	12.8	9.4	61.7	2.1	0.0	1.4	92.8	28.8	2.8
2000	157	12.9	8.6	60.8	1.2	0.0	0.9	92.0	24.8	2.2
2000	158	12.9	8.3	51.7	1.0	0.0	-0.9	84.3	21.6	2.2
2000	159	12.5	9.0	54.4	1.4	0.0	0.4	75.9	30.0	2.4
2000	160	12.5	9.2	57.9	1.1	0.0	1.1	83.5	30.3	2.1
2000	161	10.3	10.9	54.4	1.5	0.0	1.4	84.4	29.7	2.4
2000	162	8.1	13.4	53.6	2.1	0.0	5.3	78.9	34.9	2.6
2000	163	10.9	13.6	50.5	3.2	0.0	6.6	67.6	32.4	3.7
2000	164	12.4	11.0	54.9	2.0	0.0	0.6	90.4	23.6	3.1
2000	165	11.8	14.6	52.1	3.2	0.0	8.1	83.6	30.2	3.8
2000	166	12.1	14.2	50.6	2.2	0.0	9.1	73.9	27.1	3.2
2000	167	12.2	11.8	50.9	2.0	0.0	3.1	76.4	24.1	3.0
2000	168	8.3	12.7	48.6	2.7	0.0	7.1	65.9	30.4	3.3
2000	169	9.2	10.6	70.6	2.1	1.8	2.0	91.6	50.4	2.0
2000	170	12.9	5.8	55.4	1.1	0.0	-3.6	90.5	14.3	2.1
2000	171	12.1	9.3	58.9	2.8	0.0	-0.4	76.5	32.2	3.2
2000	172	10.0	9.3	70.2	1.4	0.0	2.2	92.7	44.8	1.7
2000	173	6.3	8.0	85.5	2.1	0.0	4.3	97.5	72.7	1.1
2000	174	4.2	9.9	79.2	1.9	0.4	6.3	92.4	56.0	1.6
2000	175	10.6	5.9	74.1	1.6	0.1	-1.5	99.4	31.7	1.8
2000	176	12.9	4.1	57.6	1.2	0.0	-5.2	89.3	23.0	2.0
2000	177	12.9	6.0	54.5	1.5	0.0	-3.8	83.9	21.7	2.4
2000	178	13.0	7.3	54.0	1.3	0.0	-2.6	87.6	18.5	2.5
2000	179	12.9	8.2	44.5	1.2	0.0	-2.6	77.9	16.2	2.5
2000	180	12.7	8.0	42.3	1.3	0.0	-1.9	73.1	17.9	2.6
2000	181	13.0	8.1	38.9	1.4	0.0	-0.9	66.5	13.6	2.8
2000	182	12.4	10.7	40.7	3.2	0.0	2.6	56.4	27.6	3.7
2000	183	11.7	9.1	53.1	1.5	0.0	1.6	79.2	29.9	2.3
2000	184	12.5	7.5	55.5	1.3	0.0	-1.0	85.9	27.2	2.2
2000	185	12.5	7.8	56.1	1.8	0.0	-1.2	84.0	28.3	2.5
2000	186	12.9	7.1	51.6	1.2	0.0	-2.0	85.3	19.6	2.3
2000	187	13.0	7.8	46.7	1.3	0.0	-1.5	78.2	21.1	2.4
2000	188	12.6	9.1	49.2	1.7	0.0	0.8	80.4	23.8	2.6
2000	189	12.7	10.4	51.4	2.5	0.0	5.1	76.7	26.1	3.1
2000	190	12.8	7.7	54.1	1.3	0.0	-0.5	83.4	23.7	2.3
2000	191	12.5	7.2	55.3	1.4	0.0	-0.6	78.6	30.4	2.2
2000	192	13.1	7.0	54.3	1.2	0.0	-1.6	86.7	25.4	2.2
2000	193	13.3	6.7	48.1	1.3	0.0	-2.6	81.4	20.1	2.4
2000	194	12.8	9.1	46.1	1.7	0.0	-1.4	70.1	23.3	2.9

2000	195	10.4	12.2	56.3	1.9	0.0	4.4	86.4	33.1	2.5
2000	196	11.5	15.5	36.9	5.5	0.1	10.8	51.2	20.5	6.0
2000	197	6.0	4.8	77.2	3.1	0.7	-0.7	94.5	47.1	1.8
2000	198	13.9	0.3	73.5	1.1	0.2	-7.1	96.5	40.4	1.4
2000	199	14.1	3.2	49.1	1.5	0.0	-6.7	80.5	18.9	2.4
2000	200	13.5	10.3	32.4	3.3	0.0	-1.7	61.4	13.8	4.7
2000	201	13.9	7.5	40.4	2.6	0.0	-0.7	68.1	25.9	2.8
2000	202	13.4	0.6	58.8	1.8	0.0	-4.7	86.2	29.0	1.8
2000	203	14.8	0.7	46.7	1.0	0.0	-8.6	80.4	15.3	1.9
2000	204	14.4	3.1	35.2	1.5	0.0	-8.2	67.5	10.9	2.8
2000	205	9.5	10.2	46.8	5.2	0.0	1.0	71.6	26.4	4.2
2000	206	9.5	11.4	56.8	3.2	0.3	6.6	80.5	32.8	3.1
2000	207	13.3	10.0	62.7	1.0	0.4	2.0	95.1	23.0	2.1
2000	208	14.4	7.8	52.0	1.0	0.0	-1.9	82.0	21.5	2.3
2000	209	14.1	8.6	49.9	1.4	0.0	0.9	82.6	20.1	2.7
2000	210	14.4	8.9	41.0	1.4	0.0	-0.6	74.6	15.3	3.0
2000	211	14.5	9.2	37.2	1.4	0.0	0.4	60.9	16.1	3.1
2000	212	14.5	9.3	39.3	1.3	0.0	0.1	66.8	16.3	2.9
2000	213	14.7	9.3	37.6	1.2	0.0	-0.8	66.1	15.4	2.9
2000	214	14.9	11.4	32.0	2.5	0.0	0.9	61.0	13.6	4.4
2000	215	14.2	14.0	37.4	5.5	0.0	7.4	52.9	22.9	5.8
2000	216	13.4	10.8	46.7	3.6	0.0	1.0	62.3	29.8	3.7
2000	217	11.9	4.2	42.3	1.1	0.0	-3.7	72.4	14.7	2.3
2000	218	16.7	5.5	27.2	1.5	0.0	-5.7	59.5	6.0	3.3
2000	219	16.7	6.9	19.2	1.7	0.0	-3.9	38.3	5.8	3.8
2000	220	15.8	8.5	24.0	1.5	0.0	-3.7	38.1	11.8	3.7
2000	221	15.7	10.8	31.5	1.7	0.0	-0.3	52.0	13.0	4.0
2000	222	15.8	11.6	31.0	1.5	0.0	1.3	57.2	11.6	3.8
2000	223	15.6	11.6	23.7	1.5	0.0	1.2	45.9	9.5	3.8
2000	224	15.8	11.0	25.4	1.5	0.0	1.8	45.1	13.3	3.5
2000	225	15.5	10.2	47.9	1.6	0.0	1.1	75.8	22.8	3.2
2000	226	17.1	9.8	36.2	1.8	0.0	1.1	70.7	10.1	4.0
2000	227	16.5	11.0	35.7	1.8	0.0	0.7	51.7	20.6	3.9
2000	228	16.6	12.2	38.8	1.4	0.0	2.6	68.0	16.5	3.5
2000	229	16.9	11.3	37.9	1.6	0.0	1.5	65.4	16.5	3.7
2000	230	16.9	11.6	34.8	1.5	0.0	2.0	60.7	15.1	3.8
2000	231	17.0	12.2	31.3	1.6	0.0	1.9	55.9	13.6	3.9
2000	232	12.6	15.3	41.9	4.1	0.0	11.1	68.2	16.2	5.7
2000	233	16.0	14.9	36.8	2.4	0.0	6.6	55.2	20.3	4.7
2000	234	14.3	16.8	34.1	4.4	0.0	11.0	61.6	17.2	6.2
2000	235	17.6	12.6	53.1	1.7	0.0	4.4	85.1	26.4	3.6
2000	236	15.3	15.4	43.6	3.0	0.0	5.8	63.3	21.5	5.3
2000	237	8.2	12.8	63.8	2.1	0.6	7.1	86.1	37.9	2.8
2000	238	17.1	12.8	57.3	1.5	0.0	3.7	90.8	24.7	3.6
2000	239	18.2	14.7	39.3	1.5	0.0	4.2	73.8	14.9	4.2
2000	240	18.5	14.4	30.3	1.8	0.0	3.3	58.9	12.9	4.7
2000	241	18.6	14.5	28.0	1.8	0.0	3.2	52.4	11.4	4.9
2000	242	19.3	14.9	23.2	2.1	0.0	3.6	48.5	8.3	5.5
2000	243	17.4	14.3	13.8	2.4	0.0	5.0	24.3	6.4	5.5
2000	244	18.6	12.4	24.5	2.8	0.0	3.4	40.3	15.2	5.2
2000	245	19.9	13.1	30.7	1.7	0.0	2.2	60.9	10.7	4.5
2000	246	18.8	17.9	19.5	3.9	0.0	4.4	41.1	8.8	8.2
2000	247	16.5	11.4	35.1	2.5	0.0	5.1	60.1	22.8	4.0

2000	248	20.7	8.5	43.2	1.7	0.0	-0.4	80.4	18.4	3.7
2000	249	21.0	10.4	29.6	1.7	0.0	-0.1	57.4	11.6	4.4
2000	250	21.1	11.7	24.3	2.2	0.0	0.0	47.4	9.7	5.3
2000	251	21.3	11.7	22.6	2.8	0.0	1.2	41.8	10.4	5.6
2000	252	20.2	13.0	26.0	3.5	0.0	1.0	55.4	12.4	6.3
2000	253	16.6	18.6	39.2	4.7	0.0	12.3	61.1	18.6	7.3
2000	254	20.8	14.6	30.8	3.5	0.0	3.8	64.1	11.2	5.7
2000	255	22.6	11.1	22.6	2.6	0.0	0.7	46.1	6.1	5.6
2000	256	20.1	15.5	50.1	7.3	0.0	7.8	72.9	25.9	7.1
2000	257	11.6	16.2	60.2	4.2	2.4	9.8	86.7	32.3	5.0
2000	258	16.7	13.7	61.2	2.7	0.2	8.6	92.3	30.8	4.0
2000	259	9.9	13.3	64.3	6.1	13.2	7.5	78.8	40.0	5.1
2000	260	9.0	15.1	71.1	3.5	0.0	11.1	84.7	46.8	3.4
2000	261	3.5	10.4	93.1	4.0	33.1	8.0	98.6	86.3	1.0
2000	262	19.5	9.2	75.6	3.0	0.0	5.3	94.8	52.6	3.0
2000	263	9.0	6.3	86.1	2.4	1.2	1.8	94.5	65.2	1.7
2000	264	19.3	10.6	72.3	3.7	0.0	4.9	95.4	46.8	3.5
2000	265	22.1	13.4	63.5	3.4	0.0	6.2	84.5	37.9	4.6
2000	266	21.7	17.5	52.9	2.6	0.0	12.7	79.1	27.1	5.3
2000	267	20.5	17.6	46.8	2.1	0.0	8.7	83.0	22.8	5.0
2000	268	21.1	18.9	41.8	4.7	0.0	11.4	60.5	21.6	7.4
2000	269	24.1	13.2	44.0	1.2	0.0	4.0	76.5	17.0	4.3
2000	270	24.5	12.9	35.7	2.3	0.0	3.8	72.4	9.1	5.6
2000	271	24.6	14.0	30.5	1.7	0.0	3.3	64.2	7.9	5.5
2000	272	23.6	17.5	33.4	2.2	0.0	5.4	55.4	13.4	6.6
2000	273	23.8	20.6	32.8	2.1	0.0	9.3	65.6	10.2	6.9
2000	274	18.5	23.2	25.9	3.8	0.0	14.7	40.3	12.8	8.6
2000	275	23.3	20.2	22.9	2.2	0.0	12.0	48.0	10.1	6.5
2000	276	23.1	18.3	33.6	2.7	0.0	7.6	59.4	16.5	7.0
2000	277	18.1	19.6	57.4	4.9	2.4	12.8	84.1	20.8	7.8
2000	278	15.3	17.8	71.0	5.0	19.6	14.5	99.0	35.3	5.5
2000	279	19.2	17.9	58.5	1.4	0.0	10.5	95.8	20.8	4.4
2000	280	23.7	16.7	40.4	1.5	0.0	7.1	75.8	13.1	5.2
2000	281	21.1	19.2	46.7	3.2	0.0	9.5	89.2	13.5	7.1
2000	282	11.9	18.9	61.5	6.6	0.8	14.3	83.2	36.3	5.9
2000	283	23.9	18.3	55.0	2.3	0.0	11.1	94.0	16.3	6.2
2000	284	24.6	17.9	38.8	1.5	0.0	7.3	74.2	12.8	5.7
2000	285	23.1	18.9	56.6	3.9	0.0	10.2	87.4	23.3	7.3
2000	286	23.2	20.0	56.0	4.4	0.0	12.7	81.1	32.3	6.9
2000	287	20.8	21.6	49.3	2.6	0.0	14.3	74.1	29.0	6.1
2000	288	19.1	22.0	46.6	2.0	6.6	15.2	70.5	24.6	5.7
2000	289	24.3	23.6	36.3	2.9	0.0	14.7	74.8	15.3	7.6
2000	290	25.4	24.8	23.2	3.3	0.0	18.8	34.6	12.2	9.2
2000	291	23.1	23.9	25.9	2.0	0.0	12.6	48.1	14.7	7.0
2000	292	18.8	25.2	26.1	3.3	0.0	19.5	39.5	14.5	8.4
2000	293	18.1	20.6	29.5	2.1	0.0	11.6	59.7	10.6	6.1
2000	294	11.7	18.6	59.0	4.0	0.3	15.1	75.0	32.5	5.5
2000	295	20.1	19.0	60.7	4.4	1.1	13.9	80.6	30.3	6.9
2000	296	18.9	17.7	70.9	4.4	9.6	13.0	91.7	34.0	5.9
2000	297	19.6	18.0	69.1	3.7	0.0	13.9	91.4	36.2	5.5
2000	298	19.4	18.2	61.2	3.1	5.7	13.5	85.3	33.6	5.3
2000	299	20.1	17.1	58.2	2.3	0.1	10.2	81.8	31.2	5.1
2000	300	18.0	17.3	60.8	2.1	0.0	10.4	93.2	27.3	4.8

2000	301	25.3	18.3	52.9	3.0	0.0	11.9	87.0	19.5	6.6
2000	302	24.8	19.3	56.7	3.5	0.0	12.8	89.2	29.4	6.4
2000	303	25.7	20.4	55.3	4.0	3.1	15.0	91.1	22.7	7.5
2000	304	26.4	14.3	56.8	4.3	0.0	7.6	92.5	22.6	6.0
2000	305	25.9	12.1	52.6	3.3	0.1	4.2	84.5	19.7	4.9
2000	306	28.3	11.4	49.1	1.8	0.0	2.0	85.8	23.9	6.0
2000	307	24.2	16.4	36.7	2.2	0.0	6.3	64.4	17.8	6.6
2000	308	16.5	17.6	48.1	4.6	0.4	12.4	79.7	24.0	7.1
2000	309	28.9	17.9	39.6	2.4	0.0	9.5	78.8	11.6	7.6
2000	310	28.8	19.5	27.0	2.2	0.0	7.1	60.4	10.5	8.3
2000	311	17.5	20.6	48.1	5.0	4.1	13.3	89.9	17.8	5.7
2000	312	21.1	19.1	66.5	5.1	9.8	14.1	94.3	43.2	7.1
2000	313	25.7	19.8	57.4	3.5	0.1	11.4	94.3	22.3	6.7
2000	314	28.9	19.8	53.4	2.2	0.0	11.4	87.4	24.5	7.3
2000	315	29.2	21.6	44.1	1.9	0.0	12.3	81.5	13.5	7.7
2000	316	28.2	24.1	34.5	2.0	0.0	12.5	78.8	12.3	10.1
2000	317	26.5	22.2	32.9	5.4	0.0	13.5	53.1	17.1	6.2
2000	318	27.6	15.1	49.9	4.3	0.0	7.6	72.9	31.2	5.6
2000	319	23.8	16.6	51.9	2.3	0.0	7.8	85.8	27.6	6.2
2000	320	25.6	19.2	45.1	1.8	0.0	9.3	80.7	21.0	8.2
2000	321	25.2	21.5	45.6	4.5	0.0	13.9	74.9	22.5	8.4
2000	322	23.9	20.7	57.3	6.7	15.5	14.7	94.3	25.6	3.3
2000	323	18.8	12.7	77.3	3.6	18.6	7.0	97.5	52.9	5.2
2000	324	21.7	15.4	64.6	4.2	0.0	6.6	95.3	38.8	4.2
2000	325	16.2	17.5	66.0	2.2	0.0	11.7	86.3	40.2	8.2
2000	326	30.3	18.6	55.3	3.9	0.0	10.2	90.4	13.6	5.9
2000	327	25.3	18.4	55.8	2.2	0.0	10.7	87.3	26.0	6.8
2000	328	26.3	20.0	52.5	2.7	0.0	12.9	77.6	25.9	8.5
2000	329	28.5	21.9	42.1	3.3	0.0	14.7	67.1	15.8	9.0
2000	330	28.8	20.8	52.6	4.7	0.0	11.6	83.8	19.2	7.2
2000	331	19.7	18.4	67.5	4.7	0.8	13.9	90.4	25.6	5.1
2000	332	14.9	19.4	64.7	4.0	0.5	14.3	85.8	40.2	3.4
2000	333	12.6	17.3	75.4	2.3	0.2	13.6	86.9	52.2	6.3
2000	334	26.5	19.9	60.4	2.2	0.0	12.3	92.7	29.5	7.5
2000	335	24.8	21.4	51.5	3.2	0.0	13.2	84.5	22.5	8.1
2000	336	28.5	22.9	49.8	3.3	0.0	15.5	78.7	22.0	7.9
2000	337	23.2	23.1	52.6	3.3	3.2	17.6	77.2	22.8	7.1
2000	338	23.0	20.4	61.6	3.5	2.5	13.9	84.1	29.1	9.0
2000	339	30.4	21.3	53.8	4.1	0.0	12.7	90.3	18.1	8.6
2000	340	24.1	21.5	52.9	4.3	2.3	14.7	73.1	24.3	9.0
2000	341	25.0	23.5	52.2	4.2	0.0	15.6	84.9	21.5	7.2
2000	342	22.0	21.9	56.6	4.8	3.2	16.8	83.0	32.5	4.7
2000	343	16.8	18.6	78.2	3.4	17.6	14.8	97.3	47.2	5.8
2000	344	22.6	19.7	72.7	3.6	3.8	15.1	90.1	46.2	4.1
2000	345	16.6	19.9	79.5	2.4	0.4	16.2	93.7	55.6	3.0
2000	346	11.2	17.3	85.0	3.1	25.3	14.3	97.5	56.5	6.6
2000	347	31.5	17.8	61.3	2.5	0.0	11.0	94.6	26.8	6.6
2000	348	31.4	18.6	53.4	1.8	0.0	9.2	86.1	24.6	8.7
2000	349	29.9	22.2	42.7	3.1	0.0	14.8	61.4	15.2	8.8
2000	350	30.6	23.1	45.8	3.3	0.0	13.5	86.1	16.4	6.6
2000	351	16.4	21.0	57.8	4.7	4.7	16.3	83.7	30.5	8.6
2000	352	26.9	22.1	55.0	5.1	0.0	14.9	88.8	23.9	7.7
2000	353	29.6	22.8	42.9	2.2	0.0	11.2	86.8	16.2	8.5

2000	354	29.7	23.3	49.9	3.2	0.0	15.7	75.2	24.2	6.9
2000	355	20.0	22.5	57.6	3.8	0.0	17.2	81.0	33.0	7.5
2000	356	27.8	21.9	55.0	3.3	0.0	16.2	77.3	32.8	7.7
2000	357	25.6	23.5	54.2	3.6	0.0	17.5	77.7	30.0	8.0
2000	358	28.4	24.9	49.4	2.8	0.0	15.9	83.0	25.2	11.4
2000	359	30.1	26.1	36.3	4.7	0.0	18.6	66.6	10.2	8.3
2000	360	29.6	22.4	41.6	3.1	0.0	15.2	75.0	17.1	7.3
2000	361	28.9	21.5	45.2	2.3	0.0	11.7	82.7	22.2	7.6
2000	362	23.7	21.4	58.0	4.5	10.4	17.3	81.3	29.7	7.5
2000	363	26.6	22.2	60.8	3.5	0.4	16.5	86.6	28.9	9.6
2000	364	31.1	23.6	43.7	3.5	0.0	16.9	76.4	10.3	8.7
2000	365	32.2	23.0	39.4	2.4	0.0	13.4	88.4	8.9	10.2
2000	366	28.3	22.6	31.4	3.6	0.0	12.0	59.8	10.3	4.7
2001	1	20.1	14.5	64.2	6.0	4.5	10.4	91.4	37.5	7.4
2001	2	31.6	15.7	48.9	4.4	0.0	6.9	84.0	21.1	6.9
2001	3	31.8	17.3	44.2	1.8	0.0	6.1	77.6	15.6	8.6
2001	4	31.5	22.4	32.3	2.5	0.0	13.2	58.7	12.3	9.6
2001	5	31.1	24.6	27.3	2.8	0.0	15.1	48.5	11.4	10.3
2001	6	30.5	26.6	27.8	3.1	0.0	17.0	66.6	8.9	11.4
2001	7	29.7	27.3	31.6	4.5	0.0	19.0	64.7	10.5	10.8
2001	8	29.7	25.7	38.6	4.9	0.0	17.4	67.6	17.2	12.7
2001	9	30.4	27.4	27.7	5.2	0.0	20.0	57.8	9.0	10.7
2001	10	32.0	25.7	15.2	3.0	0.0	16.1	28.1	6.7	9.5
2001	11	32.4	24.9	15.6	2.2	0.0	10.9	35.2	6.5	11.7
2001	12	28.5	27.7	34.2	4.9	0.0	16.1	81.9	12.7	8.2
2001	13	23.9	26.4	34.3	3.0	0.0	20.4	52.3	22.7	6.6
2001	14	21.3	17.3	44.1	3.5	0.0	11.9	69.4	14.4	7.3
2001	15	31.7	17.7	37.7	2.2	0.0	6.3	76.2	13.6	7.8
2001	16	31.4	21.1	31.9	1.9	0.0	10.0	63.2	12.2	8.4
2001	17	27.9	23.7	35.5	2.7	0.0	12.5	65.1	16.0	8.7
2001	18	21.6	23.7	49.4	4.9	3.8	18.0	73.6	25.7	7.5
2001	19	20.5	22.9	52.9	3.2	3.1	18.0	84.4	22.4	7.2
2001	20	22.7	22.6	58.6	3.0	0.2	16.8	85.5	25.3	8.8
2001	21	31.2	24.2	34.9	2.2	0.0	12.5	83.3	6.4	10.2
2001	22	29.0	26.1	41.2	4.2	0.1	17.2	79.7	16.0	10.1
2001	23	25.9	27.6	27.0	3.7	0.0	20.1	48.2	14.9	7.8
2001	24	20.1	25.3	42.9	3.0	0.3	18.9	78.6	20.2	7.5
2001	25	24.3	22.6	61.4	4.7	11.7	16.0	96.6	32.2	6.0
2001	26	21.2	21.6	64.2	3.2	0.0	15.7	88.6	38.5	7.3
2001	27	25.9	23.4	53.3	3.1	0.0	17.3	80.1	29.3	6.9
2001	28	22.4	22.9	56.5	3.2	0.0	16.5	79.6	31.8	6.3
2001	29	20.9	22.2	64.7	2.7	7.4	15.9	88.6	32.1	8.4
2001	30	26.7	24.6	49.2	3.1	0.0	18.0	88.9	15.4	8.3
2001	31	29.2	22.8	40.4	2.4	0.0	11.9	86.5	8.7	10.3
2001	32	28.6	24.4	40.0	4.4	0.0	17.5	78.8	8.2	9.3
2001	33	26.3	23.5	32.9	3.9	0.0	13.9	67.4	17.7	8.0
2001	34	29.7	21.5	42.3	3.1	0.0	14.4	87.8	13.4	7.2
2001	35	30.0	20.5	39.3	2.0	0.0	9.9	82.5	17.8	8.1
2001	36	29.1	22.7	45.9	2.8	0.0	15.2	77.1	17.8	8.0
2001	37	27.7	25.6	30.5	2.0	0.0	16.9	55.4	12.3	9.9
2001	38	26.9	26.5	31.9	3.7	0.0	18.3	57.6	14.2	10.5
2001	39	24.4	25.7	34.7	5.1	0.0	19.7	54.9	17.0	7.3
2001	40	22.3	21.5	48.3	3.9	0.1	13.7	71.9	28.4	7.3

2001	41	25.2	22.5	48.8	3.3	0.1	16.6	74.7	25.4	7.3
2001	42	24.3	23.6	44.3	2.8	0.0	15.7	74.9	22.5	7.6
2001	43	21.3	23.1	49.8	3.8	0.0	18.4	65.8	28.0	6.2
2001	44	19.2	22.5	57.0	2.8	0.8	16.5	90.0	28.4	6.8
2001	45	28.3	21.5	60.0	2.5	0.7	15.4	95.7	23.5	6.8
2001	46	26.5	21.6	50.5	2.0	0.0	14.1	82.9	18.9	7.6
2001	47	25.1	23.9	45.5	2.7	0.0	15.6	82.7	20.7	8.3
2001	48	17.9	23.5	50.1	4.4	0.0	18.3	71.1	24.2	2.4
2001	49	5.3	16.5	87.4	3.4	29.6	13.8	95.4	60.2	5.7
2001	50	24.0	19.1	70.1	2.3	0.0	13.9	96.3	28.7	6.1
2001	51	24.5	22.0	55.7	2.1	0.0	13.5	91.3	26.1	6.6
2001	52	25.5	22.7	56.9	2.7	0.0	15.8	84.2	31.5	6.6
2001	53	21.6	22.8	55.4	3.4	0.0	17.8	71.7	39.1	7.5
2001	54	23.9	23.7	52.5	3.0	0.0	18.1	76.7	24.0	5.8
2001	55	21.1	21.6	63.0	3.4	8.4	15.7	95.8	37.8	5.4
2001	56	21.6	21.5	66.6	2.3	0.0	16.1	91.8	37.5	4.9
2001	57	18.8	21.0	66.4	2.2	2.1	15.0	93.3	37.2	3.5
2001	58	12.0	18.0	75.8	2.6	12.5	13.9	97.0	49.3	5.1
2001	59	22.1	18.5	65.2	2.0	0.0	11.5	92.9	30.5	5.2
2001	60	24.1	19.2	61.9	1.6	0.0	11.7	92.3	30.4	6.0
2001	61	25.0	21.5	50.6	1.6	0.0	13.3	84.8	20.0	7.2
2001	62	24.2	23.3	39.9	2.3	0.0	12.8	73.9	17.7	6.2
2001	63	23.9	22.9	42.6	1.7	0.4	13.8	77.2	18.6	7.2
2001	64	16.0	24.7	42.6	3.6	0.3	19.7	55.4	28.7	5.8
2001	65	19.3	24.5	46.9	1.8	0.0	17.5	72.9	22.3	7.5
2001	66	21.0	24.9	42.2	3.0	0.0	18.5	67.1	20.7	7.1
2001	67	23.6	25.2	41.8	2.4	0.1	19.0	67.4	21.1	8.5
2001	68	21.0	23.9	44.5	4.0	0.0	15.7	64.4	21.3	7.3
2001	69	23.7	24.4	47.2	2.9	0.0	17.6	73.4	23.9	7.8
2001	70	20.6	22.7	55.8	4.6	0.1	17.5	82.2	26.0	7.1
2001	71	24.6	21.5	44.8	2.5	0.0	14.1	84.3	10.5	7.2
2001	72	23.2	20.6	52.1	3.6	0.0	9.7	82.1	24.9	6.4
2001	73	22.6	20.8	53.8	2.9	0.0	14.1	79.3	26.7	6.2
2001	74	23.1	22.0	41.5	2.1	0.0	14.9	71.6	21.5	6.6
2001	75	23.0	24.0	35.1	2.0	0.0	16.5	55.1	17.8	6.4
2001	76	21.2	24.5	35.9	2.0	0.0	15.6	60.6	16.7	4.9
2001	77	14.4	20.2	56.1	2.9	0.0	15.0	69.4	38.3	6.2
2001	78	19.9	18.8	60.0	5.8	5.0	14.1	95.7	34.3	3.5
2001	79	12.1	17.4	76.8	2.8	0.0	13.8	90.7	51.0	3.0
2001	80	12.5	16.4	81.1	2.0	0.0	11.9	94.0	55.1	2.1
2001	81	6.5	16.4	88.6	2.7	4.0	14.2	97.5	67.6	1.5
2001	82	4.5	15.6	93.0	2.8	18.0	14.5	97.2	79.2	3.6
2001	83	16.6	18.3	81.4	2.1	0.0	15.2	96.0	53.0	3.8
2001	84	16.2	18.8	75.6	1.6	0.0	14.9	97.0	36.0	4.5
2001	85	20.3	20.0	59.8	1.5	42.0	12.2	93.3	28.1	4.9
2001	86	20.5	20.2	52.7	1.5	0.0	12.0	88.7	16.7	4.5
2001	87	19.9	19.8	58.1	1.3	0.0	11.3	83.6	25.9	4.0
2001	88	16.4	20.5	59.8	1.2	0.0	13.1	86.0	27.3	6.0
2001	89	16.2	22.3	52.3	3.3	0.0	17.1	68.4	29.6	3.5
2001	90	11.1	19.5	66.5	2.6	0.0	17.0	76.9	51.8	2.0
2001	91	6.3	16.5	81.6	2.0	0.0	13.2	93.4	64.3	4.0
2001	92	16.3	16.7	76.2	2.0	32.0	8.6	99.9	35.5	2.9
2001	93	12.9	17.2	84.3	2.4	0.0	13.6	97.4	62.0	3.7

2001	94	15.6	16.9	78.3	3.1	0.0	11.3	95.2	52.6	3.9
2001	95	15.1	17.3	75.4	4.1	0.0	13.5	89.2	54.5	2.6
2001	96	9.0	16.8	76.7	3.5	0.0	13.4	85.8	66.3	1.1
2001	97	2.6	14.7	92.4	3.0	0.0	13.7	97.4	80.8	1.0
2001	98	4.5	15.1	95.2	2.5	22.0	13.6	97.6	90.6	3.1
2001	99	18.4	14.5	79.4	1.4	0.0	9.4	99.7	45.7	3.0
2001	100	17.3	14.6	73.3	1.2	0.0	7.5	93.5	45.6	3.5
2001	101	19.7	15.9	69.5	1.1	0.0	9.5	93.7	33.5	3.6
2001	102	18.7	16.5	66.3	1.3	0.0	8.4	91.6	34.6	4.0
2001	103	19.1	17.0	64.7	1.5	0.0	10.0	92.0	28.9	2.6
2001	104	9.2	15.4	81.3	2.5	0.0	12.8	95.5	55.6	3.2
2001	105	14.6	16.6	78.8	3.3	0.0	12.4	92.6	58.7	1.0
2001	106	4.0	14.5	95.6	2.5	0.0	12.1	98.3	89.4	2.4
2001	107	15.8	13.7	85.2	0.8	0.0	9.5	99.7	56.2	2.9
2001	108	18.2	14.4	76.2	1.1	0.0	8.1	96.3	45.2	2.8
2001	109	15.1	15.1	76.7	1.2	0.0	8.3	95.2	46.3	3.1
2001	110	16.7	16.7	72.6	1.0	0.0	10.2	94.7	37.2	3.2
2001	111	16.1	16.3	71.6	1.3	0.0	9.5	93.8	38.0	3.4
2001	112	15.7	16.0	75.6	2.1	3.0	10.3	95.7	44.1	3.7
2001	113	14.3	16.5	75.2	4.1	11.8	12.9	88.1	53.6	3.4
2001	114	14.1	16.6	75.3	5.5	18.0	12.6	91.1	58.8	2.6
2001	115	15.3	14.9	75.4	1.0	0.0	9.1	96.1	46.8	3.4
2001	116	14.4	15.4	77.6	2.3	6.3	9.1	95.7	44.8	1.1
2001	117	4.4	12.4	94.5	2.0	9.3	9.5	97.3	83.1	2.4
2001	118	16.5	12.5	81.9	1.1	0.1	7.0	99.6	49.9	3.2
2001	119	16.1	14.6	70.1	1.6	0.0	7.5	92.6	36.2	1.6
2001	120	5.7	13.7	82.7	2.1	1.0	9.1	94.3	72.5	1.3
2001	121	3.8	13.7	86.9	2.6	6.8	10.3	94.4	77.5	1.1
2001	122	3.0	12.9	92.1	3.8	8.4	11.6	97.4	82.0	1.3
2001	123	5.5	13.2	91.7	3.2	3.1	11.6	97.5	80.1	2.5
2001	124	12.4	14.5	83.5	3.0	5.2	11.4	96.0	58.7	1.3
2001	125	6.2	8.3	88.1	3.5	2.2	1.0	96.0	76.8	1.7
2001	126	15.9	4.1	80.9	1.7	0.1	-1.2	96.8	55.3	2.0
2001	127	15.5	7.1	75.4	1.0	0.0	0.2	96.2	42.1	2.5
2001	128	15.5	10.3	71.7	1.3	0.0	2.9	93.8	37.0	2.9
2001	129	15.6	12.8	64.0	1.3	0.0	4.6	91.2	27.4	3.4
2001	130	15.2	13.9	57.9	1.7	0.0	5.8	87.3	24.0	2.9
2001	131	15.3	12.7	66.3	1.3	0.0	4.6	91.3	27.3	2.8
2001	132	15.1	13.3	66.2	1.3	0.0	5.0	91.4	29.9	2.8
2001	133	14.7	13.5	66.5	1.2	0.0	6.0	89.7	31.1	2.8
2001	134	14.9	13.1	68.2	1.2	0.0	5.9	93.2	29.9	2.6
2001	135	14.6	12.9	66.8	1.2	0.0	5.6	91.9	30.9	2.6
2001	136	14.5	12.5	66.9	1.3	0.0	4.9	91.6	32.4	2.6
2001	137	14.2	12.1	68.5	1.3	0.0	4.3	91.7	33.0	2.6
2001	138	14.5	12.2	64.8	1.2	0.0	4.8	91.4	27.6	2.9
2001	139	14.0	12.4	60.3	1.5	0.0	4.4	88.3	27.6	2.7
2001	140	14.1	12.8	57.4	1.4	0.0	6.3	83.3	29.2	3.1
2001	141	13.7	12.6	58.5	1.9	0.0	4.6	82.2	27.8	2.3
2001	142	14.3	8.7	62.1	1.4	0.0	2.1	96.1	24.1	2.5
2001	143	14.1	9.0	56.6	1.3	0.0	1.0	82.5	22.8	2.9
2001	144	14.1	11.1	54.9	1.4	0.0	2.6	84.1	20.7	4.5
2001	145	13.6	14.8	51.3	3.6	0.0	3.5	75.5	28.0	2.6
2001	146	13.7	12.3	60.9	2.3	0.0	5.4	81.1	42.6	2.5

2001	147	14.3	8.6	64.0	1.3	0.0	-0.1	94.8	24.7	2.6
2001	148	12.9	11.9	69.1	2.1	0.0	2.4	86.5	45.3	3.0
2001	149	11.0	14.4	65.2	3.3	0.0	11.4	80.0	46.3	2.6
2001	150	11.5	14.3	67.3	2.2	0.0	7.8	88.4	44.5	3.4
2001	151	9.9	16.1	57.1	2.5	0.0	12.1	76.0	30.8	3.5
2001	152	11.0	15.3	57.9	2.8	0.0	10.9	76.8	35.2	2.5
2001	153	10.5	13.7	76.2	2.0	0.1	10.4	91.6	43.7	2.8
2001	154	12.5	14.3	66.0	1.8	0.3	7.2	93.6	33.2	2.5
2001	155	13.2	14.1	59.8	1.3	0.0	7.8	83.2	31.0	2.7
2001	156	13.2	12.5	60.7	1.5	0.0	4.2	88.4	29.2	2.9
2001	157	12.2	12.6	58.7	2.3	0.0	5.7	81.7	34.0	2.8
2001	158	11.3	12.4	62.9	2.6	0.0	7.8	77.0	43.7	2.2
2001	159	12.4	12.0	63.8	1.4	0.0	6.5	82.6	38.5	2.0
2001	160	12.6	10.2	66.9	1.0	0.0	3.6	89.9	32.7	2.3
2001	161	12.8	10.4	63.4	1.3	0.0	2.6	90.2	31.0	2.1
2001	162	12.7	10.2	58.7	1.1	0.0	3.2	83.4	28.3	2.3
2001	163	12.9	9.2	60.9	1.4	0.0	2.2	84.1	29.7	3.0
2001	164	12.4	9.8	55.0	2.1	0.0	2.9	82.3	24.1	2.2
2001	165	12.6	8.6	60.0	1.4	0.0	1.1	86.2	29.9	2.0
2001	166	12.8	8.1	60.7	1.0	0.0	0.3	87.3	29.3	2.3
2001	167	12.4	8.6	57.9	1.4	0.0	1.2	81.9	28.4	2.4
2001	168	10.9	10.4	57.9	1.7	0.0	0.9	84.5	34.3	3.0
2001	169	12.6	11.8	52.7	2.7	0.0	4.5	75.8	32.5	2.1
2001	170	13.3	6.0	62.3	1.6	0.0	-1.0	92.8	26.1	2.1
2001	171	12.9	6.1	56.6	1.2	0.0	-2.9	85.2	24.0	2.2
2001	172	12.0	7.2	59.2	1.3	0.0	-2.5	86.9	28.6	2.1
2001	173	13.0	7.1	55.7	1.0	0.0	-1.5	87.6	18.4	2.7
2001	174	13.1	8.3	48.6	1.5	0.0	-0.7	79.4	17.5	2.7
2001	175	11.1	10.2	61.3	3.1	0.0	5.7	78.1	44.6	1.2
2001	176	5.7	8.6	89.4	2.4	15.2	6.0	96.6	72.0	1.2
2001	177	8.5	6.6	88.9	1.2	0.1	1.7	98.7	64.8	1.5
2001	178	12.1	6.6	80.8	1.1	0.1	0.8	97.8	48.0	2.3
2001	179	12.9	7.6	70.3	2.2	0.0	-0.2	95.9	38.2	1.2
2001	180	3.5	7.5	82.6	2.8	2.7	5.2	96.0	64.3	1.3
2001	181	12.3	6.1	82.4	1.3	0.0	-0.5	98.7	53.2	2.0
2001	182	13.5	4.7	71.50	1.50	0.1	-2.7	95.10	29.80	3.2
2001	183	12.7	10.6	60.79	3.37	0.0	3.5	84.30	36.29	3.2
2001	184	12.7	12.1	55.30	2.61	0.0	4.2	85.90	28.16	4.2
2001	185	11.7	12.8	50.62	5.22	0.0	5.3	81.00	32.18	1.4
2001	186	13.6	2.5	73.30	1.54	0.0	-2.4	93.10	45.68	2.0
2001	187	13.4	1.8	64.64	1.61	0.0	-5.1	92.20	24.38	3.1
2001	188	10.5	10.9	70.78	5.89	0.0	5.6	87.50	49.85	2.9
2001	189	9.7	12.9	66.94	5.04	0.0	9.3	85.40	50.66	1.8
2001	190	7.3	11.5	79.08	4.05	1.7	8.4	89.30	68.57	2.6
2001	191	12.0	9.6	66.20	2.79	0.3	-0.6	91.00	32.46	2.0
2001	192	13.9	4.9	66.28	1.16	0.0	-3.6	94.00	26.51	2.4
2001	193	13.0	7.3	59.85	1.27	0.0	-1.9	88.70	21.70	2.5
2001	194	13.2	8.7	55.70	1.26	0.0	1.0	84.00	22.75	2.9
2001	195	13.0	9.6	50.93	1.79	0.0	2.7	69.55	25.72	2.6
2001	196	11.9	9.0	58.71	1.90	0.0	2.1	82.30	32.67	3.3
2001	197	12.3	11.7	49.47	2.75	0.0	5.0	67.90	32.27	2.8
2001	198	13.6	8.8	56.59	1.75	0.0	0.2	90.00	21.85	2.5
2001	199	14.1	6.1	60.72	1.91	0.0	-2.5	88.50	27.56	1.6

2001	200	9.8	3.9	73.10	2.05	0.0	-2.3	91.20	46.63	1.8
2001	201	10.1	2.9	75.09	2.28	0.0	-4.2	92.60	41.31	2.4
2001	202	12.9	4.0	68.92	2.73	0.0	-0.5	95.00	32.61	2.3
2001	203	14.6	4.6	61.68	1.49	0.0	-5.3	95.10	23.76	2.6
2001	204	14.3	4.0	60.88	4.07	0.0	-2.4	92.10	31.00	2.1
2001	205	14.8	2.8	63.84	1.80	0.0	-4.2	92.10	28.84	2.7
2001	206	15.1	5.0	56.65	1.68	0.0	-4.4	90.90	18.49	2.3
2001	207	14.5	7.1	57.79	1.43	0.0	-0.8	89.50	28.93	2.5
2001	208	14.8	6.5	57.87	1.30	0.0	-2.6	87.10	26.38	2.8
2001	209	15.2	7.0	52.67	1.41	0.0	-2.6	84.90	20.22	4.2
2001	210	15.1	9.4	43.52	2.65	0.0	-1.4	76.40	16.04	3.5
2001	211	15.0	10.8	55.52	3.33	0.0	2.9	83.90	32.42	3.6
2001	212	14.3	11.3	56.24	3.12	0.0	6.7	71.30	33.21	2.7
2001	213	15.2	10.9	54.53	1.25	0.0	2.9	82.10	28.18	3.0
2001	214	15.5	9.7	53.82	1.49	0.0	1.4	82.70	24.16	3.1
2001	215	15.5	9.5	48.42	1.33	0.0	-0.2	83.50	17.12	3.3
2001	216	15.5	10.0	42.51	1.41	0.0	-0.2	73.10	16.13	3.5
2001	217	15.3	12.0	51.56	2.01	0.0	4.4	87.40	22.22	3.4
2001	218	15.7	12.4	47.60	1.76	0.5	4.3	76.70	21.83	3.0
2001	219	15.5	11.2	49.44	1.34	0.0	2.5	79.40	23.50	3.3
2001	220	15.7	11.9	43.84	1.42	0.0	3.1	72.40	20.01	4.0
2001	221	15.0	12.0	42.65	2.61	0.0	1.5	72.80	22.58	3.5
2001	222	12.9	9.5	45.05	4.10	0.0	1.4	63.43	31.74	3.2
2001	223	17.1	6.5	57.34	2.30	0.0	-1.2	91.20	24.15	3.0
2001	224	17.5	5.6	55.27	1.64	0.0	-3.0	90.00	21.34	3.9
2001	225	17.5	8.9	40.44	2.03	0.0	-1.9	72.20	14.35	3.9
2001	226	16.8	10.9	37.16	2.89	0.0	2.1	63.72	25.36	2.8
2001	227	17.4	5.6	52.66	1.63	0.0	-3.7	84.70	23.85	3.0
2001	228	17.7	4.8	46.85	1.81	0.0	-3.7	78.70	17.91	3.1
2001	229	18.3	5.3	40.41	1.55	0.0	-3.9	67.64	16.56	3.4
2001	230	18.5	6.5	35.11	1.54	0.0	-3.7	64.63	13.25	5.1
2001	231	18.1	10.7	26.92	2.51	0.0	-2.1	51.02	10.96	3.8
2001	232	18.4	9.8	25.41	1.55	0.0	-0.7	47.00	11.45	4.1
2001	233	18.0	11.4	26.11	1.88	0.0	1.3	44.71	14.19	3.2
2001	234	18.9	6.3	44.31	1.53	0.0	-4.2	77.20	17.60	5.0
2001	235	19.2	11.5	28.68	2.28	0.0	-1.8	62.44	9.61	3.9
2001	236	18.7	10.4	32.22	2.03	0.0	1.9	61.48	19.38	3.8
2001	237	19.0	9.0	43.98	1.77	0.0	-1.1	77.80	17.42	4.8
2001	238	19.3	11.6	33.29	2.02	0.0	-0.2	64.14	11.30	4.8
2001	239	19.8	11.7	30.78	1.90	0.0	0.8	62.68	9.72	5.2
2001	240	12.6	15.2	56.53	4.94	9.6	8.4	94.50	27.81	1.7
2001	241	3.2	13.7	80.70	4.18	1.1	10.6	95.90	70.00	2.9
2001	242	6.0	13.6	76.12	5.37	5.2	10.2	94.60	52.37	2.3
2001	243	11.4	7.5	74.90	3.97	2.9	1.0	94.00	50.22	2.8
2001	244	19.6	7.0	70.40	1.20	0.1	-1.3	95.20	30.96	3.6
2001	245	20.0	9.9	58.64	1.64	0.0	1.0	91.50	24.26	5.6
2001	246	20.1	14.5	37.90	3.05	0.0	4.7	71.50	13.24	4.5
2001	247	21.0	10.6	41.98	1.94	0.0	2.7	71.90	10.73	6.0
2001	248	20.9	12.2	35.44	3.04	0.0	-0.5	69.69	10.54	3.8
2001	249	20.7	9.1	54.98	1.96	0.0	2.2	91.60	20.96	4.3
2001	250	21.0	11.5	45.47	1.42	0.0	-0.5	85.40	12.21	5.8
2001	251	19.1	16.4	39.97	2.98	0.0	6.5	64.01	19.12	7.3
2001	252	18.5	19.5	31.99	3.61	0.0	12.8	52.10	14.71	5.5

2001	253	19.7	16.2	32.61	2.03	0.0	4.9	66.18	11.18	2.5
2001	254	6.5	10.1	44.60	1.68	0.0	3.8	69.31	27.09	3.8
2001	255	14.5	9.0	62.06	3.36	0.0	1.5	81.90	29.52	1.1
2001	256	3.2	7.3	86.71	2.54	15.1	5.8	97.60	75.30	3.9
2001	257	16.9	10.3	69.39	4.50	0.4	3.6	95.80	38.71	4.9
2001	258	20.8	11.8	62.36	7.36	0.0	5.3	76.20	44.54	3.5
2001	259	15.9	13.2	74.23	2.98	1.1	8.6	91.20	50.57	4.9
2001	260	18.5	17.2	59.90	2.60	0.0	9.6	88.50	28.36	2.7
2001	261	4.8	15.6	62.94	2.76	0.2	12.6	85.40	43.16	3.4
2001	262	11.9	14.5	83.02	2.91	8.1	11.5	96.40	44.44	1.5
2001	263	5.5	13.9	87.85	1.76	1.9	11.0	94.90	72.80	4.2
2001	264	15.6	15.7	65.32	2.62	0.2	10.7	86.60	35.52	3.4
2001	265	16.9	15.1	70.17	1.62	0.0	7.6	93.10	46.28	4.2
2001	266	19.9	16.9	66.21	1.81	0.0	9.3	94.50	37.74	5.2
2001	267	21.7	17.1	54.75	2.37	0.0	8.8	90.70	27.27	4.4
2001	268	22.9	13.0	51.87	1.68	0.0	3.4	84.90	24.52	5.5
2001	269	23.3	14.7	42.19	2.18	0.0	4.1	81.00	13.81	5.1
2001	270	23.0	10.6	48.06	4.17	0.0	3.8	73.90	24.62	5.0
2001	271	23.1	12.4	49.91	2.17	0.0	2.2	85.40	20.78	5.3
2001	272	23.0	15.1	46.21	1.80	0.0	4.1	79.20	19.41	5.8
2001	273	23.1	17.8	40.75	1.86	0.0	7.1	70.90	16.92	6.7
2001	274	22.6	18.3	39.20	2.44	0.0	8.2	71.00	17.28	6.4
2001	275	22.8	19.1	42.47	2.24	0.0	7.7	79.70	15.62	6.9
2001	276	22.8	20.4	44.91	3.14	0.0	13.5	70.70	21.33	6.3
2001	277	18.0	21.0	39.80	2.68	0.0	11.6	67.21	21.26	8.3
2001	278	21.3	20.3	35.71	4.09	0.0	12.0	59.98	14.03	5.1
2001	279	25.5	12.9	36.55	1.75	0.0	2.1	73.30	13.33	5.6
2001	280	25.2	14.1	31.19	1.66	0.0	2.3	57.61	11.79	7.5
2001	281	22.3	18.9	50.92	4.93	0.0	11.4	77.00	23.24	7.0
2001	282	23.0	18.7	52.11	3.81	0.0	11.7	78.00	25.59	6.5
2001	283	23.6	21.1	39.94	2.10	0.0	11.9	68.38	17.38	7.3
2001	284	23.5	23.2	35.53	2.51	0.0	12.5	67.84	17.17	10.0
2001	285	23.4	24.3	27.26	4.21	0.0	17.4	41.72	12.82	6.4
2001	286	24.5	20.3	35.53	1.84	0.0	10.7	67.43	12.63	6.9
2001	287	23.9	20.9	43.80	2.38	0.0	12.7	80.50	16.02	4.4
2001	288	10.8	19.5	62.26	2.98	10.0	13.8	92.40	34.87	6.1
2001	289	18.6	18.6	65.55	4.42	2.4	13.6	91.00	34.02	6.8
2001	290	20.8	19.0	55.49	4.31	0.0	11.3	79.20	25.46	5.9
2001	291	26.5	15.6	49.50	2.19	0.0	6.4	90.30	17.15	5.9
2001	292	26.7	16.0	46.34	2.09	0.0	6.1	80.90	18.90	5.5
2001	293	18.0	17.4	67.92	4.78	42.2	12.3	89.60	37.95	5.1
2001	294	19.7	17.1	71.14	4.52	10.1	12.7	93.70	43.24	4.0
2001	295	14.6	17.2	75.44	2.80	0.0	12.7	89.60	50.49	7.2
2001	296	23.6	21.7	58.70	3.09	5.4	15.1	80.50	25.05	4.1
2001	297	16.8	18.5	70.35	2.84	1.4	15.1	91.40	50.31	1.9
2001	298	6.0	14.9	88.63	3.49	11.9	11.7	95.70	70.90	4.8
2001	299	14.7	17.9	78.47	3.29	6.8	14.4	94.80	38.98	4.6
2001	300	22.0	19.3	73.43	2.13	0.0	14.3	94.40	51.33	5.0
2001	301	18.4	19.2	73.85	5.06	0.0	15.1	91.10	50.51	5.5
2001	302	20.5	18.8	70.66	4.42	6.1	13.9	92.50	43.33	5.8
2001	303	21.7	19.0	62.98	4.48	0.0	12.4	89.30	43.05	3.7
2001	304	13.8	15.6	61.90	2.06	0.0	9.7	83.20	43.44	5.6
2001	305	28.2	16.9	63.06	1.68	0.0	7.2	95.90	29.37	7.1

2001	306	27.6	20.9	55.04	3.59	0.0	14.4	79.20	32.17	7.3
2001	307	24.0	22.6	50.42	3.46	0.2	17.5	69.27	30.39	5.3
2001	308	22.3	16.0	55.34	3.21	0.0	8.2	80.70	29.16	6.5
2001	309	29.7	16.6	45.15	2.12	0.0	5.3	85.40	18.42	7.4
2001	310	19.4	21.5	42.43	4.34	0.0	12.1	55.29	33.13	6.2
2001	311	28.1	17.8	40.78	1.72	0.0	9.0	70.80	22.25	2.8
2001	312	9.5	15.5	82.26	5.01	14.5	11.2	94.60	66.78	2.6
2001	313	9.4	13.3	87.74	4.26	42.4	10.4	99.90	61.76	2.4
2001	314	9.0	16.4	86.67	4.20	2.5	13.2	97.40	72.00	3.5
2001	315	16.9	18.8	80.97	1.22	0.7	14.0	97.40	62.94	5.7
2001	316	28.4	19.0	68.93	1.81	0.0	12.0	94.60	36.54	4.7
2001	317	19.7	18.9	70.00	3.43	0.0	14.0	87.20	52.65	5.3
2001	318	21.1	18.7	76.31	3.28	1.0	15.5	92.20	46.95	4.0
2001	319	16.5	18.4	80.29	2.02	3.9	13.8	95.80	50.79	2.3
2001	320	10.0	16.5	88.19	3.28	3.3	15.2	94.80	76.20	3.0
2001	321	12.0	17.9	80.25	2.55	0.0	15.3	90.50	65.75	3.6
2001	322	15.6	19.0	79.61	2.57	0.3	15.1	93.50	62.08	3.6
2001	323	14.6	18.6	81.14	3.40	4.9	15.3	97.20	60.10	3.9
2001	324	17.6	16.9	86.33	2.23	11.6	12.6	97.10	57.97	5.3
2001	325	30.9	15.7	67.43	1.24	0.1	8.3	98.20	35.18	6.2
2001	326	30.4	18.5	58.72	1.72	0.0	8.7	88.80	29.50	6.4
2001	327	21.7	21.7	55.31	3.33	2.3	16.5	79.70	37.06	5.4
2001	328	21.1	21.1	71.97	3.40	0.8	17.1	89.20	53.17	3.6
2001	329	12.3	18.7	81.13	3.58	18.8	15.7	98.10	59.27	4.1
2001	330	20.1	18.4	83.70	2.28	2.2	15.2	97.80	61.02	5.4
2001	331	24.8	20.0	73.42	1.85	0.0	14.2	97.20	39.06	5.9
2001	332	26.5	19.2	70.36	3.31	0.0	13.3	85.00	47.54	5.6
2001	333	27.7	20.0	74.60	2.28	0.0	15.5	95.90	48.54	5.6
2001	334	27.5	20.3	76.00	2.34	18.7	13.6	98.20	49.21	5.8
2001	335	26.2	21.0	70.30	2.66	0.2	15.9	94.00	48.12	5.9
2001	336	24.8	19.0	65.85	2.81	0.7	13.8	87.80	36.73	6.6
2001	337	30.7	18.7	62.91	2.50	0.0	11.5	94.60	30.28	2.6
2001	338	8.8	15.9	83.12	6.17	11.4	12.7	95.60	67.68	4.9
2001	339	24.1	17.3	78.19	2.47	3.9	11.9	95.60	49.78	5.7
2001	340	29.9	19.1	66.52	1.11	0.1	10.9	95.60	34.17	6.5
2001	341	28.4	21.0	62.65	2.08	0.0	13.0	92.10	31.66	5.1
2001	342	19.2	20.2	75.55	3.42	17.8	15.9	93.80	51.45	4.5
2001	343	20.8	20.4	77.72	1.48	2.0	15.7	96.10	52.17	3.1
2001	344	15.1	19.3	89.08	1.98	11.4	17.4	97.70	72.90	6.0
2001	345	30.9	18.9	68.93	1.82	0.1	12.5	98.90	33.21	6.3
2001	346	29.4	18.5	64.77	2.68	0.0	10.3	92.60	34.63	4.6
2001	347	19.7	19.3	75.94	4.38	16.5	14.0	100.00	55.68	6.4
2001	348	30.9	20.2	71.31	1.91	0.0	13.5	94.60	35.66	6.4
2001	349	30.9	21.0	64.09	1.41	0.0	14.0	93.90	29.62	7.3
2001	350	30.0	23.4	56.01	2.49	0.0	17.7	84.30	31.16	7.0
2001	351	31.7	21.0	58.09	1.82	0.0	12.1	91.10	21.82	6.9
2001	352	22.1	20.4	69.00	3.92	4.2	13.2	90.70	35.63	7.8
2001	353	29.8	20.2	65.20	4.22	0.0	13.4	91.50	25.31	5.8
2001	354	30.8	17.5	67.75	1.70	0.0	9.2	94.60	37.19	6.6
2001	355	31.3	20.3	55.47	1.56	0.0	11.3	91.20	26.53	7.2
2001	356	27.2	23.0	48.19	2.34	0.5	13.4	76.30	26.70	2.9
2001	357	11.0	16.7	85.29	2.29	18.4	14.0	97.90	60.48	5.2
2001	358	25.2	20.4	76.70	2.41	2.3	13.4	94.00	57.47	6.3

2001	359	30.8	19.5	63.76	2.10	1.8	13.4	95.70	31.02	6.0
2001	360	31.6	18.3	57.16	1.25	0.0	9.3	87.30	29.39	6.5
2001	361	29.6	20.7	67.20	2.29	0.0	14.6	91.00	37.13	6.9
2001	362	29.9	22.4	60.75	2.50	0.0	16.3	83.10	37.02	7.1
2001	363	28.8	23.0	57.69	2.71	4.2	16.3	86.20	36.23	6.8
2001	364	28.1	22.2	63.81	2.35	0.5	15.8	89.10	37.14	8.0
2001	365	25.8	22.2	54.42	4.05	0.0	16.8	75.40	30.23	8.9
2002	1	30.6	23.5	47.5	3.1	0.0	15.2	74.2	20.8	8.9
2002	2	31.8	22.2	48.7	2.1	0.0	9.8	83.9	13.5	8.1
2002	3	27.4	22.2	57.7	4.1	5.9	15.9	81.5	33.8	7.9
2002	4	30.5	23.8	60.2	2.7	0.4	16.4	87.6	32.8	7.6
2002	5	29.6	23.4	59.6	2.3	0.0	14.2	91.9	27.2	7.5
2002	6	27.9	24.0	60.2	3.2	4.2	17.2	92.7	27.7	7.8
2002	7	22.2	19.1	65.0	3.2	8.2	10.0	95.8	34.2	5.7
2002	8	31.4	18.2	60.1	2.1	0.0	6.8	94.2	25.9	6.9
2002	9	21.7	20.1	63.0	4.5	12.2	14.9	94.2	31.8	7.2
2002	10	30.0	22.0	67.8	3.5	0.6	14.9	92.1	43.4	6.9
2002	11	25.1	22.7	66.2	3.8	7.3	17.0	89.8	42.5	6.9
2002	12	31.4	19.1	57.9	1.8	0.0	11.7	93.0	22.7	6.4
2002	13	31.7	18.7	54.3	1.4	0.2	8.3	90.1	18.4	6.6
2002	14	31.1	21.2	57.2	2.6	0.0	9.9	93.2	21.2	7.6
2002	15	20.7	21.2	58.4	4.4	6.0	16.7	86.4	30.4	7.5
2002	16	27.4	22.6	63.6	4.3	15.5	15.9	94.3	32.9	7.9
2002	17	29.6	20.0	68.0	3.8	3.4	12.6	96.2	39.7	6.4
2002	18	31.2	16.0	58.9	1.3	0.0	8.3	88.6	29.1	5.7
2002	19	30.4	20.9	53.6	2.9	0.0	9.4	85.4	21.8	8.0
2002	20	28.9	23.4	56.2	3.0	0.1	17.1	80.4	32.0	7.6
2002	21	27.2	24.1	58.2	1.7	0.1	15.2	88.0	28.4	6.8
2002	22	26.5	24.9	54.3	2.7	0.0	17.7	79.9	28.7	7.6
2002	23	28.0	23.6	60.9	2.7	4.0	16.4	92.7	29.1	7.4
2002	24	26.1	23.5	51.4	4.1	1.8	17.7	79.0	23.7	8.6
2002	25	23.1	20.8	60.3	4.7	0.0	15.8	85.7	34.8	7.3
2002	26	13.4	18.4	76.7	3.0	2.2	15.4	93.0	60.3	3.4
2002	27	7.9	17.5	91.4	2.9	28.9	15.5	98.0	84.7	1.8
2002	28	18.9	19.7	79.6	1.8	2.9	16.6	96.2	63.0	4.0
2002	29	13.6	19.7	85.0	1.6	10.4	18.0	97.4	72.5	3.0
2002	30	26.4	21.6	69.5	1.5	0.6	16.2	98.1	40.8	5.6
2002	31	0.3	21.5	62.8	1.7	0.0	15.2	92.4	33.1	2.6
2002	32	0.3	19.6	62.4	1.5	0.0	11.9	94.7	30.1	2.6
2002	33	0.3	20.6	58.7	1.7	0.0	13.3	92.1	25.2	3.0
2002	34	0.3	22.1	55.3	1.5	0.0	12.5	86.5	24.0	3.2
2002	35	0.3	23.9	45.0	2.2	0.0	14.2	77.1	12.9	4.9
2002	36	0.3	23.2	52.0	1.8	0.0	13.1	82.3	21.6	3.8
2002	37	0.2	22.7	52.0	2.3	1.1	13.8	83.2	20.7	4.4
2002	38	0.2	20.4	65.5	3.0	1.2	13.3	90.6	40.4	3.4
2002	39	0.2	17.8	65.3	2.4	0.0	13.5	82.1	48.5	2.5
2002	40	0.3	19.2	52.7	2.1	0.0	11.4	87.2	18.1	3.7
2002	41	0.3	22.0	51.5	1.7	0.0	11.9	84.4	18.6	3.7
2002	42	0.3	23.5	47.6	2.0	0.0	13.9	82.5	12.6	4.6
2002	43	0.2	24.0	43.9	2.9	0.3	17.9	66.3	21.5	5.3
2002	44	0.3	23.8	56.4	2.9	0.0	15.4	87.4	25.4	4.6
2002	45	23.9	19.8	70.5	3.0	15.1	15.7	95.4	45.5	5.6
2002	46	17.2	19.3	72.9	2.1	1.1	14.8	94.9	50.9	4.1

2002	47	28.4	20.6	59.2	1.1	0.0	13.2	94.9	23.5	5.8
2002	48	24.9	21.4	57.1	2.9	0.0	15.0	88.5	25.6	6.8
2002	49	24.6	20.6	61.4	1.4	0.0	12.1	94.1	28.6	5.5
2002	50	25.3	20.8	64.0	2.3	0.0	13.8	92.6	35.3	6.0
2002	51	0.3	21.8	58.9	1.8	0.0	14.8	86.3	31.4	3.0
2002	52	0.2	21.0	60.3	1.8	0.4	14.4	95.4	25.1	3.0
2002	53	0.2	20.9	58.0	1.5	0.0	13.1	91.0	24.9	2.9
2002	54	0.3	22.4	52.1	1.4	0.0	13.1	83.0	21.1	3.1
2002	55	0.3	24.2	46.1	1.6	0.0	15.0	72.7	19.5	3.8
2002	56	0.2	24.5	50.6	1.9	0.0	16.4	79.6	21.6	3.9
2002	57	0.2	23.9	56.3	2.0	0.0	15.8	85.7	26.8	3.6
2002	58	0.2	22.1	64.0	2.1	1.6	16.5	92.7	35.2	3.1
2002	59	0.2	22.0	64.2	2.3	13.8	17.7	94.7	33.6	3.3
2002	60	0.2	20.6	72.1	1.7	0.0	15.6	97.3	46.8	2.0
2002	61	0.2	21.4	66.2	1.7	0.0	15.0	94.4	37.9	2.5
2002	62	0.2	21.7	65.5	1.4	0.4	14.4	94.0	36.9	2.4
2002	63	20.3	21.8	63.8	1.8	0.0	15.3	92.6	35.0	5.0
2002	64	18.0	21.4	65.2	1.7	0.0	15.2	93.4	36.9	4.5
2002	65	9.3	19.9	74.6	1.3	0.3	17.0	93.1	56.0	2.6
2002	66	22.8	20.1	67.3	1.9	4.3	14.0	97.4	37.1	5.1
2002	67	23.5	20.5	66.0	2.8	0.0	14.6	88.1	43.9	5.5
2002	68	15.7	20.2	67.2	2.0	0.0	14.8	86.2	48.1	4.0
2002	69	5.2	18.0	80.3	1.3	2.2	16.1	96.7	63.9	1.8
2002	70	12.0	18.1	78.3	1.7	3.4	15.6	95.8	60.7	2.9
2002	71	20.8	19.2	71.8	1.8	0.2	12.9	98.8	44.7	4.5
2002	72	23.5	20.8	58.5	2.8	0.0	14.5	90.3	26.6	6.2
2002	73	22.7	20.1	61.0	1.3	0.0	11.0	95.6	26.3	5.0
2002	74	22.5	21.6	55.5	1.5	0.0	12.4	87.2	23.7	5.4
2002	75	22.3	22.6	48.7	2.0	0.0	16.2	72.1	25.2	6.1
2002	76	19.5	21.9	55.2	1.2	0.0	13.1	85.1	25.2	4.7
2002	77	21.5	22.4	53.0	1.9	0.0	13.3	82.6	23.3	5.8
2002	78	20.4	22.5	53.3	1.9	0.0	16.7	81.7	24.8	5.6
2002	79	23.4	21.5	53.9	1.8	0.0	11.7	88.1	19.6	6.0
2002	80	23.1	21.8	47.2	2.0	0.0	12.3	81.0	13.4	6.7
2002	81	23.6	21.1	41.5	1.7	0.2	10.1	69.4	13.6	6.3
2002	82	22.8	21.4	43.0	1.7	0.0	10.5	69.7	16.3	6.1
2002	83	20.4	22.5	56.2	2.8	0.0	16.7	80.7	31.7	6.0
2002	84	18.7	22.0	52.8	1.5	1.8	13.7	80.8	24.8	5.0
2002	85	21.3	22.8	49.7	2.1	0.0	13.9	78.6	20.8	6.0
2002	86	16.5	20.6	59.0	2.0	2.4	14.6	89.4	28.5	4.7
2002	87	23.5	13.6	53.0	1.6	0.0	5.7	88.5	17.5	4.5
2002	88	23.2	13.9	47.9	1.4	0.0	2.0	85.1	10.6	4.9
2002	89	22.6	16.8	49.2	1.6	0.0	6.0	83.5	14.8	5.3
2002	90	20.4	18.1	44.3	1.5	0.0	5.2	79.6	8.9	7.1
2002	91	16.5	21.7	46.0	3.3	0.0	13.3	73.7	18.3	4.9
2002	92	20.8	21.0	46.4	1.7	0.0	11.8	72.1	20.6	5.9
2002	93	21.3	20.9	44.0	1.8	0.0	10.8	77.5	10.4	6.9
2002	94	13.9	21.7	31.7	2.5	0.0	10.1	52.1	11.2	5.1
2002	95	22.0	21.5	38.2	2.1	0.0	15.7	55.2	21.1	5.0
2002	96	22.0	15.0	39.9	2.0	0.0	5.7	68.7	11.0	4.9
2002	97	17.7	13.0	41.9	1.6	0.0	-0.1	72.4	11.3	6.1
2002	98	18.0	18.5	43.4	2.9	0.0	8.4	65.3	21.5	5.0
2002	99	19.0				5.0				4.0

2002	100	20.8				20.0				3.7
2002	101	15.3	13.3	64.5	1.3	30.0	6.3	99.0	29.9	3.2
2002	102	18.9	15.4	69.8	1.6	0.0	5.5	91.9	47.6	3.7
2002	103	18.9	17.6	59.7	1.2	0.0	11.1	93.3	26.1	3.7
2002	104	17.1	16.7	59.8	1.2	0.0	9.0	94.5	25.1	4.2
2002	105	16.8	17.1	55.8	1.7	0.0	9.0	86.9	24.7	5.0
2002	106	19.0	18.5	55.4	2.7	0.0	12.9	84.4	26.3	4.4
2002	107	19.4	17.9	56.3	1.6	0.0	9.2	91.9	20.6	5.4
2002	108	19.8	17.0	41.8	2.2	0.0	9.3	73.9	9.6	4.0
2002	109	19.7	13.1	49.5	1.3	0.0	4.8	86.9	12.1	4.3
2002	110	19.1	14.0	44.1	1.3	0.0	2.4	77.0	11.1	4.7
2002	111	17.9	15.9	44.3	1.6	0.0	3.0	76.2	12.4	4.5
2002	112	17.0	17.7	43.5	1.7	0.0	8.8	62.5	24.4	4.8
2002	113	11.6	18.1	49.5	2.3	0.0	10.2	78.1	20.9	3.4
2002	114	16.6	16.2	65.0	2.2	0.9	10.1	92.3	37.6	4.2
2002	115	16.7	18.3	56.5	2.0	0.0	11.1	81.3	31.7	4.0
2002	116	16.6	17.2	56.1	1.5	0.0	9.0	89.9	22.2	4.0
2002	117	16.4	17.5	49.8	1.4	0.0	5.9	80.8	18.7	4.3
2002	118	16.8	19.7	49.0	1.6	0.0	9.5	77.6	20.3	5.1
2002	119	14.3	19.9	42.4	2.0	0.0	11.3	70.9	13.8	4.7
2002	120	14.5	18.7	44.7	2.0	0.0	8.9	72.0	17.4	6.0
2002	121	13.6	19.0	53.7	4.5	0.0	13.8	81.7	25.6	4.5
2002	122	17.3	18.1	55.1	2.7	0.5	11.8	80.8	29.4	4.6
2002	123	17.0	16.0	50.4	2.2	0.0	7.9	88.1	12.7	4.3
2002	124	8.6	14.8	51.4	1.7	0.0	3.6	86.8	15.9	3.4
2002	125	16.3	13.9	66.8	2.6	8.9	6.8	96.8	36.7	2.6
2002	126	16.2	8.1	66.4	3.5	1.6	2.1	95.8	37.0	1.9
2002	127	17.0	3.1	65.0	1.3	0.0	-2.2	93.3	36.6	2.3
2002	128	16.7	4.5	61.6	1.4	0.0	-2.6	93.9	29.3	2.9
2002	129	17.0	7.2	55.0	1.4	0.0	-1.9	91.3	18.7	3.2
2002	130	15.9	8.5	51.5	1.5	0.0	-0.8	89.4	13.6	3.4

Appendix 7.1

Soil water contents (mm) for the different soil layers within the root zone of the Khumo/Swartland ecotopes during the experimental period

Date	DOY	Depth	*CON*	*ObSr*	*ObBr*	*SbOr*
12-01-00	12	0-300	50.1	63.6	62.4	73.4
		300-600	86.4	89.5	87.7	84.0
		600-900	87.0	83.8	86.7	98.2
		900-1200	80.0	91.5	77.2	87.9
		0-1200	303.5	328.3	315.8	343.5
31-01-00	31	0-300	52.9	79.4	66.4	62.4
		300-600	84.5	88.9	87.0	83.7
		600-900	83.1	86.9	85.5	101.1
		900-1200	80.0	92.0	76.8	86.2
		0-1200	300.5	347.3	315.8	333.4
29-02-00	60	0-300	113.2	133.4	119.1	109.7
		300-600	83.9	87.1	88.8	86.8
		600-900	85.8	89.7	88.3	97.4
		900-1200	83.4	96.4	78.5	89.4
		0-1200	366.3	406.6	374.8	383.3
16-03-00	76	0-300	41.7	65.6	46.7	44.2
		300-600	84.1	88.6	91.3	82.8
		600-900	84.5	87.9	87.3	97.4
		900-1200	81.0	94.5	80.1	91.3
		0-1200	291.3	336.5	305.5	315.7
04-04-00	95	0-300	65.6	87.0	76.4	74.4
		300-600	74.5	86.5	82.8	82.0
		600-900	73.8	83.0	85.1	92.1
		900-1200	78.2	87.6	79.0	88.8
		0-1200	292.2	344.2	323.3	337.4
12-05-00	133	0-300	55.7	85.3	70.2	65.4
		300-600	70.4	85.2	81.2	76.4
		600-900	68.2	74.8	77.4	79.5
		900-1200	69.1	76.3	68.0	77.8
		0-1200	263.3	321.7	296.7	299.1
05-06-00	157	0-300	40.8	58.0	49.0	45.2
		300-600	69.7	81.2	77.4	71.9
		600-900	63.9	72.0	74.6	76.1
		900-1200	64.8	73.7	65.5	76.9
		0-1200	239.2	284.9	266.5	270.0
09-10-00	283	0-300	35.8	54.5	47.2	43.6
		300-600	71.6	87.0	84.3	78.2
		600-900	69.2	79.6	82.5	86.4
		900-1200	66.9	80.6	72.7	81.2
		0-1200	243.6	301.6	286.7	289.4
04-12-00	339	0-300	47.0	95.6	78.6	81.4
		300-600	71.7	88.4	85.4	83.3
		600-900	68.4	83.4	84.9	90.2
		900-1200	68.0	84.8	78.9	85.0
		0-1200	255.0	352.2	327.8	339.9
31-01-01	31	0-300	48.7	89.1	74.1	75.2
		300-600	84.2	92.8	91.8	87.8

		600-900	77.9	89.5	93.0	98.0
		900-1200	71.4	94.9	84.0	90.9
		0-1200	282.2	366.2	342.9	351.9
21-02-01	52	0-300	52.9	91.2	70.6	76.8
		300-600	72.9	85.9	88.7	83.7
		600-900	71.2	85.5	89.3	90.6
		900-1200	63.2	86.9	80.3	83.8
		0-1200	260.2	349.5	328.9	334.8
01-03-01	60	0-300	50.9	92.4	74.7	77.6
		300-600	83.2	93.4	94.5	90.2
		600-900	80.1	90.9	94.7	100.2
		900-1200	68.6	98.0	85.9	93.7
		0-1200	282.9	374.6	349.8	361.7
19-03-01	78	0-300	33.7	46.4	34.8	33.4
		300-600	70.9	75.6	75.7	66.7
		600-900	69.3	77.5	74.9	86.9
		900-1200	71.1	90.6	81.2	85.9
		0-1200	245.0	290.1	266.5	272.8
28-03-01	87	0-300	75.3	122.8	96.0	107.8
		300-600	73.4	94.4	92.6	92.4
		600-900	68.7	85.6	89.3	98.3
		900-1200	67.3	92.0	82.3	93.5
		0-1200	284.7	394.7	360.1	392.0
10-04-01	100	0-300	75.8	116.9	94.5	105.5
		300-600	74.7	96.8	93.7	94.6
		600-900	69.3	86.7	88.3	100.2
		900-1200	66.9	91.1	81.5	95.1
		0-1200	286.7	391.5	358.0	395.4
20-04-01	110	0-300	75.9	112.0	95.3	98.0
		300-600	76.3	96.7	94.7	92.0
		600-900	70.6	93.2	91.5	101.8
		900-1200	66.9	91.7	81.9	94.5
		0-1200	289.7	393.6	363.5	386.3
24-04-01	114	0-300	58.9	106.6	86.6	94.2
		300-600	70.6	96.4	91.7	93.1
		600-900	66.8	87.7	86.4	96.9
		900-1200	67.2	85.2	77.8	92.7
		0-1200	263.6	375.9	342.5	376.8
07-05-01	127	0-300	74.9	116.4	96.6	102.5
		300-600	73.1	97.8	100.3	95.6
		600-900	67.6	95.5	94.7	104.2
		900-1200	70.4	91.1	83.5	93.2
		0-1200	286.1	400.9	375.0	395.5
25-05-01	145	0-300	52.2	87.1	74.2	71.7
		300-600	73.8	96.0	90.4	87.1
		600-900	65.4	87.5	88.1	98.4
		900-1200	69.5	87.5	80.2	97.3
		0-1200	260.9	358.0	332.8	354.4
03-09-01	246	0-300	62.0	107.1	79.9	89.1
		300-600	74.2	91.7	90.9	87.0
		600-900	68.7	90.2	91.3	95.7
		900-1200	65.3	93.6	83.2	88.9
		0-1200	270.3	382.6	345.3	360.7

27-09-01	270	0-300	51.9	84.1	68.1	66.1
		300-600	75.8	91.9	90.6	87.6
		600-900	68.8	89.3	92.0	90.8
		900-1200	66.3	92.4	81.6	93.2
		0-1200	262.8	357.7	332.3	337.8
09-10-01	282	0-300	49.4	76.4	62.4	59.2
		300-600	77.4	94.3	92.3	89.4
		600-900	68.6	90.6	92.8	98.7
		900-1200	66.6	93.8	81.6	93.6
		0-1200	262.1	355.1	329.1	341.0
06-11-01	310	0-300	58.2	92.2	71.3	73.3
		300-600	84.9	97.8	94.4	92.3
		600-900	74.5	93.9	94.2	98.9
		900-1200	66.0	97.1	82.8	96.4
		0-1200	283.5	381.0	342.7	360.9
06-12-01	340	0-300	95.3	120.5	98.4	106.9
		300-600	93.5	101.7	100.3	97.4
		600-900	93.1	97.0	98.6	104.4
		900-1200	91.5	104.1	93.2	98.0
		0-1200	373.4	423.3	390.5	406.7
02-01-02	2	0-300	53.2	91.2	70.3	68.7
		300-600	89.9	96.9	93.1	91.5
		600-900	89.7	95.5	95.5	100.9
		900-1200	89.1	99.3	90.0	97.7
		0-1200	321.9	382.9	349.0	358.8
21-01-02	21	0-300	47.7	55.0	43.9	41.0
		300-600	83.7	91.2	87.8	83.1
		600-900	87.5	93.6	94.7	98.3
		900-1200	87.6	98.2	90.3	96.2
		0-1200	306.5	338.0	316.7	318.6
04-02-02	35	0-300	56.9	68.2	55.9	56.7
		300-600	82.9	86.6	83.9	80.2
		600-900	83.1	85.8	88.5	91.8
		900-1200	83.0	91.9	85.3	89.9
		0-1200	305.8	332.5	313.5	318.7
11-02-02	42	0-300	45.4	50.0	35.7	40.2
		300-600	79.0	81.4	77.1	73.8
		600-900	79.8	80.2	80.4	86.8
		900-1200	79.1	88.9	80.9	87.4
		0-1200	283.2	300.5	274.1	288.3
27-02-02	58	0-300	55.0	56.5	56.3	54.6
		300-600	66.3	71.8	67.6	63.0
		600-900	69.0	73.2	68.3	77.2
		900-1200	75.1	78.6	66.4	75.5
		0-1200	265.4	280.0	258.6	270.4
11-03-02	70	0-300	39.6	50.0	43.7	35.3
		300-600	69.4	74.7	70.1	62.9
		600-900	69.3	67.7	67.3	73.2
		900-1200	73.1	76.0	61.8	71.9
		0-1200	251.3	268.4	242.8	243.4
22-03-02	81	0-300	36.0	40.5	35.4	31.3
		300-600	69.4	68.4	67.1	63.3
		600-900	66.1	65.9	64.4	70.1

		900-1200	65.8	74.6	56.0	68.6
		0-1200	237.3	249.3	222.9	233.3
04-04-02	94	0-300	34.8	43.5	34.4	31.3
		300-600	67.7	71.8	67.7	61.0
		600-900	65.7	66.9	64.7	73.2
		900-1200	71.3	74.7	57.9	69.0
		0-1200	239.5	256.8	224.7	234.5
16-04-02	106	0-300	35.6	49.4	54.5	38.9
		300-600	67.9	73.6	65.2	58.5
		600-900	63.3	60.0	67.3	66.7
		900-1200	63.2	64.4	58.1	66.3
		0-1200	230.0	247.4	245.2	230.4

Appendix 7.2

Soil water contents (mm) for the different soil layers within the root zone of the Vlakspruit /Arcadia ecotopes during the experimental period.

Date	DOY	Depth	*CON*	*ObSr*	*SbOr*	*ObBr*
11-01-00	11	0-300	87.8	111.2	101.2	101.3
		300-600	92.4	101.7	103.0	103.7
		600-900	82.2	109.7	112.3	116.8
		900-1200	75.9	93.5	97.2	112.7
		0-1200	338.3	416.2	407.6	434.4
01-02-00	32	0-300	75.9	94.3	90.8	76.4
		300-600	92.7	102.0	101.6	103.1
		600-900	83.8	110.2	115.0	115.9
		900-1200	73.7	96.5	100.2	112.7
		0-1200	326.1	402.9	407.6	408.1
29-02-00	60	0-300	90.8	128.8	117.7	109.6
		300-600	97.0	110.1	113.0	110.9
		600-900	88.6	117.7	123.6	125.4
		900-1200	79.0	103.4	104.8	118.8
		0-1200	355.3	460.0	459.3	464.6
16-03-00	75	0-300	56.3	82.5	82.8	68.8
		300-600	85.3	98.0	103.3	101.3
		600-900	79.3	106.3	113.8	114.8
		900-1200	73.8	97.9	98.7	110.8
		0-1200	294.6	384.7	398.6	395.7
07-04-00	98	0-300	56.1	103.7	97.0	85.9
		300-600	78.6	95.5	97.9	97.0
		600-900	77.7	102.7	109.7	110.1
		900-1200	74.0	95.3	98.0	80.8
		0-1200	286.4	397.3	402.5	409.1
12-05-00	133	0-300	68.2	86.7	91.7	76.3
		300-600	84.0	95.4	97.8	96.5
		600-900	84.0	98.8	102.0	109.4
		900-1200	77.6	89.8	95.1	100.5
		0-1200	313.8	370.6	386.6	382.6
05-06-00	157	0-300	61.3	73.4	77.2	58.0
		300-600	81.8	86.0	89.0	93.8
		600-900	80.1	90.0	94.3	101.0
		900-1200	76.3	87.3	91.0	98.7
		0-1200	299.5	336.7	351.5	351.5
25-10-00	299	0-300	57.7	76.8	79.5	66.5
		300-600	77.7	87.9	89.6	92.1
		600-900	77.4	87.2	93.5	99.8
		900-1200	73.2	83.8	87.5	98.4
		0-1200	286.1	335.7	350.2	356.7
04-12-00)	339	0-300	70.2	113.9	104.2	79.6
		300-600	79.7	96.8	103.2	96.4
		600-900	75.7	95.6	108.2	107.2
		900-1200	74.6	89.6	95.7	103.9
		0-1200	300.2	395.8	411.2	387.0
31-01-01	31	0-300	58.6	98.2	93.1	78.2
		300-600	79.7	101.1	99.5	99.6

		600-900	75.8	104.8	111.0	111.3
		900-1200	71.3	93.5	96.3	106.9
		0-1200	285.4	397.6	399.9	396.0
21-02-01	52	0-300	69.9	102.5	96.7	81.0
		300-600	80.5	104.8	103.6	102.2
		600-900	82.6	113.3	121.1	115.0
		900-1200	78.0	101.7	105.4	111.7
		0-1200	311.0	422.3	426.8	409.9
01-03-01	60	0-300	70.1	113.8	92.8	78.3
		300-600	82.5	102.0	103.1	76.8
		600-900	84.3	111.2	118.6	115.4
		900-1200	78.8	98.7	105.8	114.8
		0-1200	315.7	425.8	420.2	385.3
09-03-01	68	0-300	58.5	74.3	62.7	51.7
		300-600	83.3	93.8	92.6	90.4
		600-900	80.9	103.5	106.6	103.6
		900-1200	77.4	97.2	102.9	102.7
		0-1200	300.1	368.7	364.7	348.3
19-03-01	77	0-300	54.3	67.5	61.6	48.4
		300-600	79.6	89.3	87.9	86.3
		600-900	82.8	93.6	96.5	97.9
		900-1200	75.0	95.4	96.3	99.3
		0-1200	291.6	345.8	342.3	331.9
28-03-01	87	0-300	96.5	119.7	109.6	108.8
		300-600	84.3	103.3	105.9	106.2
		600-900	82.8	102.7	111.4	107.5
		900-1200	76.9	93.7	96.3	101.7
		0-1200	340.6	419.4	423.3	424.2
04-04-01	94	0-300	80.1	113.0	104.9	98.5
		300-600	83.7	100.0	101.2	102.7
		600-900	81.5	96.9	103.8	105.9
		900-1200	76.5	91.2	94.7	98.4
		0-1200	321.8	401.0	404.5	405.5
10-04-01	100	0-300	102.0	132.2	123.1	123.4
		300-600	84.8	102.6	107.3	103.7
		600-900	79.5	98.1	107.2	106.4
		900-1200	77.0	91.4	96.0	100.4
		0-1200	343.3	424.2	433.6	433.9
20-04-01	110	0-300	107.9	128.6	124.3	116.9
		300-600	89.4	107.2	107.6	105.3
		600-900	83.7	99.9	106.3	101.9
		900-1200	79.0	90.8	95.5	98.1
		0-1200	359.9	426.5	433.6	422.3
07-05-01	127	0-300	118.8	135.6	125.0	125.3
		300-600	91.2	107.1	111.0	109.2
		600-900	78.3	101.8	112.0	109.8
		900-1200	77.2	89.1	93.0	99.6
		0-1200	365.4	433.7	440.9	443.8
21-05-01	141	0-300	100.6	119.8	111.0	103.8
		300-600	91.2	106.5	108.6	108.3
		600-900	78.7	101.7	113.0	110.6
		900-1200	76.7	89.4	94.5	99.7
		0-1200	347.2	417.3	427.1	422.4

03-09-01	246	0-300	103.8	130.5	121.0	120.4
		300-600	87.0	106.5	107.6	108.3
		600-900	77.9	108.4	113.5	113.6
		900-1200	75.8	89.4	95.5	100.8
		0-1200	344.4	434.8	437.5	443.0
26-09-01	269	0-300	104.5	129.2	113.2	117.3
		300-600	89.2	107.1	108.6	107.1
		600-900	78.9	109.1	112.6	114.4
		900-1200	77.4	89.8	95.9	102.2
		0-1200	350.0	435.1	430.4	441.0
09-10-01	282	0-300	104.5	127.9	113.9	121.5
		300-600	88.5	106.2	109.3	108.6
		600-900	81.9	109.1	113.2	108.2
		900-1200	77.0	90.4	95.1	103.2
		0-1200	351.8	433.6	431.6	441.5
06-11-01	310	0-300	112.6	145.0	130.2	131.9
		300-600	89.1	109.8	111.7	109.4
		600-900	78.6	115.1	118.6	119.1
		900-1200	78.8	99.0	98.4	106.3
		0-1200	359.1	468.9	458.9	466.6
20-12-01	354	0-300	95.9	126.8	122.1	101.3
		300-600	97.4	111.8	112.9	110.9
		600-900	88.8	122.2	125.1	125.5
		900-1200	78.3	114.3	114.9	118.8
		0-1200	360.4	475.1	475.0	456.5
26-01-02	26	0-300	59.8	68.7	63.2	52.3
		300-600	90.6	104.2	105.1	100.4
		600-900	87.5	118.2	123.2	123.8
		900-1200	77.8	111.7	112.9	119.3
		0-1200	315.7	402.9	404.3	395.8
04-02-02	35	0-300	72.9	93.2	89.3	70.2
		300-600	91.5	100.1	102.9	99.6
		600-900	88.9	116.8	121.2	117.9
		900-1200	79.4	111.0	113.9	118.7
		0-1200	332.7	421.2	427.4	406.4
11-02-02	42	0-300	46.8	56.3	55.9	47.0
		300-600	82.8	89.6	91.1	85.2
		600-900	86.0	103.1	110.0	105.7
		900-1200	79.4	106.7	112.0	109.3
		0-1200	294.9	355.7	369.0	347.3
27-02-02	58	0-300	43.4	47.9	48.1	41.5
		300-600	79.0	78.4	85.2	82.4
		600-900	78.8	91.5	93.9	91.9
		900-1200	79.6	85.8	94.4	98.6
		0-1200	280.9	303.7	321.6	314.4
11-03-02	70	0-300	57.5	53.8	53.1	47.1
		300-600	81.6	80.6	80.6	81.8
		600-900	78.2	85.4	88.4	92.4
		900-1200	78.7	84.6	88.0	92.4
		0-1200	296.0	304.4	310.2	313.7
22-03-02	81	0-300	49.7	49.0	48.4	43.2
		300-600	79.2	77.6	78.3	79.1
		600-900	75.9	84.3	85.6	89.7

		900-1200	75.7	84.2	85.8	91.6
		0-1200	280.6	295.1	298.0	303.5
04-04-02	94	0-300	48.4	47.5	47.0	42.6
		300-600	78.0	77.9	82.3	79.9
		600-900	76.8	83.8	87.4	90.3
		900-1200	77.2	85.3	86.7	93.7
		0-1200	280.4	294.6	303.4	306.6
16-04-02	106	0-300	94.1	103.3	91.3	81.0
		300-600	83.8	82.8	93.7	88.9
		600-900	79.6	82.9	94.7	94.0
		900-1200	76.7	85.3	91.6	92.7

Appendix 7.3

Soil water contents (mm) for the different soil layers within the root zone of block C on the Glen/Bonheim ecotope during the experimental period.

Date	DOY	Depth	MBM *ObBr*	BMB *ObBr*	MBM *SbSr*	BMB *SbSr*	MBM *CON*	BMB *CON*	MMM *CON*	BBB *CON*
10-01-00	10	0-300	106.2		119.4		83.2		86.0	
		300-600	109.4		125.1		102.2		117.2	
		600-900	99.6		94.8		77.5		80.4	
		900-1200	89.8		73.2		70.9		68.3	
		0-1200	405.0		412.5		333.8		351.9	
07-02-00	48	0-300	92.0		92.4		82.3		81.3	
		300-600	92.9		96.9		88.5		90.8	
		600-900	92.2		92.8		78.6		78.9	
		900-1200	87.7		79.0		70.4		67.7	
		0-1200	364.8		361.1		319.7		318.8	
21-02-00	53	0-300		56.8		63.6		54.1		59.6
		300-600		112.1		124.2		94.4		125.2
		600-900		106.1		108.4		76.4		108.7
		900-1200		97.4		95.8		76.4		98.5
		0-1200		372.4		392.0		301.2		391.9
07-03-00	67	0-300	56.4	60.2	58.2	67.2	48.7	56.8	51.1	58.6
		300-600	87.9	114.3	93.1	124.1	89.6	93.3	89.2	124.6
		600-900	91.3	108.5	91.6	107.1	80.5	77.2	81.2	106.3
		900-1200	93.2	96.6	84.0	94.0	74.4	77.8	72.0	97.8
		0-1200	328.7	379.5	326.9	392.4	293.3	305.2	293.6	387.4
24-03-00	84	0-300	62.7	63.1	69.4	70.7	49.1	53.2	58.1	56.1
		300-600	87.6	99.0	90.7	103.1	86.3	91.8	88.3	101.5
		600-900	83.4	95.6	82.0	94.9	78.7	73.9	75.3	0.0
		900-1200	85.6	91.0	80.7	89.6	73.1	73.2	69.2	92.2
		0-1200	319.3	348.7	322.8	358.2	287.2	292.1	290.9	344.3
10-04-00	101	0-300	56.2	60.3	60.5	66.2	51.0	58.5	56.8	61.1
		300-600	81.5	90.4	84.9	92.1	81.5	86.4	81.0	95.7
		600-900	78.9	91.0	80.2	92.1	73.9	73.4	71.7	91.5
		900-1200	81.6	87.9	78.0	86.5	69.9	73.2	68.0	89.4
		0-1200	298.2	329.6	303.6	336.9	276.3	291.6	277.4	337.6
15-05-00	136	0-300	73.9	72.2	78.3	76.6	65.6	55.1	64.8	56.1
		300-600	82.5	93.3	90.9	94.7	87.1	84.2	81.1	89.2
		600-900	76.8	90.1	79.1	90.0	74.9	73.4	71.2	88.7
		900-1200	80.6	87.7	76.3	85.8	69.8	73.1	67.5	88.6
		0-1200	313.8	343.3	324.5	347.1	297.4	285.7	284.6	322.6
30-05-00	150	0-300	56.1	60.6	62.5	60.9	55.7	51.3	55.9	51.6
		300-600	79.8	90.4	85.1	94.5	84.8	82.3	80.6	86.4
		600-900	75.9	88.4	77.3	88.6	73.1	71.8	70.8	86.0
		900-1200	79.8	85.3	75.5	84.4	69.2	72.7	67.3	87.4
		0-1200	291.6	324.7	300.5	328.4	282.7	278.2	274.5	311.4
01-12-00	336	0-300	84.7	71.6	103.6	88.5	54.2	49.8	58.3	54.0
		300-600	93.4	105.9	110.8	120.7	91.3	86.1	85.4	96.2
		600-900	85.0	100.8	83.9	103.8	75.6	78.1	73.8	87.8
		900-1200	81.6	92.0	78.2	90.1	73.1	76.1	69.9	86.6
		0-1200	344.6	370.3	376.5	403.1	294.1	290.1	287.3	324.5
09-01-01	9	0-300	102.9	83.7	109.4	100.8	71.9	64.3	75.6	73.5

		300-600	99.2	101.2	105.0	104.3	94.7	88.7	92.3	98.4
		600-900	91.2	99.9	95.2	100.8	77.2	80.0	73.2	90.4
		900-1200	85.8	95.7	83.2	95.6	72.7	77.4	73.9	89.0
		0-1200	379.1	380.5	392.8	401.4	316.5	310.4	315.0	351.3
07-02-01	38	0-300	61.9	58.5	73.9	69.7	55.3	52.6	58.2	60.3
		300-600	92.9	93.2	98.8	98.0	89.5	85.2	87.0	93.3
		600-900	87.1	93.9	89.2	93.7	72.4	74.6	70.5	86.9
		900-1200	81.4	89.9	80.2	90.1	70.0	72.9	65.9	85.1
		0-1200	323.2	335.4	342.2	351.4	287.2	285.2	281.6	325.6
21-02-01	52	0-300	90.7	75.7	107.2	99.7	58.0	63.1	71.9	67.6
		300-600	97.6	93.5	102.9	99.4	94.1	88.3	89.0	99.0
		600-900	91.3	94.4	94.8	94.3	78.2	81.5	73.9	91.3
		900-1200	87.2	92.0	84.5	92.9	72.3	76.9	69.4	89.2
		0-1200	366.8	355.5	389.5	386.3	302.7	309.8	304.2	347.1
28-02-01	59	0-300	90.9	84.0	105.9	97.3	54.2	55.2	57.1	60.5
		300-600	93.2	94.5	109.4	96.8	89.4	83.6	83.0	102.5
		600-900	88.5	101.7	92.0	93.5	76.1	76.8	75.2	90.3
		900-1200	86.8	92.7	83.2	90.2	73.2	76.7	68.1	87.9
		0-1200	359.5	373.0	390.4	377.7	292.9	292.3	283.4	341.3
09-03-01	68	0-300	55.6	52.7	58.0	56.9	50.4	49.3	51.4	53.5
		300-600	90.6	86.8	96.8	91.1	91.6	81.4	85.5	98.8
		600-900	87.1	89.2	92.5	86.1	76.5	78.8	75.4	88.5
		900-1200	83.9	91.5	83.4	89.9	72.7	76.2	70.4	87.6
		0-1200	317.1	320.2	330.7	324.1	291.2	285.7	282.5	328.5
26-03-01	85	0-300	98.4	87.9	114.0	102.0	51.6	53.8	58.8	65.0
		300-600	97.2	96.8	107.4	104.0	86.0	78.8	80.1	95.3
		600-900	88.1	86.2	90.6	83.0	76.2	77.7	74.6	87.1
		900-1200	83.5	88.5	85.2	84.8	71.0	76.9	69.9	86.3
		0-1200	367.2	359.4	397.1	373.9	284.9	287.1	283.4	333.6
06-04-01	96	0-300	103.3	86.1	106.3	100.2	49.9	53.4	57.8	60.2
		300-600	90.6	91.0	96.9	95.4	83.4	78.2	80.6	90.8
		600-900	84.7	86.8	89.3	81.9	73.8	76.5	73.3	86.4
		900-1200	83.1	86.7	81.8	84.2	71.9	75.7	69.2	86.1
		0-1200	361.7	350.6	374.3	361.7	279.1	283.7	281.0	323.6
11-04-01	101	0-300	107.3	87.6	117.1	111.4	53.8	62.9	68.0	65.5
		300-600	104.4	103.9	109.4	109.6	84.7	79.2	81.1	98.9
		600-900	86.4	87.1	90.7	81.4	76.1	76.1	75.0	87.8
		900-1200	85.2	88.3	84.4	86.3	70.9	75.4	69.9	85.3
		0-1200	383.3	366.9	401.6	388.8	285.5	293.6	294.1	337.5
18-04-01	108	0-300	111.1	99.7	119.3	114.5	59.1	68.9	79.2	75.2
		300-600	108.3	100.6	106.9	108.9	81.3	80.9	81.1	94.1
		600-900	87.1	86.7	90.9	82.9	75.2	75.7	74.1	84.1
		900-1200	82.9	87.7	83.0	83.5	71.7	74.9	68.8	84.3
		0-1200	389.5	374.8	400.2	389.7	287.3	300.3	303.2	337.6
26-04-01	116	0-300	109.7	100.7	119.7	120.6	57.0	70.3	73.6	72.6
		300-600	110.2	101.0	110.8	107.7	81.6	79.2	80.2	94.4
		600-900	92.7	90.6	95.0	84.7	74.5	77.2	72.4	85.2
		900-1200	82.9	90.8	83.9	83.4	71.4	76.0	69.9	85.1
		0-1200	395.5	383.1	409.4	396.3	284.5	302.7	296.0	337.3
04-05-01	124	0-300	115.5	106.3	121.9	113.4	73.0	80.2	94.6	91.8
		300-600	113.5	101.6	120.8	100.8	82.1	82.4	84.0	103.3
		600-900	94.7	94.2	98.8	88.4	72.0	76.3	71.2	88.8
		900-1200	87.8	84.8	86.1	83.1	70.1	74.7	70.0	88.7

		0-1200	411.5	386.9	427.6	385.6	297.3	313.7	319.9	372.6
09-05-01	129	0-300	111.8	108.9	119.0	111.5	73.3	72.8	92.5	87.0
		300-600	110.6	106.1	118.2	117.2	85.6	81.6	88.6	105.4
		600-900	99.5	98.1	108.6	91.2	75.4	78.2	74.6	86.8
		900-1200	85.6	93.4	89.2	86.3	68.3	75.4	66.9	84.1
		0-1200	407.5	406.5	434.9	406.2	302.5	307.9	322.6	363.3
14-05-01	134	0-300		90.5	115.0					66.7
		300-600		97.6	120.3					101.6
		600-900		88.8	104.5					86.0
		900-1200		82.6	88.9					83.5
		0-1200		359.6	428.6					337.8
05-06-01	156	0-300	88.6		101.1		54.6			58.8
		300-600	107.8		116.5		86.9			103.5
		600-900	101.2		105.7		76.2			89.2
		900-1200	91.5		89.1		71.3			87.8
		0-1200	389.1		412.5		289.0			339.2
05-10-01	278	0-300	66.0	64.4	92.7	87.0	51.4	56.9	59.1	55.8
		300-600	100.6	103.6	115.6	112.8	88.1	87.4	94.5	100.1
		600-900	98.4	95.3	98.2	94.0	75.5	79.7	74.4	91.2
		900-1200	90.7	89.0	87.3	87.4	71.9	77.2	69.4	87.5
		0-1200	355.7	352.3	393.8	381.2	286.9	301.3	297.4	334.6
01-11-01	305	0-300	96.5	84.0	114.3	109.8	61.0	62.9	72.8	71.5
		300-600	117.8	114.2	127.7	124.3	92.3	91.9	98.2	104.2
		600-900	116.9	112.6	116.9	113.8	75.8	81.4	75.5	88.7
		900-1200	102.4	105.2	99.2	104.7	70.7	76.4	69.8	89.3
		0-1200	433.6	416.0	458.2	452.6	299.8	312.6	316.3	353.7
13-11-01	317	0-300	100.7	86.1	116.9	111.4	62.6	66.6	65.0	73.0
		300-600	119.9	117.5	128.1	125.7	94.8	93.5	103.1	104.9
		600-900	120.7	118.8	119.7	115.6	78.6	81.1	76.4	92.9
		900-1200	108.6	106.2	100.0	106.0	79.1	76.0	68.8	89.9
		0-1200	449.8	428.7	464.7	458.5	315.1	317.2	313.4	360.7
22-12-01	356	0-300	114.6	105.1	128.9	130.4	74.8	67.8	68.5	82.1
		300-600	129.6	129.0	130.5	125.0	125.1	112.0	117.7	114.7
		600-900	122.4	125.0	126.0	124.4	87.1	90.4	81.5	111.9
		900-1200	113.4	123.0	111.0	113.6	74.8	82.3	74.5	101.4
		0-1200	480.1	482.1	496.3	493.4	361.9	352.5	342.2	410.1
09-01-02	9	0-300	103.0	76.2	124.6	114.0	61.7	66.3	63.0	68.8
		300-600	117.4	114.6	128.8	122.4	108.5	98.5	116.8	113.1
		600-900	113.4	112.3	113.1	109.3	81.3	86.4	81.6	98.0
		900-1200	104.5	101.7	96.6	102.5	72.2	77.8	68.5	93.7
		0-1200	438.3	404.9	463.1	448.1	323.8	329.0	330.0	373.6
18-01-2002	18	0-300	124.5	99.7	141.7	134.5	75.4	82.0	75.8	92.7
		300-600	124.3	121.6	130.9	127.8	119.4	108.8	118.4	120.6
		600-900	123.3	122.4	127.3	119.0	85.1	91.8	84.2	86.2
		900-1200	112.4	106.6	106.3	111.0	75.7	80.1	72.8	103.3
		0-1200	484.4	450.2	506.2	492.3	355.7	362.7	351.1	402.8
25-01-02	25	0-300	93.0	62.9	122.8	95.7	57.9	65.3	56.9	64.7
		300-600	122.1	116.2	130.2	126.6	108.8	105.2	111.2	117.6
		600-900	119.8	116.4	123.6	120.4	83.7	92.7	83.8	108.0
		900-1200	116.7	108.8	104.2	109.2	74.9	81.5	72.6	101.7
		0-1200	451.6	404.3	480.7	451.7	325.3	344.8	324.6	392.0
01-02-02	32	0-300	102.1	74.4	122.5	106.3	60.5	63.8	59.6	70.3
		300-600	120.7	115.2	128.8	124.8	100.9	105.3	105.5	123.6

		600-900	111.4	106.8	121.5	114.1	82.8	91.1	82.5	103.7
		900-1200	103.8	104.7	100.2	101.4	79.1	79.9	71.8	98.2
		0-1200	438.0	401.1	473.0	446.6	323.3	340.1	319.4	395.9
12-02-02	43	0-300	59.7	65.7	75.5	89.4	59.2	57.5	56.6	58.3
		300-600	93.1	103.3	117.0	109.3	85.2	96.8	83.8	100.2
		600-900	102.0	101.3	110.3	106.9	80.1	91.7	80.6	96.8
		900-1200	101.2	99.1	96.9	100.2	75.4	81.4	74.1	95.4
		0-1200	356.2	369.3	399.8	405.8	300.0	327.4	295.1	350.7
25-02-02	56	0-300	58.2	60.9	61.4	62.9	57.5	57.3	57.0	57.9
		300-600	79.9	90.0	89.1	92.7	79.9	82.3	80.0	80.1
		600-900	89.9	93.5	98.3	97.7	76.7	87.2	75.6	78.7
		900-1200	96.0	97.3	92.3	95.9	76.5	80.2	73.7	73.3
		0-1200	323.9	341.7	341.0	349.1	290.5	307.1	286.4	290.0
08-03-02	67	0-300	51.1	53.6	62.2	58.4	42.3	47.9	41.9	53.7
		300-600	80.8	86.0	88.9	91.7	79.1	81.0	78.9	85.7
		600-900	84.1	89.3	88.1	91.0	73.5	84.9	73.0	87.1
		900-1200	90.1	92.0	88.2	92.2	71.2	81.5	70.3	90.1
		0-1200	306.1	321.0	327.3	333.3	266.1	295.3	264.2	301.2
20-03-02	79	0-300	46.5	48.9	51.0	52.7	39.4	43.9	38.9	47.2
		300-600	75.7	84.1	82.4	84.2	78.6	78.6	77.7	82.5
		600-900	77.5	89.3	80.6	86.6	72.3	80.8	0.0	84.3
		900-1200	84.2	94.8	85.9	89.5	73.1	80.6	71.2	87.1
		0-1200	284.0	317.2	299.9	312.9	263.4	283.9	259.7	301.2
03-04-02	93	0-300	41.2	46.0	44.8	49.6	39.0	40.3	36.0	42.9
		300-600	75.7	79.8	79.3	83.7	77.1	78.3	76.5	81.3
		600-900	74.4	86.7	78.3	84.6	72.4	80.0	72.1	82.0
		900-1200	81.3	89.7	82.5	88.4	70.8	80.6	71.4	86.9
		0-1200	272.6	302.2	284.9	306.4	259.3	279.2	255.9	293.1
11-04-02	101	0-300	112.0	94.8	114.3	101.5	57.1	66.4	71.0	88.4
		300-600	93.3	89.8	111.8	94.1	85.0	82.5	87.3	92.1
		600-900	75.1	93.9	83.6	86.7	74.2	80.1	72.4	82.6
		900-1200	83.4	90.6	83.6	89.8	70.2	78.4	68.5	87.2
		0-1200	363.7	369.2	393.2	372.1	286.5	307.3	299.2	350.3
22-04-02	112	0-300		71.0		81.9		53.6		62.9
		300-600		93.3		91.9		81.9		92.2
		600-900		86.8		86.3		80.6		84.1
		900-1200		89.8		86.6		79.6		86.5
		0-1200		341.0		346.8		295.6		325.7
25-04-02	115	0-300	88.8		90.3		47.9		56.4	
		300-600	89.3		102.6		84.1		87.9	
		600-900	75.7		82.4		72.6		72.7	
		900-1200	83.6		82.5		70.3		69.0	
		0-1200	337.5		357.8		274.9		286.0	
25-06-02	176	0-300	83.4	69.5	92.5	81.2	62.8	59.9	69.8	67.1
		300-600	87.8	101.7	103.9	108.6	86.1	84.9	93.0	101.9
		600-900	79.3	94.8	81.3	0.0	74.1	81.7	72.5	90.0
		900-1200	84.4	90.1	82.4	86.6	72.5	79.4	72.7	88.0
		0-1200	334.9	356.0	360.1	368.2	295.5	305.8	308.0	346.9

Appendix 7.4

Soil water contents (mm) for the different soil layers within the root zone of block D on the Glen/Bonheim ecotope during the experimental period.

Date	DOY	Depth	SBS *ObBr*	BSB *ObBr*	SBS *SbSr*	BSB *SbSr*	SBS *CON*	BSB *CON*	SSS *CON*	BBB *CON*
08-01-00	8	0-300	103.1		104.0		67.0		74.8	
		300-600	89.0		89.2		82.8		94.6	
		600-900	75.7		76.5		82.8		83.4	
		900-1200	71.9		75.5		82.8		76.2	
		0-1200	339.8		345.3		315.3		329.0	
09-01-00	9	0-300		98.1		116.5		57.5		83.0
		300-600		80.7		92.1		77.1		89.7
		600-900		71.7		75.2		81.1		80.9
		900-1200		71.4		68.8		77.8		77.2
		0-1200		321.9		352.5		293.4		330.9
04-02-00	35	0-300	96.2		95.9		86.6		82.4	
		300-600	91.9		91.9		89.2		92.2	
		600-900	76.7		81.9		84.4		83.7	
		900-1200	70.8		73.9		83.5		75.7	
		0-1200	335.6		343.7		343.7		334.0	
21-02-00	52	0-300		67.7		84.9		54.9		60.4
		300-600		95.0		107.8		85.4		96.2
		600-900		78.1		89.7		82.4		83.2
		900-1200		74.8		72.7		81.8		70.1
		0-1200		315.5		355.1		304.5		309.8
22-02-00	53	0-300	88.9		91.4		64.3		67.2	
		300-600	92.9		91.9		89.2		92.4	
		600-900	80.3		82.7		85.5		84.6	
		900-1200	71.4		75.2		82.8		77.4	
		0-1200	333.5		341.3		321.8		321.6	
10-03-00	70	0-300	55.6	62.2	59.5	68.3	57.9	54.9	56.7	59.8
		300-600	81.2	83.0	84.7	92.8	86.8	80.1	84.8	87.7
		600-900	77.6	73.9	81.0	79.5	84.8	79.9	82.6	84.7
		900-1200	71.4	73.9	76.1	68.5	83.3	77.5	77.0	77.8
		0-1200	285.7	292.9	301.2	309.1	312.9	292.4	301.1	310.0
24-03-00	84	0-300	52.0	71.0	60.9	81.0	55.2	55.9	53.2	62.2
		300-600	81.0	88.5	81.3	100.1	83.0	81.9	79.7	91.6
		600-900	76.5	77.8	79.5	83.1	86.5	80.0	79.0	87.0
		900-1200	69.8	73.2	76.4	68.5	84.0	76.2	76.7	79.5
		0-1200	279.3	310.5	298.2	332.7	308.6	294.0	288.7	320.4
10-04-00	101	0-300	48.8	60.0	50.3	71.2	50.7	54.5	48.2	59.3
		300-600	74.2	82.4	73.7	94.5	79.5	79.9	74.7	87.2
		600-900	70.6	76.4	72.9	82.7	82.8	79.2	72.6	83.7
		900-1200	66.3	72.5	72.9	68.1	81.1	77.1	71.2	78.5
		0-1200	260.0	291.3	269.8	316.6	294.2	290.7	266.8	308.7
15-05-00	136	0-300	55.1	76.6	54.9	76.8	58.3	57.4	49.4	58.1
		300-600	75.9	84.2	74.9	93.9	83.0	80.4	76.2	86.6
		600-900	71.8	78.7	74.0	83.7	85.3	82.0	74.2	85.9
		900-1200	67.0	75.9	74.4	70.5	82.2	80.6	70.7	79.7
		0-1200	269.8	315.5	278.2	325.0	308.8	300.4	270.4	310.3
30-05-00	151	0-300	50.7	58.3	48.7	58.2	50.2	51.3	47.6	52.9

		300-600	70.4	77.6	70.3	83.1	79.0	75.7	70.9	79.6
		600-900	67.6	74.1	69.4	78.6	80.6	77.8	71.7	79.9
		900-1200	63.6	72.5	70.3	67.3	78.8	76.3	70.2	73.8
		0-1200	252.4	282.5	258.8	287.4	288.5	281.1	260.3	286.3
01-12-00	336	0-300	102.8	83.2	101.1	99.8	70.8	55.6	53.7	53.3
		300-600	82.3	90.6	84.9	101.7	92.5	83.9	81.1	84.8
		600-900	69.0	78.2	72.2	80.9	84.2	80.4	72.5	81.0
		900-1200	65.7	73.9	71.6	69.2	79.1	77.5	70.1	77.0
		0-1200	319.8	326.0	329.8	351.6	326.6	297.3	277.3	296.2
09-01-01	9	0-300	105.1	86.4	101.0	93.4	67.7	55.2	57.5	59.6
		300-600	91.7	97.6	93.1	106.3	93.1	86.5	83.8	86.0
		600-900	70.0	84.6	76.8	89.7	87.2	82.0	74.2	81.4
		900-1200	66.4	76.3	72.6	76.2	81.0	78.9	69.2	77.9
		0-1200	333.2	344.8	343.4	365.7	329.1	302.7	284.7	304.8
06-02-01	37	0-300	93.5	61.5	94.2	72.2	74.0	56.0	52.6	65.8
		300-600	92.2	88.2	91.3	92.2	93.1	84.6	80.1	87.6
		600-900	72.5	87.6	78.3	91.9	91.1	84.7	73.5	84.0
		900-1200	67.0	77.5	72.7	77.3	80.6	79.0	69.3	77.4
		0-1200	325.2	314.8	336.5	333.6	338.8	304.3	275.5	314.9
21-02-01	52	0-300	95.8	64.8	104.2	74.7	66.6	53.9	49.0	55.7
		300-600	86.9	76.2	87.7	80.9	89.9	76.9	74.9	84.5
		600-900	70.8	77.9	76.3	79.3	86.2	81.5	71.0	80.2
		900-1200	65.5	76.1	72.5	74.9	80.3	78.1	69.0	76.9
		0-1200	319.1	295.0	340.6	309.8	323.0	290.5	263.9	297.3
02-03-01	61	0-300	96.6	60.1	105.7	65.2	71.9	52.9	51.9	58.0
		300-600	88.3	76.7	91.8	80.1	92.4	76.8	75.0	87.9
		600-900	74.2	76.9	81.0	76.9	90.4	83.7	72.0	84.2
		900-1200	67.2	75.0	73.1	71.1	82.1	78.6	71.2	77.5
		0-1200	326.3	288.7	351.6	293.3	336.8	292.0	270.0	307.6
09-03-01	68	0-300	67.5	51.1	69.4	52.2	65.2	49.1	48.0	56.8
		300-600	85.7	73.4	88.8	75.4	88.0	76.1	71.6	87.1
		600-900	73.7	71.7	79.2	72.2	89.1	80.7	70.9	83.0
		900-1200	66.7	70.7	72.9	64.9	82.3	77.7	69.2	77.0
		0-1200	293.5	266.8	310.3	264.7	324.7	283.7	259.6	303.9
26-03-01	85	0-300	127.0	110.8	123.4	122.7	89.9	63.9	73.5	61.4
		300-600	90.7	81.7	86.3	85.7	88.7	77.8	79.5	85.1
		600-900	74.6	70.4	76.9	70.3	88.0	78.3	74.2	83.7
		900-1200	66.5	68.1	73.8	61.6	84.5	75.6	69.8	76.3
		0-1200	358.9	330.9	360.5	340.2	351.1	295.6	297.0	306.5
06-04-01	96	0-300	124.3	98.8	121.2	114.6	78.9	58.9	70.6	65.4
		300-600	87.4	79.4	83.7	80.3	85.9	73.9	75.7	82.1
		600-900	72.5	68.4	75.7	69.5	88.0	77.4	72.1	80.6
		900-1200	65.7	68.7	73.9	62.2	81.8	74.5	68.4	75.9
		0-1200	349.9	315.3	354.5	326.6	334.6	284.7	286.9	304.0
11-04-01	101	0-300	126.9	104.6	119.1	123.0	83.0	62.6	70.5	60.1
		300-600	94.6	83.7	92.9	86.6	89.6	75.5	78.3	84.3
		600-900	81.6	70.7	78.1	71.3	88.6	78.2	71.8	81.4
		900-1200	65.9	68.6	73.4	62.3	80.8	74.9	68.8	76.1
		0-1200	369.0	327.7	363.5	343.1	342.0	291.2	289.4	301.9
18-04-01	77	0-300	128.0	111.0	123.8	124.9	96.7	77.8	85.0	76.1
		300-600	93.8	87.6	94.0	88.8	89.6	74.9	80.4	84.0
		600-900	83.1	70.7	78.4	70.7	87.6	78.8	70.8	81.5
		900-1200	65.9	69.0	73.4	61.7	81.0	74.7	68.6	75.8

		0-1200	370.8	338.2	369.5	346.1	354.9	306.1	304.7	317.5
26-04-01	116	0-300	128.9	113.8	126.6	129.9	96.5	83.2	85.6	71.6
		300-600	94.9	87.2	99.8	93.7	92.5	76.2	81.1	83.4
		600-900	85.9	72.7	82.1	73.3	88.5	76.3	70.7	80.7
		900-1200	69.1	68.5	72.9	62.3	82.2	74.8	68.9	75.4
		0-1200	378.8	342.2	381.5	359.1	359.7	310.6	306.3	311.1
04-05-01	124	0-300	130.1	116.0	127.8	130.1	108.1	97.1	99.4	86.4
		300-600	98.3	87.4	101.2	98.7	94.9	80.8	81.9	83.1
		600-900	86.8	74.6	93.0	77.8	89.4	76.6	72.3	81.4
		900-1200	71.7	67.9	74.5	61.8	80.2	74.6	67.2	75.1
		0-1200	386.9	345.9	396.6	368.4	372.6	329.1	320.9	326.1
09-05-01	129	0-300	130.3	115.8	126.7	127.5	106.7	89.4	93.7	87.0
		300-600	98.1	89.4	103.5	100.9	97.2	87.5	85.9	83.8
		600-900	90.9	74.7	94.3	84.3	92.4	78.5	71.6	84.9
		900-1200	75.6	71.6	79.2	62.5	81.3	75.3	67.3	77.9
		0-1200	394.9	351.5	403.7	375.2	377.6	330.7	318.5	333.7
17-05-01	137	0-300		106.1		118.6		82.2	81.0	
		300-600		91.5		101.3		89.5	85.0	
		600-900		78.0		84.9		78.4	73.6	
		900-1200		69.9		62.5		74.6	67.0	
		0-1200		345.5		367.3		324.6	306.6	
05-06-01	156	0-300	106.5		99.6		78.0			64.2
		300-600	97.8		96.4		93.5			85.1
		600-900	90.5		93.5		92.9			81.3
		900-1200	77.3		87.4		82.7			74.2
		0-1200	372.1		376.9		347.0			304.8
27-08-01	239	0-300	89.9	64.1	80.5	76.8	57.5	52.5	52.5	54.6
		300-600	94.6	87.6	93.4	95.5	90.3	81.6	83.2	83.8
		600-900	90.3	79.9	92.1	87.7	91.9	80.3	74.5	79.6
		900-1200	78.9	72.2	86.4	66.9	83.7	75.2	67.8	75.8
		0-1200	353.7	303.7	352.4	326.8	323.5	289.6	277.9	293.8
05-10-01	278	0-300	101.0	82.0	99.3	94.9	63.2	59.3	58.5	59.5
		300-600	94.9	87.5	94.0	96.3	91.2	81.0	82.1	85.1
		600-900	90.1	81.1	92.6	88.6	91.2	80.9	74.0	81.4
		900-1200	79.6	71.5	86.4	68.0	84.5	74.3	68.2	75.6
		0-1200	365.6	322.1	372.3	347.7	330.1	295.6	282.9	301.5
01-11-01	305	0-300	125.5	105.1	116.2	118.8	97.1	81.0	78.2	71.4
		300-600	105.5	102.0	103.5	105.1	93.9	90.1	90.7	84.4
		600-900	102.0	89.8	99.1	100.6	93.0	84.6	74.9	81.7
		900-1200	90.0	75.6	96.3	72.7	85.4	76.9	68.7	78.7
		0-1200	423.0	372.4	415.1	397.2	369.4	332.5	312.6	316.2
13-11-01	317	0-300	123.0	110.7	116.4	120.2	92.2	74.9	80.8	76.2
		300-600	105.3	103.7	104.7	105.6	92.4	93.3	91.3	84.6
		600-900	104.8	98.9	102.0	102.6	93.3	85.9	75.7	82.1
		900-1200	94.8	84.9	96.9	83.1	84.1	75.1	68.2	75.3
		0-1200	427.9	398.3	420.0	411.4	362.0	329.2	316.0	318.2
22-12-01	326	0-300	113.5	98.3	108.4	107.4	81.2	62.7	64.3	68.8
		300-600	99.9	100.5	99.9	102.3	96.8	95.0	92.9	87.0
		600-900	96.7	98.1	97.7	99.4	92.9	87.7	77.7	80.0
		900-1200	91.7	91.8	94.2	90.5	83.0	74.0	66.8	73.7
		0-1200	401.7	388.7	400.3	399.6	354.0	319.4	301.7	309.5
09-01-02	9	0-300	112.9	100.4	117.5	116.1	89.7	65.3	70.5	73.8
		300-600	102.1	101.5	101.0	103.7	99.5	96.4	94.8	90.5

		600-900	99.4	98.1	98.8	100.6	96.3	92.5	80.5	82.4
		900-1200	92.2	93.9	95.8	91.7	85.9	78.0	69.0	75.7
		0-1200	406.6	394.0	413.0	412.1	371.3	332.2	314.9	322.4
18-01-02	18	0-300	118.2	103.7	122.8	119.6	74.5	58.6	57.2	64.1
		300-600	112.9	107.7	106.7	121.1	104.1	99.4	91.5	90.7
		600-900	103.9	100.3	101.7	110.5	100.8	90.7	80.2	82.2
		900-1200	90.7	94.9	96.8	89.3	83.8	78.2	71.0	75.3
		0-1200	425.8	406.5	428.1	440.6	363.1	326.8	299.8	312.3
25-01-02	25	0-300	61.5	76.0	65.9	92.0	59.2	58.2	60.2	62.3
		300-600	96.4	107.8	98.2	117.6	93.6	95.7	82.6	91.5
		600-900	101.0	100.8	98.2	108.7	99.1	92.2	81.2	83.0
		900-1200	91.1	94.2	94.9	90.1	84.7	83.6	73.1	78.8
		0-1200	350.0	378.8	357.2	408.4	336.6	329.7	297.2	315.6
01-02-02	32	0-300	104.0	105.4	103.8	117.5	64.7	68.0	57.4	72.2
		300-600	92.5	102.3	90.9	105.2	89.9	96.3	81.7	92.3
		600-900	95.0	97.5	94.8	102.3	96.1	94.6	78.0	84.8
		900-1200	90.1	92.9	95.1	91.3	86.7	80.7	71.4	75.2
		0-1200	381.5	398.1	384.6	416.4	337.3	339.5	288.5	299.3
12-02-02	43	0-300	52.9	62.4	54.2	84.4	49.3	49.5	45.0	50.3
		300-600	81.1	94.0	77.1	99.6	79.8	90.1	73.2	87.9
		600-900	80.6	96.3	81.7	100.9	87.9	93.2	0.0	85.2
		900-1200	80.7	92.8	89.0	90.2	82.9	80.9	68.6	75.9
		0-1200	295.3	345.6	302.0	375.0	299.9	313.5	256.7	299.3
21-02-02	52	0-300	57.4	68.9	56.8	83.1	54.7	56.0	51.4	56.0
		300-600	73.3	87.6	71.5	93.6	77.9	84.9	69.0	79.9
		600-900	70.4	93.3	73.5	96.2	80.8	91.6	69.1	81.8
		900-1200	70.2	92.3	79.0	90.7	78.4	77.6	67.8	76.2
		0-1200	271.2	342.2	280.8	363.6	291.8	310.2	257.2	294.0
08-03-02	67	0-300	52.0	56.8	55.4	61.0	51.2	49.2	47.8	51.2
		300-600	73.9	83.1	73.3	86.6	79.1	78.8	70.6	77.0
		600-900	71.1	91.8	71.1	92.1	81.9	88.9	69.3	81.0
		900-1200	64.7	90.4	71.8	88.0	75.6	78.6	66.6	75.5
		0-1200	261.7	322.0	271.7	327.7	287.8	295.5	254.3	284.7
20-03-02	79	0-300	49.1	53.1	50.7	54.9	49.2	47.3	46.0	50.0
		300-600	71.1	77.3	70.5	80.9	79.6	76.9	70.0	76.5
		600-900	69.5	88.2	71.5	88.3	80.0	85.9	68.7	80.1
		900-1200	64.4	90.5	70.4	85.4	74.0	79.8	66.7	75.5
		0-1200	254.1	309.0	263.1	309.5	282.8	289.9	251.3	282.0
03-04-02	93	0-300	47.8	51.5	49.5	53.6	48.6	46.4	45.2	49.0
		300-600	70.4	74.5	70.1	78.7	77.7	76.0	69.3	75.9
		600-900	68.8	85.1	69.9	84.6	79.3	85.0	68.2	78.4
		900-1200	64.3	87.9	69.7	83.1	73.5	78.2	65.6	75.6
		0-1200	251.3	299.0	259.3	300.0	279.2	285.7	248.3	278.9
11-04-02	101	0-300	106.2	93.7	116.9	108.6	83.4	68.7	62.6	57.5
		300-600	92.2	80.1	80.3	87.5	78.2	77.2	72.0	78.1
		600-900	74.0	84.9	71.4	0.0	78.9	84.0	67.4	77.7
		900-1200	64.1	86.5	70.6	82.0	73.0	78.6	66.7	75.4
		0-1200	336.5	345.2	339.2	362.6	313.5	308.5	268.7	288.7
22-04-02	112	0-300	27.1	81.4	27.1	89.0	27.1	54.9	27.1	53.7
		300-600	22.3	79.9	22.3	86.3	22.3	79.9	22.3	77.3
		600-900	22.3	85.4	22.3	84.9	22.3	83.1	22.3	76.3
		900-1200	22.3	86.5	22.3	81.6	22.3	80.0	22.3	75.4
		0-1200	93.9	333.1	93.9	341.8	93.9	297.9	257.3	282.6

25-04-02	115	0-300	79.3	27.1	92.6	27.1	66.1	27.1	52.0	27.1
		300-600	88.4	22.3	82.3	22.3	79.7	22.3	72.5	22.3
		600-900	73.3	22.3	71.3	22.3	79.3	22.3	66.9	22.3
		900-1200	64.1	22.3	69.6	22.3	72.7	22.3	65.9	22.3
		0-1200	305.2	93.9	315.8	93.9	297.9	93.9	257.3	93.9
25-06-02	176	0-300	87.6	87.4	92.3	93.0	72.2	61.4	60.5	65.4
		300-600	90.4	89.0	85.5	95.0	83.0	84.4	77.7	77.9
		600-900	71.3	84.9	70.1	85.5	78.6	83.3	67.0	77.2
		900-1200	63.8	84.3	69.2	80.0	72.6	77.0	65.2	74.5
		0-1200	313.0	345.6	317.1	353.5	306.4	306.0	270.4	295.2

Appendix 7.5

Climate data for the Khumo/Swartland and Vlakspruit/Arcadia ecotopes during the experimental period

Year	DOY	T	RH	WS	Rain Ks	Rain Va	Tx	Tn	RHx	RHn	Evap
99	300	14.1	66.0	1.6	0.0	0.0	21.6	6.7	99.5	29.7	4.3
99	301	16.8	51.8	1.8	0.0	0.0	23.7	9.2	85.4	23.9	4.4
99	302	18.2	52.4	2.5	0.0	0.0	25.5	9.5	80.3	24.8	4.9
99	303	17.6	64.7	2.9	0.9	0.9	25.0	12.3	87.6	31.9	5.1
99	304	19.2	56.9	1.3	0.0	0.0	27.8	9.4	96.1	24.1	5.6
99	305	22.5	47.0	1.6	0.0	0.0	31.1	13.3	83.4	17.4	6.2
99	306	22.4	43.3	1.3	0.0	0.0	31.5	12.4	79.9	16.6	6.3
99	307	22.2	55.0	1.8	0.0	0.0	31.7	13.2	98.1	17.8	6.2
99	308	22.6	37.2	4.0	0.0	0.0	31.9	13.4	63.4	14.2	7.3
99	309	20.1	35.3	2.0	0.0	0.0	27.9	12.0	67.2	13.4	6.3
99	310	21.0	51.6	3.6	0.0	0.0	29.3	14.0	80.8	19.5	5.6
99	311	21.9	46.5	4.1	0.0	0.0	29.4	13.9	79.4	24.0	6.1
99	312	21.6	36.2	3.1	0.0	0.0	28.7	12.5	64.9	14.4	7.0
99	313	19.5	62.8	3.8	3.4	3.4	28.3	14.1	86.3	30.2	4.9
99	314	20.2	59.6	2.2	0.0	0.0	28.9	13.3	98.5	26.5	5.4
99	315	21.4	46.3	1.2	0.0	0.0	29.3	12.9	83.2	19.5	5.9
99	316	23.0	44.2	2.5	0.0	0.0	30.6	14.9	82.9	18.3	6.3
99	317	23.6	33.7	2.2	0.0	0.0	31.2	15.7	60.9	14.4	6.9
99	318	23.6	33.5	3.2	0.0	0.0	30.4	17.0	53.8	15.7	6.2
99	319	21.0	52.1	2.7	1.6	1.6	27.6	16.8	74.0	26.7	5.0
99	320	20.7	57.6	4.4	2.7	2.7	28.7	14.1	93.5	17.7	5.6
99	321	20.6	58.3	2.0	0.0	0.0	28.4	11.8	98.8	25.5	6.3
99	322	21.5	37.9	3.3	0.0	0.0	28.2	13.2	80.6	15.7	7.4
99	323	18.0	33.9	1.4	0.0	0.0	26.5	8.2	69.4	10.6	5.8
99	324	19.9	45.0	2.3	0.0	0.0	27.3	11.3	88.5	15.4	6.1
99	325	21.4	44.5	2.3	0.0	0.0	28.9	13.4	86.6	15.0	5.9
99	326	21.9	33.7	2.4	0.0	0.0	30.6	13.6	68.0	10.4	7.0
99	327	23.5	25.4	2.0	0.0	0.0	32.2	10.1	48.2	10.7	7.1
99	328	23.0	52.7	3.8	5.3	5.3	32.1	16.3	90.6	18.2	6.9
99	329	21.5	57.2	3.3	0.1	0.1	28.2	15.5	87.8	32.2	5.2
99	330	21.8	51.1	2.8	1.7	1.7	29.3	14.9	91.1	20.4	6.7
99	331	22.2	49.2	3.1	0.2	0.2	28.0	15.2	84.2	27.1	5.6
99	332	20.5	65.1	4.3	0.9	0.9	28.9	14.8	93.2	21.0	5.1
99	333	20.8	56.2	2.5	0.0	0.0	27.6	13.0	90.2	27.0	5.8
99	334	20.6	54.3	5.0	0.1	0.1	27.7	13.9	90.4	23.3	6.1
99	335	21.0	56.6	2.9	9.9	9.9	27.7	14.9	89.0	27.2	5.6
99	336	16.2	86.5	2.1	45.5	45.5	22.5	13.9	100.0	52.5	2.1
99	337	16.8	91.5	1.2	7.0	7.0	20.3	13.9	100.0	75.7	2.0
99	338	20.4	73.9	1.1	0.0	0.0	26.1	15.7	99.2	41.2	5.8
99	339	22.4	60.3	2.7	0.0	0.0	29.4	16.3	95.0	25.1	6.3
99	340	21.5	46.6	2.1	0.0	0.0	28.2	14.1	82.3	17.0	7.1
99	341	20.9	53.7	2.2	0.0	0.0	28.9	12.4	97.6	19.3	6.4
99	342	19.8	69.3	3.9	0.0	0.0	26.9	15.5	89.8	39.0	3.9
99	343	18.3	68.7	2.0	0.0	0.0	22.6	13.7	92.2	45.1	3.4
99	344	17.2	81.7	2.7	2.3	2.3	21.9	11.6	98.5	57.9	2.7
99	345	18.0	71.6	1.5	2.3	2.3	25.4	11.1	98.2	34.1	5.1
99	346	18.1	67.1	1.9	0.0	0.0	25.6	11.0	99.6	31.7	5.3

99	347	18.9	64.2	1.5	0.0	0.0	25.7	10.2	98.2	33.8	5.8
99	348	21.0	55.6	1.9	0.0	0.0	28.5	13.7	89.2	27.9	6.1
99	349	21.4	56.3	2.4	2.0	2.0	27.9	15.6	83.2	30.3	5.1
99	350	18.3	72.3	2.8	17.7	17.7	25.3	14.3	96.3	40.8	3.0
99	351	17.9	78.7	2.5	6.0	6.0	22.1	14.7	91.6	54.3	3.0
99	352	20.7	67.0	2.1	0.0	0.0	26.7	14.7	95.4	39.3	4.4
99	353	18.3	80.3	2.6	2.3	2.3	21.7	15.5	98.9	65.2	2.6
99	354	17.3	91.4	2.0	6.0	6.0	20.2	15.6	100.0	76.2	2.1
99	355	18.9	86.8	2.1	11.9	11.9	22.7	14.7	100.0	69.4	3.5
99	356	18.1	90.3	2.6	36.7	36.7	23.2	16.4	100.0	66.0	2.4
99	357	17.1	95.7	2.7	9.1	9.1	20.5	15.6	100.0	79.2	1.6
99	358	17.7	89.1	3.0	24.2	24.2	21.8	15.2	99.3	71.4	2.7
99	359	16.6	87.2	2.2	17.7	17.7	21.7	14.3	100.0	67.3	2.4
99	360	20.2	77.0	1.5	0.0	0.0	26.5	12.8	100.0	45.1	5.2
99	361	19.3	83.4	1.7	0.2	0.2	22.3	17.0	100.0	59.8	2.4
99	362	19.6	85.0	2.5	11.3	11.3	25.5	15.0	100.0	56.1	4.0
99	363	20.2	73.2	1.6	1.0	1.0	26.5	13.6	99.8	41.7	5.4
99	364	20.6	72.7	2.7	4.7	4.7	27.4	15.6	91.9	42.0	5.4
99	365	21.2	67.4	2.3	0.4	0.4	27.8	15.3	97.8	33.2	6.0
2000	1	20.0	74.1	2.8	1.6	1.4	25.7	16.1	94.1	48.5	4.7
2000	2	20.3	68.4	1.9	0.0	0.0	26.4	14.6	98.1	30.5	6.1
2000	3	19.6	76.7	2.3	0.0	0.0	25.8	13.4	98.8	47.9	4.7
2000	4	19.6	76.3	2.4	0.8	0.0	25.4	13.9	99.7	49.4	4.7
2000	5	17.4	94.4	2.1	14.5	11.0	20.0	14.8	100.0	78.8	1.6
2000	6	20.6	83.0	1.5	0.0	0.0	25.9	16.1	100.0	55.2	4.6
2000	7	21.6	79.1	2.5	0.0	0.0	26.1	18.2	100.0	51.1	4.6
2000	8	20.9	74.7	2.1	0.0	0.0	27.6	14.4	100.0	39.1	5.4
2000	9	18.8	80.1	2.6	0.0	0.0	25.3	13.3	100.0	53.1	4.4
2000	10	21.8	68.1	1.8	0.0	0.0	28.3	15.6	97.6	33.6	5.9
2000	11	22.0	67.4	2.7	0.0	0.0	27.7	16.7	93.2	34.5	5.5
2000	12	19.2	80.3	2.2	2.4	2.8	25.6	15.6	98.3	49.5	3.0
2000	13	16.4	82.7	2.3	0.3	0.0	19.5	12.2	99.1	62.7	2.3
2000	14	13.9	83.1	3.5	13.7	9.8	17.1	10.2	100.0	60.9	2.0
2000	15	11.9	92.1	1.8	9.0	9.0	13.8	9.1	100.0	79.6	1.1
2000	16	15.9	72.8	1.2	0.0	0.0	22.5	9.4	99.2	42.7	5.3
2000	17	17.5	65.0	1.7	0.0	0.0	24.3	10.4	91.1	40.5	5.3
2000	18	16.4	70.9	1.4	0.0	0.0	23.0	8.2	100.0	42.3	5.2
2000	19	17.7	66.9	1.8	0.0	0.0	25.2	9.4	90.8	39.4	5.9
2000	20	19.5	60.5	1.8	0.0	0.0	26.9	12.8	87.7	30.5	6.1
2000	21	20.9	57.1	1.4	0.0	0.0	28.4	13.4	90.4	28.7	6.1
2000	22	20.9	57.4	1.6	0.0	0.0	28.5	12.8	90.1	25.6	6.0
2000	23	21.1	55.8	2.0	0.0	0.0	27.6	14.4	83.8	33.7	5.6
2000	24	19.0	69.4	1.9	0.0	0.0	24.5	12.2	90.2	45.0	3.7
2000	25	19.5	73.2	1.3	0.0	0.0	25.1	13.3	98.4	46.4	4.1
2000	26	19.8	75.8	1.7	0.0	0.0	25.3	16.1	96.5	52.5	4.2
2000	27	18.7	81.0	2.2	19.0	19.0	24.8	14.3	100.0	51.4	3.8
2000	28	19.1	77.5	1.8	0.0	0.0	25.1	15.3	100.0	41.4	4.8
2000	29	17.2	65.8	2.1	0.0	0.0	23.1	11.2	97.8	29.3	5.8
2000	30	17.6	58.5	1.8	0.0	0.0	26.1	7.7	97.4	21.4	6.3
2000	31	19.0	53.6	1.4	0.0	0.0	28.2	8.3	95.3	21.7	6.6
2000	32	20.2	53.7	1.7	0.0	0.0	29.1	9.8	91.6	20.2	6.7
2000	33	21.7	49.1	1.2	0.0	0.0	29.9	11.0	89.0	19.2	6.0
2000	34	21.1	66.8	3.4	0.4	0.4	27.9	15.6	92.7	42.5	5.1

2000	35	21.1	61.7	2.2	0.0	0.0	28.8	11.9	97.2	30.6	6.0
2000	36	22.2	56.1	1.8	0.0	0.0	30.3	15.1	91.7	21.2	6.0
2000	37	22.7	56.4	1.8	0.0	0.0	30.4	15.2	84.9	26.0	5.8
2000	38	21.9	66.8	2.1	0.0	0.0	27.2	15.5	95.1	46.9	4.4
2000	39	22.3	64.4	2.4	0.0	0.0	29.2	15.9	90.2	34.6	5.7
2000	40	21.1	71.1	2.4	1.1	0.0	26.6	16.6	98.3	48.7	5.1
2000	41	18.3	92.3	2.3	16.3	21.0	22.2	15.2	100.0	68.3	2.0
2000	42	19.9	87.6	1.0	19.4	17.2	25.3	16.2	100.0	55.6	3.1
2000	43	21.0	85.0	1.4	16.5	12.8	27.7	17.6	100.0	48.0	4.5
2000	44	20.8	76.8	2.2	0.1	0.1	27.5	17.4	96.9	48.2	4.0
2000	45	20.8	76.4	2.4	0.0	0.0	26.4	14.8	100.0	50.5	5.2
2000	46	20.9	77.7	1.8	9.4	8.6	27.1	15.2	100.0	41.7	5.0
2000	47	20.7	71.9	1.5	0.0	0.4	27.7	14.0	100.0	35.6	5.0
2000	48	19.0	68.6	2.5	0.0	0.0	26.2	13.0	94.9	34.4	4.7
2000	49	17.4	67.7	2.8	0.0	0.0	23.4	11.8	90.7	40.5	4.5
2000	50	19.6	73.0	1.9	0.0	0.0	24.6	14.2	95.1	52.0	3.7
2000	51	21.6	71.8	1.7	1.0	1.0	27.9	16.3	95.0	41.7	4.7
2000	52	20.1	84.9	1.7	14.0	12.0	26.6	17.4	98.8	57.8	3.7
2000	53	21.2	78.3	1.5	0.0	0.0	26.3	16.5	99.1	54.9	4.4
2000	54	18.5	88.2	1.1	2.5	2.8	21.7	16.8	97.2	73.7	1.6
2000	55	19.8	78.5	1.2	0.0	0.0	26.5	14.9	99.9	50.2	4.8
2000	56	20.2	73.3	1.1	0.0	0.0	27.3	13.1	99.8	37.1	5.1
2000	57	20.1	79.4	1.4	10.4	9.8	26.9	16.8	93.9	48.9	4.0
2000	58	19.2	80.4	1.5	4.9	3.2	26.6	14.5	99.0	49.4	3.9
2000	59	19.6	76.6	1.6	0.0	0.0	24.4	15.6	99.3	49.5	3.3
2000	60	20.3	74.0	1.2	0.0	0.0	25.8	15.9	95.7	42.8	4.2
2000	61	20.6	78.7	0.8	0.0	0.0	25.7	14.4	99.9	54.4	3.7
2000	62	20.6	80.2	2.2	0.0	0.0	24.9	17.7	94.9	56.6	2.7
2000	63	20.7	84.3	2.4	6.3	2.7	26.8	17.3	99.5	49.8	3.4
2000	64	19.2	92.2	0.9	4.5	11.0	25.8	16.5	100.0	61.0	2.4
2000	65	20.2	82.5	1.4	2.6	2.6	25.0	15.8	100.0	57.7	3.9
2000	66	21.0	74.6	1.8	0.0	0.0	27.5	15.8	99.7	38.4	4.6
2000	67	20.5	74.6	1.2	0.2	0.2	26.4	14.6	100.0	44.9	4.8
2000	68	20.5	72.3	1.8	0.0	0.0	26.2	14.8	96.8	38.5	4.6
2000	69	19.3	73.3	1.2	0.0	0.0	26.0	14.6	96.5	38.8	4.6
2000	70	20.3	67.0	1.3	0.0	0.0	27.4	14.6	94.3	31.7	4.4
2000	71	21.2	63.7	1.7	0.0	0.0	27.7	15.3	94.4	35.7	4.4
2000	72	19.9	70.2	1.8	5.8	7.0	27.1	14.4	91.1	33.3	3.7
2000	73	19.6	73.2	1.9	0.0	0.0	26.6	15.1	93.6	37.8	4.0
2000	74	19.6	73.2	2.1	0.0	0.0	25.9	14.5	94.2	45.8	3.4
2000	75	19.4	74.7	2.1	0.0	0.0	25.5	15.3	93.5	49.5	3.4
2000	76	18.6	87.9	1.9	9.1	11.2	24.1	15.5	99.6	63.7	2.1
2000	77	18.3	89.6	1.4	6.3	5.0	21.4	15.2	100.0	72.0	1.7
2000	78	20.5	77.5	1.1	0.7	0.7	26.7	15.7	99.6	45.5	3.9
2000	79	20.2	76.6	0.9	0.0	0.0	26.2	15.5	99.3	42.8	4.1
2000	80	19.7	82.8	2.2	8.7	8.7	25.5	16.1	100.0	56.8	3.7
2000	81	18.1	85.9	1.8	0.3	0.3	22.0	15.3	100.0	67.1	2.2
2000	82	18.6	82.8	0.7	0.0	0.0	25.6	12.6	100.0	52.7	3.8
2000	83	20.4	70.3	1.1	0.0	0.0	27.8	13.6	98.4	31.3	4.4
2000	84	20.5	67.2	1.5	0.0	0.0	27.0	15.0	92.4	41.1	4.0
2000	85	18.4	84.4	1.9	4.8	4.8	23.0	14.0	100.0	59.4	2.2
2000	86	17.0	93.1	1.6	25.5	17.2	22.8	14.5	100.0	66.1	2.2
2000	87	14.9	97.8	2.5	10.2	11.0	16.2	13.6	100.0	92.9	0.5

2000	88	17.6	87.6	1.4	10.3	6.2	22.7	13.2	100.0	59.2	2.9
2000	89	15.9	93.0	1.5	3.8	0.0	20.4	13.2	100.0	65.1	1.4
2000	90	17.4	85.8	1.4	0.0	0.0	23.4	12.8	100.0	35.7	3.1
2000	91	17.4	77.3	1.0	0.0	0.0	24.3	11.6	99.4	34.2	3.7
2000	92	16.3	81.5	3.0	0.0	0.0	22.7	12.0	99.2	56.0	3.3
2000	93	16.5	77.7	1.3	0.0	0.0	23.3	11.2	96.8	46.4	3.5
2000	94	16.3	80.4	1.5	0.0	0.0	21.9	10.7	100.0	53.3	1.7
2000	95	13.4	87.1	1.8	13.9	9.0	18.8	10.5	100.0	59.8	2.0
2000	96	11.9	79.4	1.6	1.3	0.0	17.1	7.9	98.8	48.3	2.3
2000	97	12.1	84.4	0.5	0.0	0.0	16.3	8.2	100.0	59.7	1.5
2000	98	12.5	76.8	0.7	0.1	0.0	20.9	5.0	100.0	37.7	3.5
2000	99	13.7	72.4	0.8	0.0	0.0	22.8	5.2	100.0	33.5	3.7
2000	100	14.3	68.4	0.6	0.0	0.0	24.4	6.0	98.7	28.5	3.7
2000	101	14.5	69.5	1.0	0.0	0.0	23.1	6.6	99.3	32.6	3.5
2000	102	14.9	71.4	1.1	0.0	0.0	23.6	6.5	97.5	40.0	3.5
2000	103	16.0	70.3	1.0	0.0	0.0	23.8	7.7	99.7	34.2	3.3
2000	104	16.4	69.3	0.9	0.0	0.0	22.5	12.9	91.4	41.2	2.5
2000	105	14.6	78.4	1.0	0.0	0.0	21.5	9.3	100.0	45.1	2.9
2000	106	14.3	70.4	0.9	0.0	0.0	22.6	6.3	100.0	27.9	3.3
2000	107	13.9	75.1	1.1	0.0	0.0	21.8	7.3	99.9	35.1	3.2
2000	108	14.0	76.3	1.3	3.7	2.8	22.1	6.7	99.5	36.3	2.9
2000	109	14.4	76.5	0.7	0.0	0.0	21.4	8.1	100.0	42.0	2.9
2000	110	14.0	82.4	1.3	0.0	0.0	19.6	8.9	100.0	58.6	2.2
2000	111	13.1	91.7	1.6	2.0	2.0	15.2	11.8	96.5	84.6	0.7
2000	112	12.2	89.0	1.4	3.8	2.0	18.5	7.4	100.0	60.3	1.7
2000	113	12.0	88.9	0.9	3.6	6.8	19.3	6.2	100.0	64.0	1.6
2000	114	12.1	88.5	1.4	0.2	0.2	16.9	7.1	99.9	63.5	2.1
2000	115	11.4	73.8	1.0	0.0	0.0	20.3	4.3	100.0	27.8	3.0
2000	116	12.7	67.3	1.4	0.0	0.0	21.1	4.9	97.4	33.7	3.3
2000	117	12.1	75.3	1.3	0.0	0.0	19.9	4.3	100.0	44.5	2.8
2000	118	9.8	68.7	1.3	0.0	0.0	16.9	4.5	100.0	18.2	2.8
2000	119	9.4	78.0	1.9	0.0	0.0	18.3	0.2	100.0	48.2	2.6
2000	120	13.2	85.2	3.2	23.9	22.0	16.5	10.7	100.0	68.7	1.2
2000	121	12.0	94.4	1.7	2.0	10.0	15.3	9.9	100.0	79.9	0.8
2000	122	12.7	90.1	2.4	9.5	4.2	17.4	10.1	98.5	68.8	1.5
2000	123	12.7	85.3	2.2	4.3	11.4	18.2	8.6	100.0	61.3	1.7
2000	124	10.0	94.0	2.2	6.7	0.0	14.2	5.2	100.0	81.0	0.9
2000	125	8.0	87.1	0.8	0.0	0.0	14.9	2.5	100.0	50.1	1.9
2000	126	8.2	85.9	1.0	2.6	0.0	15.8	3.0	100.0	58.4	1.8
2000	127	7.8	83.8	0.7	0.1	0.0	16.4	0.9	100.0	47.7	2.3
2000	128	9.1	79.3	0.8	0.0	0.0	18.3	1.1	100.0	44.2	2.5
2000	129	10.5	78.3	1.1	0.0	0.0	18.3	3.8	99.3	38.3	2.4
2000	130	10.3	76.1	0.6	0.0	0.0	19.9	2.8	99.3	36.6	2.5
2000	131	10.9	73.9	0.9	0.0	0.0	19.3	4.0	97.4	39.5	2.5
2000	132	12.1	64.4	0.9	0.0	0.0	20.3	4.8	98.9	23.1	2.7
2000	133	9.7	75.9	0.8	0.0	0.0	17.9	2.5	100.0	35.1	2.3
2000	134	7.6	75.8	0.7	0.0	0.0	17.1	0.9	100.0	30.6	2.3
2000	135	7.3	74.6	1.3	0.0	0.0	17.5	-1.4	100.0	36.2	2.4
2000	136	8.1	73.2	0.6	0.0	0.0	18.0	1.9	95.8	29.8	2.2
2000	137	8.0	72.1	0.9	0.0	0.0	17.1	0.9	97.7	34.3	2.3
2000	138	10.2	70.6	0.8	0.0	0.0	18.3	2.7	98.4	32.5	2.4
2000	139	12.2	63.2	1.9	0.1	0.0	17.9	8.1	88.2	41.2	1.8
2000	140	10.8	79.1	1.8	0.0	0.0	16.5	6.1	98.1	51.0	2.0

2000	141	11.1	72.3	1.4	0.0	0.0	19.0	3.7	98.3	37.4	2.3
2000	142	11.1	68.0	1.2	0.0	0.0	20.5	2.4	98.6	33.1	2.5
2000	143	11.4	65.6	1.3	0.0	0.0	20.5	4.1	91.4	32.4	2.5
2000	144	11.1	67.9	0.9	0.0	0.0	19.6	2.1	97.2	37.8	2.2
2000	145	12.5	73.1	2.9	0.1	0.0	18.3	9.2	94.8	43.6	1.8
2000	146	11.7	75.0	2.4	0.4	0.0	19.0	6.8	96.0	43.6	2.1
2000	147	8.1	72.7	1.6	0.0	0.0	15.6	1.4	100.0	34.5	2.2
2000	148	5.8	71.8	0.8	0.0	0.0	14.9	-2.2	100.0	30.8	2.1
2000	149	5.3	71.5	1.0	0.0	0.0	15.7	-2.4	100.0	28.2	2.2
2000	150	5.0	69.1	1.0	0.0	0.0	15.7	-2.1	96.1	28.1	2.2
2000	151	5.3	64.0	1.0	0.0	0.0	16.6	-2.4	94.7	19.6	2.4
2000	152	5.8	60.2	0.5	0.0	0.0	17.2	-2.8	91.3	15.5	2.1
2000	153	6.0	53.4	0.9	0.0	0.0	18.4	-3.5	85.7	16.5	2.3
2000	154	9.3	45.2	1.8	0.0	0.0	19.4	-0.7	76.8	22.9	2.6
2000	155	9.7	54.8	1.9	0.0	0.0	17.7	1.7	85.9	27.3	2.3
2000	156	8.2	70.6	0.8	0.0	0.0	17.6	2.1	98.3	31.2	1.9
2000	157	7.0	68.3	0.6	0.0	0.0	18.5	-1.0	100.0	21.9	2.0
2000	158	7.5	61.5	0.5	0.0	0.0	20.1	-2.0	97.5	18.2	2.1
2000	159	7.6	66.1	0.8	0.0	0.0	18.1	0.0	96.2	30.7	2.0
2000	160	7.5	68.2	0.6	0.0	0.0	18.2	-0.0	94.7	31.9	2.0
2000	161	8.6	66.5	0.9	0.0	0.0	17.7	0.5	96.1	33.5	2.0
2000	162	11.5	62.7	1.2	0.0	0.0	18.1	5.0	82.3	43.6	1.7
2000	163	12.0	62.7	2.4	0.0	0.0	19.8	5.2	82.8	38.9	2.2
2000	164	9.8	62.9	1.2	0.0	0.0	20.0	1.2	94.4	27.0	2.3
2000	165	11.6	70.7	2.2	0.0	0.0	19.5	4.6	92.8	40.8	2.1
2000	166	11.0	68.1	1.2	0.0	0.0	19.9	5.3	89.8	33.7	2.1
2000	167	9.5	63.6	1.4	0.0	0.0	18.9	1.7	92.9	30.9	2.3
2000	168	9.8	63.7	2.0	0.0	0.0	16.6	2.8	87.1	38.2	1.8
2000	169	9.0	84.1	1.7	1.7	0.0	16.1	0.5	100.0	56.7	1.4
2000	170	5.8	66.2	0.5	0.1	0.0	17.2	-3.2	100.0	17.0	1.9
2000	171	6.5	72.9	1.3	0.0	0.0	17.1	-1.4	94.7	39.0	1.9
2000	172	7.2	79.0	1.0	0.0	0.0	15.5	1.7	100.0	45.0	1.7
2000	173	6.9	93.2	1.5	0.0	0.0	11.7	4.3	100.0	76.2	1.0
2000	174	9.0	87.1	1.8	0.2	0.2	13.1	4.1	100.0	71.7	0.7
2000	175	6.3	81.6	1.2	0.0	0.0	12.7	-2.8	100.0	47.0	1.5
2000	176	2.5	69.6	0.6	0.0	0.0	13.9	-5.4	98.5	29.4	1.8
2000	177	4.1	65.7	0.6	0.0	0.0	16.8	-5.0	95.2	23.8	1.9
2000	178	5.6	57.7	0.6	0.0	0.0	20.1	-4.9	92.1	14.4	2.2
2000	179	7.0	54.2	0.6	0.0	0.0	20.1	-2.3	86.3	14.9	2.2
2000	180	6.8	54.2	0.6	0.0	0.0	18.6	-2.1	83.3	18.8	2.1
2000	181	6.5	53.6	0.6	0.0	0.0	18.9	-2.6	85.2	17.8	2.1
2000	182	6.9	56.7	1.8	0.0	0.0	17.2	-0.8	83.4	24.6	2.4
2000	183	6.0	70.7	0.8	0.0	3.2	16.1	-1.0	92.1	36.0	1.9
2000	184	5.5	69.6	0.6	0.0	0.0	16.3	-2.3	99.7	32.5	1.9
2000	185	6.1	66.2	1.2	0.0	0.0	16.9	-2.2	93.9	31.6	2.1
2000	186	6.5	59.1	0.7	0.0	0.0	17.2	-0.9	87.5	22.6	2.1
2000	187	6.6	58.3	0.6	0.0	0.0	17.8	-1.4	88.6	23.9	2.0
2000	188	5.9	66.4	0.6	0.0	2.0	16.5	-3.2	98.2	31.6	1.9
2000	189	6.3	67.5	1.0	0.0	0.0	16.2	-1.0	95.4	31.1	1.9
2000	190	5.7	66.3	0.6	0.0	7.0	16.1	-1.9	94.4	29.6	1.9
2000	191	5.6	66.5	1.0	0.0	0.0	15.2	-2.7	93.2	34.2	1.9
2000	192	5.3	65.5	0.9	0.0	0.0	15.3	-3.2	94.9	30.7	2.1
2000	193	5.1	60.8	0.6	0.0	0.0	16.1	-3.5	95.3	24.1	2.1

2000	194	7.1	60.5	1.0	0.0	0.0	18.0	-1.9	86.6	27.3	2.2
2000	195	10.1	66.8	1.4	0.0	0.0	15.9	4.1	85.8	45.4	1.8
2000	196	13.1	49.3	4.1	0.1	0.0	19.5	7.2	78.9	25.0	2.9
2000	197	4.1	86.0	3.3	1.6	0.0	9.9	-1.0	100.0	66.6	0.7
2000	198	0.2	74.0	2.0	0.2	0.0	7.6	-6.1	98.0	33.7	1.6
2000	199	2.3	56.0	1.2	0.0	0.0	13.7	-7.0	93.7	18.7	2.2
2000	200	7.7	43.3	2.3	0.0	0.0	18.8	-2.8	74.0	18.1	2.8
2000	201	6.2	48.7	2.5	0.0	7.4	13.1	-2.5	86.7	23.2	2.3
2000	202	-0.2	67.3	2.1	0.0	9.0	6.8	-5.8	95.1	32.0	1.6
2000	203	0.2	54.3	0.8	0.0	0.0	11.7	-8.9	89.3	14.1	2.1
2000	204	1.9	41.4	0.8	0.0	0.0	14.4	-9.2	79.3	11.7	2.2
2000	205	6.8	49.0	2.6	0.0	0.0	14.4	-2.2	65.5	27.0	2.0
2000	206	9.4	67.9	2.4	0.5	0.0	14.8	4.3	87.6	46.1	1.8
2000	207	9.0	69.7	1.2	1.0	0.0	16.2	3.7	100.0	32.3	2.2
2000	208	7.8	58.4	1.0	0.0	0.0	17.6	0.9	82.8	26.9	2.2
2000	209	7.6	60.6	0.8	0.0	0.0	18.0	-0.5	92.8	25.8	2.4
2000	210	7.9	52.8	0.9	0.0	0.0	19.4	-0.9	88.1	19.4	2.6
2000	211	8.2	46.9	0.9	0.0	0.0	19.0	0.2	76.7	18.3	2.7
2000	212	8.3	48.7	0.7	0.0	0.0	19.1	-0.2	76.9	18.2	2.4
2000	213	8.0	49.5	0.7	0.0	0.0	19.3	-0.8	78.6	18.5	2.6
2000	214	9.4	44.2	1.9	0.0	0.0	19.2	-0.9	78.8	18.3	3.0
2000	215	11.1	50.9	3.4	0.0	0.0	18.6	6.2	71.0	29.2	2.9
2000	216	9.0	59.6	2.8	0.0	0.0	15.4	-1.5	74.2	39.8	2.2
2000	217	4.6	45.2	0.8	0.0	0.0	14.2	-4.4	71.9	10.1	2.2
2000	218	4.2	36.9	0.9	0.0	0.0	17.6	-5.5	66.6	8.2	2.6
2000	219	5.8	29.7	0.6	0.0	0.0	18.9	-4.4	52.4	9.0	2.7
2000	220	6.8	36.4	1.2	0.0	0.0	20.2	-5.8	59.2	12.9	3.1
2000	221	9.0	42.3	1.0	0.0	0.0	21.3	-0.8	68.4	16.8	3.0
2000	222	10.4	39.0	0.7	0.0	0.0	22.4	0.5	72.3	14.1	3.0
2000	223	10.1	33.8	0.8	0.0	0.0	21.7	0.6	62.4	11.8	3.0
2000	224	9.3	34.5	0.8	0.0	0.0	20.0	0.1	60.1	13.9	2.7
2000	225	9.1	59.6	1.0	0.0	0.0	18.6	-0.3	96.5	24.1	2.7
2000	226	9.5	39.6	1.4	0.0	0.0	20.0	-1.0	81.0	11.0	3.3
2000	227	9.9	45.7	0.7	0.0	0.0	20.2	0.8	75.7	22.2	2.6
2000	228	10.5	49.1	1.2	0.0	0.0	20.6	2.3	82.0	17.6	2.8
2000	229	9.7	46.4	1.0	0.0	0.0	20.4	0.6	77.9	17.6	3.1
2000	230	10.5	44.2	0.8	0.0	0.0	20.9	1.9	76.4	17.2	3.0
2000	231	11.1	39.5	1.0	0.0	0.0	20.6	2.5	65.8	16.2	3.1
2000	232	13.8	47.1	3.0	0.0	0.0	19.8	8.4	68.4	20.0	3.0
2000	233	12.8	48.2	2.3	0.0	0.0	20.8	5.7	67.6	25.8	3.2
2000	234	14.1	42.5	3.4	0.0	0.0	21.1	7.6	61.0	20.9	3.6
2000	235	12.2	50.5	2.0	0.0	0.0	21.1	4.6	78.5	24.5	3.6
2000	236	14.2	51.0	3.0	0.0	0.0	23.2	4.8	79.9	25.2	3.6
2000	237	12.1	66.1	2.3	0.0	0.0	17.9	5.6	88.8	41.0	1.9
2000	238	11.7	59.9	1.5	0.0	0.0	21.4	2.7	94.8	28.1	3.5
2000	239	12.6	47.5	1.1	0.0	0.0	22.9	3.5	83.0	17.5	3.5
2000	240	12.5	41.7	1.2	0.0	6.0	23.5	2.4	74.8	15.2	3.8
2000	241	12.8	39.5	1.3	0.0	4.5	23.7	3.9	63.6	14.2	3.8
2000	242	12.2	36.5	1.8	18.0	22.0	24.0	0.8	71.7	10.3	4.4
2000	243	11.4	24.2	2.3	0.0	4.8	21.9	2.0	56.4	9.4	4.3
2000	244	10.1	37.2	2.8	9.0	11.0	20.2	0.8	72.9	13.9	4.1
2000	245	10.8	41.7	1.4	0.0	3.5	21.7	0.9	78.9	14.8	3.8
2000	246	17.3	21.8	4.1	0.0	0.0	27.2	5.2	42.0	11.1	5.5

2000	247	9.6	43.2	2.0	0.0	0.0	16.2	2.1	75.5	26.5	3.1
2000	248	7.5	50.4	1.2	0.0	0.0	17.0	-2.4	90.5	19.4	3.0
2000	249	9.3	38.6	1.2	0.0	0.0	19.7	-0.1	68.7	14.1	3.5
2000	250	10.1	34.3	1.8	0.0	0.0	21.7	-1.7	64.6	11.7	4.1
2000	251	9.9	30.4	2.7	0.0	0.0	19.5	0.2	64.0	12.3	4.1
2000	252	11.6	33.7	2.6	0.0	0.0	21.4	-0.6	46.2	18.4	3.8
2000	253	17.1	45.5	4.6	0.0	0.0	25.3	10.0	71.7	21.7	4.4
2000	254	13.2	37.3	3.7	0.0	0.0	19.7	4.3	74.4	11.3	4.5
2000	255	10.6	26.6	1.4	0.0	0.0	20.0	1.2	57.1	8.1	3.7
2000	256	12.7	60.9	5.4	0.0	0.0	19.8	5.5	81.6	38.8	3.3
2000	257	14.5	70.6	3.6	3.1	9.0	23.5	7.1	95.4	35.0	2.7
2000	258	12.7	68.3	2.1	1.9	7.0	19.3	8.5	97.3	35.2	3.2
2000	259	13.2	67.9	4.0	0.1	0.0	19.0	7.9	81.5	50.4	2.5
2000	260	14.8	69.7	3.8	0.0	0.0	19.3	11.4	86.5	47.5	2.3
2000	261	10.0	98.0	3.7	43.5	38.4	14.6	7.7	100.0	77.9	0.5
2000	262	8.5	87.0	2.2	0.4	1.4	12.3	6.3	100.0	61.1	2.0
2000	263	6.7	92.4	1.9	3.6	0.0	8.4	5.1	98.1	78.5	1.0
2000	264	10.3	75.7	3.2	0.0	0.0	15.2	6.0	91.4	55.6	3.1
2000	265	11.5	75.3	1.9	0.0	0.0	18.0	4.0	95.7	49.8	2.9
2000	266	14.7	72.0	2.0	0.0	0.0	21.0	10.3	96.2	39.0	3.1
2000	267	15.0	62.1	1.4	0.0	0.0	22.6	6.9	94.3	29.7	4.0
2000	268	16.5	54.1	3.9	0.0	0.0	23.5	10.4	75.6	25.8	4.6
2000	269	12.3	53.0	1.0	0.0	0.0	20.8	2.7	98.6	19.4	4.2
2000	270	11.9	45.6	2.1	0.0	0.0	20.6	4.4	83.3	11.6	4.8
2000	271	12.7	46.0	1.1	0.0	0.0	23.3	2.6	78.9	12.7	4.6
2000	272	15.7	45.8	1.9	0.0	0.0	26.7	4.3	78.4	20.0	5.2
2000	273	18.4	44.9	1.6	0.0	0.0	28.9	8.4	76.7	13.1	5.3
2000	274	20.3	41.6	3.1	0.3	0.0	27.7	10.9	62.6	20.3	4.6
2000	275	18.8	35.9	2.2	0.0	0.0	25.8	8.0	65.5	14.7	5.3
2000	276	17.4	44.2	1.9	0.0	0.0	27.0	7.6	77.3	21.2	5.0
2000	277	17.8	66.0	3.5	4.3	3.0	27.2	12.2	92.3	26.0	4.2
2000	278	16.4	79.3	3.3	3.9	0.8	24.3	12.4	96.4	43.7	2.8
2000	279	17.6	61.5	2.7	0.0	0.0	24.1	12.4	95.6	17.4	4.1
2000	280	15.7	45.7	1.0	0.0	0.0	24.2	6.6	83.1	15.5	4.9
2000	281	17.8	57.0	3.0	0.0	0.0	26.8	7.7	85.0	22.7	4.8
2000	282	16.5	74.9	4.9	0.6	0.0	22.5	12.1	94.7	45.2	2.7
2000	283	16.3	65.9	2.1	0.0	0.0	25.8	9.1	100.0	22.1	4.8
2000	284	16.4	46.1	1.4	0.0	0.0	26.6	5.6	84.8	14.0	5.6
2000	285	17.0	69.4	3.4	0.0	0.0	25.4	7.9	98.7	36.8	4.7
2000	286	18.0	66.3	4.4	0.0	0.0	25.5	10.9	92.1	39.2	4.6
2000	287	19.3	62.8	2.0	0.0	4.2	26.7	13.8	84.9	34.5	4.5
2000	288	20.0	55.9	1.7	0.0	0.0	27.2	13.9	80.5	29.2	4.8
2000	289	21.1	46.2	2.3	0.0	5.5	29.2	13.2	75.8	16.8	5.8
2000	290	21.6	35.7	2.4	0.0	0.0	29.5	15.5	54.9	15.4	6.1
2000	291	21.7	33.5	1.8	0.0	0.0	30.3	11.6	63.0	17.7	5.8
2000	292	22.9	37.5	3.3	0.0	0.0	30.6	13.8	72.6	16.9	5.7
2000	293	19.0	44.1	2.0	0.0	0.0	27.4	8.8	78.9	11.6	4.9
2000	294	16.4	74.1	3.5	0.6	0.0	22.7	12.6	94.2	45.3	2.4
2000	295	18.2	64.6	4.3	0.0	0.0	26.0	12.2	95.5	33.8	5.0
2000	296	17.1	72.8	3.4	2.1	1.6	23.6	12.1	97.5	42.9	3.9
2000	297	17.4	71.8	4.1	0.0	0.0	24.7	12.3	100.0	34.3	4.3
2000	298	16.5	69.2	3.2	0.0	5.0	23.4	11.7	96.5	32.3	4.0
2000	299	15.5	68.7	2.8	0.1	0.0	23.9	6.8	97.9	29.5	4.4

2000	300	16.0	63.9	2.2	0.0	0.0	23.8	9.2	93.0	25.0	3.9
2000	301	16.6	57.8	2.0	0.0	2.0	24.3	10.2	95.5	21.8	4.1
2000	302	17.4	64.6	2.7	0.0	6.5	24.3	11.4	96.5	34.7	4.8
2000	303	18.1	63.0	3.3	12.2	5.5	26.5	10.2	100.0	27.2	5.6
2000	304	13.6	68.4	2.7	0.0	0.0	19.4	8.0	100.0	30.3	4.6
2000	305	10.8	63.1	2.3	0.0	0.0	18.3	3.8	96.7	28.8	3.9
2000	306	10.3	55.9	1.6	0.0	0.0	17.5	1.9	96.8	24.8	4.6
2000	307	15.0	47.9	2.2	0.0	0.0	23.6	4.0	84.4	21.8	5.5
2000	308	14.8	65.2	2.8	2.4	0.0	23.9	8.8	96.9	23.6	3.5
2000	309	15.8	54.9	2.1	0.0	0.0	25.0	6.7	97.9	14.8	6.0
2000	310	17.4	40.4	1.4	0.0	0.0	27.8	4.8	83.3	12.8	6.2
2000	311	18.3	56.8	3.0	10.1	0.0	28.8	9.4	96.5	22.3	5.2
2000	312	18.0	74.8	4.1	4.0	8.0	23.4	12.7	100.0	49.9	4.3
2000	313	18.1	65.9	3.7	3.6	2.8	26.3	11.8	97.9	26.5	5.3
2000	314	18.6	58.1	1.9	0.0	14.0	25.9	11.1	87.2	29.5	6.1
2000	315	19.7	51.9	1.8	0.0	0.0	28.9	11.0	88.8	13.7	6.0
2000	316	21.6	45.4	1.9	0.0	0.0	31.0	12.7	84.9	12.6	6.5
2000	317	20.3	42.3	5.4	0.0	0.0	28.8	11.0	62.7	22.8	6.7
2000	318	13.7	59.6	4.0	0.0	0.0	19.9	6.2	82.4	33.2	4.7
2000	319	15.6	55.3	1.4	0.0	0.0	22.8	8.4	83.7	30.1	4.0
2000	320	17.7	54.3	1.3	0.0	0.0	26.2	7.7	87.6	24.8	5.3
2000	321	19.2	57.1	2.6	0.0	0.0	26.8	10.2	92.8	28.4	5.7
2000	322	19.5	62.5	4.5	14.1	14.2	27.6	11.8	98.7	29.7	6.3
2000	323	13.0	81.9	3.9	22.9	18.0	16.3	7.1	100.0	53.1	2.9
2000	324	14.7	71.4	2.8	0.0	10.5	20.7	6.7	99.4	46.6	4.1
2000	325	17.3	67.2	1.3	0.0	0.0	22.0	11.9	90.4	42.2	4.0
2000	326	17.8	63.7	2.3	0.0	0.0	25.9	10.6	93.0	17.5	6.1
2000	327	16.7	65.7	1.9	0.0	10.0	23.8	8.3	100.0	30.1	5.6
2000	328	18.1	60.3	2.2	0.0	0.0	24.9	10.7	90.4	30.3	5.6
2000	329	19.7	57.3	3.3	0.0	2.0	28.4	12.5	84.7	26.4	6.1
2000	330	18.8	63.3	3.4	0.0	2.0	27.5	10.0	91.9	30.0	5.7
2000	331	17.3	73.7	3.8	0.6	0.0	25.7	13.0	92.0	33.8	4.4
2000	332	17.5	76.5	2.9	0.5	0.0	22.1	13.6	93.8	59.2	3.1
2000	333	15.4	91.6	1.7	3.1	14.0	17.8	13.6	100.0	77.7	1.5
2000	334	18.8	66.7	2.0	0.0	0.0	25.7	11.8	100.0	32.2	5.3
2000	335	18.0	71.0	1.8	0.5	1.8	25.4	11.0	96.4	41.6	4.9
2000	336	20.0	63.6	2.4	0.0	0.0	27.5	12.7	97.3	29.2	5.4
2000	337	20.6	65.8	2.4	10.6	19.0	29.1	15.4	92.2	28.3	5.0
2000	338	18.0	76.6	2.6	5.0	3.0	27.6	12.3	97.2	35.1	4.4
2000	339	19.2	66.4	3.1	0.0	4.5	27.4	11.9	94.2	30.3	5.5
2000	340	19.9	61.5	3.8	3.1	0.0	28.4	13.5	90.3	28.3	6.1
2000	341	20.8	67.7	3.5	7.4	0.0	28.8	15.1	86.0	37.2	5.3
2000	342	20.0	71.2	4.3	2.8	0.0	26.0	15.4	94.9	41.4	4.8
2000	343	16.8	88.2	2.5	16.3	18.0	22.4	13.8	98.7	69.1	3.0
2000	344	18.8	80.6	3.2	1.1	8.0	25.6	13.2	97.2	51.7	4.7
2000	345	18.9	85.1	1.8	0.6	0.0	24.5	15.8	100.0	63.2	3.7
2000	346	16.1	90.3	2.4	21.6	17.0	18.2	13.3	100.0	72.6	1.5
2000	347	16.8	65.8	2.2	0.0	0.0	23.3	11.2	100.0	31.8	6.1
2000	348	17.7	57.3	1.6	0.0	0.0	24.8	9.1	87.1	26.2	6.2
2000	349	19.8	55.9	2.4	0.0	0.0	28.2	11.3	88.8	21.1	6.6
2000	350	21.2	56.2	3.0	0.0	0.0	29.6	13.2	94.9	17.4	6.8
2000	351	19.3	70.0	3.9	2.5	0.0	25.7	15.1	91.0	39.3	4.0
2000	352	19.5	68.4	4.2	8.6	11.0	27.6	13.5	95.7	32.0	5.9

2000	353	21.4	55.9	2.3	0.0	0.0	29.0	12.0	94.1	21.9	6.8
2000	354	21.5	60.0	2.7	0.0	0.0	28.7	14.3	88.0	30.0	6.0
2000	355	19.0	78.8	2.5	22.4	18.0	26.7	15.2	97.1	45.1	3.2
2000	356	19.3	72.5	1.6	0.3	0.0	26.1	12.2	97.1	39.3	5.3
2000	357	20.2	77.7	1.8	0.0	0.0	25.8	14.1	99.4	49.0	4.6
2000	358	21.9	68.3	2.3	0.0		28.8	14.6	97.9	35.0	5.7
2000	359	22.5	53.2	3.8	0.0		31.1	15.3	94.7	13.9	7.2
2000	360	20.3	53.9	3.7	0.0		27.0	14.0	87.3	23.0	6.8
2000	361	19.3	61.1	2.2	0.0		26.7	11.8	94.5	32.3	5.5
2000	362	20.2	64.6	4.0	0.0		26.7	15.2	94.4	33.0	6.0
2000	363	20.7	65.6	3.3	5.3		27.1	14.9	89.9	35.0	5.4
2000	364	21.3	55.0	3.2	0.0		29.4	14.6	94.6	13.3	6.9
2000	365	20.8	50.0	2.3	0.0	0.0	29.8	11.8	94.1	11.7	7.3
2000	366	21.0	42.6	3.7	0.0	0.0	30.9	10.0	82.3	14.6	7.1
2001	1	14.5	67.7	6.0	1.0	0.0	17.4	9.3	98.0	47.1	4.3
2001	2	15.0	51.9	3.0	0.0	0.0	22.4	6.3	87.2	26.8	5.7
2001	3	15.8	54.0	1.1	0.0	0.0	25.3	5.0	91.5	22.5	5.6
2001	4	19.8	45.7	2.2	0.0	0.0	28.7	11.1	79.5	16.5	6.2
2001	5	21.6	43.1	2.6	0.0	0.0	30.5	12.2	78.8	15.1	6.6
2001	6	23.5	42.0	2.4	8.0	14.0	33.3	13.9	82.6	12.5	7.3
2001	7	24.5	42.8	2.6	0.0	0.0	32.8	14.0	82.2	13.4	6.9
2001	8	22.5	53.7	3.9	0.0	0.0	30.6	14.6	89.9	26.8	6.8
2001	9	24.9	36.7	4.2	0.0	0.0	33.3	15.3	55.3	10.9	7.9
2001	10	22.9	24.7	3.0	0.0	0.0	33.1	11.9	53.6	9.8	7.5
2001	11	22.9	22.9	2.1	0.0	0.0	33.9	8.7	59.5	8.1	6.5
2001	12	25.3	44.7	3.9	0.0	0.0	34.3	13.7	92.1	17.0	7.7
2001	13	24.6	48.1	3.0	0.7	0.0	31.2	17.7	77.4	25.4	7.0
2001	14	16.8	50.1	3.3	0.0	0.0	22.3	10.9	77.6	16.5	4.2
2001	15	17.3	40.3	2.1	0.0	0.8	25.9	6.1	80.9	15.4	6.8
2001	16	20.2	39.9	2.3	0.0	0.0	28.6	10.4	95.8	12.9	7.1
2001	17	22.5	46.5	2.4	0.0	0.0	30.1	11.7	88.3	22.0	6.3
2001	18	21.8	59.9	3.6	0.6	0.0	28.5	15.2	89.0	33.2	5.2
2001	19	20.7	65.4	2.7	14.7	17.0	29.6	13.6	94.7	28.0	4.4
2001	20	21.2	66.7	2.9	0.0	0.0	28.5	15.0	99.2	34.4	5.4
2001	21	22.3	51.7	2.0	0.0	0.0	31.8	12.9	91.8	12.1	7.2
2001	22	24.0	56.7	3.4	0.0	0.0	31.3	17.3	92.4	22.8	6.5
2001	23	24.4	47.4	3.7	0.0	0.0	32.4	17.5	87.9	20.9	7.4
2001	24	23.2	55.0	2.2	2.7	0.0	32.1	17.1	90.0	23.7	5.2
2001	25	20.8	69.2	3.5	20.5	28.0	28.4	14.6	99.4	39.3	5.8
2001	26	20.1	74.1	2.4	0.0	0.0	26.0	15.2	93.6	48.6	4.9
2001	27	21.4	61.1	2.9	0.0	0.0	27.9	15.5	86.2	38.3	5.6
2001	28	19.7	76.6	1.9	2.3	13.5	27.0	16.1	90.6	46.4	3.4
2001	29	21.4	68.9	2.3	0.1	3.5	27.8	15.7	93.9	39.9	5.2
2001	30	22.4	65.6	2.7	0.0	0.0	29.7	16.3	95.3	20.7	5.7
2001	31	21.7	56.3	2.6	0.0	0.0	30.3	14.0	98.7	14.0	6.5
2001	32	21.1	56.6	3.3	0.0	0.0	30.1	14.3	95.9	14.0	6.2
2001	33	19.6	62.6	3.3	1.1	0.0	28.8	12.5	93.0	28.3	5.2
2001	34	19.6	54.0	3.0	0.0	0.0	27.5	11.6	98.7	18.2	6.7
2001	35	19.3	48.7	1.5	0.0	0.0	27.8	10.3	81.8	23.3	6.0
2001	36	20.1	59.4	2.4	0.0	0.0	29.0	12.7	94.7	26.3	6.0
2001	37	23.0	40.8	1.9	0.0	3.0	31.4	13.0	72.3	17.8	5.8
2001	38	23.6	45.6	2.9	0.2	0.0	31.3	15.4	70.5	22.3	6.0
2001	39	22.3	52.2	3.8	16.3	9.8	31.1	16.7	85.8	24.8	5.7

2001	40	19.8	64.4	2.5	0.0	0.0	26.1	14.1	90.9	39.8	5.2
2001	41	20.0	65.5	2.3	0.0	0.0	26.3	13.7	97.6	31.4	5.3
2001	42	20.6	62.0	2.7	0.0	1.4	27.9	13.8	94.5	28.9	5.7
2001	43	20.6	64.0	2.7	0.4	1.2	26.2	16.3	82.7	35.8	4.0
2001	44	20.4	73.0	2.4	1.6	0.0	28.1	13.6	100.0	34.9	4.3
2001	45	20.3	66.1	2.5	0.6	0.0	27.0	14.7	100.0	29.8	6.0
2001	46	19.5	62.4	2.2	0.0	0.0	27.5	11.7	97.8	22.9	5.5
2001	47	21.5	58.8	2.4	0.0	0.0	30.4	13.5	91.9	26.2	5.6
2001	48	20.4	69.5	3.3	19.6	23.0	28.8	16.9	89.1	37.8	3.8
2001	49	15.2	96.2	2.2	30.0	38.6	16.7	13.7	100.0	84.5	0.7
2001	50	17.7	78.2	2.4	0.1	2.0	23.8	12.9	100.0	47.1	4.3
2001	51	20.0	65.1	1.4	0.0	0.0	27.3	11.8	94.8	30.9	5.4
2001	52	20.5	72.0	1.8	0.0	0.0	27.6	13.5	100.0	38.4	5.2
2001	53	21.0	69.9	2.7	0.0	0.0	27.6	15.7	96.5	41.8	4.9
2001	54	20.6	73.1	2.6	2.2	0.0	28.3	14.7	97.4	36.3	4.8
2001	55	19.4	74.9	2.7	13.2	15.0	25.7	13.7	100.0	45.4	4.3
2001	56	20.1	75.3	1.9	0.6	0.0	26.4	13.9	100.0	46.3	4.7
2001	57	19.5	73.6	1.5	1.1	0.0	25.8	13.5	98.7	40.8	4.5
2001	58	17.1	79.9	2.0	5.6	2.0	21.5	13.1	98.7	63.8	1.9
2001	59	17.4	72.4	1.8	0.0	0.0	23.9	12.3	97.9	38.1	4.4
2001	60	18.0	68.1	1.7	0.0	0.0	25.4	11.6	97.1	30.5	5.0
2001	61	20.1	57.0	1.7	0.0	0.0	29.0	11.5	94.5	23.4	5.5
2001	62	21.2	53.3	1.5	0.0	0.0	29.7	13.1	81.7	26.1	5.5
2001	63	21.2	49.9	1.6	0.0	0.0	29.0	11.9	88.5	22.0	5.5
2001	64	21.8	57.1	2.4	0.0	1.8	27.7	16.7	72.6	38.5	3.8
2001	65	22.5	54.7	1.5	0.0	0.0	29.3	15.1	85.6	30.4	4.9
2001	66	23.4	51.7	2.4	0.0	0.0	30.6	18.3	76.4	22.2	5.6
2001	67	23.3	49.6	2.6	0.0	0.0	30.2	17.0	78.9	25.7	5.6
2001	68	19.6	68.1	2.7	18.3	23.5	28.1	13.9	87.2	33.4	3.0
2001	69	21.1	67.8	2.1	0.0	1.5	28.2	13.9	93.4	40.2	4.7
2001	70	21.6	63.4	3.1	6.3	3.0	28.7	15.4	96.9	30.9	5.0
2001	71	19.5	62.1	2.2	0.0	0.0	27.5	13.6	100.0	17.3	5.2
2001	72	18.8	66.5	2.7	0.0	0.0	26.4	10.7	99.3	39.9	4.6
2001	73	18.6	68.4	2.1	0.0	0.0	26.4	11.9	97.1	36.9	4.4
2001	74	19.6	59.8	1.3	0.0	0.0	27.9	11.5	90.2	29.0	4.6
2001	75	21.7	49.9	1.6	0.0	0.0	28.8	14.2	78.6	24.3	4.9
2001	76	22.4	52.0	2.3	0.2	0.0	29.6	15.4	78.7	23.2	4.9
2001	77	18.9	64.2	3.0	0.8	9.0	23.8	14.2	91.0	42.1	3.7
2001	78	16.6	69.8	4.0	1.9	0.0	22.9	10.2	93.6	46.4	3.9
2001	79	15.1	88.8	2.3	1.5	0.0	18.8	12.6	96.5	75.3	1.3
2001	80	15.7	83.0	1.5	0.4	0.4	22.4	9.3	100.0	50.7	2.8
2001	81	15.2	93.8	2.4	45.3	34.2	19.7	13.8	100.0	75.7	1.1
2001	82	14.7	98.7	2.1	43.9	41.7	17.0	13.4	100.0	90.5	0.6
2001	83	16.3	91.7	1.9	12.6	14.4	20.5	14.1	100.0	66.1	2.3
2001	84	17.1	86.2	1.6	0.0	0.0	22.7	13.7	100.0	58.5	2.7
2001	85	17.5	73.7	1.3	0.0	0.0	24.4	11.0	100.0	37.3	4.0
2001	86	17.8	71.7	1.4	0.0	0.0	26.0	11.0	97.7	23.5	4.0
2001	87	18.0	74.5	1.0	0.0	0.0	26.4	10.7	99.5	36.4	3.6
2001	88	19.4	69.0	0.7	0.0	0.0	27.8	11.9	98.9	28.4	3.6
2001	89	19.4	69.3	2.0	0.0	0.0	25.6	14.9	93.2	39.3	3.4
2001	90	17.6	80.5	2.2	0.0	0.0	22.2	14.5	93.1	63.0	2.2
2001	91	14.9	94.7	1.8	5.7	9.9	18.4	11.0	100.0	81.5	1.1
2001	92	15.8	81.1	1.4	1.2	1.2	23.0	8.3	100.0	46.9	3.0

2001	93	16.3	85.9	2.2	4.0	6.7	22.2	11.6	100.0	63.3	1.8
2001	94	15.8	84.8	2.0	8.8	6.4	22.7	10.3	100.0	56.3	3.0
2001	95	16.0	84.9	2.4	0.0	0.0	21.7	11.2	99.2	62.0	3.0
2001	96	15.5	85.4	2.4	0.0	0.0	19.2	11.6	100.0	66.6	2.3
2001	97	13.7	96.9	2.9	7.4	7.4	15.3	12.5	100.0	86.2	0.6
2001	98	14.0	99.9	2.7	29.2	26.2	16.1	12.5	100.0	98.4	0.1
2001	99	14.6	85.3	1.2	0.1	0.1	19.5	9.0	100.0	56.3	2.8
2001	100	13.6	78.5	0.9	0.0	0.0	20.3	7.0	100.0	42.0	2.9
2001	101	14.1	79.8	1.2	0.0	0.0	21.4	7.9	100.0	44.3	3.2
2001	102	14.4	78.0	1.2	0.0	0.0	22.0	8.1	100.0	45.4	3.4
2001	103	15.1	74.7	1.0	0.0	0.0	23.1	8.4	100.0	35.8	3.4
2001	104	14.4	87.9	1.8	2.2	5.9	19.0	12.3	99.1	65.5	1.4
2001	105	14.6	91.5	2.2	7.2	2.0	19.4	10.9	100.0	74.6	1.7
2001	106	13.8	99.3	2.5	25.7	27.5	14.8	11.8	100.0	95.2	0.6
2001	107	13.0	86.5	0.9	0.1	0.2	18.6	9.1	100.0	54.9	2.8
2001	108	13.3	81.7	0.7	0.0	0.0	20.0	7.2	100.0	52.6	3.0
2001	109	13.6	82.4	1.1	0.1	0.1	20.6	6.7	100.0	51.8	2.9
2001	110	14.9	82.4	0.7	0.0	0.0	21.8	9.0	100.0	48.7	2.6
2001	111	15.8	72.3	1.6	0.0	0.0	22.6	9.1	99.3	44.9	3.1
2001	112	14.7	79.5	1.5	0.0	1.2	21.7	8.7	100.0	46.5	2.8
2001	113	15.4	82.7	3.2	1.9	5.0	21.1	11.4	98.6	60.5	2.5
2001	114	14.6	87.6	4.5	5.5	3.7	18.9	11.4	100.0	68.9	1.9
2001	115	13.8	85.6	1.0	0.0	0.0	20.5	8.1	100.0	55.6	2.6
2001	116	15.4	80.0	2.5	1.5	2.0	22.6	8.9	100.0	44.3	2.8
2001	117	11.8	98.1	1.8	9.2	10.9	14.4	9.7	100.0	91.5	0.5
2001	118	11.3	87.5	0.8	0.1	0.2	18.0	5.4	100.0	58.0	2.5
2001	119	12.8	78.5	1.5	0.0	0.0	21.4	5.6	100.0	41.9	3.0
2001	120	13.7	82.2	1.7	0.1	0.2	19.7	10.3	97.6	64.0	1.6
2001	121	12.3	94.3	1.4	1.5	1.2	15.7	9.0	100.0	78.7	0.9
2001	122	12.3	95.9	2.0	10.5	12.4	14.1	11.2	100.0	86.2	0.7
2001	123	12.3	95.9	2.2	1.0	1.4	15.3	10.1	100.0	83.4	1.1
2001	124	13.2	90.7	2.9	9.6	4.4	17.3	10.7	100.0	66.9	1.4
2001	125	7.8	93.9	3.9	1.6	4.4	11.8	0.6	100.0	79.0	0.9
2001	126	3.0	86.7	1.4	0.0	0.4	8.7	-1.5	100.0	57.3	1.6
2001	127	6.2	80.7	0.9	0.1	0.0	13.9	-0.6	100.0	48.5	2.2
2001	128	9.1	80.8	0.6	0.0	0.0	17.7	2.2	100.0	47.1	2.5
2001	129	10.7	76.1	1.1	0.0	0.0	20.1	3.3	100.0	29.2	2.6
2001	130	11.5	72.0	1.2	0.0	0.0	21.1	4.2	96.3	31.5	2.7
2001	131	11.6	72.1	0.6	0.0	0.0	21.5	3.7	97.0	30.6	2.7
2001	132	11.9	72.3	0.5	0.0	0.0	21.7	4.6	97.6	30.1	2.6
2001	133	12.5	74.7	0.8	0.0	0.0	21.3	5.1	96.7	37.8	2.6
2001	134	12.4	71.7	0.7	0.0	0.0	22.0	5.1	96.6	32.9	2.6
2001	135	11.9	72.1	0.8	0.0	0.0	21.1	4.9	96.3	33.5	2.6
2001	136	10.9	76.1	0.8	0.0	0.0	19.5	4.3	98.2	34.8	2.5
2001	137	11.1	74.8	0.8	0.0	0.0	19.6	3.9	99.8	37.5	2.5
2001	138	10.7	74.1	0.6	0.0	0.0	20.2	3.5	99.3	31.5	2.5
2001	139	10.7	71.8	1.1	0.0	0.0	20.2	3.5	96.3	34.5	2.6
2001	140	10.1	74.1	1.0	0.0	0.0	19.1	3.5	97.5	37.2	2.4
2001	141	10.7	70.5	1.7	0.0	0.0	19.9	3.8	97.0	34.6	2.6
2001	142	7.3	73.1	0.9	0.0	0.0	15.6	0.6	100.0	28.9	2.2
2001	143	7.5	68.4	0.8	0.0	0.0	17.3	-0.1	96.6	28.1	2.3
2001	144	9.4	67.1	0.8	0.0	0.0	20.3	1.8	93.7	31.3	2.4
2001	145	11.8	64.1	2.8	0.0	0.0	21.1	1.8	91.6	34.7	2.7

2001	146	10.9	71.8	1.8	0.0	0.0	16.9	2.0	99.5	49.2	2.2
2001	147	7.3	71.3	0.6	0.0	0.0	19.2	-0.5	100.0	22.0	2.3
2001	148	9.7	80.4	1.7	0.0	0.0	18.5	1.2	100.0	53.5	1.8
2001	149	11.8	80.6	2.3	0.0	0.0	16.9	8.4	94.2	60.0	1.6
2001	150	12.2	79.4	1.7	0.0	0.5	18.8	8.5	93.2	55.1	1.5
2001	151	13.8	69.6	2.1	0.0	0.0	20.2	9.8	92.0	35.0	2.0
2001	152	13.0	71.1	2.0	0.0	0.9	20.3	8.7	90.2	44.0	2.0
2001	153	12.2	85.6	1.7	1.4	1.9	19.9	8.4	100.0	48.5	1.9
2001	154	12.4	77.0	1.4	0.2	1.0	19.6	6.2	100.0	43.9	2.1
2001	155	12.5	70.6	1.0	0.0	0.0	20.9	5.4	93.5	34.4	2.4
2001	156	11.7	65.0	0.6	0.0	0.0	21.0	4.8	93.4	33.1	2.2
2001	157	10.8	68.1	1.5	0.0	0.0	19.1	4.1	92.9	36.2	2.1
2001	158	9.4	77.7	1.6	0.0	0.0	17.0	4.1	95.6	49.1	1.8
2001	159	8.8	77.2	0.8	0.0	0.0	18.2	2.6	98.9	42.0	1.9
2001	160	8.9	75.2	0.8	0.0	0.0	18.9	2.4	100.0	38.0	2.0
2001	161	9.1	71.0	0.5	0.0	0.0	19.1	2.1	96.9	33.1	2.1
2001	162	9.0	66.1	0.8	0.0	0.0	18.7	2.6	91.5	28.1	2.0
2001	163	8.6	68.8	0.7	0.0	0.0	18.0	1.9	95.2	32.3	2.1
2001	164	8.2	68.2	1.6	0.0	0.0	17.1	1.1	95.8	36.3	2.1
2001	165	6.8	70.5	1.3	0.0	0.0	16.1	0.3	92.8	37.1	2.0
2001	166	6.8	68.3	0.5	0.0	0.0	17.3	-1.6	97.9	29.8	1.9
2001	167	7.5	64.0	1.1	0.0	0.0	17.1	1.0	89.5	30.2	2.0
2001	168	8.0	68.1	1.0	0.0	0.0	16.7	-0.5	95.1	41.4	1.8
2001	169	10.2	61.8	2.2	0.0	0.0	17.0	2.7	92.4	39.0	2.2
2001	170	6.2	64.2	1.8	0.0	0.0	14.1	0.9	97.4	24.9	2.1
2001	171	7.3	55.3	1.2	0.0	0.0	15.9	-0.4	80.8	25.8	2.0
2001	172	6.6	63.7	1.2	0.0	0.0	17.1	-2.6	95.4	30.0	2.1
2001	173	6.7	62.5	0.7	0.0	0.0	18.5	-2.3	94.9	24.6	2.1
2001	174	6.8	59.9	1.1	0.0	0.0	18.2	-1.7	88.7	22.7	2.2
2001	175	8.6	70.4	2.2	0.0	0.0	15.0	3.4	90.7	43.2	1.7
2001	176	7.1	93.6	1.7	26.0	32.0	10.2	5.7	100.0	73.1	0.4
2001	177	6.2	89.8	0.7	0.0	0.0	13.1	0.9	100.0	63.4	1.4
2001	178	5.8	83.9	0.6	0.1	0.1	13.8	0.3	100.0	46.2	1.6
2001	179	6.2	75.3	1.3	0.0	0.0	14.1	-0.6	100.0	41.3	1.9
2001	180	6.0	87.7	1.9	4.4	3.8	7.9	2.5	100.0	70.3	0.4
2001	181	4.7	88.6	1.0	0.0	0.0	10.5	-0.8	100.0	51.0	1.3
2001	182	4.4	76.3	1.2	0.0	0.0	14.1	-3.2	100.0	43.9	1.8
2001	183	8.9	73.8	2.7	0.0	0.0	16.4	3.7	90.2	43.0	1.8
2001	184	10.3	63.4	2.6	0.0	0.0	17.9	6.0	78.1	37.5	2.1
2001	185	10.7	62.0	4.0	0.0	0.0	17.4	5.1	88.0	39.2	2.2
2001	186	2.0	79.5	1.5	0.0	0.0	7.3	-2.6	100.0	41.9	1.5
2001	187	2.3	69.6	0.9	0.0	0.0	11.7	-5.1	99.0	25.8	1.7
2001	188	9.7	77.5	3.5	0.0	0.0	15.4	1.1	94.7	55.4	1.6
2001	189	11.3	77.0	4.0	0.0	0.0	14.2	7.3	97.2	61.3	1.3
2001	190	10.1	88.2	3.1	2.1	2.0	14.5	6.8	98.2	67.4	1.1
2001	191	8.3	76.6	2.3	0.6	0.0	13.7	-1.3	99.5	33.0	1.9
2001	192	4.3	74.1	0.9	0.0	0.0	15.8	-3.0	98.4	31.0	1.9
2001	193	5.8	68.5	0.9	0.0	0.0	17.0	-1.9	96.5	26.0	2.0
2001	194	8.2	61.8	0.9	0.0	0.0	19.0	-0.6	93.8	24.1	2.3
2001	195	7.8	61.5	1.2	0.0	0.0	18.9	-0.8	92.6	21.3	2.4
2001	196	6.9	70.7	1.4	0.0	0.0	17.0	0.5	95.4	36.1	2.0
2001	197	9.1	62.4	2.4	0.0	0.0	16.3	1.4	89.2	38.0	2.2
2001	198	8.6	65.3	2.1	0.0	0.0	17.7	1.0	89.2	30.4	2.4

2001	199	5.9	64.5	2.2	0.0	0.0	14.9	-0.5	91.0	24.7	2.4
2001	200	2.8	81.3	2.3	0.0	0.0	8.4	-3.7	98.9	50.7	1.2
2001	201	1.9	83.0	2.2	0.3	2.0	9.5	-5.2	100.0	46.5	1.5
2001	202	3.2	79.8	3.2	0.0	0.0	10.8	-1.3	100.0	41.4	1.5
2001	203	4.8	64.4	1.8	0.0	0.0	13.4	-2.5	98.0	25.4	2.3
2001	204	2.6	68.6	3.0	0.0	0.0	8.5	-2.8	99.8	32.5	1.9
2001	205	2.2	69.6	1.1	0.0	0.0	10.7	-4.2	96.6	32.4	1.8
2001	206	3.6	63.6	1.1	0.0	0.0	14.0	-4.1	94.3	22.9	2.1
2001	207	6.2	66.7	1.4	0.0	0.0	15.0	-1.1	89.5	34.9	2.0
2001	208	5.4	67.0	0.7	0.0	0.0	16.4	-2.8	95.7	28.6	2.4
2001	209	6.0	61.3	0.7	0.0	0.0	18.1	-2.9	93.5	19.0	2.5
2001	210	8.4	49.8	1.2	0.0	0.0	18.9	-2.0	86.5	19.3	2.5
2001	211	8.2	70.3	2.2	0.0	0.0	16.0	0.6	99.5	39.4	2.2
2001	212	7.8	70.1	1.2	0.0	0.0	16.8	0.2	97.4	34.9	2.3
2001	213	8.7	66.3	0.7	0.0	0.0	18.6	0.9	92.8	30.3	2.5
2001	214	8.2	64.0	0.8	0.0	0.0	19.7	0.3	93.9	26.4	2.6
2001	215	8.3	57.4	0.8	0.0	0.0	20.6	-0.8	92.8	14.9	2.8
2001	216	9.0	50.2	0.9	0.0	0.0	20.1	0.1	83.4	17.6	2.9
2001	217	9.8	64.0	1.6	0.0	0.0	19.3	2.1	95.8	26.6	2.6
2001	218	9.9	59.3	1.4	0.0	0.0	19.1	0.8	93.4	27.9	2.7
2001	219	10.2	56.6	1.1	0.0	0.0	20.3	1.9	91.4	24.7	2.8
2001	220	10.8	53.3	1.2	0.0	0.0	19.7	3.1	80.5	24.8	2.8
2001	221	10.2	50.5	2.1	0.0	0.0	18.5	1.8	82.9	27.4	2.8
2001	222	7.3	57.1	3.7	0.0	0.0	13.0	0.6	75.8	36.1	2.3
2001	223	6.9	64.0	1.7	0.0	0.0	15.2	1.8	94.9	26.3	2.6
2001	224	6.5	54.5	1.3	0.0	0.0	16.8	-1.8	91.1	19.7	2.8
2001	225	6.7	50.4	1.4	0.0	0.0	18.5	-3.8	86.6	17.1	3.2
2001	226	9.4	44.8	3.0	0.0	0.0	18.3	-0.3	84.6	24.4	3.4
2001	227	4.8	59.2	1.4	0.0	0.0	14.8	-4.6	95.4	22.9	2.9
2001	228	3.8	55.6	1.7	0.0	0.0	13.4	-4.4	90.1	19.0	2.8
2001	229	4.3	51.1	1.0	0.0	0.0	15.7	-5.1	85.2	17.8	2.9
2001	230	5.5	46.1	1.1	0.0	0.0	16.8	-4.6	82.6	13.5	3.1
2001	231	9.4	36.2	2.3	0.0	0.0	21.6	-3.5	67.7	12.9	3.9
2001	232	7.8	37.5	1.0	0.0	0.0	19.0	-3.1	70.1	12.4	3.2
2001	233	10.8	31.0	2.2	0.0	0.0	20.3	1.1	50.6	12.5	3.8
2001	234	6.1	50.0	1.0	0.0	0.0	16.8	-3.7	89.9	16.5	3.0
2001	235	9.5	37.3	1.7	0.0	0.0	22.1	-2.1	76.4	11.1	3.9
2001	236	10.4	34.4	2.4	0.0	0.0	19.3	-0.5	78.4	17.6	3.6
2001	237			1.3	0.0		19.9	-2.1	89.2	15.4	3.6
2001	238	10.1	43.5	1.7	0.0	0.0	22.6	-1.2	80.7	12.5	4.2
2001	239	11.6	39.0	1.2	0.0	0.0	23.1	1.3	79.2	10.2	3.9
2001	240	14.0	63.5	4.2	7.4	7.0	21.2	8.5	99.0	32.2	3.3
2001	241	12.7	85.6	3.2	0.9	0.8	15.6	9.8	98.0	71.9	0.7
2001	242	12.0	86.1	3.9	7.3	9.0	14.9	9.5	100.0	66.7	1.1
2001	243	6.8	86.2	4.2	19.6	12.6	10.5	0.3	100.0	57.4	1.1
2001	244	6.5	77.0	0.6	0.0	0.0	15.6	-1.7	100.0	38.9	-3.6
2001	245	8.1	69.6	1.0	0.0	0.0	17.2	0.2	99.7	29.4	0.9
2001	246	10.5	59.1	2.3	0.0	0.0	21.0	0.4	99.2	19.1	2.6
2001	247	10.5	50.3	1.5	0.0	0.0	19.9	0.4	91.4	12.6	2.9
2001	248	11.0	44.1	3.3	0.0	0.0	21.9	-1.6	92.3	11.2	4.1
2001	249	8.7	60.0	2.4	0.0	0.0	17.6	1.8	99.1	24.2	3.3
2001	250	12.2	50.4	1.1	0.0	0.0	23.0	3.9	81.2	17.4	3.5
2001	251	13.8	55.9	2.6	0.0	0.0	23.0	7.1	78.4	24.4	3.7

2001	252	16.6	46.7	3.4	0.0	0.0	26.5	8.3	79.3	18.2	4.7
2001	253	15.1	46.2	1.9	0.0	0.0	25.9	5.2	86.3	14.6	4.6
2001	254	10.3	50.2	1.5	0.0	0.0	14.2	5.4	76.0	28.8	1.8
2001	255	7.8	71.1	2.8	0.0	0.0	15.1	0.1	96.1	41.3	1.8
2001	256	7.9	88.7	2.4	11.7	9.8	10.5	5.9	100.0	72.7	0.6
2001	257	9.9	69.5	3.6	1.6	1.6	17.9	3.2	92.1	41.4	3.3
2001	258	10.0	75.4	5.5	0.0	0.0	17.4	4.1	93.2	52.5	2.8
2001	259	11.4	86.0	2.8	0.8	0.8	18.1	8.1	99.9	61.5	1.9
2001	260	14.6	70.5	2.0	0.0	0.0	22.9	6.1	100.0	35.1	3.7
2001	261	14.9	65.7	3.4	0.2	0.2	17.6	11.4	89.8	47.0	2.1
2001	262	15.8	67.2	3.7	2.0	2.0	21.6	11.0	92.5	39.8	3.4
2001	263	14.9	79.3	2.1	0.8	0.8	19.3	11.7	94.8	54.1	2.0
2001	264	15.6	63.2	3.4	0.0	0.0	22.0	10.5	95.4	27.8	3.4
2001	265	14.1	73.5	1.2	0.0	0.0	20.4	6.3	98.4	44.0	3.1
2001	266	15.9	69.5	1.9	0.0	0.0	22.7	10.0	92.6	41.2	3.6
2001	267	15.8	59.6	2.7	0.0	0.0	24.9	7.9	96.9	24.4	5.2
2001	268	12.6	51.4	1.3	0.0	0.0	21.1	3.5	88.5	21.0	4.5
2001	269	12.3	51.2	2.0	0.0	0.0	22.7	1.7	93.1	14.9	5.0
2001	270	9.1	56.2	3.1	0.0	0.0	16.5	3.2	80.5	26.0	3.5
2001	271	10.2	59.8	1.2	0.0	0.0	20.7	-0.4	99.1	24.1	4.2
2001	272	13.4	53.0	1.2	0.0	0.0	24.1	2.8	85.1	19.6	4.8
2001	273	15.3	52.8	1.4	0.0	0.0	26.3	4.1	88.4	21.2	5.0
2001	274	17.0	47.6	1.8	0.0	0.0	28.0	6.5	84.8	22.2	5.4
2001	275	18.1	50.8	2.3	0.0	0.0	27.1	7.2	79.2	20.0	4.9
2001	276	17.5	60.1	2.7	0.0	0.0	25.7	11.1	83.0	29.0	4.6
2001	277	19.1	47.9	2.5	0.6	0.6	26.5	9.2	80.7	26.7	5.0
2001	278	19.2	43.9	4.4	0.0	0.0	27.5	11.5	75.3	17.7	6.0
2001	279	11.9	48.0	1.4	0.0	0.0	20.9	2.1	90.6	16.1	4.8
2001	280	12.8	43.6	1.5	0.0	0.0	23.6	0.0	81.1	13.8	5.1
2001	281	16.0	65.4	3.3	0.0	0.0	24.3	6.9	94.5	36.6	4.6
2001	282	16.3	63.1	2.3	0.0	0.0	25.1	8.2	91.8	28.4	4.6
2001	283	17.8	58.9	1.6	0.4	0.4	27.5	9.7	84.4	25.8	5.0
2001	284	19.3	53.2	1.5	0.0	0.0	28.8	9.2	91.1	23.1	5.3
2001	285	22.2	34.0	3.7	0.0	0.0	30.7	15.8	50.7	15.3	6.4
2001	286	19.0	42.3	1.7	0.0	0.0	27.2	10.7	74.6	14.7	5.6
2001	287	18.6	57.5	2.2	0.0	0.0	27.8	12.0	90.2	23.5	5.2
2001	288	17.0	75.6	3.0	6.9	6.9	23.5	12.9	98.2	43.8	1.9
2001	289	16.6	77.4	3.3	7.3	7.3	25.1	11.1	99.7	41.3	3.7
2001	290	17.0	73.3	4.6	0.0	0.0	24.2	12.0	96.7	40.2	4.1
2001	291	14.4	60.0	2.1	0.0	0.0	22.8	5.6	100.0	19.8	5.4
2001	292	15.2	55.1	1.5	0.0	0.0	23.8	4.5	89.8	25.1	5.3
2001	293	15.6	74.4	3.4	3.5	3.5	21.9	9.4	97.4	37.9	3.2
2001	294	15.9	78.8	3.2	18.3	17.0	22.1	11.9	100.0	51.8	3.8
2001	295	16.2	78.4	1.8	0.0	0.0	21.5	11.8	92.4	58.7	3.1
2001	296	20.2	67.7	3.0	7.4	7.4	28.4	13.2	90.8	29.6	5.4
2001	297	17.4	81.2	2.2	1.3	1.3	21.7	14.3	98.2	59.5	3.0
2001	298	14.0	95.2	2.0	11.2	11.2	15.9	11.0	100.0	82.6	0.8
2001	299	16.0	89.2	1.9	0.8	0.8	21.8	13.4	100.0	59.7	2.1
2001	300	17.6	82.1	1.8	0.0	0.0	23.8	11.9	100.0	53.1	4.1
2001	301	16.5	92.3	3.4	11.4	11.4	20.8	13.6	100.0	73.5	1.7
2001	302	16.1	81.4	3.6	12.8	10.0	23.0	9.7	98.8	59.4	3.5
2001	303	17.2	77.5	3.4	0.2	0.2	24.1	11.7	97.0	53.7	4.3
2001	304	15.0	74.4	1.8	0.0	0.0	21.7	8.6	97.6	31.1	3.1

2001	305	15.3	71.9	1.0	0.0	0.0	23.4	6.2	100.0	33.8	5.0
2001	306	18.4	69.4	2.5	0.0	0.0	25.1	12.2	91.0	35.4	5.0
2001	307	20.7	61.8	2.9	0.0	0.0	26.8	14.0	87.1	42.3	5.4
2001	308	14.7	65.6	2.9	0.8	1.5	18.2	5.8	94.1	35.4	3.3
2001	309	14.4	59.5	1.5	0.0	0.0	24.3	4.1	97.1	23.4	5.6
2001	310	19.0	55.0	3.9	0.2	0.2	27.4	10.4	80.7	35.0	4.4
2001	311	16.6	51.4	1.9	0.0	0.0	25.4	7.8	95.9	24.6	5.8
2001	312	12.9	92.1	3.6	14.9	13.8	15.9	10.5	100.0	84.2	1.1
2001	313	11.9	91.9	2.8	62.7	58.0	17.3	8.0	100.0	67.8	1.6
2001	314	14.7	95.1	3.5	2.0	2.0	19.0	11.8	100.0	79.7	1.0
2001	315	18.3	80.2	1.6	0.0	0.0	24.3	13.5	100.0	53.5	4.7
2001	316	17.4	75.3	1.1	0.0	0.0	24.3	10.3	99.2	38.7	4.7
2001	317	17.9	76.3	2.8	0.0	0.0	23.6	13.0	99.1	43.4	4.4
2001	318	17.2	84.4	2.0	1.0	1.0	22.3	13.0	96.8	61.9	3.2
2001	319	17.6	85.1	1.7	2.4	2.4	24.1	13.8	100.0	54.5	3.8
2001	320	15.6	95.4	1.4	9.3	9.3	17.9	14.2	100.0	81.0	1.8
2001	321	17.0	86.4	1.6	0.1	0.1	21.0	14.3	99.5	67.1	3.1
2001	322	17.5	87.2	1.8	0.0	0.0	21.0	14.3	97.5	69.8	2.7
2001	323	17.8	86.9	3.0	4.3	4.3	21.6	13.9	99.3	66.2	2.6
2001	324	17.1	87.1	3.2	11.5	11.5	24.7	12.0	100.0	53.7	3.7
2001	325	15.7	71.5	0.9	0.1	0.1	22.0	9.4	100.0	40.0	5.5
2001	326	17.0	69.7	1.6	0.0	0.0	24.8	7.3	100.0	27.5	5.7
2001	327	19.5	72.0	3.0	3.7	3.7	27.9	12.1	94.1	39.8	4.8
2001	328	18.9	80.8	2.9	11.3	12.0	26.7	14.7	98.4	54.4	4.1
2001	329	17.9	88.1	3.2	21.6	14.7	23.5	15.0	100.0	61.8	3.2
2001	330	16.6	92.7	1.9	1.5	1.5	20.7	14.3	100.0	71.7	2.4
2001	331	18.9	77.9	1.7	0.0	0.0	25.1	13.0	100.0	44.2	5.1
2001	332	17.6	79.4	3.1	0.0	0.0	24.2	11.3	98.8	52.2	5.1
2001	333	19.0	80.4	1.9	0.0	0.0	24.1	14.5	100.0	50.8	5.0
2001	334	19.4	78.8	1.7	11.6	11.6	25.6	13.6	100.0	52.3	5.1
2001	335	20.4	77.3	2.2	0.7	0.7	26.3	15.0	98.1	49.9	5.2
2001	336	18.3	71.2	1.9	0.0	0.0	24.0	11.5	96.7	41.2	4.4
2001	337	18.4	67.9	2.2	0.0	0.0	25.7	11.5	100.0	28.5	6.0
2001	338	14.3	92.4	3.5	29.4	24.0	16.2	11.4	100.0	77.2	1.0
2001	339	15.7	84.8	2.1	1.9	1.9	22.8	10.6	100.0	57.1	3.8
2001	340	18.0	71.8	0.9	0.0	0.0	24.8	10.2	99.1	37.7	5.6
2001	341	19.2	74.0	1.4	0.0	0.0	25.9	11.6	98.5	35.9	5.3
2001	342	18.5	83.9	3.1	12.0	12.0	26.9	13.5	98.5	52.3	3.9
2001	343	19.6	79.9	1.6	1.2	1.2	24.9	14.4	100.0	53.8	4.2
2001	344	18.1	94.9	1.6	11.1	10.0	21.2	16.2	100.0	77.0	2.1
2001	345	18.9	70.5	1.9	0.0	0.0	23.8	11.6	100.0	37.4	6.0
2001	346	17.4	74.2	2.4	0.0	0.0	24.4	9.6	100.0	37.0	5.1
2001	347	17.6	85.7	3.7	10.9	10.9	22.8	12.4	100.0	68.0	3.0
2001	348	19.0	74.9	1.6	0.0	0.0	25.6	12.5	100.0	41.5	5.9
2001	349	19.9	70.7	1.5	0.0	0.0	26.6	14.0	100.0	30.8	5.9
2001	350	22.0	64.4	2.1	0.0	0.0	28.1	13.6	89.1	36.6	6.1
2001	351	21.0	63.4	2.1	0.0	0.0	27.8	13.4	98.6	18.4	6.7
2001	352	18.9	76.1	3.1	10.1	5.1	28.6	12.5	99.8	32.5	5.0
2001	353	18.6	73.9	3.5	1.6	0.8	26.5	12.8	98.3	30.0	5.7
2001	354	16.9	73.4	1.7	0.0	0.0	23.7	9.8	98.9	45.2	5.4
2001	355	18.7	68.9	1.4	0.0	0.0	26.3	10.1	100.0	32.9	5.7
2001	356	21.3	59.9	2.2	0.4	0.2	28.8	12.0	94.1	29.2	6.1
2001	357	15.2	93.1	1.8	21.7	10.9	18.2	12.8	100.0	76.5	1.7

2001	358	19.1	81.6	1.8	0.0	0.0	25.1	11.2	100.0	61.1	4.1
2001	359	19.4	68.7	2.3	4.5	2.3	24.7	12.2	100.0	28.1	6.0
2001	360	17.5	64.4	0.8	0.0	0.0	24.8	8.5	99.3	28.9	6.0
2001	361	19.4	74.7	1.8	0.0	0.0	25.9	13.6	100.0	39.3	5.7
2001	362	21.2	72.1	2.0	0.0	0.0	27.5	15.7	92.7	44.3	5.7
2001	363	21.2	68.5	2.1	4.5	2.3	28.2	15.0	94.3	41.7	5.8
2001	364	21.1	69.6	2.4	1.9	1.0	28.3	14.1	97.7	43.6	5.8
2001	365	20.6	66.1	3.0	1.7	0.9	28.0	14.6	95.5	41.2	5.9
2002	1	21.8		2.1	0.0	0.0	30.0	12.5	94.0	25.0	
2002	2	21.7		2.3	0.0	0.0	29.9	11.4	94.5	18.2	
2002	3	20.7		3.4	0.0	0.0	26.7	14.0	95.2	48.9	
2002	4	22.5		2.4	0.0	0.0	29.2	14.1	92.6	37.7	
2002	5	21.9		1.9	0.0	0.0	30.1	13.3	97.1	33.2	
2002	6	22.7		3.1	0.0	0.0	29.6	16.8	91.4	33.1	
2002	7	17.7		2.7	20.3	14.0	23.8	9.9	100.0	51.8	
2002	8	17.9		1.9	0.0	0.0	26.9	6.4	98.0	33.4	
2002	9	18.8		3.9	5.9	5.9	26.9	14.3	96.4	39.5	
2002	10	21.0		2.9	0.1	0.1	27.2	13.9	96.1	49.4	
2002	11	21.7		3.9	6.0	6.0	28.5	16.7	93.2	43.7	
2002	12	18.7		2.0	0.0	0.0	24.9	10.4	98.7	18.4	
2002	13	17.3		1.2	0.0	0.0	26.5	6.9	96.9	20.0	
2002	14	19.6		2.3	0.0	0.0	27.7	9.2	97.4	22.0	
2002	15	19.8		3.9	4.2	4.2	29.0	14.9	94.0	38.7	
2002	16	21.4		4.0	6.5	8.0	28.8	14.2	97.9	36.5	
2002	17	20.0		4.5	5.2	7.0	27.8	11.3	99.4	45.8	
2002	18	15.1		1.4	0.0	0.0	22.2	6.8	95.3	28.0	
2002	19	18.9		2.4	0.0	0.0	28.6	7.2	97.4	22.7	
2002	20	21.6		2.5	0.0	0.0	29.4	15.0	93.5	32.7	
2002	21	22.9		1.5	0.0	0.0	30.6	13.7	97.0	32.4	
2002	22	23.1		2.0	0.0	0.0	30.4	14.8	92.4	32.1	
2002	23	22.9		2.7	3.7	3.0	30.0	16.4	94.2	31.9	
2002	24	21.3		3.1	2.1	2.1	29.0	14.8	97.4	34.4	
2002	25	19.2		3.7	0.0	0.0	27.3	13.4	99.9	43.8	
2002	26	18.1		2.9	1.2	1.2	21.6	14.9	98.3	59.0	
2002	27	16.6		3.4	32.1	47.5	18.1	15.5	100.0	89.8	
2002	28	19.1		1.8	6.2	6.2	24.1	16.3	100.0	63.5	
2002	29	19.0		1.8	10.7	13.5	22.4	17.0	100.0	73.6	
2002	30	20.6		1.2	0.9	3.5	26.8	15.8	100.0	49.2	
2002	31	20.2		2.0	0.0	0.0	26.8	14.4	100.0	36.9	
2002	32	19.0		1.2	0.0	0.0	26.0	12.5	99.3	35.6	
2002	33	19.5		1.8	0.0	0.0	26.8	12.8	100.0	30.3	
2002	34	20.4		1.6	0.0	0.0	28.5	11.6	93.4	28.7	
2002	35	22.0		2.2	0.0	0.0	31.1	13.2	93.2	17.7	
2002	36	21.9		1.3	0.0	0.0	30.7	13.3	92.3	24.2	
2002	37	21.5		2.6	0.2	0.0	30.9	12.1	90.9	23.3	
2002	38	19.5		3.5	2.7	0.0	24.8	14.1	97.2	50.5	
2002	39	15.8		1.7	0.5	0.0	22.2	12.5	96.3	58.5	
2002	40	17.0		1.4	0.0	0.0	25.9	8.6	100.0	32.7	
2002	41	19.6		1.5	0.0	0.0	28.8	10.2	100.0	26.7	
2002	42	21.5		1.7	0.0	0.0	31.0	12.4	88.8	17.0	
2002	43	22.2		2.7	0.4	1.4	29.7	16.4	72.9	25.4	
2002	44	21.8		3.3	2.1	0.0	28.7	16.2	94.0	32.7	
2002	45	19.2		2.7	16.3	15.0	25.6	14.3	100.0	54.3	

2002	46	17.6		1.3	0.0	0.0	22.4	14.4	98.3	64.9	
2002	47	19.2		1.1	0.0	0.0	26.9	12.3	100.0	26.7	
2002	48	19.2		2.1	4.5	2.8	26.8	12.3	100.0	30.9	
2002	49	19.3		0.9	0.0	0.0	26.9	11.8	100.0	31.9	
2002	50	19.2		1.7	0.0	0.0	25.8	13.5	98.0	42.0	
2002	51	18.4		1.4	6.9	4.0	25.7	11.9	99.0	45.9	
2002	52	19.4		1.7	0.1	0.0	26.3	14.0	100.0	33.9	
2002	53	18.7		1.1	0.0	0.0	27.0	11.6	100.0	31.4	
2002	54	20.4		1.4	0.0	0.0	30.8	11.4	93.7	23.3	
2002	55	22.1		1.5	0.0	0.0	30.6	10.9	96.2	25.8	
2002	56	23.7		1.5	0.0	0.0	30.4	16.3	83.5	28.3	
2002	57	21.5		1.9	0.2	0.0	28.6	14.7	95.3	37.7	
2002	58	20.1		2.1	2.3	5.0	27.3	15.1	98.0	47.3	
2002	59	20.3		1.7	1.9	2.8	28.0	16.7	100.0	49.9	
2002	60	19.7		1.7	1.0	0.0	25.9	14.4	100.0	52.2	
2002	61	20.7		1.9	4.5	6.0	29.5	13.0	100.0	35.9	
2002	62	21.3		1.3	0.0	0.0	28.7	13.7	100.0	37.5	
2002	63	20.2		1.1	0.0	0.0	27.4	13.0	99.6	40.5	
2002	64	20.2		1.6	0.0	0.0	26.0	14.9	99.4	46.6	
2002	65	18.6		0.9	11.4	13.5	24.6	16.0	97.8	58.6	
2002	66	19.9		1.5	0.3	0.0	26.4	13.6	99.4	41.7	
2002	67	18.4		1.9	0.0	0.0	24.5	12.8	100.0	51.2	
2002	68	18.5		1.2	0.0	0.0	25.4	11.7	100.0	44.6	
2002	69	18.4		1.5	0.3	0.0	25.3	15.5	98.1	54.3	
2002	70	17.9		1.7	0.2	0.0	23.8	14.5	100.0	61.7	
2002	71	17.0		1.7	3.6	1.5	23.5	12.8	100.0	58.1	
2002	72	18.1		1.8	0.0	0.0	25.8	12.1	100.0	30.9	
2002	73	18.6		1.0	0.0	0.0	27.8	10.0	100.0	29.6	
2002	74	20.0		1.4	0.0	0.0	28.8	11.3	94.5	29.8	
2002	75	20.3		1.9	0.0	0.0	28.6	13.7	92.6	27.3	
2002	76	20.8		1.2	0.0	0.0	28.3	13.1	91.8	32.4	
2002	77	21.0		1.9	0.0	0.0	28.3	13.2	87.0	30.1	
2002	78	20.3		1.8	0.0	0.0	28.5	13.6	91.8	28.8	
2002	79	19.3		1.7	0.0	0.0	29.4	10.5	98.1	25.4	
2002	80	20.3		2.2	0.0	0.0	31.0	10.6	87.2	17.4	
2002	81	18.9		2.0	0.0	0.0	30.8	7.2	82.7	16.5	
2002	82	19.3		1.5	0.0	0.0	29.8	8.1	74.6	22.2	
2002	83	20.8		2.2	0.0	0.0	28.2	14.9	91.0	35.1	
2002	84	20.2		1.5	0.0	0.0	28.3	11.5	89.5	30.9	
2002	85	20.3		1.7	0.0	0.0	27.5	10.6	93.0	33.9	
2002	86	19.3		2.0	2.2	0.8	25.8	12.8	97.6	35.4	
2002	87	12.6		1.6	0.0	0.0	21.4	4.2	99.8	18.9	
2002	88	13.8		0.9	0.0	0.0	25.2	3.8	76.9	13.7	
2002	89	15.0		1.3	0.0	0.0	27.5	4.4	84.9	17.8	
2002	90	16.1		1.3	0.0	0.0	28.7	5.0	85.6	11.9	
2002	91	18.5		2.2	0.0	0.0	28.7	7.3	83.8	23.5	
2002	92	18.9		1.2	0.0	0.0	28.2	10.6	81.0	25.4	
2002	93	19.4		1.4	0.0	0.0	29.8	9.8	82.4	12.0	
2002	94	18.8		1.6	0.0	0.0	28.9	8.1	71.9	13.7	
2002	95	20.0		2.0	0.0	0.0	27.0	14.0	52.6	23.3	
2002	96	14.9		1.6	0.0	0.0	22.1	7.9	76.9	13.4	
2002	97	12.2		1.2	0.0	0.0	24.6	0.1	79.4	12.3	
2002	98	15.9		2.2	1.1	6.0	26.9	5.2	79.6	25.6	

2002	99	14.0		2.6	16.4	27.5	16.8	11.8	100.0	70.9	
2002	100	13.6		2.1	8.4	16.0	20.4	8.6	100.0	59.9	
2002	101	12.8		1.1	0.2	0.0	22.7	5.8	100.0	26.7	
2002	102	14.0		1.2	0.0	0.0	22.8	4.2	99.4	50.8	
2002	103	15.8		0.9	0.6	0.0	23.8	10.8	100.0	43.1	
2002	104	15.8		1.1	0.0	0.0	24.0	9.2	96.9	30.3	
2002	105	15.9		1.4	0.0	0.0	24.4	9.1	93.7	29.7	
2002	106	15.6		1.9	0.5	0.0	23.8	10.5	97.4	37.6	
2002	107	16.8		1.7	0.0	0.0	25.4	9.9	93.5	24.7	

Appendix 8.1

An example of a simulation with the CYP-SA (Maize) crop model

Glen/Bonheim *ObSr* 2000/2001 season

q_p	376.5	**Maize** *ObSr*	Planting	4	Jan2001
DUL	456				
LL	247				

ObSr

Plant. Date	Har. Date	DUL	LL	TESW	0	P	P-R	Eo	CF	EoCF	OpESWb	FTESW	FTESWaa	SWE	Ora	Orb	ESWe	SF
04/2001	144/2001	456	247	209	1	0.0	0.0	8.6	0.01	0.10377	129.5	0.62	0.62	-0.05	376.45	376.4	129.45	
					2	0.0	0.0	9.6	0.03	0.32	129.45	0.62	0.62	-0.16	376.28	376.3	129.28	
					3	0.0	0.0	10.3	0.06	0.62	129.28	0.62	0.62	-0.32	375.97	376.0	128.97	
					4	0.0	0.0	11.4	0.09	1.03	128.97	0.62	0.62	-0.53	375.43	375.4	128.43	
					5	0.0	0.0	10.8	0.12	1.34	128.43	0.61	0.61	-0.69	374.74	374.7	127.74	
					6	0.0	0.0	12.7	0.16	2.03	127.74	0.61	0.61	-1.04	373.70	373.7	126.70	
					7	0.0	0.0	10.7	0.20	2.10	126.70	0.61	0.61	-1.07	372.64	372.6	125.64	
					8	0.0	0.0	9.5	0.23	2.22	125.64	0.60	0.60	-1.12	371.52	371.5	124.52	
					9	0.0	0.0	11.7	0.27	3.18	124.52	0.60	0.60	-1.59	369.93	369.9	122.93	
					10	0.0	0.0	8.2	0.31	2.54	122.93	0.59	0.59	-1.25	368.67	368.7	121.67	
					11	0.0	0.0	6.6	0.35	2.30	121.67	0.58	0.58	-1.12	367.55	367.5	120.55	
					12	0.0	0.0	7.3	0.39	2.82	120.55	0.58	0.58	-1.36	366.19	366.2	119.19	
					13	0.0	0.0	7.8	0.42	3.30	119.19	0.57	0.57	-1.58	364.61	364.6	117.61	
					14	0.0	0.0	8.4	0.46	3.86	117.61	0.56	0.56	-1.82	362.79	362.8	115.79	
					15	3.8	4.3	8.7	0.50	4.31	115.79	0.55	0.66	1.71	364.50	364.5	117.50	0.60
					16	3.1	3.4	7.5	0.53	3.98	117.50	0.56	0.66	0.93	365.43	365.4	118.43	
					17	0.2	0.2	7.2	0.56	4.06	118.43	0.57	0.57	-1.76	363.67	363.7	116.67	
					18	0.0	0.0	8.8	0.60	5.25	116.67	0.56	0.56	-2.46	361.21	361.2	114.21	
					19	0.1	0.1	10.2	0.63	6.41	114.21	0.55	0.55	-2.85	358.36	358.4	111.36	
					20	0.0	0.0	10.1	0.66	6.65	111.36	0.53	0.53	-2.97	355.39	355.4	108.39	
					21	0.3	0.3	7.8	0.69	5.36	108.39	0.52	0.52	-2.08	353.31	353.3	106.31	
					22	11.7	14.5	7.5	0.72	5.36	106.31	0.51	1.00	10.58	363.89	363.9	116.89	
					23	0.0	0.0	6.0	0.74	4.45	116.89	0.56	0.56	-2.09	361.80	361.8	114.80	
					24	0.0	0.0	7.3	0.77	5.60	114.80	0.55	0.55	-2.58	359.22	359.2	112.22	
					25	0.0	0.0	6.9	0.79	5.46	112.22	0.54	0.54	-2.46	356.76	356.8	109.76	
					26	7.4	8.9	6.3	0.81	5.13	109.76	0.53	0.93	4.86	361.62	361.6	114.62	
					27	0.0	0.0	8.4	0.84	7.02	114.62	0.55	0.55	-3.23	358.39	358.4	111.39	
					28	0.0	0.0	8.3	0.86	7.10	111.39	0.53	0.53	-3.18	355.21	355.2	108.21	
					29	0.0	0.0	10.3	0.87	9.01	108.21	0.52	0.52	-3.91	351.30	351.3	104.30	
					30	0.0	0.0	9.3	0.89	8.30	104.30	0.50	0.50	-3.47	347.83	347.8	100.83	0.60
					31	0.0	0.0	8.0	0.91	7.27	100.83	0.48	0.48	-2.94	344.88	344.9	97.88	
					32	0.0	0.0	7.2	0.92	6.66	97.88	0.47	0.47	-2.61	342.27	342.3	95.27	
					33	0.0	0.0	8.1	0.94	7.60	95.27	0.46	0.46	-2.91	339.36	339.4	92.36	
					34	0.0	0.0	8.0	0.95	7.61	92.36	0.44	0.44	-2.82	336.54	336.5	89.54	
					35	0.0	0.0	9.9	0.96	9.54	89.54	0.43	0.43	-3.43	333.11	333.1	86.11	
					36	0.0	0.0	10.5	0.97	10.23	86.11	0.41	0.41	-3.54	329.57	329.6	82.57	
					37	0.1	0.1	7.3	0.98	7.19	82.57	0.40	0.40	-2.30	327.28	327.3	80.28	
					38	0.1	0.1	7.3	0.99	7.25	80.28	0.38	0.38	-2.25	325.03	325.0	78.03	
					39	0.0	0.0	7.3	1.00	7.31	78.03	0.37	0.37	-2.29	322.74	322.7	75.74	
					40	0.0	0.0	7.6	1.01	7.66	75.74	0.36	0.36	-2.33	320.41	320.4	73.41	
					41	0.8	0.8	6.2	1.01	6.28	73.41	0.35	0.35	-1.18	319.23	319.2	72.23	
					42	0.7	0.7	6.8	1.02	6.92	72.23	0.35	0.35	-1.42	317.81	317.8	70.81	
					43	0.0	0.0	6.8	1.02	6.95	70.81	0.34	0.34	-1.98	315.84	315.8	68.84	
					44	0.0	0.0	7.6	1.03	7.79	68.84	0.33	0.33	-2.15	313.68	313.7	66.68	
					45	0.0	0.0	8.3	1.03	8.53	66.68	0.32	0.32	-2.28	311.40	311.4	64.40	0.39
					46	29.6	37.5	2.4	1.03	2.47	64.40	0.31	1.00	40.69	352.09	352.1	105.09	
					47	0.0	0.0	5.7	1.03	5.87	105.09	0.50	0.50	-2.48	349.62	349.6	102.62	
					48	0.0	0.0	6.1	1.03	6.28	102.62	0.49	0.49	-2.59	347.03	347.0	100.03	
					49	0.0	0.0	6.6	1.03	6.79	100.03	0.48	0.48	-2.73	344.30	344.3	97.30	
					50	0.0	0.0	6.6	1.03	6.79	97.30	0.47	0.47	-2.65	341.65	341.7	94.65	
					51	0.0	0.0	7.5	1.03	7.70	94.65	0.45	0.45	-2.92	338.73	338.7	91.73	
					52	8.4	10.2	5.8	1.02	5.94	91.73	0.44	0.95	5.31	344.04	344.0	97.04	
					53	0.0	0.0	5.4	1.02	5.51	97.04	0.46	0.46	-2.15	341.89	341.9	94.89	
					54	2.1	2.1	4.9	1.02	4.98	94.89	0.45	0.55	-0.54	341.35	341.4	94.35	
					55	12.5	15.5	3.5	1.01	3.54	94.35	0.45	1.00	13.89	355.24	355.2	108.24	

56	0.0	0.0	5.11.01	5.14	108.24	0.52	0.52	-2.23	353.01	353.0	106.01	
57	0.0	0.0	5.21.00	5.22	106.01	0.51	0.51	-2.22	350.79	350.8	103.79	
58	0.0	0.0	6.01.00	5.98	103.79	0.50	0.50	-2.49	348.30	348.3	101.30	
59	0.0	0.0	7.20.99	7.14	101.30	0.48	0.48	-2.90	345.40	345.4	98.40	
60	0.4	0.4	6.20.98	6.11	98.40	0.47	0.47	-2.08	343.32	343.3	96.32	0.59
61	0.3	0.3	7.20.98	7.04	96.32	0.46	0.46	-2.47	340.85	340.9	93.85	
62	0.0	0.0	5.80.97	5.63	93.85	0.45	0.45	-2.12	338.73	338.7	91.73	
63	0.0	0.0	7.50.96	7.22	91.73	0.44	0.44	-2.66	336.07	336.1	89.07	
64	0.1	0.1	7.10.96	6.78	89.07	0.43	0.43	-2.34	333.73	333.7	86.73	
65	0.0	0.0	8.50.95	8.05	86.73	0.41	0.41	-2.80	330.93	330.9	83.93	
66	0.0	0.0	7.30.94	6.85	83.93	0.40	0.40	-2.31	328.62	328.6	81.62	
67	0.1	0.1	7.80.93	7.25	81.62	0.39	0.39	-2.29	326.33	326.3	79.33	
68	0.0	0.0	7.10.92	6.54	79.33	0.38	0.38	-2.08	324.25	324.2	77.25	
69	0.0	0.0	7.20.91	6.57	77.25	0.37	0.37	-2.04	322.21	322.2	75.21	
70	0.0	0.0	6.40.90	5.78	75.21	0.36	0.36	-1.74	320.47	320.5	73.47	
71	0.0	0.0	6.20.89	5.54	73.47	0.35	0.35	-1.63	318.84	318.8	71.84	
72	0.0	0.0	6.60.88	5.83	71.84	0.34	0.34	-1.68	317.15	317.2	70.15	
73	0.0	0.0	6.40.87	5.59	70.15	0.34	0.34	-1.57	315.58	315.6	68.58	
74	0.0	0.0	4.90.86	4.23	68.58	0.33	0.33	-1.16	314.42	314.4	67.42	
75	5.0	5.9	6.20.85	5.29	67.42	0.32	0.58	3.26	317.67	317.7	70.67	0.40
76	0.0	0.0	3.50.84	2.95	70.67	0.34	0.34	-0.84	316.84	316.8	69.84	
77	0.0	0.0	3.00.83	2.50	69.84	0.33	0.33	-0.70	316.14	316.1	69.14	
78	4.0	4.6	2.10.82	1.73	69.14	0.33	1.00	3.30	319.44	319.4	72.44	
79	18.0	22.6	1.50.81	1.22	72.44	0.35	1.00	24.81	344.25	344.2	97.25	
80	0.0	0.0	3.60.80	2.88	97.25	0.47	0.47	-1.13	343.12	343.1	96.12	
81	0.0	0.0	3.80.79	3.00	96.12	0.46	0.46	-1.16	341.96	342.0	94.96	
82	42.0	53.5	4.50.78	3.51	94.96	0.45	1.00	58.01	399.98	400.0	152.98	
83	0.0	0.0	4.90.77	3.77	152.98	0.73	0.73	-2.31	397.66	397.7	150.66	
84	0.0	0.0	4.50.76	3.41	150.66	0.72	0.72	-2.06	395.60	395.6	148.60	
85	0.0	0.0	4.00.75	2.99	148.60	0.71	0.71	-1.78	393.82	393.8	146.82	
86	0.0	0.0	6.00.74	4.42	146.82	0.70	0.70	-2.60	391.21	391.2	144.21	
87	0.0	0.0	3.50.73	2.54	144.21	0.69	0.69	-1.47	389.74	389.7	142.74	
88	0.0	0.0	2.00.72	1.43	142.74	0.68	0.68	-0.82	388.92	388.9	141.92	
89	32.0	40.6	4.00.70	2.82	141.92	0.68	1.00	43.87	432.79	432.8	185.79	
90	0.0	0.0	2.90.69	2.01	185.79	0.89	0.89	-1.50	431.29	431.3	184.29	0.72
91	0.0	0.0	3.70.68	2.53	184.29	0.88	0.88	-1.87	429.42	429.4	182.42	
92	0.0	0.0	3.90.67	2.62	182.42	0.87	0.87	-1.92	427.50	427.5	180.50	
93	0.0	0.0	2.60.66	1.72	180.50	0.86	0.86	-1.25	426.25	426.3	179.25	
94	0.0	0.0	1.10.65	0.72	179.25	0.86	0.86	-0.52	425.74	425.7	178.74	
95	22.0	27.7	1.00.64	0.64	178.74	0.86	1.00	31.46	457.20	457.2	210.20	
96	0.0	0.0	3.10.63	1.95	210.20	1.01	1.01	-1.65	455.55	455.5	208.55	
97	0.0	0.0	3.00.62	1.86	208.55	1.00	1.00	-1.56	453.99	454.0	206.99	
98	0.0	0.0	3.50.61	2.13	206.99	0.99	0.99	-1.77	452.22	452.2	205.22	
99	0.0	0.0	3.60.60	2.16	205.22	0.98	0.98	-1.78	450.44	450.4	203.44	
100	0.0	0.0	4.00.59	2.36	203.44	0.97	0.97	-1.93	448.52	448.5	201.52	
101	0.0	0.0	2.60.58	1.51	201.52	0.96	0.96	-1.22	447.30	447.3	200.30	
102	0.0	0.0	3.20.57	1.82	200.30	0.96	0.96	-1.46	445.83	445.8	198.83	
103	0.0	0.0	1.00.56	0.56	198.83	0.95	0.95	-0.45	445.39	445.4	198.39	
104	0.0	0.0	2.40.55	1.32	198.39	0.95	0.95	-1.05	444.34	444.3	197.34	
105	0.0	0.0	2.90.54	1.57	197.34	0.94	0.94	-1.24	443.10	443.1	196.10	0.95
106	0.0	0.0	2.80.53	1.49	196.10	0.94	0.94	-1.17	441.93	441.9	194.93	
107	0.0	0.0	3.10.52	1.61	194.93	0.93	0.93	-1.26	440.66	440.7	193.66	
108	0.0	0.0	3.20.51	1.64	193.66	0.93	0.93	-1.27	439.39	439.4	192.39	
109	3.0	3.3	3.40.50	1.71	192.39	0.92	1.00	1.83	441.22	441.2	194.22	
110	11.8	14.6	3.70.49	1.82	194.22	0.93	1.00	14.84	456.06	456.1	209.06	
111	18.0	22.6	3.40.48	1.65	209.06	1.00	1.00	24.31	480.38	480.4	233.38	
112	0.0	0.0	2.60.47	1.23	233.38	1.12	1.12	-1.16	479.22	479.2	232.22	
113	6.3	7.5	3.40.47	1.58	232.22	1.11	1.00	6.90	486.12	482.0	235.00	
114	9.3	11.4	1.10.46	0.50	235.00	1.12	1.00	12.64	494.64	482.0	235.00	
115	0.1	0.1	2.40.45	1.08	235.00	1.12	1.12	-0.93	481.07	481.1	234.07	
116	0.0	0.0	3.20.44	1.41	234.07	1.12	1.12	-1.32	479.75	479.7	232.75	
117	1.0	1.0	1.60.43	0.69	232.75	1.11	1.00	0.36	480.11	480.1	233.11	
118	6.8	8.2	1.30.42	0.55	233.11	1.12	1.00	8.85	488.96	482.0	235.00	
119	8.4	10.2	1.10.42	0.46	235.00	1.12	1.00	11.35	493.35	482.0	235.00	
120	3.1	3.4	1.30.41	0.53	235.00	1.12	1.00	3.35	485.35	482.0	235.00	1.01
P	273	337						143.92	4524045201			
		-64							D	0		0.59
												YIELD2980

Appendix 8.2

Details concerning various processes and parameters

Catering for runoff (R) with *CON* and run-on with IRWH by adjusting rainfall (P) for different treatments. (P - R or P + R)

***CON* (P - R):**

P_{CON} = @ IF ((P< 8), (P–O), (P–((0.473*P)–2.168)*0.4))……………..…(r^2 = 0.60) (after Hensley *et al.*, 2000)

IRWH (P + R) - bare, organic mulch and stone mulch: (see Section 4.1.1 for details).

Bare:

P_{BARE} = @ IF ((-0.8791+0.4742*P)<0, (P*0), (-0.8791+0.4742*P))…....(r^2 = 0.64)

Stone:

P_{STONE} = @ IF ((-0.6635+0.2900*P)<0, (P*0), (-0.6635+0.2900*P))……..(r^2 = 0.51)

Organic:

$P_{ORGANIC}$ = @IF ((-0.2124+0.0768*P)<0, (P*0), (-0.2124+0.0768*P))..…..(r^2 = 0.55)

CF: crop factor

Dry beans:

CF = 0. 0003*$DAP^{2.8128}$*EXP*(-0.0577*DAP)…………………………..(r^2 = 0.98)

Maize and sunflower:

CF = 0.0119*$DAP^{1.5582}$*EXP*(-0.0327*DAP)……………………..………(r^2 = 0.98)

This is an adaptation of the equation of Bennie, Strydom & Very (1998) to give one which only has one input i.e. DAP. The dry bean, maize and sunflower cultivars used have a growth period of approximately 100 days, 120 days and 120 days respectively.

EoCF: Crop water requirement

In order to get the crop water requirement per day, Eo must be multiplied by CF.

EoCF = Eo*Cf

ESW_b: Extractable soil water at the beginning of a day

$ESW_b = \theta r – LL$

FTESW: Fraction of total extractable soil water

FTESW = (ESW_b/TESW)

$FTESW_{aa}$: Adapted Fraction of total extractable soil water

$FTESW_{aa}$ = @ IF ((P/Eo<0.2), (FTESW+0), (FTESW+(P/Eo)*0.4052 – 0.0729)) only up to a maximum of 1

During a period where ESW_b is low and it rains during that day, the model did not take the rain in consideration, and penalized the extraction too much. That is why there is an adapted: $FTESW_{aa}$ which takes the rain during a day into consideration.

SWE: Soil water Extraction

Empirical constans, based on observations, have been included in the equations for the different kinds of cover on the runoff area to compensate for their differing influence on SWE, especially on Es.

***CON*:**
$(-EoCF*FTESW_{aa}))+P_{CON}$

***BbBr*:**
$(-EoCF*FTESW_{aa}))+P_{BARE}$

***ObBr*:**
@ IF $(-(EoCF*FTESW_{aa})+P_{BARE})<0$, $((-(EoCF*FTESW_{aa})+P_{BARE})*0.982)$, $((-EoCF*FTESW_{aa})+P_{BARE})*1.018)))$

***ObOr*:**
@ IF $((-(EoCF*FTESW_{aa})+P_{ORGANIC})<0$, $((-(EoCF*FTESW_{aa})+P_{ORGANIC})*0.802)$, $((-(EoCF*FTESW_{aa})+P_{ORGANIC})*1.198)))$

***ObSr*:**
@ IF $((-(EoCF*FTESW_{aa})+P_{STONE})<0$, $((-(EoCF*FTESW_{aa})+P_{STONE})*0.839)$, $((-(EoCF*FTESW_{aa})+P_{STONE})*1.161)))$

***SbOr*:**
@ IF $((-(EoCF*FTESW_{aa})+P_{ORGANIC})<0$, $((-(EoCF*FTESW_{aa})+P_{ORGANIC})*0.807)$, $((-(EoCF*FTESW_{aa})+P_{ORGANIC})*1.193)))$

***SbSr*:**
@ IF $((-(EoCF*FTESW_{aa})+P_{STONE})<0$, $((-(EoCF*FTESW_{aa})+P_{STONE})*0.844)$, $((-(EoCF*FTESW_{aa})+P_{STONE})*1.156)))$

θr_a: Water content of rootzone, not adapted to cater for values above CMUL

Dry beans:

CON, *BbBr* and *ObBr*:

$\theta r_a = ((ESW_b*0.99)+Extraction+LL)$

ObOr, *ObSr*, *SbOr* and *SbSr*:

$\theta r_a = (ESW_b+Extraction+LL)$

Maize and sunflower:

CON, *BbBr* and *ObBr*:

$\theta r_a = ((ESW_b*0.997)+Extraction+LL)$

ObOr, *ObSr*, *SbOr* and *SbSr*:

$\theta r_a = (ESW_b+Extraction+LL)$

θr_b: Adapted water content of rootzone, to cater for values not to exceed CMUL

@ IF $((\theta r_a<CMUL), (\theta r_a+0), (\theta r_a*0+CMUL))$

This equation is to make sure that θr_b does not exceed CMUL, because when θr > CMUL, D occurs, and therefore everything above CMUL is wasted as D.

ESW_e: Extactable soil water at the end of a day

$ESW_e = (\theta r_b - LL)$

ESW_e is used to start the following day (ESW_b)

SF: Stress factor

Dry beans:

$SF_{0\text{-}10}$ = sum of $FTESW_{aa}$ for a period of 10 days. Each period is calculated separately. SF is the average $FTESW_{aa}$ for each 10 day period up to a maximum of 10 periods.

Period 1 (SF_1): $SF_{0\text{-}10\ DAP}$

Period 2 (SF_2): $SF_{11\text{-}20\ DAP}$

Period 3 (SF_3): $SF_{21\text{-}30\ DAP}$
Period 4 (SF_4): $SF_{31\text{-}40\ DAP}$
Period 5 (SF_5): $SF_{41\text{-}50\ DAP}$
Period 6 (SF_6): $SF_{51\text{-}60\ DAP}$
Period 7 (SF_7): $SF_{61\text{-}70\ DAP}$
Period 8 (SF_8): $SF_{71\text{-}80\ DAP}$
Period 9 (SF_9): $SF_{81\text{-}90\ DAP}$
Period 10 (SF_{10}): $SF_{91\text{-}100\ DAP}$

Maize and sunflower:

$SF_{0\text{-}15}$ = sum of $FTESW_{aa}$ for a period of 15 days. Each period is calculated separately. SF is the average $FTESW_{aa}$ for a set of 15 day periods up to a maximum of 8 periods.

Period 1 (SF_1): $SF_{0\text{-}15\ DAP}$
Period 2 (SF_2): $SF_{16\text{-}30\ DAP}$
Period 3 (SF_3): $SF_{31\text{-}45\ DAP}$
Period 4 (SF_4): $SF_{46\text{-}60\ DAP}$
Period 5 (SF_5): $SF_{61\text{-}75\ DAP}$
Period 6 (SF_6): $SF_{76\text{-}90\ DAP}$
Period 7 (SF_7): $SF_{91\text{-}105\ DAP}$
Period 8 (SF_8): $SF_{106\text{-}120\ DAP}$

ISF: Integrated stress factor and the stress weighting factor (λ)

For every SF period a stress weigh factor (λ) is allocated according to the critical importance of the period with regard to yield determination. The λ values range between 0 and 1 and their sum equals 1. The ISF value is obtained by a multiplicative summation of the individual SF values. For sunflower the period DAP 46-60 is the critical period just before flowering. DAP 61-75 is the critical flowering period. Any water deficiency during these two periods has an important influence on sunflower yield. That is why these two periods in the case of sunflower have high λ values. The periods 0-15 DAP; 91-105 DAP and 106-end DAP were considered to be of very low importance regarding sunflower yield, especially the last two periods. The λ values allocated to each SF period for dry beans, maize and sunflower are presented below:

Dry beans:

$ISF = (SF_1^{0.05}*SF_2^{.0.07}*SF_3^{0.10}*SF_4^{0.15}*SF_5^{0.16}*SF_6^{0.15}*SF_7^{0.13}*SF_8^{0.10}*SF9^{0.06}*SF10^{0.03})$

Maize:

$ISF = (SF_1^{0.06}*SF_2^{.0.05}*SF_3^{0.04}*SF_4^{0.15}*SF_5^{0.30}*SF_6^{0.20}*SF_7^{0.15}*SF_8^{0.05})$

Sunflower:

$ISF = (SF_1^{0.03}*SF_2^{.0.07}*SF_3^{0.15}*SF_4^{0.27}*SF_5^{0.30}*SF_6^{0.10}*SF_7^{0.03}*SF_8^{0.01})$

Formulation of CYP-SA:

An empirical approach was used. For each of the crops the regression of yield on ISF as determined for a number of growing seasons. The resultant equation describes the model. The r^2 value of the regression equation is considered to provide a calibration index.

Dry beans:

Yield = (704.6899*ISF)+(402.5764)...………………..…………..…...(r^2 = 0.73)

Maize:

Yield = 10772.60*(1+((-0.3478)-1)*EXP(-(0.5460)*((ISF)-(-0.3091))))$^{(1/1-(-0.3478))}$..(r^2 = 0.97)

Sunflower:

Yield = (6188.56*ISF)-1607.37…..…….…………………………………...(r^2 = 0.81)
(after Hensley *et al.*, 2000)

The yield equations for dry beans, maize and sunflower were then used to make long-term simulations on all ecotopes. The input requirements for the model are DUL, LL, CMUL, daily P, daily Eo and θp. These were available for all the ecotopes.

Appendix 8.3 (a)

Simulated long-term dry bean yields (kg ha^{-1}) on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes using different production techniques

Crop	Detail	Ecotope	Probability	Treatment						
				CON	*BbBr*	*ObBr*	*SbOr*	*ObOr*	*SbSr*	*ObSr*
Beans	Half Profile, December	Bo	20	586	663	667	689	691	700	701
			50	644	737	743	778	780	803	806
			75	704	829	835	867	869	891	893
		Ks	20	603	709	715	715	717	736	738
			50	677	817	825	816	818	851	854
			75	746	938	949	958	961	1001	1004
		Va	20	573	659	663	672	673	690	692
			50	643	758	764	772	774	807	809
			75	708	848	854	877	878	913	915

Crop	Detail	Ecotope	Probability	Planting date		
				Early	Intermediate	Late
Beans	*ObSr*, Half profile	Bo	20	660	701	757
			50	773	806	840
			75	848	893	941
		Ks	20	694	738	789
			50	794	854	921
			75	883	1004	1025
		Va	20	643	691	724
			50	748	809	846
			75	817	915	938

Crop	Detail	Ecotope	Probability	Water content at planting				
				empty	¼	½	¾	Full
Beans	*ObSr*, January	Bo	20	586	646	753	842	906
			50	696	741	840	914	960
			75	815	852	941	1013	1038
		Ks	20	556	724	789	851	901
			50	765	861	921	972	1015
			75	906	975	1025	1076	1130
		Va	20	544	720	724	850	880
			50	752	844	846	949	972
			75	865	936	938	1021	1043

Appendix 8.3 (b)

Simulated long-term maize yields (kg ha^{-1}) on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes using different production techniques

Crop	Detail	Ecotope	Probability	Treatment						
				CON	*BbBr*	*ObBr*	*SbOr*	*ObOr*	*SbSr*	*ObSr*
Maize	Half Profile, December	Bo	20	775	1620	1617	1850	1861	2001	2018
			50	1443	2234	2278	2388	2406	2600	2620
			75	2040	3000	3065	3203	3200	3463	3490
		Ks	20	428	1463	1527	1637	1656	1845	1864
			50	1454	2524	2604	2678	2697	2966	2989
			75	2154	3234	3287	3469	3489	3602	3624
		Va	20	551	1548	1606	1753	1773	1967	1985
			50	1538	2560	2623	2719	2742	2962	2981
			75	2173	3234	3289	3495	3514	3613	3631

Crop	Detail	Ecotope	Probability	Planting date		
				Early	Intermediate	Late
Maize	*ObSr*, Half profile	Bo	20	1116	2016	2140
			50	2141	2620	3003
			75	2684	3483	3691
		Ks	20	1018	1864	2094
			50	1992	2989	3056
			75	2759	3624	3921
		Va	20	1198	1985	2333
			50	2014	2981	3078
			75	2784	3631	3880

Crop	Detail	Ecotope	Probability	Water content at planting				
				empty	¼	½	¾	Full
Maize	*ObSr*, January	Bo	20	886	1707	2140	2496	2775
			50	1985	2637	3003	3285	3581
			75	2720	3462	3691	3982	4090
		Ks	20	940	1921	2094	2209	2331
			50	2317	2846	3056	3251	3426
			75	3343	3740	3921	4003	4082
		Va	20	876	2115	2333	2446	2576
			50	2274	2842	3078	3329	3549
			75	3168	3584	3880	4019	4094

Appendix 8.3 (c)

Simulated long-term sunflower yields (kg ha^{-1}) on the Glen/Bonheim, Khumo/Swartland and Vlakspruit/Arcadia ecotopes using different production techniques

Crop	Detail	Ecotope	Probability	Treatment						
				CON	*BbBr*	*ObBr*	*SbOr*	*ObOr*	*SbSr*	*ObSr*
Sunflower	Half Profile, December	Bo	20	324	742	783	1002	1014	1106	1119
			50	796	1431	1473	1685	1700	1813	1830
			75	1322	2148	2265	2510	2527	2719	2738
		Ks	20	31	577	616	730	904	790	881
			50	761	1510	1552	1641	1659	1786	1894
			75	1338	2404	2472	2627	2648	2770	2868
		Va	20	154	626	664	819	831	938	954
			50	818	1514	1572	1726	1743	1945	1964
			75	1386	2407	2466	2655	2675	2879	2898

Crop	Detail	Ecotope	Probability	Planting date		
				Early	Intermediate	Late
Sunflower	*ObSr*, Half profile	Bo	20	668	1002	1574
			50	1658	1685	2244
			75	2158	2510	3034
		Ks	20	557	881	1379
			50	1157	1894	2209
			75	1930	2868	3155
		Va	20	680	954	1461
			50	1286	1964	2272
			75	2023	2898	3104

Crop	Detail	Ecotope	Probability	Water content at planting				
				empty	¼	½	¾	Full
Sunflower	*ObSr*, January	Bo	20	153	1101	1574	1999	2406
			50	900	1746	2244	2583	2912
			75	2056	2725	3034	3455	3723
		Ks	20	347	1045	1379	1672	1911
			50	1631	1908	2209	2510	2642
			75	2371	2859	3155	3451	3572
		Va	20	230	1048	1461	1839	2122
			50	1483	1970	2272	2629	2786
			75	2203	2698	3104	3463	3576

Appendix 8.4

Sunflower, maize and dry beans gross margins (R/ha) for the different production techniques for the past 81 years (1923-2003)

	Sunflower							Maize							Beans						
Year	*CON*	*BbBr*	*ObBr*	*ObOr*	*ObSr*	*SbOr*	*SbSr*	*CON*	*BbBr*	*ObBr*	*ObOr*	*ObSr*	*SbOr*	*SbSr*	*CON*	*BbBr*	*ObBr*	*ObOr*	*ObSr*	*SbOr*	*SbSr*
1923	444.44	1004.85	1943.45	2080.71	2406.05	2061.06	2315.85	-59.39	761.68	804.14	1104.61	1201.96	1092.55	1194.39	529.26	1120.37	1034.39	1162.61	1165.86	1160.65	1163.85
1924	319.24	532.65	1455.64	1627.42	1908.73	1611.41	1824.39	199.13	861.40	892.92	1137.98	1265.28	1129.11	1254.04	497.67	1035.04	962.72	1072.48	1137.17	1067.93	1132.17
1925	-323.59	-410.33	497.20	666.76	833.13	655.03	780.57	-162.58	397.98	420.49	667.44	754.75	660.83	745.34	312.60	758.38	716.70	814.76	864.81	811.08	860.74
1926	-315.43	-280.26	633.01	766.75	970.63	753.59	913.09	-96.91	539.77	567.35	773.68	901.18	765.86	890.22	281.19	762.75	721.44	789.81	839.24	786.15	835.43
1927	-356.05	-366.15	545.25	714.94	916.51	702.87	861.14	-369.24	230.96	260.35	533.84	654.80	525.80	643.82	253.73	713.94	677.67	779.55	829.75	776.13	826.02
1928	-208.18	-95.99	823.65	980.84	1238.91	965.76	1171.81	-413.87	208.21	240.97	516.79	644.29	507.36	631.85	389.15	904.57	848.73	969.87	1045.95	965.00	1040.55
1929	-831.76	-1104.11	-201.55	7.80	103.45	-2.37	70.66	-661.48	-145.57	-117.78	168.07	260.83	160.09	250.68	128.41	502.97	490.53	586.31	616.84	583.33	613.65
1930	-518.76	-566.08	348.30	565.08	749.03	551.20	695.85	-692.93	-87.65	-54.60	253.88	364.53	244.20	352.42	267.50	726.97	691.35	836.31	897.07	831.61	891.91
1931	-206.78	-7.04	916.09	1060.72	1344.45	1044.97	1273.97	-579.44	100.18	135.76	432.44	569.39	422.13	556.09	363.40	890.15	836.34	951.66	1026.29	946.77	1020.85
1932	-541.75	-619.05	290.22	423.30	601.48	411.59	554.26	-533.48	56.10	85.51	329.98	449.60	321.65	438.63	239.16	684.75	652.38	727.98	779.37	724.41	775.44
1933	-1044.85	-1347.67	-446.41	-220.44	-144.28	-230.45	-170.56	-1172.02	-556.24	-525.66	-210.22	-120.26	-218.99	-130.44	101.48	456.59	449.22	556.59	582.32	553.56	579.08
1934	671.20	1113.39	2041.56	2109.65	2508.66	2092.88	2407.67	184.21	925.06	958.29	1176.17	1345.84	1166.88	1332.24	658.14	1315.21	1212.50	1318.48	1422.18	1312.99	1416.24
1935	-531.05	-663.34	244.14	416.11	573.98	404.71	527.79	-473.19	91.43	119.32	368.74	483.01	360.76	472.31	253.50	682.27	649.89	755.21	803.47	751.47	799.36
1936	-39.30	230.02	1158.38	1317.45	1624.89	1300.20	1545.87	-227.82	478.98	515.55	791.20	933.98	780.93	920.34	415.78	982.74	919.64	1037.76	1122.64	1032.40	1116.64
1937	297.40	575.46	1496.70	1575.03	1891.35	1560.29	1808.43	-158.42	554.39	587.78	828.06	979.05	818.63	966.04	506.80	1080.50	1003.25	1088.36	1172.15	1083.84	1167.05
1938	-596.42	-756.82	147.93	309.41	457.89	299.14	415.93	-748.44	-198.16	-169.31	115.34	219.74	107.21	209.44	237.82	649.51	619.24	699.57	742.40	696.65	739.18
1939	-188.56	-117.65	805.18	1068.53	1310.41	1051.30	1239.31	-537.98	51.24	84.97	428.17	543.93	417.48	530.36	383.03	876.19	819.83	1031.32	1098.56	1025.28	1094.03
1940	-447.21	-676.05	224.94	381.73	505.79	372.41	463.69	-353.50	164.55	189.34	425.49	529.62	418.50	519.88	238.80	644.61	614.89	692.77	730.02	689.88	726.87
1941	726.33	1297.55	2201.10	2421.48	2585.40	2411.00	2492.11	-56.57	688.14	707.46	1100.94	1102.97	1095.22	1094.32	663.36	1293.91	1186.70	1332.49	1368.81	1329.11	1365.28
1942	-416.73	-585.79	317.82	451.18	602.31	441.13	556.92	-326.18	177.80	202.04	420.45	527.84	413.74	518.41	263.01	677.33	643.78	709.25	751.43	706.38	748.26
1943	-36.86	48.54	964.89	1100.38	1362.88	1086.45	1293.80	-265.99	347.47	378.12	623.62	763.71	614.87	751.61	446.59	981.15	916.35	1054.70	1139.69	1049.58	1134.05
1944	-169.38	-135.09	783.28	984.75	1210.95	969.81	1144.82	-498.69	102.68	136.17	442.85	561.37	432.98	548.64	372.02	875.74	823.71	962.30	1030.67	957.20	1025.20
1945	-624.93	-637.19	277.71	453.46	644.31	439.63	593.86	-733.61	-73.39	-39.18	247.44	372.59	237.52	360.16	249.46	704.85	670.82	764.55	818.77	760.57	814.39
1946	134.81	648.51	1592.75	1791.96	2110.13	1769.59	2023.87	-237.81	588.93	631.73	923.42	1052.34	910.97	1040.34	521.57	1114.17	1030.09	1191.57	1228.08	1187.54	1223.81
1947	-1044.85	-1305.64	-395.36	-148.49	-33.72	-161.44	-66.05	-1172.02	-1045.25	-964.30	-494.09	-407.84	-506.63	-420.91	72.57	455.70	450.98	583.82	623.40	579.81	619.05
1948	-29.15	227.12	1157.79	1383.15	1666.09	1364.40	1584.47	38.00	711.36	741.87	1013.25	1128.55	1004.39	1115.75	459.15	1037.61	968.13	1102.67	1185.10	1096.82	1178.78
1949	-1044.85	-1580.71	-687.23	-498.89	-464.37	-506.22	-479.65	-1172.02	-770.43	-742.26	-424.71	-360.96	-432.17	-369.29	39.45	337.23	341.23	412.03	422.60	410.26	420.75
1950	-749.74	-1024.97	-120.67	114.57	211.68	103.43	175.16	-602.07	-156.73	-131.22	160.79	239.96	153.25	230.21	171.00	547.50	530.77	658.28	692.92	654.61	688.94

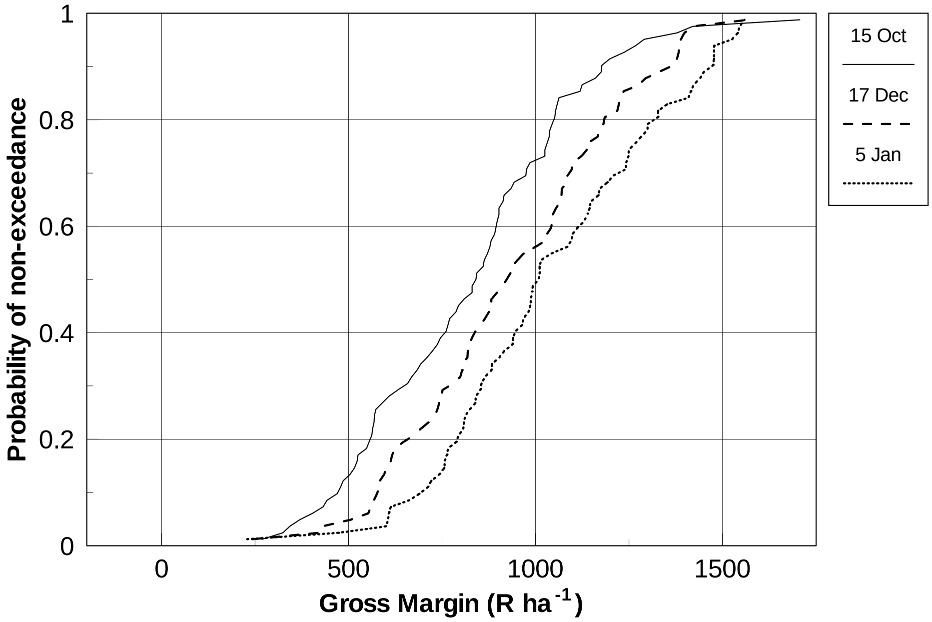
1951	-439.43	-494.50	418.02	886.47	926.58	870.98	868.41	-560.07	-8.30	22.18	450.44	483.91	440.53	471.72	348.70	742.41	702.65	963.59	968.38	958.81	963.57
1952	-578.70	-709.46	193.65	311.15	464.81	301.36	423.18	-666.65	-45.38	-16.45	222.83	345.66	214.80	335.21	229.13	646.99	616.40	674.66	713.94	672.03	711.07
1953	-781.14	-1005.04	-102.65	81.85	184.18	71.64	149.47	-1007.68	-347.51	-315.19	-18.38	86.14	-27.65	75.09	106.70	481.05	470.57	550.48	576.00	547.77	573.12
1954	58.50	171.25	1085.78	1172.10	1431.82	1158.66	1362.31	82.53	735.44	763.58	954.13	1094.59	946.31	1083.25	458.27	981.17	914.01	994.41	1069.35	990.42	1064.93
1955	1190.92	1184.08	2070.32	2319.11	2391.71	2313.25	2306.38	260.36	716.04	731.09	1105.05	1100.59	1100.44	1092.68	628.80	1091.95	1003.25	1093.39	1096.75	1091.78	1095.12
1956	-342.55	-588.71	312.39	531.51	630.18	521.50	584.99	22.15	537.22	557.70	794.08	873.36	788.03	864.44	190.32	562.91	540.62	636.35	647.15	633.71	644.89
1957	-570.59	-586.04	333.63	593.07	780.24	577.16	724.10	-746.58	-145.76	-110.31	226.67	332.76	216.18	319.79	261.43	733.84	699.14	858.82	922.96	853.48	917.06
1958	-433.48	-498.98	408.77	552.79	744.82	541.09	694.05	-618.78	-54.63	-25.86	252.19	362.66	243.69	351.72	312.75	761.03	718.78	818.87	875.35	815.21	871.31
1959	-416.06	-393.26	522.37	691.25	903.77	677.59	846.80	-747.60	-92.02	-57.43	235.81	362.93	225.96	350.56	310.96	778.67	736.30	852.02	911.15	847.81	906.51
1960	-193.24	-216.39	692.62	797.85	1005.21	786.47	948.05	-79.18	539.94	567.07	764.00	896.20	756.67	885.38	330.70	803.60	756.55	828.71	882.21	825.36	878.49
1961	-474.20	-529.25	385.97	613.23	803.20	598.97	748.20	-586.57	-40.44	-9.40	293.62	400.65	284.52	388.95	304.59	764.48	724.55	873.95	937.23	869.14	931.91
1962	-287.77	-328.50	578.58	673.92	870.49	662.98	817.46	-350.06	265.62	292.80	494.26	628.77	486.59	618.27	308.47	752.67	709.92	759.54	806.05	756.72	802.99
1963	-115.07	-22.12	897.45	1085.65	1337.10	1070.64	1267.76	-310.29	282.80	314.00	599.22	719.85	590.01	707.58	418.11	929.22	870.40	1011.92	1085.27	1006.96	1079.78
1964	-1044.85	-1533.41	-634.28	-445.65	-378.26	-455.03	-397.84	-1172.02	-771.11	-736.22	-407.11	-317.63	-416.81	-328.08	-2.32	330.10	336.47	412.36	430.75	410.05	428.33
1965	-902.91	-958.17	-44.76	152.63	332.31	139.34	290.12	-1172.02	-894.55	-841.94	-401.24	-292.68	-413.80	-306.18	145.67	566.06	548.84	684.83	737.67	680.70	733.09
1966	433.36	843.80	1777.17	1936.79	2293.42	1918.15	2195.90	-249.78	507.51	549.17	879.61	1030.49	867.69	1014.83	494.45	1098.40	1021.55	1134.73	1181.88	1129.44	1178.80
1967	712.67	1106.25	2033.01	2130.24	2485.52	2113.32	2385.48	223.76	944.58	978.41	1205.79	1362.35	1196.17	1348.80	649.35	1273.81	1175.62	1291.88	1388.58	1286.39	1382.53
1968	-1044.85	-1363.89	-457.22	-197.08	-117.71	-208.82	-146.43	-1027.15	-426.80	-391.50	-30.27	53.24	-40.30	41.47	118.22	488.61	478.44	585.80	612.74	582.47	609.20
1969	-721.51	-1036.82	-137.76	68.63	145.05	59.43	112.37	-466.23	2.41	25.98	283.08	366.03	276.27	356.89	109.38	461.66	453.11	545.55	567.81	542.80	564.88
1970	-753.47	-815.41	102.22	374.57	538.09	359.16	488.75	-1172.02	-526.59	-485.10	-81.47	18.11	-93.62	4.27	202.39	643.26	618.32	769.37	822.66	764.46	817.31
1971	-140.96	-28.08	888.95	1011.56	1282.11	997.94	1215.53	-491.97	127.29	159.33	430.20	565.37	421.17	553.42	399.51	919.76	861.51	985.52	1066.66	980.95	1061.52
1972	524.82	766.91	1680.08	1863.40	2084.88	1850.72	1999.42	474.45	1068.14	1083.57	1329.57	1378.12	1325.37	1369.89	567.20	1140.22	1055.50	1169.24	1222.69	1164.80	1220.19
1973	-683.18	-950.27	-49.46	138.17	235.19	128.64	199.85	-526.82	5.56	31.59	281.75	380.96	274.39	371.17	144.94	508.59	494.39	577.48	601.32	574.84	598.50
1974	1792.76	1817.35	2702.79	2818.00	2954.32	2813.16	2855.62	865.66	1319.01	1331.38	1577.97	1612.83	1574.88	1605.35	925.87	1416.34	1289.85	1357.97	1384.63	1356.04	1382.57
1975	525.60	839.87	1763.32	1853.19	2187.48	1837.56	2095.77	133.00	832.63	865.70	1106.14	1259.57	1096.80	1246.05	562.59	1145.16	1060.10	1139.03	1218.63	1134.43	1213.59
1976	1375.72	1871.15	2760.54	2972.97	3075.19	2966.37	2972.24	573.75	1244.72	1260.34	1557.70	1581.33	1553.37	1572.86	929.48	1541.93	1400.42	1561.10	1569.08	1558.82	1566.87
1977	40.35	171.15	1086.56	1183.64	1451.86	1170.64	1381.55	-53.70	602.77	633.18	849.32	994.26	841.07	982.30	476.20	1003.00	932.92	1001.41	1070.19	997.65	1066.09
1978	-382.74	-389.54	522.62	659.50	871.24	647.04	816.24	-373.12	190.82	219.01	464.95	582.87	456.96	571.98	284.62	760.53	720.09	816.62	880.63	812.59	876.13
1979	-263.45	-309.92	601.74	773.66	971.24	760.88	913.58	-603.44	-33.80	-2.83	293.18	404.87	284.13	393.28	370.60	828.14	778.76	893.32	951.71	889.33	947.31
1980	-428.91	-550.22	359.04	546.56	711.14	534.25	660.64	-611.37	-64.52	-34.45	254.36	361.03	245.53	349.76	276.08	717.47	681.67	798.11	853.14	794.04	848.67
1981	1221.68	1838.78	2740.83	2775.62	3017.53	2766.24	2916.80	516.56	1276.07	1292.06	1531.82	1577.50	1527.51	1571.03	791.87	1453.06	1320.86	1363.35	1378.05	1361.52	1376.98
1982	-370.20	-226.36	696.86	900.33	1140.81	883.41	1074.48	-381.83	321.43	356.83	625.87	764.71	615.30	751.10	314.72	828.47	782.87	926.76	998.76	921.28	992.77
1983	-887.38	-1120.64	-217.93	-27.77	71.27	-38.06	39.26	-1172.02	-529.05	-496.44	-176.63	-82.60	-186.05	-93.46	115.68	494.60	482.44	555.51	583.69	552.82	580.83

1984	-1044.85	-1615.42	-710.68	-427.28	-367.12	-438.85	-389.42	-1172.02	-1045.25	-1045.25	-693.38	-629.48	-708.25	-643.62	6.22	336.73	344.84	481.40	505.91	477.79	502.05
1985	245.24	407.82	1326.68	1470.53	1735.78	1455.41	1656.30	-39.32	638.10	669.72	911.05	1051.41	901.82	1038.48	457.13	1003.69	935.13	1017.29	1085.49	1012.75	1080.60
1986	-994.22	-1327.01	-427.40	-184.27	-123.82	-193.99	-150.17	-776.68	-248.71	-220.97	85.52	168.98	77.32	158.84	95.80	437.37	431.36	533.29	552.77	530.58	549.91
1987	-741.05	-925.79	-22.74	166.15	274.50	155.57	237.22	-627.44	-13.28	15.45	273.00	381.43	264.55	370.71	93.56	460.39	452.10	540.53	559.31	537.82	556.47
1988	169.36	-98.04	799.61	1026.41	1117.15	1017.42	1060.73	552.55	829.85	841.72	1112.62	1131.57	1109.13	1124.85	357.83	753.08	709.11	795.75	818.00	793.14	815.21
1989	842.69	1159.90	2085.03	2225.62	2562.27	2208.88	2460.05	336.98	1052.52	1085.62	1322.23	1475.30	1312.82	1461.44	657.10	1273.83	1175.68	1308.24	1382.81	1302.51	1378.43
1990	-211.16	-26.32	894.30	1010.30	1288.61	995.52	1220.46	-335.04	348.25	380.92	622.06	765.78	612.82	753.24	394.65	931.03	871.61	964.71	1041.51	960.13	1036.42
1991	613.45	1109.09	2040.56	2135.16	2526.92	2117.22	2425.19	147.91	913.63	950.08	1191.83	1340.10	1181.60	1327.87	624.88	1249.97	1153.36	1243.97	1294.56	1239.23	1292.62
1992	-1044.85	-1627.40	-755.80	-773.69	-773.69	-773.69	-773.69	-1172.02	-1045.25	-1045.25	-860.82	-860.82	-860.82	-860.82	-141.00	94.02	127.30	243.67	239.98	241.62	237.92
1993	-481.87	-612.00	293.35	461.76	609.31	450.98	563.20	-473.50	87.95	115.68	375.68	483.64	367.88	473.18	241.71	660.60	629.10	710.28	748.93	707.33	745.71
1994	1072.54	1399.41	2293.79	2498.53	2635.61	2490.64	2541.80	256.52	856.06	872.71	1223.59	1235.74	1218.72	1227.27	749.26	1307.74	1196.98	1298.63	1330.60	1295.93	1327.71
1995	-790.22	-964.14	-59.24	129.43	256.22	118.48	218.59	-844.58	-302.09	-274.14	22.11	113.78	13.68	103.42	165.06	568.27	548.23	636.04	675.69	632.83	672.18
1996	200.79	352.28	1265.50	1334.09	1609.55	1321.50	1535.93	-126.26	575.08	605.71	810.97	969.32	802.58	957.33	440.66	972.44	905.80	974.32	1044.98	970.64	1040.85
1997	-471.85	-472.85	442.43	634.29	838.80	620.20	783.18	-511.91	88.40	119.77	398.76	519.35	389.60	507.63	303.12	785.88	743.29	867.80	933.28	863.25	928.33
1998	683.43	1209.06	2129.06	2366.71	2608.20	2351.29	2507.35	261.57	1051.97	1082.62	1336.43	1461.07	1327.80	1448.31	674.26	1274.48	1172.93	1368.03	1398.24	1364.06	1395.60
1999	-842.61	-913.20	1.77	223.39	393.26	209.19	348.83	-1172.02	-563.52	-524.19	-166.48	-54.09	-177.80	-66.89	188.04	624.82	601.55	742.60	798.77	737.91	793.69
2000	236.96	291.78	1213.23	1562.34	1803.08	1546.52	1721.25	-42.51	475.09	504.80	862.49	960.48	853.87	948.43	469.35	1008.85	941.27	1159.78	1235.84	1154.19	1229.69
2001	-779.92	-1049.89	-148.07	88.83	179.09	78.93	144.89	-717.84	-188.07	-159.82	152.69	239.58	144.67	229.51	116.80	487.25	475.66	569.73	595.22	567.08	592.38
2002	404.84	577.51	1495.58	1709.10	2012.52	1695.30	1927.17	-118.89	502.30	534.28	876.16	1005.85	867.47	993.51	536.23	1107.98	1027.18	1191.53	1276.56	1186.85	1271.35
2003	136.92	142.69	1056.21	1264.23	1489.83	1251.11	1418.86	-133.76	464.26	494.70	777.49	902.16	768.89	890.31	424.85	918.18	858.72	992.78	1054.44	988.61	1049.94

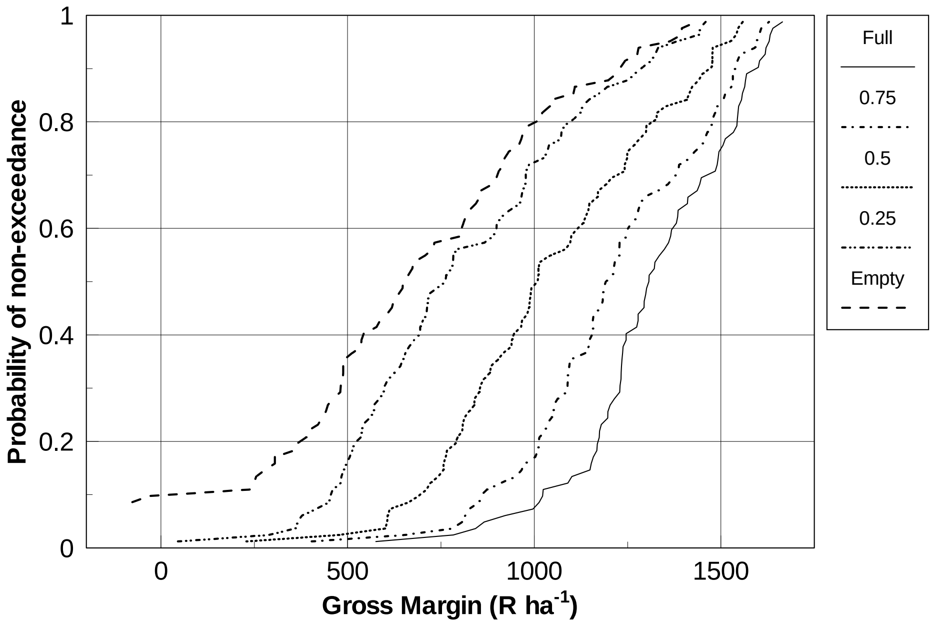
Appendix 8.5

CPF's of long-term gross margins for dry beans for the 81 year period, 1922- 2003, on the Glen/Bonheim ecotope using (a) 3 different planting dates and (b) 5 different initial soil water contents planted on 5 January

(a)



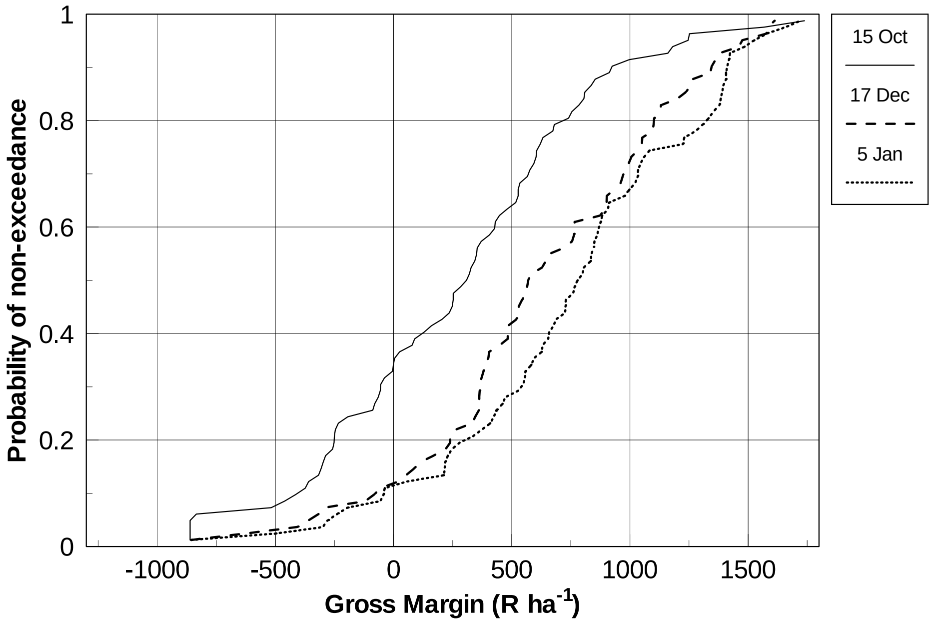
(b)



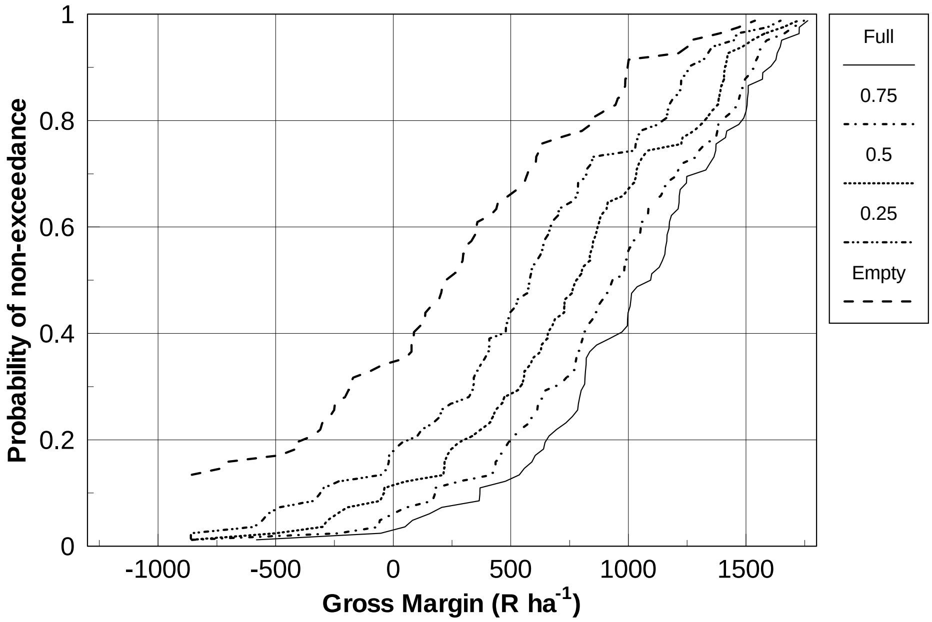
Appendix 8.6

CPF's of long-term gross margins for maize for the 81 year period, 1922- 2003, on the Glen/Bonheim ecotope using (a) 3 different planting dates and (b) 5 different initial soil water contents planted on 5 January

(a)



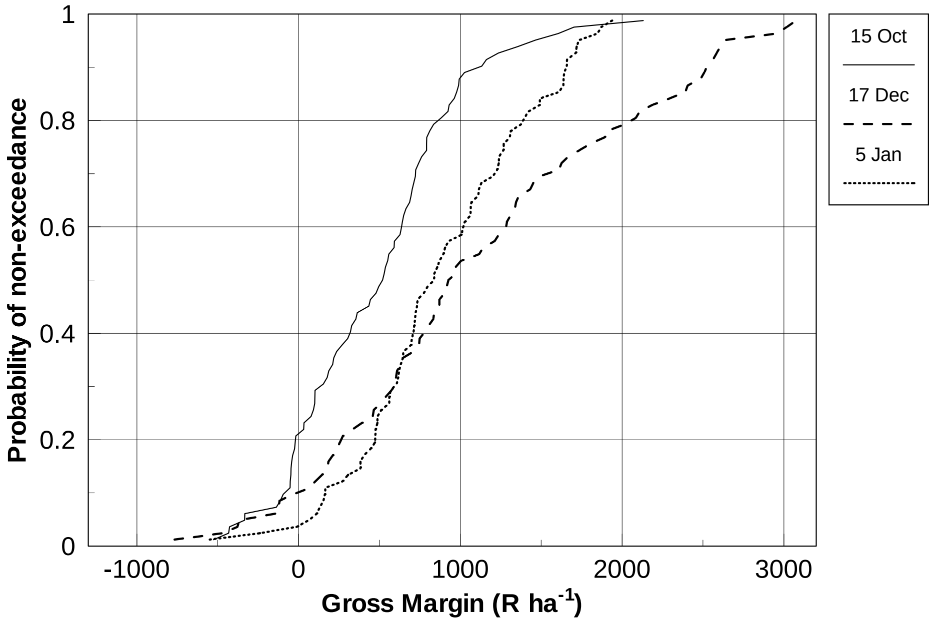
(b)



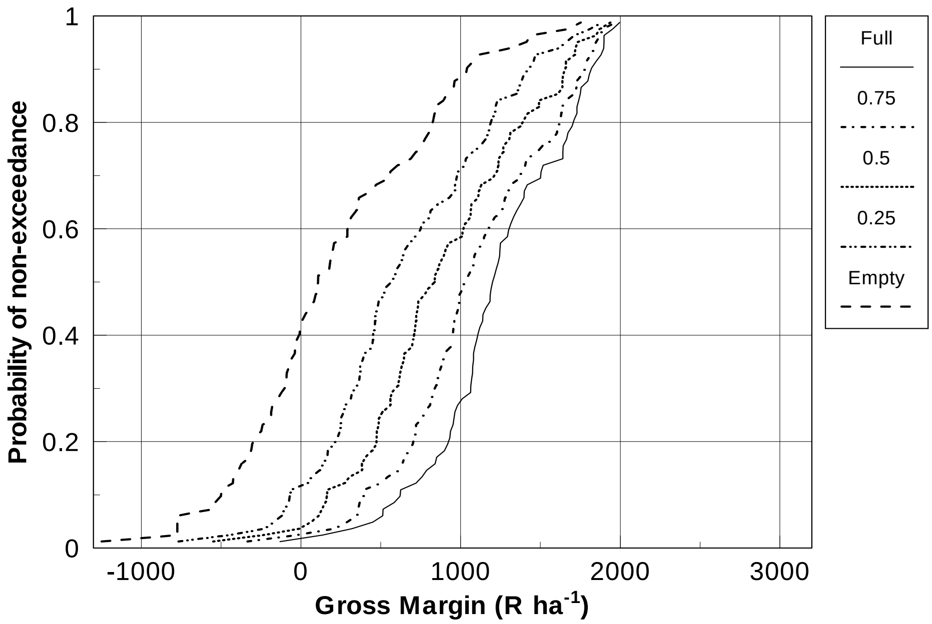
Appendix 8.7

CPF's of long-term gross margins for sunflower for the 81 year period, 1922- 2003, on the Glen/Bonheim ecotope using (a) 3 different planting dates and (b) 5 different initial soil water contents planted on 5 January

(a)



(b)



Appendix 9.1 **An example of minutes of a meeting that took place at Yoxford regarding IRWH**

MINUTES OF THE 2ND GENERAL MEETING OF MAHATA-MMOHU HELD AT YOXFORD ON THE 25TH FEBRUARY 2003.

AGENDA

1 OPENING & WELCOME
2. APOLOGIES.
3. EXPERIENCES IN REGARD TO THE TECHNIQUE
4. PROGRESS REPORT
5. DISCIPLINARY REPORT
6. FINANCIAL REPORT
7. ANY OTHER BUSSNESS
8. B. O. D ~~8~~.1 REAPING RIPE MAIZE FOR CONSUMPTION
B.2 OTHER CROPS.
9. DATE OF NEXT MEETING
10 CLOSURE

1. OPENING & WELCOME
CHAIRPERSON MR JOSEPH DIKGOATHE DECLAIRED THE MEETING OPENED. HE WELCOMED EVERYONE AND HANDED OVER TO MR ESAU MOTLAWLE TO CHAIR THE MEETING.

2. APOLOGIES
GLORIA JANTJIES AND MASABATA MOAHLODI WILL BE ABSENT FOR THE MEETING.

3. EXPIERIENCES ON W.H. B.
MR MOTLAWLE [CHAIRPERSON OF THE DAY] ASKED MEMBERS TO MENTION ANY EXPERIENCES THEY HAVE REGARDING THE TECHNOLOGY. THE FOLLOWING WERE MENTIONED.:.
3.1. CROPS GROWN NEARER TO BLUEGUM TREES ARE STRUGGLING

3.2. MOST BACKYARDS OWNED BY WOMEN ARE NOT PROPERLY MAINTAINED AND ARE NOT LOOKING ATTRACTIVE EITHER.

3.3. THE WHITE MAIZE IS NOT GROWING WELL IN COMPARISON TO THE YELLOW MAIZE. THE FOLLOWING ARE SOME OF THE FACTORS ALIGNED TO THE EXPERIENCE ABOVE :.

3.3.1. THE WHITE MAIZE IS LIKED BY INSECTS.

3.3.2. GROWS WELL WERE THE SOIL WAS PREVIOUSLY USED.OR PREPARED THROUGH PLOUGHING PRIOR CONSTRUCTION OF BASINS.

3.3.3. GROWS WELL ON THE UPPER REGION/HALF OF THE VILLAGE.

3.3.4. DOESN'T LIKE GROWING IN WEED NO MATTER HOW SMALL.

3.4. CROPS GROWN ON BASINS WHICH WERE RECENTLY CONSTRUTED ARE NOT GROWING WELL DUE TO LACK OF STORED WATER IN THE SOIL.

3.5. CROPS GROWING ON BASINS WITH HIGH CAPACITY OF CATCHING WATER ARE YELLOWISH AND SEEMS TOBESTRUGGLING

3.6. BEANS SOMETIMES DIE WITHOUT SHOWING ANY SIGN OF BEING EATEN BY A WORM.

4. PROGRESS REPORT BY MR T. DIPTISE

MR DIPTISE REPORTED THAT CROPS ARE GROWING WELL AND THAT PEOPLE ARE REALLY WORKING HARD TO CONTROLL WEEDS. HE ALSO ENCOURAGED THOSE WHO HAVEN'T STARTED WEEDING TO DO SO IMMIDIATELY AS THE WEED HAS TAKEN VALUABLE POINTS FROM US, IN THE COMPETITION. HE ALSO STATED THAT THE PROBLEMS WE HAVE IS THAT OF LIVESTOCK DESTROYING OUR CROPS AND SUGGESTED MEMBERS SHOULD START TAKING CONTROLL OF ~~OUR~~ THIER LIVESTOCK. 3 CASES OF LIVESTOCK INVASION INTO BACKYARDS WAS REPORTED. DAMAGE IN 1 YARD WAS EXTREME.

5. DISCIPLINARY REPORT BY MR THABO MOLATUDI
MR MOLATUDI REPORTED THAT ON MONDAY THE 24 TH THERE SHOULD HAVE BEEN A DISCIPLINARY HEARING BUT THE ACUSED DID NOT SHOW UP ON TIME. THE HEARING WAS POSTPONED UP TILL FURTHER NOTICE BY DISCIPLINARY COMMITTEE.

6. FINANCIAL REPORT BY TREASURER MR SAMUEL ESEU.
FIRSTLY THE TREASURER REMINDED THE MEMBERS WHO HAVEN'T PAID THE COMMITMENT FEE TO DO SO BEFORE THE END OF MARCH WHICH WAS AGREED UPON AS THE DUE DATE. HE ALSO URGED THE FUNRAISING COMMITTEE TO MEET AND DISCUSS ABOUT STRATERGIES TO INCREASE THE BALANCE IN OUR COFERS.
THE OVERALL MONEY WE HAVE WAS R411.02c
EXPENDITURE WAS R50,00 DONATION TO THE MBOTHO FAMILY WHO ARE MEMBERS, FOR THE BURIAL OF THIER LATE SON.
THE BALANCE IS R361,02
HE ALSO STATED THAT THE COMMITTEE HAS DECIDED TO REFUND THE R50 DONATION. EVERY MEMBER IS EXPECTED TO PAY R1.00 FOR THAT PURPOSE.

7. ANY OTHER BUSSNESS
7.1. MR DANIEL THUTHANE OUR GEUST INFORMED MEMBERS ABOUT THE COMPETITION. HE ALSO SAID HE WILL BRING THE COMPETITION CRITERIA AND FORMS ON WEDNESDAY. HE BROUGHT TO THE ATTENTION OF OUR MEMBER THE DISSAPPOINTMENT AS FAR AS THE TIDINESS IN THE BACKYARS IS CONCERNED. HE STRONGLY ENCOURAGED MEMBERS TO CLEAN UP THEIR GARDENS BECAUSE HE WANTED US TO WIN THE COMPETITION.

7.2. HE ALSO ELABORATED ON THE HARVESTING FESTIVAL WE ARE GOING TO HAVE SOON BEFORE THE END OF MARCH HE SAID THE RESULTS OF THE COMPETITION WILL BE ANNOUNCED AT THE FESTIVAL.

8. G.O.D.

8.1. REAPING RIPE MAIZE

MR MOTLANLE LED THE DISCUSSION ON WHETHER WE ARE READY TO LET THOSE WITH RIPE MAIZE TO START EATING OR SELLING. THE MEMBERS AGREED TO GIVE GREEN LIGHT TO THOSE MEMBER TO CONSUME OR SELL. REASONS BEHIND THE DECISION BEING A. AS ONE OF THE OBJECTIVES, IT IS CAPTURED IN OUR CONSTITUTION THAT WE WANT TO CREATE FOOD SECURITY IN POVERTY STRICKEN FAMILIES, MOSTLY OF THE PARTICIPANTS. IN W.H.B. TECHNOLOGY.

B. BIRDS ARE EATING THE RIPE MAIZE. IT WAS STATED THAT MEMBERS MUST RECORD AS TO HOW MUCH THEY HAVE CONSUMED.

8.2. OTHER CROPS.

DISCUSSIONS ON WHETHER TO START CONSUMING OTHER CROPS LIKE BEANS, PUMPKINS, WATERMELON WAS LENGTHY AND INTENSE. MR MOTLANLE REMINDED MEMBERS THAT, THE ORIGINAL IDEA OF PLANTING OTHER CROPS IN BLOCK FORM, WAS THAT EVERY MEMBER MUST HAVE ALL CROPS AT THE END EVEN IF HE/SHE DIDN'T GREW THEM ALL IN HIS/HER BACKYARD. HE SAID THAT THIS CREATED A SENSE OF OWNERSHIP AND MUTUAL UNDESTANDING AMONG MEMBERS ON CROPS GROWNED, ~~BECAUSE~~ FOR EXAMPLE, IF A MEMBER DOESN'T MAINTAIN THE GARDEN WELL, AS A MEMBER U WILL ENCOURAGE HIM/HER BECAUSE U KNOW U HAVE A SHARE IN THOSE CROPS. OR U WON'T LET LIVESTOCK DESTROY YOUR NEIGHBOURS CROPS BECAUSE U TOO WILL LOOSE. IT WAS DECIDED THAT ALL THESE CROPS WILL BE SHARED ON HARVESTING FESTIVAL AFTER DISPLAY

Appendix 9.2

(a) Maize yields recorded at some of the homesteads in Yoxford during the 2002/2003 growing season

Name	Area (m^2)	Crop	Yields	SALES (R)	YIELD (kg ha^{-1})
S. Esau	1050	Maize	4 x 50 kg bags	460	1905
l. Phale	780	Maize	6 x 50 kg bags	340	3846
E. Motladile	600	Maize	3 x 50 kg bags	100	2500
B. Seloka	468	Maize	3 x 50 kg cobs		
E. Khati	324	Maize	1 x 50 kg	40	1543
J. Dikgaatlhe	756	Maize	5 x 50 kg	300	3307
S. Phale	255	Maize	4 x 50 kg	584	7843
A. Moahlodi	504	Maize	1 x 50 kg		992
B. Molatudi	300	Maize	2.5 x 50 kg	100	4167
J. Moahlodi	729	Maize	2.5 x 50 kg		1714
T. Molatudi	891	Maize	1.5 x 50 kg		841
D. Ramalebo	126	Maize	1 x 5 liters		
E. Hloele	231	Maize	1 x 25 kg		1082
A. Mokgoera	180	Maize	1 x 10 liters		
I. Tau	136.2	Maize	1 x 25 kg		1835
G. Maseme	384	Maize	1 x 50 kg		1302
T. Masakala	370	Maize	1 x 75 kg		
M. Khaiane	200	Maize	1 x 25 kg		1250
J. Ramatsa	252	Maize	1 25 kg		992
E. Khara	288	Maize	1 x 50 kg		1736
I. Mbotho	661.5	Maize	2 x 50 kg		1511
T. Dipitsi	384	Maize	4 x 50 kg		5208
E. Mompe	384	Maize	1 x 50 kg		1302
M. Mokolobate	105	Maize	1 x 25 kg		2380
A. Phale	636.3	Maize	1 x 75 kg		1178
I. Sephula	398.4	Maize	1 x 25 kg		627
M. Mokolobate	417.6	Maize	1 x 75 kg		1795
M. Setouto	384	Maize	1 x 50 kg		1302
J. Khumisi	465.5	Maize	1 x 75 kg	50	1611
G. Jantjies	72	Maize	1 x 50 kg		6944
M. Dipitsi	297	Maize	1 x 50 kg		1683
E. Esau	216	Maize	1 x 75 kg		3472
M. Motladile	777	Maize	1 x 25 kg		321
L. Monyaki	186	Maize	1 x 25 kg		1344
M. Mothupi	363	Maize	1 x 50 kg		1377
School	2112.8	Maize	5 x 50 kg		1183
Church	379.48	Maize	1 x 50 kg		1317

(b) Watermelon and pumpkin yields recorded at some of the homesteads in Yoxford during the 2002/2003 growing season

Name	Area (m^2)	Crop	Yield	SALES (R)
S. Esau	150	watermelons	62 heads	350
l. Phale	270	watermelons	81 heads	200
E. Khati	216	pumpkins	32 heads	20
A. Mokgoera	108	pumpkin	21 heads	
G. Maseme	54	pumpkin	17 heads	
E. Khara	144	pumpkin	15 heads	

(c) Dry bean yields recorded at some of the homesteads in Yoxford during the 2002/2003 growing season

Name	Area (m^2)	Crop	Yields	SALES (R)
B. Seloka	132	Beans	1 x 5 liters	
J. Dikgaatlhe	180	Beans	1 x 25 kg	50
B. Molatudi	103	Beans	5 x 5 liters	80
J. Moahlodi	158	Beans	1 x 25 kg	
T. Molatudi	87	Beans	4 x 5 liters	
D. Ramalebo	117	Beans	1 x 2 liters	
E. Hloele	231	Maize	1 x 25 kg	
I. Tau	68	Beans	1.5 x 5 liters	
T. Masakala	54	Beans	1 x 5 liters	
M. Khaiane	62	Beans	1 x 5 liters	
J. Ramatsa	63	Beans	1 x 2.5 liter	
T. Dipitsi	90	Beans	3 x 5 liters	
E. Mompe	144	Beans	1 x 15 liters	
M. Mokolobate	45	Beans	1 x 2.5 liters	
A. Phale	126	Beans	1 x 5 liters	
I. Sephula	99	Beans	1 x 2.5 liters	
M. Mokolobate	172	Beans	1 x 25 kg	
M. Setouto	180	Beans	2 x 5 liters	
J. Khumisi	105	Beans	1 x 5 liters	
G. Jantjies	180	Beans	1 x 5 liters	
M. Dipitsi	180	Beans	1 x 5 liters	
E. Esau	72	Beans	2 x 5 liters	
M. Motladile	111	Beans	1 x 1 liter	
L. Monyaki	111	Beans	1 x 1 liter	
M. Mothupi	54	Beans	1 x 10 liters	
Church	280	Beans	1 x 20 liters	

Appendix 10.1 Technology exchange actions for the period 2000 to 2003

Event	Date	Number of people	Venue	Target group	Aims	Remarks
Farmer's day	22 March 2000	± 150	Khumo	Farmers & Extension officers from Botshabelo & Thaba Nchu area	• Introduction of IRWH	• Visited demonstration trials at Khumo.
Farmer's day	18 April 2000	± 30	DOA, Glen	Farmers & Extension officers from Botshabelo area	• Introduction of IRWH	• Visited demonstration trials at Glen, Khumo & Vlakspruit
Farmers day	10 May 2000	± 30	DOA, Glen	Farmers & Extension officers from Thaba Nchu area	• Introduction of IRWH	• Visited demonstration trials at Glen, Khumo & Vlakspruit
Information day	18 May 2000	± 50	DOA, Glen	Farmers & Extension officers from Thaba Nchu & Botshabelo	• Introduction of IRWH	• Explained visually with slides, posters & 3D scale model
Combined pre-and post-harvest group discussions	04 July 2000	± 80	DOA, Botshabelo	Farmers & Extension officers from Thaba Nchu & Botshabelo	• Introduction of IRWH	• Explained visually with slides, posters & 3D scale model
Pre-harvest group discussions	15 March 2001	± 50	DOA, Glen	Farmers & Extension officers from Botshabelo & Thaba Nchu	• Benefits of IRWH vs. *CON* • Emphasize financial incentives of IRWH	• Excursion to the Glen, Khumo & Vlakspruit trials
Expo	23 March 2001	± 800	DOA, Glen	Commercial & developing farmers in the Free State Province	• Demonstrate & explain advantages and principals of IRWH vs. *CON*	• Service providers exhibit themselves • Theme: "Forging links in training a public – private partnership"
National Agricultural week	21-22 May 2001	± 2000	DOA, Cedara	National & international people in the Agricultural sector	• Give IRWH international exposure • Demonstrate the advantages of IRWH	• Water conservation techniques not a priority in high rainfall areas of Natal midlands
Post-harvest group	23 August 2001	46	DOA, Thaba Nchu	Thaba Nchu focus group	• Compare the1999/2000 yields of *CON* vs. IRWH	• IRWH explained visually with posters, pictures, slides &

discussions					• Explain economic implications of IRWH	3-D scale model
Post-harvest group discussions	30 August 2001	45	DOA, Botshabelo	Botshabelo area focus group	• Compare the1999/2000 yields of *CON* vs. IRWH • Explain economic implications of IRWH	• IRWH explained visually with posters, pictures, slides & 3-D scale model
SPFS	18 September 2001	30	Pretoria, Gauteng	Scientists & Extension officers	• Discussion on water components of crop production in KZN, eastern Cape & Limpopo Province	• Extension officers were informed about the water components
Integrated food security workshop	11 October 2001	25	Indaba Lodge, Bloemfontein	DOA officials	• Explain the role that IRWH can play in poverty elevation & malnutrition	• An exhibition & video on IRWH was also displayed
Glen Research Open Day	23 Nov. 2001	± 300	DAO, Glen	DOA officials, extension officers & farmers	• Demonstrate & explain the advantages and principles of IRWH	• Event in association with the Free State DOA
PRA			Paradys -Local church Talla – Headman's compound Yoxford – Community hall	Villages in Thaba Nchu area that needed immediate poverty alleviation	• Meet the communities and the community leaders • Discuss the constraints and opportunities for increasing agricultural production	• Talla: relatively poor, without community development projects; lack of cooperation among community members. • Paradys: already farmed collectively producing sunflower & wheat for the market. • Yoxford: producing livestock successfully; crop production limited to backyard gardens
Selection of farmers for field trials				Farmers in the villages of Paradys, Talla, Yoxford & Feloane	• Determine the level of interest among farmers to participate in field trials of the IRWH techniques during the 2001/2002 cropping season • Plan for the carrying out	• In all villages, some farmers expressed interest in applying IRWH in their backyard plots. • Soil surveys were conducted to determine suitability for implementation of IRWH

					of the trials – selection of plots where the trials would be located • Select a team of farmers to act as a project committee • Determine choice of crop for each village for the first season • Discuss the supply of inputs	
Formal survey		124 house-holds	Individual households	Households from the three villages of Paradys, Talla & Yoxford	• To gain an in-depth understanding of the agricultural households in the Thaba Nchu area, and a better insight of how the adoption IRWH will affect the participating households and the factors that might influence its success	• Detailed household level data was gathered in a socio-economic survey using a structured questionnaire. • The survey gathered information on household characteristics (e.g., household size, educational attainment of the head of the household, household wealth and income), farming practices, household food intake and expenditure, use of agricultural support services and households' opinions on production and support services constraints.
On-farm application of the IRWH technique	2001/2002 season		Arable land & backyards in the respective villages.	Talla, Paradys, Yoxford & Feloane	• Construct demonstration plots representing both *CON* & IRWH practices in the respective villages • Assist to plant crop of their choice (maize, sunflower & dry beans) • Inform communities that weeding & watching birds was the responsibility of the	• Yoxford: maize was planted in the plough land in two backyard gardens on 22nd Dec 01. • Talla: dry beans were planted on the 29th Nov 01 in one backyard garden. Harvest was poor due to unsuitable soil and implementation of IRWH discontinued.

					community • The research team regularly visited the villages and kept in touch with the committee members to monitor the progress and growth of the trials.	• Paradys: sunflower was planted on the 10th Jan 02 on a *CON* plot and two IRWH plots on the plough land. Community not actively involved and it was decided to discontinued IRWH in subsequent years • Feloane: maize & sunflower were planted on 29th Nov 01 on the plough land & maize was planted on 11th Dec 01 in one backyard garden. Villagers worked actively in the plough land, but were reluctant to expand the IRWH to their respective backyard gardens.
Information day	22 February 2002	45	UFS	Students, researchers, farmers	• Introduce IRWH to Agriculture students	• Formal presentation
Farmers day	13 March 2002	125	School at Yoxford	Farmers from Thaba Nchu & Botshabelo	• Provide more information on IRWH • Discuss possible expansion of IRWH technique	• Farmers involved in IRWH visited IRWH sites in other villages
Farmers day	14 March 2002	130	Paradys	Farmers from Thaba Nchu & Botshabelo	• Provide more information on IRWH • Discuss possible expansion of IRWH technique	• Farmers involved in IRWH visited IRWH sites in other villages
IRWH information day for FSDA	15 March 2002	10	DOA, Glen	Senior management of FSDA	• Introduce IRWH to management • Formal request to get involved in IRWH	• Provide an opportunity to FSDA to use their knowledge and skills to get involved in IRWH
Water week	23 March 2002		Lephoi School Hall, Bethulie	Farmers, school children	• Introduce & demonstration of IRWH	• Theme: Water for basic human needs and our water feeds our nation
Extension information	03 April 2002	20	DOA, Thaba Nchu	Extension personal	• Give an overview on IRWH	• Concern for lack of support from extension personnel was

day					• Make extension officers to realize that strong relationships with farmers could only be established with their help • Propose an information day for extension personnel on IRWH	raised • Mr. Esau Motladile, a farmer from Yoxford, made a plea to extension officers to assist them to alleviate poverty in the rural communities
Training of extension officers and youth workers	16 April 2002	25	Blue room, DOA offices (Glen)	Extension officers and youth workers	• Improve their knowledge & understanding of the basic concepts of IRWH • Establish their role in the particular project.	• Topics discussed; aims of extension officers, youth workers & researchers regarding IRWH technique, benefits and problems of IRWH, role of extension officers, youth workers & researchers in implementation of IRWH
SET week	6-10 May 2002	> 4000	Calie Human Hall, University of the Free State	People with a interest in Science	• To demonstrate & market the IRWH technique	• More than 3000 school children were made aware of the importance of water conservation for crop production
Letsema day	17 May 2002	± 200	Quawa-Quawa	Developing farmers & Extension	• Demonstrate IRWH	• Exhibition of 3-D scale model
Land care Exhibition	11-12 July 2002		Polekwane	Developing farmers & school children	• Demonstrate IRWH to people of the Limpopo Province	• Exhibition of posters, video & 3-D scale model was well supported
IRWH Workshop	16-18 July 2002		DOA, Glen	Extension officers & leading farmers in the villages	• Training on basic concepts of climate, pedology, teamwork, leadership and the IRWH technique	• Field excursions formed integral part of workshop
Information day	11 July 2002	100	Tweefontein	Small scale farmers	• Introduce & demonstrate IRWH	• IRWH introduced to farmers of Tweefontein, Balaclava & Grootdam
Launch of new Strategic	25 July 2002	± 250	DOA, Glen	Policy makers, community leaders	• Introduce IRWH to policy makers at highest	• The premier (Ms Winkie Direko) & MEC for Agriculture

Plan of DOA					level in Free State Province	(Mr. Mann Oelrich) gave their blessing and support to the IRWH project.
IRWH workshop	6-8 August 2002	20	DOA, Glen	Three representatives from existing and new villages where IRWH will be implemented	• Give training to participants on basic principals of IRWH	• A manual on "10 Steps to convert land into an effective IRWH system" was provided to all participants
World Summit	26-28 August 2002	> 5000	Botanical Gardens - Pretoria, WSSD	Local & international delegates	• Exhibition of the 3D scale model of the IRWH	• Video on IRWH was shown
Post-harvest-pre-plant focus group discussion	17 October 2002	> 70	Tweefontein	Farmers from Tweefontein, Balaclava, Grootdam & Yoxford	• Formally introduce IRWH in Tweefontein	• Villagers indicated that they prefer to plant vegetables with IRWH
Expansion of the on-farm application of the IRWH technique	2002/2003 season		Crop lands & homesteads in respective villages	Yoxford, Feloane, Balaclava, Grootdam, Woodbridge & Tweefontein	• Provide support and assistance with implementation & expansion of the IRWH • Regular visits to villages & committee members to monitor the progress and growth of the crops.	• Feloane: Backyards were planted with maize & dry beans (5th Nov 02), pumpkin & watermelons (22nd Nov 02) and potatoes (10th Jan 03). Maize & sunflower were planted 21st Nov 02 in the plough land with only two people from the community present. Community plans to expand IRWH for the future. • Yoxford: IRWH implemented in 46 out of 86 homesteads in entire village. Planting started on the 30th Oct 02. Maize, as their staple food was planted in every garden, in addition to the other selected crops that included pumpkins, watermelons, spinach, etc. Association of community members promotes ownership and cooperation amongst members. • Balaclava: IRWH

						introduced to people on 26th Sep 02. Planting of the main crops (maize & dry beans) commenced on 5th Nov 02 in 5 gardens. Carrots, spinach, beetroot, pumpkin, carrots & potatoes planted in another 22 gardens early in Jan 03. • Tweefontein: demonstration plots were laid out at the clinic & a remote piece of land in the field to represent the croplands. Community member constructed basins in 27 backyard gardens. Maize, dry beans, watermelon, pumpkin, carrots, spinach & beetroot were planted. Only the maize seemed to grow well. On 26th March more people were taught about IRWH at a mass meeting.
Information day	24-25 February 2003		DOA, Glen	Farmers in Thaba Nchu area	• Training of farmers in IRWH	• IRWH explained with visual aids
Community water harvesting festival	17-20 March 2003	± 400	IPJ Hall DOA Glen, experimental site at Glen, Sepane 7, Grootdam, Balaclava, Tweefontein, Willow Park, Woodbridge 1, Yoxford, Municipality Thaba Nchu	Community members of the villages in which the IRWH technique has already been implemented and neighbouring villages that have not yet heard or seen IRWH	• Bringing farmers, extension, researchers, politicians and the municipal body together in exchanging knowledge on the IRWH techniques • Exposure and promotion of IRWH • Empowering people (farmers) to fight poverty and food insecurity	• Veteran villages: Feloane, Yoxford, Tweefontein, Sepane 7, Woodbridge I, Grootdam & Balaclava. Newly invited villages: Potsane, Middledeel, Tiger River, Merino, Modutung, Kgalala, Paradys, Mokwena, Excelsior, Ratlou, Woodbridge II, Gladstone, Nogas Post, Springfontein, Klipfontein and Rietfontein. • MEC for Agriculture encouraged farmers to implement the IRWH • Farmers from the various

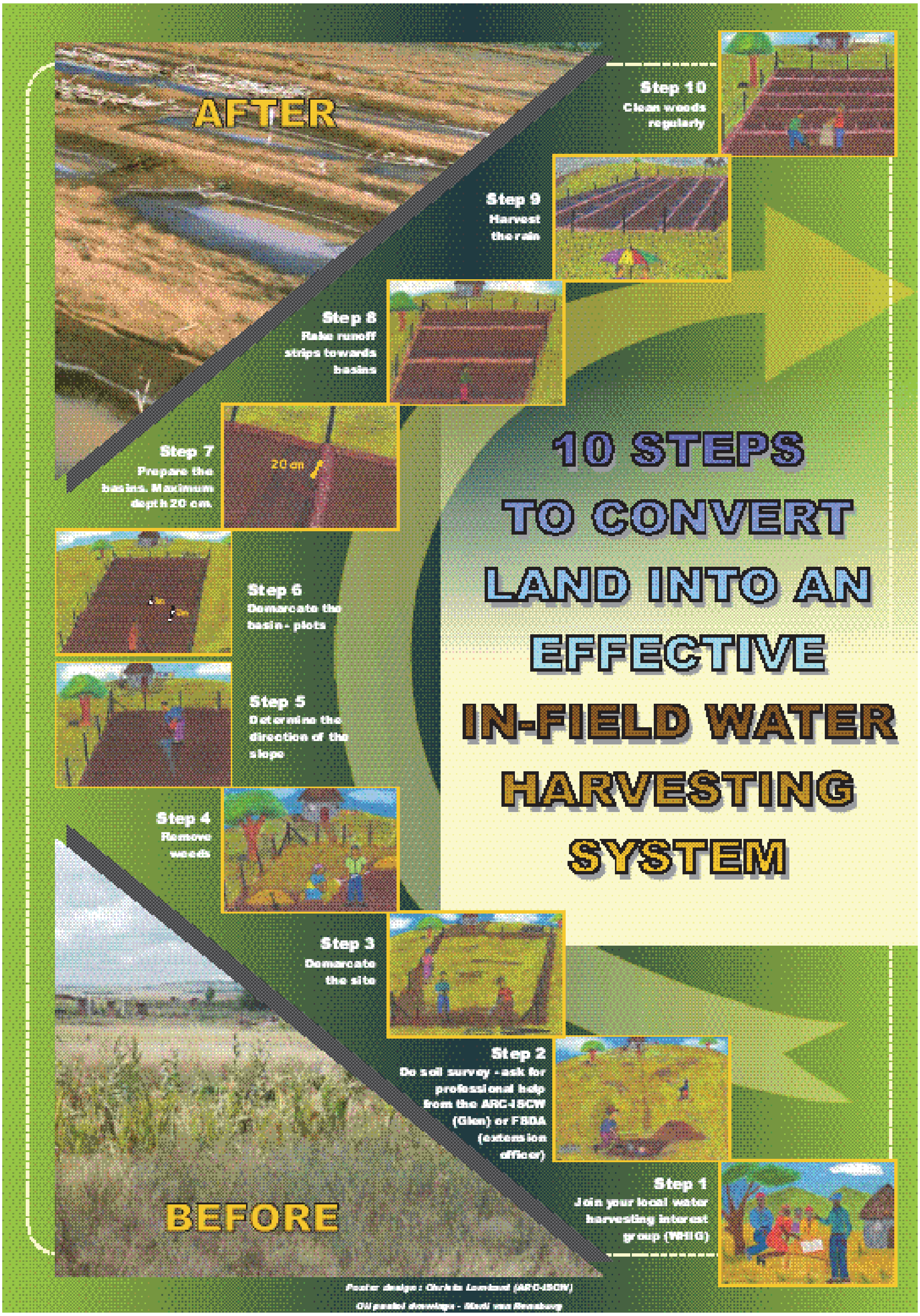
						villages shared their experiences with IRWH & promote and encourage good relations amongst groups • Farmers requested more training and information on IRWH and assistance from extension officers on various issues. • Farmers are very exited about the IRWH technique and pledged to take ownership of the project.

Appendix 10.2 A physical three-dimentional scale model representing a *CON* and IRWH system

CON

IRWH

Appendix 10.3 **A poster demonstrating the 10 steps to convert land into an effective IRWH system**



Appendix 11.1 Examples of minutes taken by the TA's

27/02/2003 **Meeting (Executive committee) Balaclava**

Agenda

1. Opening and welcome

The headman officially opened meeting and he thanked all those who attended the meeting.

2. Attendance register

Only 5 executive committee members were present including the headman.

3. Apologies

Mr. Sello Maptla and Mrs Magdelinah Ramaduane apologized for being absent.

4. Purpose of the meeting

How to make sure that people understand measurements of basins and distances between different crops at planting. Mr. Monyaki (chairperson) suggested that I should draw basins and make marked measurements on the paper so that everybody can use them during planting. Marked sticks should also be used by those who cannot read.

5. Matters arising

(a) Most people said that the rug sack is too heavy for them and they asked whether there is no alternative for spraying weeds and insectices. I suggested that those who have difficulty in carrying the rug sack should hire or ask someone to help.

(b) Chairperson asked what are we going to do during planting time to save time. Headman suggested that they should split into at least three groups so that they can plant at least 9 backyards per day.

(c) What to do so that more people can make basins in their backyards? Chairperson suggested that the ARC-ISCW should arrange an information day whereby we can demonstrate by means of models or arrange so that Balaclava community can visit Glen on-farm demonstration plots.

6. Closure

a) Provide secretary with a program of the harvesting festival which will be held on 17/03/2003 to 20/03/2003.
b) Made an appointment for a meeting on 07/03/2003 at 10:00.

07/03/2003

Agenda

1. Opening and welcome
   Meeting was officially opened by the Headman.

2. Attendance register
   Twenty people were present at the meeting.

3. Apologies
   No apologies made for absent people.

4. Workshop
   The Headman proposed that the community should be given workshops of the in-field water harvesting technique (IRWH). Mr. Botha told them that there would be workshops after harvesting and before we start planting for the 2003/2004 season.

5. Problems
   I told them that IRWH is for people in areas who have problems with low rainfall, so that they can obtain increased yield compared to the normal conventional tillage. How can the ARC help so that they can till their soils? New backyard people who do not have money to hire a tractor asked how is the ARC going to help them? I told them that it will be unfair to hire a tractor for them while the ARC did not hire a tractor for the people for their backyards they already erected water harvest basins themselves.

6. New / extended backyards
   Eight people are interested and they will be erecting basins so that they can plant during 2003/04 season. Backyard owner of K said that she is going to extend her basins.

7. Chosen backyard for evaluation
   Community chose backyards A, D and E for evaluation during community Water Harvesting Festival.

8. Closure
   Meeting was officially closed by a prayer.

Names and surnames of people who will be present during the community Water Harvesting Festival:

1. Andries Mathealtaba
2. Alinah Diphala
3. Annah Masukela
4. Bornman Matekwane
5. Christinah Ntsherwa
6. Emely Mahlwane
7. Francis Mokane
8. Josiah Monyaki

9. Johnson Mosweu
10. Magdelinah Ramoduane
11. Moses Tshweni
12. Matakelo Mokane
13. Nelly Monyaki
14. Phillimon Mapetla
15. Rosaliah Majela
16. Sello Mapetla
17. Sebatoe Lekeke
18. Tello Mokhethi
19. Thembani Piet
20. Loniah Moseni
21. Zakaria Monyaki