# Sustainable Techniques and Practices for Water Harvesting and Conservation and their Effective Application in Resource-Poor Agricultural Production

Report to the

**Water Research Commission**

by


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## EXECUTIVE SUMMARY


## BACKGROUND

The Water Research Commission (WRC) contracted a consortium made up of teams from the University of Fort Hare (UFH) and the Agricultural Research Council (ARC) to undertake research on sustainable techniques and practices for water harvesting and conservation and their effective application in resource-poor agricultural production. The research was conducted in the Eastern Cape Province of South Africa.

In the Eastern Cape Province, as in most parts of rural South Africa, households rely on purchasing food from urban markets as their main food security strategy. This is primarily due to the failure of cropping activities and low animal productivity, a result of erratic rainfall. Dryland agriculture is the mainstay of agricultural activities in the Eastern Cape Province. Understanding opportunities for collecting, storing and conserving water is, therefore, vital for improving the contribution of agriculture to household food security. This was the main objective of the work commissioned by WRC. The study area consisted of the Khayalethu and Guquka villages in the Tyhume Valley, just below the escarpment of the Amatola Mountains.

In-field rainwater harvesting (*IRWH)* techniques, which is a micro-catchment technique (Runoff strips), have been shown to have a positive effect on agricultural production elsewhere in South Africa and these were, therefore, selected for evaluation for possible use in the semi-arid areas of the Eastern Cape.

## KEY FINDINGS

Key findings are outlined below. Subheadings correspond to the objectives contained in the contract terms of reference.

1) ***Conduct a literature review of techniques and practices for water harvesting and conservation in sub-Saharan, West-Asian and North-African countries and also capture the existing knowledge by sourcing specific individuals in South Africa. Furthermore, organize a project specific workshop to share, capture and distil knowledge on water harvesting and conservation for implementation in field trials.***

   A thorough literature review was conducted and a short list of possible treatments was made and presented to stakeholders at the Stakeholder Consultation Workshop. During the workshop the techniques that need to be tested and evaluated were chosen by the stakeholders and farmers. Rainwater harvesting is a term that describes a number of different practices which have been used for centuries in dry areas to collect and utilize rainfall more efficiently. Rainwater harvesting systems are generally classified according to the size of the catchment and are divided into micro- and macro-catchment systems.

   The Stakeholder Consultation Workshop was held in November 2004. Delegates actively participated and agreed to the objectives of the workshop.

Workshop resolutions were that:

- Project participants from the five villages (Khayalethu, Guquka, Sompondo, Gilton, Mpundu) would work together as a team, supporting each other across village borders.
- A combination of rainwater harvesting technologies would be applied to ensure the maximum water available in homestead backyards. Farmers preferred to start with the *IRWH* technique.
- The point of departure would be backyard gardens and also school food gardens.
- Participants would endorse the MoU, should they agree to the responsibilities allocated to them, and would comply with the stipulations of the MoU.

***2) Obtain endorsement of stakeholders in the selected study area to conduct the project.***

An MoU was agreed to by stakeholders, who attended the stakeholder workshop held in November 2004. This paved the way for the successful implementation of the project.

***3) Determine the institutional arrangements of the selected study area.***

A survey conducted in 2005 confirmed the findings of earlier studies conducted in the area that poverty and unemployment are important problems. Social grants obtained from the state are now the most important source of income. The contribution of agriculture to the livelihoods of rural homesteads was mainly in the form of food for own consumption.

Implementation of the rainwater harvesting project needs to pay attention to the diversity of livelihoods encountered in the two villages (Khayalethu and Guquka), and focus its attention on households that are most vulnerable to food insecurity, i.e. those falling in the category of the ultra-poor.

***4) Describe the agro-ecology (including indigenous practices) of the selected study area. Conduct a baseline study to determine, e.g. the status quo of crop production systems, livestock production systems and production data.***

Long-term climate data indicates that the area is semi-arid with an aridity index of 0.35. The mean annual precipitation for the study area is 607 mm. The study area receives 69% of its annual rainfall between October and March. Over this region, at any one given point, the average number of hail events per annum is about two, usually occurring during late spring (November), when lapse rates are steep and temperatures high. The mean annual temperature is 15.6ºC with the maximum peaking in February at 30ºC and the minimum falling to 5.6ºC in July. Frost can be expected from 13 June lasting until 15 October.

A soil survey was conducted in the area in order to create a detailed soil map. The following soils were found to dominate the study area: Cartref (**Cf**), Wasbank (**Wa**), Vilafontes (**Vf**), Oakleaf (**Oa**), Westleigh (**We**), Sepane (**Se**), Swartland (**Sw**), Valsrivier (**Va**) and Longlands (**Lo**). CF and Wa soils dominate and are not recommended for crop production due to shallow to moderate depth. Vf, Oa, We, Sw, Se, and Va soils are found on the banks of the river and areas adjacent to them. These soil types are recommended for crop production especially if rainwater harvesting and conservation techniques can be used.

Veld in good condition accompanied by a dense basal cover ensures efficient harvesting and utilization of rainwater. Basal cover was excellent in all the selected sample sites indicating good soil protection, better harvesting of rainwater and efficient use of such water through good plant growth.

Although the selected rangeland sample sites showed that rangelands are good condition in terms of being protected against soil erosion and runoff, one of the major impediments would seem to be the inability of the two communities to apply veld management practices.

5) ***Introduce and test one water harvesting and one conservation technique on-farm for one crop and rangeland/livestock production system, following a participatory approach. Conduct on-station experiments for fine-tuning of the techniques. Further, evaluate agronomic performance of various rainwater harvesting and conservation techniques***

On-station and on-farm field experiments were conducted in order to test RWH&C techniques. The on-station field experiments were conducted at the Research Farm at the University of Fort Hare over a period of four seasons (2004/05-2007/08). An additional on-station field experiment, funded by the ARC – Institute for Soil, Climate and Water (ISCW), was conducted at Phandulwazi Agricultural School next to the village of Guquka during two seasons (2006/07 and 2007/08). An on-farm field demonstration experiment was conducted on a farmer’s cropland in the village of Guquka over a period of four seasons (2004/05-2007/08). Rainfall records revealed that the rainfall seasons were normal, below- and above-normal with ample opportunities to harvest water in the basins.

Normal conventional tillage (*CON*) was compared with strip cropping (*STRIP*) and various in-field rainwater harvesting (*IRWH*) treatments on three ecotopes, *viz*. Fort Hare/Oakleaf; Phandulwazi/Westleigh and Guquka/Cartref. The treatments were *CON*; *STRIP*; *IRWH* with a bare runoff area and bare basin area ($IRWH_{Bare}$); *IRWH* with organic mulch both on the runoff area and basin area ($IRWH_{Mulch}$); *IRWH* with lucerne as a cover crop on the runoff area ($IRWH_{Lucerne}$); *IRWH* with green leaf desmodium as a cover crop on the runoff area ($IRWH_{GLDM}$) and *IRWH* with vetiver as a cover crop on the runoff area ($IRWH_{Vet}$). The indicators used to show crop response to the different treatments were grain yield, dry matter production, transpiration, runoff and RWP. Detailed measurements were conducted on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes while mainly grain and biomass yield were monitored on the Guquka/Cartref ecotope.

Plant-available water at planting ($PAW_p$) indicated that both the $IRWH_{Mulch}$ and $IRWH_{Bare}$ treatments conserved more rainwater during the fallow period than *CON* and *STRIP*. This gave a significantly higher $PAW_p$ or pre-plant water advantage to $IRWH_{Mulch}$ and $IRWH_{Bare}$ compared to *CON* and *STRIP*. Ex-field runoff ($R_{Ex}$) was zero for all the *IRWH* treatments during all seasons while *CON* lost on average 10% of precipitation (P) to $R_{Ex}$. Expressing evaporation from the soil surface (Es) in relation to evapotranspiration (ET) indicated that *IRWH* treatments showed either similar or slightly higher Es/ET values than *CON* and *STRIP*. $IRWH_{Mulch}$ and $IRWH_{Bare}$, through their ability to stop $R_{Ex}$ completely, increased maize grain and biomass yields significantly compared to *CON* and *STRIP*. $IRWH_{Mulch}$ and $IRWH_{Bare}$ produced on average a 20 to 37% higher grain yield than *CON* and *STRIP* and their rainwater productivity (RWP) values were on average between 20%

and 33% higher. These results indicated clearly that $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ are far more efficient than *CON* and *STRIP* at converting rainwater into grain yield.

A comparison of the *IRWH* techniques revealed that there was a consistent trend in grain yield during the experimental period, *viz*. $IRWH_{\text{Mulch}} > IRWH_{\text{Bare}} > IRWH_{\text{Vet}} > IRWH_{\text{Lucerne}} > IRWH_{\text{GLDM}}$. $IRWH_{\text{Mulch}}$ out-performed all the other *IRWH* treatments in all aspects. $IRWH_{\text{Mulch}}$ induced 3-16% and 9-14% higher grain yield and RWP, respectively, compared to $IRWH_{\text{Bare}}$. *IRWH* treatments without cover crops on the runoff areas produced higher grain yield and RWP increases of 59-86% and 60-100%, respectively, compared to *IRWH* treatments with cover crops. *IRWH* treatments with cover crops on the runoff areas ($IRWH_{\text{GLDM}}$; $IRWH_{\text{Vet}}$; $IRWH_{\text{Lucerne}}$) gave significant lower $PAW_p$, grain yield and RWP compared to *IRWH* treatments without cover crops on the runoff areas ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$).

Overall it was found that $IRWH_{\text{Mulch}}$ outperformed all the other treatments followed by $IRWH_{\text{Bare}}$ > *CON* > *STRIP* > $IRWH_{GLDM}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$. It can be concluded that subsistence farmers in semi-arid areas could improve maize yields considerably by replacing the traditional *CON* practices with *IRWH* without cover crops and, if possible, apply mulch on the basin and runoff areas. This would improve their level of food security. *IRWH* without cover crops is agronomically more sustainable than *CON*.

Use of cover crops clearly suppresses yields. However, cover crops play an important dual role in runoff control and residues provide much needed forage for livestock. Therefore, they are important in semi-arid environments, where livestock form a significant part of rural livelihood strategy.

The use of brush and micro-catchments in rangelands is similar in purpose and principle to the use of basins and mulch in cropping areas. These *IRWH* techniques allow for the direct harvesting of the water and its use by the roots of the plants.

***6) Test and evaluate of RWH&C techniques in rangeland/livestock production***

The tiller numbers were higher on the plots where there was combination of micro-catchments and brush packs. The specific micro-catchment technique used was a modified semi-circular bund, ideally suited for grasses. The bunds were used to capture water for direct use by the grasses. Brush packing involves the strategic placement of brush to protect emerging seedlings. The performance of grass seedlings on micro-catchments with brush pack could serve as an early indicator of vegetation restoration success in degraded rangelands. Seedling mortality was lower on the micro-catchment and brush pack combination plots. The flowering rate was also higher on the plots covered with brush pack. Micro-catchments collect and store water and brush packs provide shade on the micro-catchment, resulting in reduced evaporation from the soil and improved soil moisture in terms of both amount and duration of storage.

In terms of rainwater harvesting efficiency, the experiments showed that the use of brush pack alone was higher than the control in soil moisture retention. The combination of brush pack with minimal soil disturbance using *Panicum maximum* seeds had the highest moisture retention. Minimal soil disturbance with both *P. maximum* and *Eragrostis curvula* and without brush pack showed no improvement in moisture storage. This implies that brush pack had a positive effect on soil water storage: this could be due to reduced evaporation from the soil resulting from the shading effect of brush pack. The plots with micro-catchment, brush pack and minimum soil disturbance retained the most soil water.

These results suggest that a combination of micro-catchments with brush pack for rangeland restoration leads to higher soil moisture retention. This observation is similar to the one on the impact of micro-catchments and mulching in the cropping system.

7) ***Measure the impact in terms of increased water use efficiency in the crop and livestock production systems and identify factors that influence the introduction, implementation and adoption of RWH&C techniques***

The household food security situation of villagers in Guquka and Khayalethu improved greatly with the introduction of the *IRWH* technique. The nutritional status of households also improved as a result of access to a variety of vegetables grown in homestead gardens. The project also helped to reduce poverty. The majority of households (95%) were able to harvest enough maize for household food consumption and had surplus produce to feed animals, sell or give away to family and friends. Those who actually sold excess produce earned between R200 and R1500. Previously, using the conventional or “old” way of cultivation, food had always been in short supply. The majority (60%) of people who participated in the project were women and their new found ability to be self-sufficient, through generating income and showing enthusiastic participation/leadership in the application of the technique, contributed to improving their status in the villages.

The introduction of the *IRWH* technique has created more jobs at homesteads. Different cultivation practices were learned and more family members got involved in the production process. The project has also brought about a general revival of committee structures and their activities, especially to coordinate joint actions. The project also brought about a more positive attitude amongst village members.

Knowledge and skills level of the village members and extension officers were vastly improved through participation in the project. The majority of participants in the project confirmed their intention to allocate more land, where available, for cultivation using the *IRWH* technique. The *IRWH* committees in each village are functional and are able to support other village members who want to implement the *IRWH* crop production system.

The youth were also exposed to the *IRWH* techniques, which were implemented at six schools in the Tyhume valley. Water tanks and gutter systems were installed at the schools and scholars and teachers were taught the principles of rainwater harvesting, and how to take measurements from the water tanks as well as from the rain gauges. The scholars were also taught the importance of taking these measurements and were encouraged to do so.

Farmers are willing to implement *IRWH* and roof water harvesting to collect and save enough water to produce food for household consumption, but still lack sufficient technical skills and support to apply the techniques effectively.

8) ***Measure the technical feasibility, risk, economic viability, social acceptability and environmental impact of the selected water harvesting and conservation techniques and assist in the development of institutional arrangements***

Low levels of education found in the study areas are likely to hamper the application and adoption of new farming practices as well as on institutional arrangements. This alone calls for continuous capacity building in these communities.

Land tenure and ownership are major challenges in both arable and rangeland, and affect the management of these resources. A number of options on how to access and manage these resources were explored with the communities and institutional arrangements have been put in place. Through the study it was shown that both regulative and normative institutions are either weak or absent. In the case of arable land, the main problem is access to land. Options were explored with the landless and landlords on how best to access arable land. Two options were identified, namely, rental and a formalized share-cropping arrangement. An attempt was made to formalize governance structures and improve enforcement of institutional agreements. The communities formed the Nobantu Community Based Organization, which by now is a legal community structure, and its main responsibility is to put regulative institutions governing arable land in place.

While access to arable land is a major problem in the study area, survey results showed that almost everyone has access to rangeland. But it is exactly that free access as well as absence of institutions that make this resource so difficult to manage. The Dalindyebo Farmer's Association (still to be registered) was formed, based on a collective action model and its main responsibility is to put in place rules and regulations governing the use and management of rangeland. Other responsibilities included issuing sanctions and grazing licences.

Rules and regulations are important in any community to ensure that the community looks after its natural resources. It is important that rules must be clearly conveyed to every community member to ensure that they are aware what is expected from them.

***Impact of RWH&C techniques on social and economic status of households***

The *IRWH* technology had a positive impact on home garden production, even though it did not quite address seasonal production of food. Own production is now the main source of vegetables consumed by villagers in Guquka and Khayalethu during spring and summer compared to only autumn in the past. The strength of the technique lies in its potential (through improved crop production) to improve the intake of vitamins A and C, which are usually lacking in the diet of rural households. There appears to be a strong relationship between own production of food and household nutrition. When own production of food improves, the nutrition of household members improves as well. The project members clearly demonstrate this.

The findings of this investigation also revealed income to be a key determinant of food security, having a large influence over both diet quantity and diet quality. The non-poor households had a higher diet diversity and energy consumption in both seasons (spring and summer), while the diet of the ultra-poor households showed a deficiency in both variables in all seasons. The poor households, whose diet showed better diversity, were obviously limited by their incomes in obtaining and consuming sufficient quantities.

*Impact of RWH&C techniques on agronomic production and natural resources*

**Agronomic productivity (improved production):** The short-term field experiments (on-station and on-farm experiments) and long-term RWP results show that *IRWH* treatments without cover crops on the runoff area ($IRWH_{Mulch}$ and $IRWH_{Bare}$) significantly increased crop yields and RWP compared to *CON*, *STRIP*, and *IRWH* treatments with cover crops on the runoff areas ($IRWH_{Vet}$, $IRWH_{Lucerne}$ and $IRWH_{GLDM}$).

**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 with maize on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes using different production techniques. Results obtained from simulations done with CYP-SA indicate that maize yields could be increased on average by 54% by changing from *CON* to $IRWH_{Bare}$, and by an additional 13% by changing to $IRWH_{Mulch}$. Results indicate that $IRWH_{Mulch}$ was the best treatment in terms of risk reduction, followed by $IRWH_{Bare}$, *CON*, $IRWH_{Vet}$, $IRWH_{Lucerne}$ and $IRWH_{GLDM}$.

**Conservation techniques (conservation of natural resources):** The carbon cycle processes in the soil were drastically influenced by tillage with the carbon content tending towards a lower equilibrium with long-term cultivation. Carbon trends predict (based on short-term data) that carbon losses from the no-till *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) will be lower than from the *CON* treatment. It is also believed that the carbon content might stabilize at a relatively higher C content for the *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) than the *CON* treatment. The highest carbon loss occurred from the *CON* treatment and the lowest from $IRWH_{GLDM}$.

Short-term data indicate that *IRWH* without cover crops on the runoff areas ($IRWH_{Mulch}$ and $IRWH_{Bare}$) is far more sustainable than *CON* and *IRWH* treatments with cover crops on the runoff areas (*IRWHVet*, *IRWHLucerne* and $IRWH_{GLDM}$) in this specific study area. Of all the techniques tested, $IRWH_{Mulch}$ has been shown to be the best, followed by $IRWH_{Bare}$. In general, evaluation of the project in terms of the different sustainability criteria really needs to be done in the long-term and the evaluation needs to consider the role cover crops play in the livestock subsystem, where they provide the much needed forage, which in many instances can be stored for winter use.

## KEY CONCLUSIONS AND RECOMMENDATIONS

Clearly from the research findings the use of micro-catchments in combination with either mulch or brush improves moisture retention enhancing productivity both in croplands and rangelands. Furthermore the use of cover crops, whilst depressing maize yields, can be supported because of the important role they play in the livestock subsystem, where they provide much needed forage. *IRWH* techniques, therefore, are important for household food security in semi-arid areas, where productivity is limited largely by moisture availability.

Many homestead gardeners in the selected villages, who are using the *IRWH* technique, are already making full use of their gardens for food production. However, if village members want to eradicate poverty completely in their villages, they will have to expand their activities in include cropland farming. It is, therefore, recommended that the *IRWH* technique be implemented on croplands in order to minimize water losses, secure a more even distribution of water over the land and increase crop production.

Although some village members have indicated that they would like to expand their production to the croplands, this has not been possible due to a lack of fencing and implements. Government departments, such as the Department of Agriculture, should assist communities with necessary infrastructure and inputs to cultivate the croplands. Fences can be put up using CASP funds and inputs, such as seeds and fertilizer, can be provided through the Food Security Programme of the Provincial Department of Agriculture. Proper markets should be established where farmers can sell their produce.

Youth involvement in agriculture should receive high priority. Schools that showed interest in the use of the *IRWH* technique should be supported with the necessary technical advice, inputs and fencing material.

In order to eradicate poverty in the Eastern Cape Province, *IRWH* should be expanded to other districts using the villages Khayalethu and Guquka as examples.

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| | | |
|---|---|---|
| A-Pan | = | Average daily evaporation (mm) |
| AE | = | Adult equivalent |
| AI | = | Aridity index |
| ANOVA | = | Analysis of Variance |
| ARC | = | Agricultural Research Council |
| ARDRI | = | Agricultural and Rural Development Research Institute |
| ATA | = | Amakuze Tribal Authority |
| AU | = | Animal unit |
| BD | = | Bulk density (kg $m^{-3}$) |
| BM | = | Benchmark |
| BP | = | Brush pack |
| BT | = | *Bacillus thuringiensis* |
| C3 | = | Plant that utilizes the $C_3$ carbon fixation pathway |
| C4 | = | Plant that utilizes the $C_4$ carbon fixation pathway |
| Ca | = | Calcium |
| CAM | = | Plant that utilizes the Crassulacean acid metabolism pathway |
| CASP | = | Comprehensive Agriculture Support Programme |
| CBNRM | = | Community based natural resource management |
| CC | = | Carrying capacity |
| CEC | = | Cation Exchange Capacity |
| Cf | = | Cartref soil form |
| *CON* | = | Conventional tillage |
| CPF | = | Cumulative probability function |
| CPI | = | Consumer price index |
| CU | = | Cold units ($^{o}$C) |
| CYP-SA | = | Crop Yield Predictor for Semi-Arid areas |
| D | = | Deep drainage (mm) |
| D-index | = | Index of agreement |
| DiEr | = | *Digitaria erienta* |
| DPCU | = | Daily positive chilling units ($^{o}$C) |
| DSS | = | Decision support system |
| DUL | = | Drained upper limit of available water (mm) |
| DWEA | = | Department of Water and Environmental Affairs |
| EC | = | Electrical conductivity |
| ECDA | = | Eastern Cape Department of Agriculture |
| EI | = | Ecological index values |
| Eo | = | Evaporative demand (mm) |
| ErCu | = | *Eragrostis curvula* |
| $E_S$ | = | Evaporation from the soil surface (mm) |
| ET | = | Evapotranspiration |
| $ET_O$ | = | Potential evaporation |
| Ev | = | Evaporation from the crop (transpiration) (mm) |
| FAM | = | Food account method |
| $F_p$ | = | Fallow period |
| Fsat | = | Field saturation |
| FSDA | = | Free State Department of Agriculture |
| GI | = | Galvanized iron |
| $G_p$ | = | Crop growing period |

| | | |
|---|---|---|
| Gs | = | Glenrosa soil form |
| GIS | = | Geographical Information System |
| GLM | = | Generalized linear model |
| GPS | = | Global positioning system |
| Ha | = | Hectare |
| HCZ | = | Homogeneous climate zone |
| HG | = | Home garden |
| HRM | = | Holistic range management |
| HI | = | Harvest index |
| HU | = | Heat units ($^{o}$C) |
| ICARDA | = | International Center for Agricultural Research in the Dry Areas |
| IE | = | Institutional environment |
| If | = | Final infiltration rate (mm $h^{-1}$) |
| *IRWH* | = | In-field rainwater harvesting |
| $IRWH_{\text{Bare}}$ | = | *IRWH* with a bare runoff area and bare basin area |
| $IRWH_{\text{GLDM}}$ | = | *IRWH* with green leaf Desmodium as a cover crop on the runoff area |
| $IRWH_{\text{Lucerne}}$ | = | *IRWH* with lucerne as a cover crop on the runoff area |
| $IRWH_{\text{Mulch}}$ | = | *IRWH* with organic mulch both on the runoff area and the basin area |
| $IRWH_{\text{Vet}}$ | = | *IRWH* with Vetiver as a cover crop on the runoff area |
| ISCW | = | Institute for Soil, Climate and Water |
| IWM | = | Integrated watershed management |
| IWUE | = | Intrinsic water use efficiency |
| K | = | Potassium |
| k | = | Hydraulic conductivity |
| LAI | = | Leaf area index |
| LFA | = | Less favoured areas |
| LL | = | Lower limit of plant-available water (mm) |
| Lo | = | Longlands soil form |
| LSD | = | Least significant difference |
| LSF | = | Linear structure vs. Function model |
| LSU | = | Livestock standard unit |
| LT | = | Long-term |
| LU | = | Livestock unit |
| LWP | = | Livestock water productivity |
| MACRF | = | Macro-catchment runoff farming |
| MB | = | Mechanized basin |
| MBP | = | Mechanized basin plough |
| MC | = | Micro-catchment |
| MCBPGS | = | Micro-catchment with brush pack and grass seedlings |
| MCGS | = | Micro-catchment with grass seedlings |
| MCWH | = | Micro-catchment water harvesting |
| Mg | = | Magnesium |
| MICRF | = | Micro-catchment runoff farming |
| MIN | = | Minimum tillage |
| MNCRF | = | Mini-catchment runoff farming |
| MoA | = | Memorandum of Agreement |
| MoU | = | Memorandum of Understanding |
| MSD | = | Minimum soil disturbance |
| Na | = | Sodium |
| NCBO | = | Nobantu Community Based Organization |
| NEP | = | Non-equilibrium persistent |

| | | |
|---|---|---|
| NGO | = | Non-Governmental Organization |
| NPM | = | Non-poor members |
| NPN | = | Non-poor non-members |
| NT | = | No-till |
| NTC | = | Northern Transvaal Corporation |
| NWM | = | Neutron water meter |
| Oa | = | Oakleaf soil form |
| OP | = | Own production |
| P | = | Precipitation/rainfall (mm) |
| PaDi | = | *Paspalum dilitatum* |
| PaMa | = | *Panicum maximum* |
| $PAW_H$ | = | Plant-available water at harvesting (mm) |
| $PAW_P$ | = | Plant-available water at planting (mm) |
| $PAW_{PM}$ | = | Plant-available water at physiological maturity (mm) |
| $PAW_T$ | = | Plant-available water at tasseling (mm) |
| PDA | = | Provincial Department of Agriculture |
| $P_f$ | = | Rainfall during the fallow season (mm) |
| PM | = | Poor member |
| PN | = | Poor non-member |
| PTO | = | Permission to occupy |
| $P_p$ | = | Production period |
| R | = | Runoff (-); run-on (+) (mm) |
| $R^2$ | = | Correlation coefficient |
| RA | = | Residents Association |
| RC | = | Rangeland condition |
| RDA | = | Recommended daily allowance |
| RDP | = | Rural development project |
| $R_{Ex}$ | = | Ex-field runoff (mm) |
| RFWH | = | Runoff farming water harvesting |
| RH | = | Average daily relative humidity (%) |
| RHn | = | Average daily minimum relative humidity (%) |
| RHx | = | Average daily maximum relative humidity (%) |
| $R_{In}$ | = | In-field runoff |
| RMSE | = | Root mean square error |
| $RMSE_s$ | = | Systematic root mean square error |
| $RMSE_u$ | = | Unsystematic root mean square error |
| $R_p$ | = | Reproductive period |
| Rs | = | Average total radiation (MJ $m^{-2}$) |
| RSE | = | Rainfall storage efficiency (%) |
| RUE | = | Rainwater use efficiency |
| RULIV | = | Rural livelihoods |
| RWH | = | Rainwater harvesting |
| RWH&C | = | Rainwater harvesting and conservation |
| RWP | = | Rainwater productivity (kg $ha^{-1}$ $mm^{-1}$) |
| $RWP_n$ | = | Rainwater productivity over a period of n consecutive years |
| SAS | = | Statistical analysis system |
| SAWS | = | South African Weather Service |
| Se | = | Sepane soil form |
| SEIA | = | Socio-economic impact assessment |
| SD | = | Grass seed |
| SD | = | Standard deviation |

| | | |
|---|---|---|
| SL | = | Grass seedling |
| SPAC | = | Soil-plant-atmosphere continuum |
| SSA | = | Sub-Saharan Africa |
| *STRIP* | = | Strip cropping |
| S-value | = | Sum of exchangeable cations |
| Sw | = | Swartland soil form |
| SWC | = | Soil water content |
| SWR | = | Soil water repellency |
| t | = | Time (hours) after field saturation |
| T | = | Time in days after saturation |
| T | = | Average daily temperature ($^oC$) |
| TA | = | Tribal Authority |
| TBCL | = | Tipping bucket counter logger |
| TE | = | Tree equivalent |
| TESW | = | Total extractable soil water |
| ThTr | = | *Themeda triandra* |
| Tn | = | Average daily minimum temperature ($^oC$) |
| TRC | = | Transitional Rural Council |
| TSP | = | Theoretical saturation point |
| Tx | = | Average daily maximum temperature ($^oC$) |
| U2 | = | Average daily wind speed |
| UCS | = | Unconfined compressive strength |
| UFH | = | University of Fort Hare |
| UPM | = | Ultra-poor member |
| UPN | = | Ultra-poor non-member |
| UTot | = | Average daily wind speed (km $day^{-1}$) |
| Va | = | Valsrivier soil form |
| VCS | = | Veld condition Score |
| Vf | = | Villafontes soil form |
| Vp | = | Vegetative period |
| Wa | = | Wasbank soil form |
| WANA | = | West Asia and North Africa |
| We | = | Westleigh soil form |
| WHA | = | Water Harvesting Association |
| WRC | = | Water Research Commission |
| WUE | = | Water use efficiency |
| $Y_{(0-1200)}$ | = | Water content of the root zone |
| Yb | = | Total above-ground biomass (kg $ha^{-1}$) |
| Yg | = | Grain yield (kg $ha^{-1}$) |
| ZCC | = | Zion Christian Church |
| $\theta_{h(n-1)}$ | = | Root zone water content at harvesting of the previous crop (mm) |
| $\theta m$ | = | Gravimetric soil water content (mm) |
| $\theta_{p(n)}$ | = | Root zone water content at planting of the current crop (mm) |
| $\theta v$ | = | Volumetric soil water content (mm) |
| $\sum P_n$ | = | Total precipitation over n consecutive years |
| $\Delta S$ | = | Change in soil water content (mm) |
| $\sum Yg_n$ | = | Total grain yield over *n* consecutive years |

# 1 INTRODUCTION

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## 1.1 BACKGROUND

Poverty in South Africa is greatest amongst rural households. The majority of these households struggle to meet basic needs, especially food, as they earn incomes below the minimum level (poverty line). Households try to escape poverty by employing different livelihood strategies. The most important livelihood strategy is to diversify income sources, i.e. earn income from different sources (Monde, 2003). In terms of contributions to total household income, external economic activities tend to be more important than local economic activities.

Studies conducted in the Eastern Cape Province on rural livelihoods show that agriculture seldom constitutes the main livelihood strategy (Van Averbeke *et al.*, 1998; Monde, 2003). Rural households in the province are engaged in both animal and crop production systems. Livestock are kept in communal rangelands and are one of the few key resources that smallholder farmers can use to alleviate poverty in their communities. However, the condition of communal rangelands is being threatened and they have shown a significant deterioration over the last fifty years (Trollope, 2005; personal communication). Although there is an increase in communal rangeland degradation, there is also an ever increasing need for members of the rural communities to own animals because of their increasing dependence on livestock products to fight poverty. The crop production system is usually a dryland system. Crops and vegetables grown are usually for home consumption. In a study on food security in the Eastern Cape, Monde (2003) indicated that households in the province employed a variety of strategies, including producing their own food, to secure their food needs. However, households relied on purchasing food from urban markets as their main food security strategy.

Small-scale resource-poor farmers live in rural villages near Alice in the Eastern Cape. The area is marginal for crop production due to relatively low and erratic rainfall, predominantly clay soils, and high water losses due to runoff and evaporation from the soil surface.

It should be possible to improve crop and livestock/rangeland production systems through the introduction of irrigation, water harvesting and conservation techniques. With reference to South African conditions, Lipton (1996) suggested that irrigated agriculture is one of the most promising avenues for small-scale farming to develop. In the Eastern Cape there are a few irrigation projects where small-scale farming makes a modest contribution to household income. Elsewhere in South Africa, water harvesting technologies have been introduced and adopted by small-scale farmers. According to Botha *et al.* (2003a), the in-field rainwater harvesting (*IRWH*) technique (Figure 1.1) introduced at Thaba Nchu in the Free State Province was agronomically sustainable for the production of summer crops. Maize yield increased by 40%, sunflower by 30% and dry beans by 90%.

The *IRWH* technique developed by Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW) researchers at Glen (Hensley *et al*., 2000) combines the advantages of water harvesting, no-till, basin tillage and mulching on high drought risk clay soils. This innovative water conservation technique has the potential to reduce total runoff to zero and also reduces evaporation considerably from the soil surface (Es), resulting in increased yields due to increased plant-available water.

The specific advantages of each of the elements in the *IRWH* technique are as follows:

1. Basin tillage minimizes overall runoff from the land.
2. 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.
3. Mulch in the basins minimizes Es.

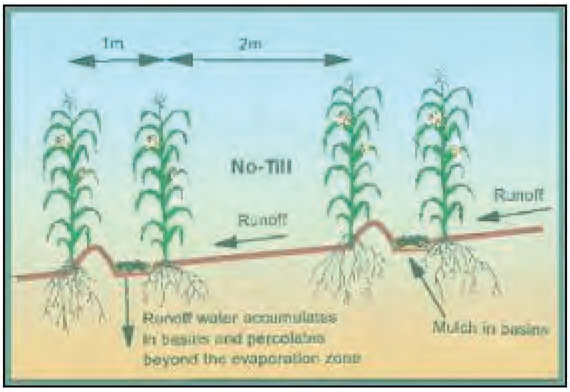


**Figure 1.1** A diagrammatic representation of the in-field rainwater harvesting technique.

The *IRWH* technique consists of promoting rainfall runoff on a 2-m wide strip between alternate crop rows, and storing the runoff water in the basins. Water collected this way can infiltrate deep into the soil below the surface layer from which evaporation takes place. After the basins have been constructed no-till is applied to the land as a whole. Due to the absence of cultivation a crust soon develops on the runoff strip.

## 1.2 PROJECT OBJECTIVES

The objectives of the project were to:

1. Conduct a literature review of techniques and practices for water harvesting and conservation in sub-Saharan, West-Asian and North-African countries and also capture existing knowledge consulting specific individuals in South Africa.
2. Organize a project specific workshop to share, capture and distil knowledge on water harvesting and conservation for implementation in field trials.
3. Obtain endorsement of stakeholders in the selected study area to conduct the project.
4. Determine the institutional arrangements of the selected study area.
5. Describe the agro-ecology (including indigenous practices) of the selected study area.
6. Do a baseline study to determine the *status quo* of crop production systems, livestock production systems and production data.

7. Introduce and test one water harvesting and one conservation technique on-farm for one crop and rangeland/livestock production system, following a participatory approach. Conduct on-station experiments to fine tune techniques.
8. Evaluate the impact of the selected water harvesting techniques on the crop and livestock production systems.
9. Measure the impact in terms of increased water use efficiency in the crop and livestock production systems.
10. Measure the technical feasibility, risk, economic viability, social acceptability and environmental impact of the selected water harvesting and conservation techniques.

## 1.3 TERMINOLOGY

Some terms contained in this report need to be described to ensure an understanding of the context in which they are used in this report

*Food security*

Food security has been defined by a number of scholars throughout the years. Household food security has been defined as "access by all people at all times to enough food for an active, healthy and productive life" (World Bank, 1986; Maxwell & Smith, 1992; Hoddinott, 1999). FAO (1996) adds that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". FAO's (1996) contribution to the World Bank's definition is that food security does not only include the ready availability of enough food, but also nutritionally adequate and safe foods, and an assured ability to acquire acceptable foods in socially acceptable ways.

*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 and quality of land. The requirements for sustainable crop production according to Smyth & Dumanski (1993) are:

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

*In-field rainwater harvesting (IRWH)*

Water harvesting in its broadest sense is be defined as the "collection and storing of runoff for its productive use". Runoff can be harvested from roofs and ground surfaces, as well as from intermittent or ephemeral watercourses. There is a wide variety of water harvesting techniques with many different applications. 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 *et al.* (1999) in which 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) suggested that in-field water harvesting be classified as mini-catchment runoff farming according to the system of Oweis *et al.* (1999). For the purposes of this report it is suggested that in-field water harvesting be referred to as *IRWH.*

*Institutions and organizations*

According to Powelson (2003), institutions consist of both the formal and informal rules governing peoples' behaviour and this distinguishes them from organizations which, along with individuals, are considered as players in the game. Institutions set targets for organizations and define the rules within which organizations should operate (Holden & Bazeley, 1999). Institutions include rules that structure human integration. Formal or informal institutions include among others, customs, laws, constitutions, norms and behaviour.

# 2 LITERATURE REVIEW

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## 2.1 INTRODUCTION

Rainwater harvesting is a term that describes a number of different practices, which have been used for centuries in dry areas to collect and utilize rainfall more efficiently. Rainwater harvesting can be defined in simple terms as the process of collecting runoff from a catchment area and using it in a target area productively. Boers & Ben-Asher (1982) compiled a comprehensive review of literature between 1970 and 1980 on rainwater harvesting and its potential application for crop production and concluded that all the different methods described have three common characteristics; namely:

1. They are applied in arid and semi-arid areas.
2. They depend upon local water such as surface runoff, springs or soaks and, therefore, do not include storing river water in large dams or the extraction of groundwater.
3. They are consequently relatively small-scale operations in terms of catchment area, storage volume and capital investment.

Methods developed for runoff collection were divided into two categories by Boers & Ben-Asher (1982):

1. Micro-catchment water harvesting (MCWH), which is defined the collection of surface runoff from a catchment area over a flow distance of less than 100 m and storing it in the root zone.
2. Runoff farming water harvesting (RFWH), which is defined as a method of collecting surface runoff from a catchment area using a system of channels and storing it in a surface reservoir or in the root zone for direct consumption by the crop.

In an attempt to standardize the varying terminology in use, Oweis *et al*. (1999) subdivided RFWH into three categories, depending on the size of the catchment area from which water is collected for use in the production area:

1. Micro-catchment runoff farming (MICRF), primarily used for crops and trees.
2. Mini-catchment runoff farming (MNCRF), primarily used for row crops or strips of annual crops. Categories 1 and 2 effectively replace the MCWH of Boers & Ben-Asher (1982).
3. Macro-catchment runoff farming (MACRF), where a natural stream is diverted to flood irrigate an adjacent field.

Van Rensburg *et al*. (2005) proposed an alternative classification system, whereby rainwater harvesting methods are categorized simply as ex-field (outside the farm boundary), in-field (within the farm) or non-field (e.g. rooftops), according to the location of the catchment area.

Boers & Ben-Asher (1982) reported that in addition to the USA, Mexico and Australia, rainwater harvesting is practised on a limited scale in many countries throughout the Middle East, the Indian subcontinent and in Sub-Saharan Africa. According to Oweis *et al*. (2001), the West Asia and North Africa (WANA) region played a key role in the development of ancient rainwater harvesting techniques. Early structures in southern Jordan are believed to have been constructed over 9000 years ago. There is evidence that simple rainwater harvesting techniques were used in southern Mesopotamia as long ago as 4500 BC, whilst runoff agriculture in the Negev Desert can be traced back as far as the $10^{th}$ century BC.

A large number of rainwater techniques have been developed. The majority of these are intended for irrigation, while others are geared towards human and animal consumption. All rainwater harvesting systems have the following three components (Oweis *et al*., 2001; 2004):

1. A catchment area: Agricultural, marginal or rocky land, or even a paved road or rooftop.
2. A storage area/facility: Reservoir or the soil profile.
3. A target area: Area where the harvested water is used.

In the context of this study it is important to highlight the similarities in purpose between the water harvesting techniques of mulch and micro-catchment in cropland, and brush packing and micro-catchment in rangeland. In both cases the purpose of the micro-catchments is to trap the water: in croplands mulch reduces evapotranspiration enhancing the rate of water uptake by crop roots, while in the rangelands the brush packs provide a dual purpose reducing evapotranspiration and protecting young seedlings from grazing. It is also important to highlight that cover crops used in croplands couple the crop subsystem to the livestock subsystem as crop residues and cover crops are an important component of feed for livestock. When assessing the impact of cover crops on yields of primary crops their dual purpose should be taken into account.

In the following sections detailed descriptions of *IRWH* techniques are provided. A comprehensive literature review on rainwater harvesting was done by Fyfield *et al.* (2005), but for the purposes of this report the summaries in the following sections focus on micro-catchment systems.

## 2.2 RAINWATER HARVESTING IN CROPLANDS

### 2.2.1 Micro-catchment systems

Micro-catchment systems are those in which surface runoff water is collected from a small catchment area over a short distance and applied to an adjacent area, where it is either stored in the root zone and used directly by plants or retained in a small reservoir for later use.

#### 2.2.1.1 On-farm systems

The purpose of these *in situ* rainwater harvesting techniques is to ensure that the water is held long enough on the cropping area to maximize infiltration into the soil. Such systems are simple in design and may be constructed at low cost, making them easily replicable and adaptable. Since all the components of the systems lie within the farm boundary, the farmer has full control over maintenance and management. The most important on-farm rainwater harvesting systems in the dry areas of the WANA region and Sub-Saharan Africa summarized from Oweis *et al*. (2001) and Finkel (1995) are as follows:

#### 2.2.1.1.1 *Contour ridges*

These are bunds or ridges constructed along the contour line, usually spaced at between 5 and 20 m intervals. The first 1-2 m above the ridge is for cultivation whilst the rest forms the catchment area. The height of the ridge varies from 0.3-1 m, depending on the slope gradient and the expected runoff storage capacity. Ridges may be reinforced with stones if necessary, e.g. on sandy soils which are susceptible to erosion. Ridging is a simple technique that can be carried out by farmers using animal or tractor-drawn implements. Ridges may be constructed on a wide range of slopes, from 1-50%. However, it is vital that the ridge is located as precisely as possible along the contour to avoid water flowing along it and accumulating at the lowest point. Alternatively, cross-bunds or tied ridges may be added at suitable spacing along the ridge to prevent the flow of water. Contour ridging is one of the most important techniques for supporting the regeneration of grass and tree plantations on gentle to steep slopes in the steppe, whilst in the semi-arid tropics it is used for arable crops such as sorghum and cowpeas. The technique is found in Botswana, Kenya, and is widespread throughout Burkina Faso. A special form of contour ridge may be constructed for use with permeable stone bunds on gentle slopes, and soil added to the upstream side of the bund to create an impermeable contour ridge. In the semi-arid tropics this system is sometimes combined with other techniques such as the pitting system (Oweis *et al*., 2001; Finkel, 1995).

#### 2.2.1.1.2 *Semi-circular and trapezoidal bunds*

These are usually earthen bunds (30-50 cm high) in semi-circle shape (1-40 m in diameter), a crescent or a trapezoid facing directly upslope. They are created at a spacing that allows sufficient catchment to collect the runoff water and it accumulates in front of the bund where the plants are grown. These bunds are used mainly for the rehabilitation of rangeland or for fodder production, but may also be used for growing trees, field crops (e.g. sorghum) or vegetables (e.g. water melon). Semi-circular bunds (also termed *demi-lunes* on account of their half-moon shape) are mostly found in Kenya, whilst trapezoidal bunds are widespread in Burkina Faso and north-western Somalia. An “eyebrow terrace” is a form of small semi-circular bund found in Egypt which is supported by stones on the downstream side. The disadvantage of the eyebrow terrace is that it is more labour-intensive to establish and maintain (Oweis *et al*., 2001; Finkel, 1995).

#### 2.2.1.1.3 *Small pits*

The most famous pitting system is the *zay* (or *zai*) system used in Burkina Faso, whilst a similar planting pit technique found in Niger is known as *tassa* (Van Dijk & Reij, 1993). A pit is dug to a depth of 5-15 cm and 0.3-2 m in diameter. A mixture of manure, grass and soil is put into the pit and the rest of the soil is used to form a small dyke down the slope of the pit. Pits are implemented in combination with bunds, which slow down and help conserve runoff. Pitting systems are used mainly for the cultivation of annual crops, especially cereals, and are excellent for rehabilitating degraded agricultural lands. The main disadvantage of the *zay* system is the high labour requirement to dig the pits.

2.2.1.1.4 *Small runoff basins*

The basins are triangular shaped structures surrounded by low earth bunds. They are usually 5-10 m wide and 10-25 m long and are oriented so that runoff flows to the lowest corner where the plant is placed. *Negarims* are best used on even ground with a maximum gradient of 1-2%. They are most suitable for growing trees such as pistachios, apricots and olives. Once constructed, the *negarim* system requires little maintenance, but weeds may have to be controlled by hand or with chemicals in order to maximize runoff from the catchment area (Oweis *et al*., 2001; Finkel, 1995).

2.2.1.1.5 *Runoff strips*

This technique is suitable for gentle slopes. The farm is divided into strips along the contour: an upstream strip is used as a catchment (the width being dependent on the amount of runoff water required) while the adjacent downstream strip (1-3 m wide) supports field crops. Runoff strip-cropping can be fully mechanized, thus requiring relatively low labour inputs. The same cropped strips are cultivated each year, but the runoff area may require clearing and/or compaction. This technique is highly recommended for growing barley and other field crops. A special implement was developed by ICARDA to create small corrugations to enhance the uniformity of flow of runoff water within the cropped area. Hensley *et al.* (2000) in South Africa adapted the runoff strip system to include basins for runoff water storage in their in-field rainwater harvesting (*IRWH*) technique.

2.2.1.1.6 *Inter-row systems*

Inter-row systems, also called “roaded catchments” in Australia, may be the best technique to apply on flat lands. Triangular cross-sectional bunds or levees, 0.4-1 m in height, are constructed across the main slope of the land at 2-10 m intervals. Runoff flowing down the slope is collected between the ridges and directed to the crop being cultivated there. The bunds and catchment area should be weeded and compacted on a regular basis to ensure high runoff output, especially when high value crops such as fruit trees or vegetables are being grown (Oweis *et al*., 2001; Finkel, 1995).

2.2.1.1.7 *Meskat*

This is an indigenous system used in Tunisia mainly for olives and figs. It consists of a catchment or *meskat* (sometimes surrounded by a bund) on the slope adjacent to a flat cultivated area called *manqa* (or *mankaa*). Large plots of 1000-5000 $m^2$ are divided in two, the upper part serving as a catchment to supply runoff to the lower cropping area. One of the disadvantages of this system is non-uniform water distribution across the cropping area. However, if the width of the cropping area is reduced to improve uniform water distribution, then this system comes to resemble the runoff strips described above (Oweis *et al*., 2001; Finkel, 1995).

#### 2.2.1.1.8 *Contour-bench terraces*

These are constructed on very steep slopes, in Yemen for example. Level cropping terraces supported by stone walls slow down the flow of runoff and control soil erosion. They are used mainly to grow trees and bushes. Their main disadvantage is the high construction and maintenance costs (Oweis *et al*., 2001; Finkel, 1995).

#### 2.2.1.1.9 *Off-contour bunds*

This variation of contour bunding is used where large amounts of water are intercepted and require safe drainage through the field. Off-contour bunds are earth or stone embankments, 30-60 cm in height and up to a few hundred metres in length built along slopes of 0.5-2%. The technique is widely used for crop irrigation in Burkina Faso (Oweis *et al*., 2001; Finkel, 1995).

#### 2.2.1.2 Rooftop systems

Rainwater can be collected from roofs of houses and other buildings, as well as from other impermeable surfaces such as courtyards or roads, and stored in a tank. Such systems provide a low-cost water supply for humans and animals. Although mainly used for domestic purposes, water that is unsuitable for drinking may be used for supplemental irrigation (Oweis *et al*., 2001; Finkel, 1995).

### 2.2.2 Rainwater harvesting research studies for crop production: South African case studies

#### 2.2.2.1 Glen Agricultural Institute case study (Free State Province)

The *IRWH* technique was originally proposed in South Africa by Hensley *et al.* (2000) as an alternative to conventional (*CON*) crop production. It was designed to minimize unproductive losses due to ex-field runoff and evaporation from the soil surface (Es). By combining the advantages of water harvesting, no-till, basin tillage and mulching on high drought-risk clay soils, the *IRWH* technique reduces runoff to zero and evaporation from the soil surface considerably. *IRWH* promotes rainfall runoff on a 2-m wide strip between crop rows, storing the runoff water in 1-m wide basins where it infiltrates deep into the soil below the surface layer from which evaporation losses occur. The technique falls under the micro-catchment systems category of Oweis *et al*. (2004).

The results of a 6-year field study by Hensley *et al.* (2000) and Botha *et al.* (2003a) to compare the *IRWH* and *CON* techniques were summarized by Botha *et al*. (2003b). *IRWH* produced significantly higher grain yield and rainwater productivity (RWP) than *CON*, with yield increases averaging 40% for maize, 30% for sunflowers and 90% for dry beans. The *IRWH* technique proved to be agronomically sustainable for crop production, as well as meeting the other requirements for sustainability proposed by Smyth & Dumanski (1993) as cited by Botha *et al.* (2003a). The requirements include reduction in the level of risk, conservation of the natural resources and economic viability. The social acceptability of the technique was clearly demonstrated by its subsequent adoption with great enthusiasm and success by developing farmers at their homesteads (Botha *et al.*, 2003a; Kundhlande *et al.*, 2004).

A further study on the benefits of mulching by Botha *et al.* (2003c) recommended that farmers should apply mulch to the basins of the *IRWH* technique first and then, if enough is available, on the runoff area too. The highest maize yields were obtained with organic mulch in the basins and stone mulch on the runoff area. The latter also helped to prevent the movement of soil from the runoff area into the basins.

#### 2.2.2.2 Bafokeng case study (North West Province)

A research study was conducted by Van der Merwe (2004) on the application of a version of the *IRWH* technique on vertisols in the Bafokeng district of the North West Province. The research trial was conducted on a commercial scale. The sunflower yield recorded during the 2003/04 season with rainwater harvesting treatments was 2-3 times that of conventional tillage plots, with the addition of mulch to the basins producing the highest yield.

#### 2.2.2.3 Umgungundlovu case study (KwaZulu-Natal Province)

Zakhe Training Institute and other researchers have investigated different water harvesting techniques in two communities, Entembeni and KwaMncane, in the Umgungundlovu District Municipality in KwaZulu-Natal, with the aim of enhancing food production in this area (Everson et al., 2011). They used different techniques like rainwater harvesting from roofs, roads, rivers and springs, and in-field techniques such as swales, planting in furrows, and the use of organic material. They found that the use of swales and vetiver grass resulted in a great improvement in soil water availability if designed correctly. They also indicated that the two communities have started to benefit from the research work by producing vegetables throughout the year. The area under production and the yields have also increased.

#### 2.2.2.4 Bach’s Fen case study (KwaZulu-Natal Province)

Auerbach practised rainwater harvesting in combination with conservation tillage and organic farming in the steep areas of KwaZulu-Natal on the farm Bach’s Fen at the Rainman Landcare Foundation (Auerbach, 2005). He used a variety of techniques: swales to retard runoff and promote infiltration; detention of upstream sub-catchment and highway runoff in a wetland on the farm and pumping from this wetland to the gardens; mulches to reduce evaporation; and compost to increase the water- and nutrient-holding capacity of the soil. The value of the rainwater harvesting measures is evident in the volumes of water available for use on the farm, dominated by the water-retention capacity of the wetland.

#### 2.2.2.5 MaTshepo case study (Gauteng Province)

MaTshepo Khumbane has practised rainwater harvesting for homestead household food production in South Africa since 1967 with huge success (Khumbane, 2005; personal communication). She uses a number of ex-field rainwater harvesting techniques like harvesting runoff water from fields, roads, dongas, mountains (rocks) and roofs, and redirecting it to pits, dams and crops (vegetables, cash crops and fruit trees) in order to produce food throughout the year. She also combines rainwater harvesting with digging of trenches and grey water recycling. The principles and techniques have been captured in Stimie *et al.* (2010).

### 2.2.3 Rainwater harvesting research studies: International case studies

#### 2.2.3.1 Somalia and Burkina Faso case studies

Although Reij *et al.* (1988) reported that there was very little data from Sub-Saharan Africa to support the assumption that the use of water harvesting techniques leads to substantial and sustained yield increases, they do cite a few studies. In a World Bank project in Somalia the construction of 1 m high bunds produced yield increases in the range 55-78% over a 4-year period. Similarly, in Burkina Faso a study by Wright (1978) showed that the use of stone bunds resulted in yields 12-90% higher than on adjacent control plots, a difference which became increasingly significant as annual rainfall decreased.

#### 2.2.3.2 Zimbabwe case study

Kronen (1994) presented results obtained by Jones & Nyamudeza (1991) over seven seasons at Chiredzi in Zimbabwe, comparing *CON* with tied furrows on soils with relatively high clay content. The tied furrow system increased precipitation use efficiency (PUE) by 29% and resulted in average yield increases of 42% for cotton and 35% for sorghum. However, such advantages were not as evident on relatively coarse textured soils characterized by low water retention properties and poor soil fertility.

#### 2.2.3.3 Niger case study

Van Dijk & Reij (1993) reported on the success achieved by a group of farmers in Niger upon implementing an improved planting pit (*tassa*) technique to rehabilitate degraded land. For example, in one season an average millet yield of 522 kg $ha^{-1}$ was obtained on the rehabilitated land compared to zero on untreated land. However, the authors noted that the sustainability of these comparatively high yields was unproven and would depend on adequate fertility management. The fact that these farmers implemented the technique after observing the similar *zay* system in Burkina Faso, led Van Dijk & Reij (1993) to state that farmer exchange visits are a key factor in the adoption of water harvesting techniques.

#### 2.2.3.4 Mexico case study

A more mechanized approach to *in situ* rainwater harvesting is the integrated “reservoir tillage system” (RTS) developed by Ventura *et al*. (2003). The system includes a plastic roller, fitted to a modified planter or sub-soiler, which creates indentations on the soil surface. These act as mini-reservoirs, each with a capacity of up to 1 litre, that retain rainwater until it can infiltrate into the soil. Field tests in semi-arid Central Mexico showed that the reservoirs harvested almost 100% of the rainfall, with no significant evidence of runoff. Soil surface sealing was also reduced significantly since about 50% of the surface area is protected by the harvested water, dissipating the energy of impact caused by falling raindrops. Despite a mid-season drought, the RTS resulted in an almost 100% increase in the grain yield of a bean crop, compared with conventionally tilled plots, due to a higher soil water content.

## 2.3 RAINWATER HARVESTING IN RANGELANDS

### 2.3.1 Hydrologic and biogeochemical dynamics in arid and semi-arid rangeland areas

#### 2.3.1.1 Significance of water in arid and semi-arid rangelands

In arid and semi-arid ecosystems, water is the major limiting factor (Chen *et al*., 2007). Performance of landscape functions relies heavily on the availability of water (Vohland & Barry, 2009). In southern Africa, a number of studies in rangeland ecology have been conducted. However, most of them are limited to traditional disciplines such as grazing management, fire ecology and vegetation characteristics. The rangeland environment generally consists of abiotic components such as soil and climate parameters, and biotic communities including plants and animals. Processes such as photosynthesis, hydrological cycle, respiration and many others explain the interaction between the biotic and abiotic components of the ecosystems. Therefore, there is a need for a better understanding of the complex nature of the rangeland environment and the various interactions and feedbacks between the different processes.

Water is probably the least understood natural resource, especially within rangeland ecosystems. An understanding of the relationship between soil water dynamics and vegetation density is essential before recommendations can be made on soil erosion control and vegetation rehabilitation in semi-arid and arid areas (Braud *et al*., 2001). Water covers almost three quarters of the earth surface as rivers, lakes and oceans, but only 3% of the planet's water is fresh, and two thirds of it is ice. Plants, animals and soils contain a small (0.003%), but very important amount of water, while about 0.6% is in the earth's underground aquifers. Water is a transient resource, in continual motion: any stasis in time or space is a fleeting phase (Morse, 1996), therefore, the factors that influence its stasis and dynamism within the rangelands have to be understood in order to improve rangeland management and utilization.

The hydrologic cycle (Figure 2.1) refers to the continuous process by which water is transported from the oceans to the atmosphere to the land and back to the sea. Interaction between the water cycle and the vegetated surface of the earth determines both the partitioning of water and energy, and sustainable supply of ecosystem goods and services such as grazing, wood and river runoff (De Michele *et al.*, 2008). These interactions are especially sensitive in water-limited ecosystems, such as deserts, grasslands, shrublands and semi-arid savannas that occupy over a fifth of the earth's land surface (Scholes & Walker, 1993).

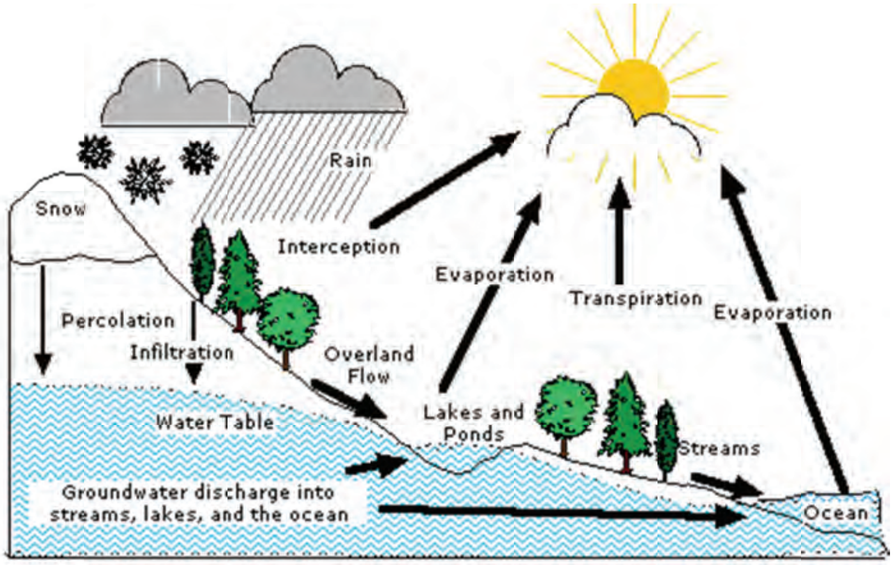


**Figure 2.1** Hypothetical picture of hydrologic cycle.

Rainfall is one of the most limiting environmental factors influencing plant production (Noy-Meir, 1973; Bennie *et al*., 1997; O'Connor *et al*., 2001) and plant survival in arid and semi-arid climates (Chen *et al*., 2007; Snyman, 2004). The availability of water is relatively limited in arid and semi-arid areas, and in turn sustainable animal production in these ecologically sensitive areas is in danger. Therefore, the combined effects of plant water requirements and influence of defoliation on vegetation should be investigated (Snyman, 1999). Understanding rangeland water dynamics and WUE is of particular importance due to low water availability in arid areas (Yu *et al*., 2005).

Soil water is the limiting factor in determining the vegetation density in the arid and semi-arid areas (Xia & Shao, 2008). One of the most important principles in the sustainable utilization of arid and semi-arid rangelands is efficient soil-water management (Snyman, 1998) and, therefore, it is essential to know how water use efficiency is affected by rangelands (Snyman & Fouche, 1993) and soil conditions over the short and long term (Emmerich & Heitschmidt, 2002). Understanding the effects of vegetation on soil water dynamics will provide a background for understanding the mechanism of soil water shortage and in addressing the problem of poor long-term vegetation recovery (Chen *et al.*, 2007).

The formation, vulnerability and resilience of spatio-temporal patterns in water-controlled ecosystems have been tied to phenomena that link the cycling of water, sediments, nutrients and other biogeochemically active elements (Lago *et al.*, 2010). Understanding the perturbations in these cycles that trigger impacts on ecosystem spatio-temporal characteristics is a challenge that generally transcends disciplinary and geographical boundaries and key to sustaining diversity of life on earth (Lago *et al*., 2010).

Water flowing into the ecological system comprises precipitation, surface water and groundwater (Descheemaeker *et al.*, 2010), and leaves it through deep percolation into the soil, stream flows, evaporation from the soil surface, and transpiration by plants or incorporation into plant tissues (Morse, 1996). Transpiration, evaporation, contaminated water, and degraded runoff water all form part of depleted water flows, which cannot be used again within the system (Descheemaeker *et al*., 2010).

#### 2.3.1.1.1 *Landscape formation on water recharge, storage and discharge in rangelands*

Landform governs the lateral flow of water in the soils and controls incoming solar radiation. Therefore, it has a great impact on site conditions and affects the distribution of plant species (McVicar *et al.,* 2010). The land slope and roughness are of paramount importance in controlling the movement and deposition of water-borne soil (Cogo *et al.,* 1984). Therefore, relief and slope of the land are prime considerations when implementing structural and vegetative soil conservation measures on watersheds (Sarangi *et al.,* 2004). Arid and semi-arid landscapes fulfil a range of functions, from ecological processes such as water and nutrient cycling, through biomass production and biodiversity conservation to socio-economic services such as providing the basis for sustainable rural livelihoods (Vohland & Barry, 2009).

In arid and semi-arid regions, banded landscapes are comprised of alternating bands of vegetation and bare ground aligned along the contours on very gentle and non-uniform slopes (Valentin *et al.,* 1999). Vegetated bands can be perpendicular to the direction of the dominant wind, or more frequently to the slope. Mean annual rainfall determines the contrast between the vegetated and bare phase, as well as the band length and the interband width: band width ratio. One of the most conspicuous patterns in arid or semi-arid environments is a two-phase mosaic characterized by vegetated, roughly parallel stripes or bands alternating with lanes of bare or very thinly vegetated soil, with composition varying from entirely wooded, grassy or shruby, to such combinations as woodland-grass or grass-shrubs (Esteban & Fairén, 2006).

Topsoil in the vegetated bands is generally slightly more sandy than in bare interbands due to sand trapping by the vegetation (White, 1971). The runoff-run-on systems of semi-arid and arid regions function as source-sink systems (Noy-Meir, 1973). On banded vegetation patterns, water is shed from the bare zones to accumulate in the waterways (Valentin *et al.*, 1999).

#### 2.3.1.1.2 *Relationship between rangeland vegetation and water dynamics*

Detention of water on vegetation is the basic process controlling interactions of precipitation with plant canopies. Water temporarily stored on canopy surfaces is readily evaporated and is, therefore, an important component of the hydrological cycle in most regions (Keim *et al.*, 2006). Keim *et al.* (2006) concluded that storage of water in plants varies with rainfall intensity and suggested that morphological characteristics of vegetation play a role in the process.

In order to improve our understanding of soil water-vegetation interactions it is necessary to integrate hydrological and biogeochemical processes to estimate, not only water dynamics, but also its influence on vegetation density (Xia & Shao, 2008). Soil water carrying capacity is defined as a maximum vegetation density that an arid or semi-arid area will support without soil water experiencing decreases in its ability to support future generations during plant growth periods, given desired climatic conditions, soil texture and management programme (Xia & Shao, 2008).

Vegetation has been identified as an efficient way to prevent soil erosion. It is widely used as an important measure of soil and water conservation (Morgan & Rickson, 1995). Grasses have an important effect on slope runoff and sediment accumulation (Pan & Shanguan, 2006). Increasing vegetation density can significantly reduce sedimentary yield resulting in effective control of soil erosion (Gardiol *et al.,* 2003; Yu *et al.,* 2006). Vegetation modifies the hydrology of overland flow; this modification has effects on transfer and deposition of sediment (Kang *et al.,* 2001; Neave & Abrahams, 2002).

Grass cover reduces the kinetic energy of raindrops, reducing surface soil sealing. Grassland surface roughness impedes overland flow and increases infiltration time. Furthermore, grass improves soil infiltration capacity (Pan & Shanguan, 2006). Pan & Shanguan (2006) suggested that the effects of vegetation in controlling erosion rate could be due to an increase in the interception of raindrops, which may reduce raindrop energy approaching the soil surface, preventing soil crusting and reducing runoff.

In arid and semi-arid regions, the hydrologic regime exerts a strong influence on the fate of the ecosystem (Sugita *et al*., 2007). In these environments, the response of plants to water deficits and the variable environment is complex because conditions vary: the frequency of drought and wet periods; the degree of drought; the speed of onset of drought; and patterns of soil water and atmospheric water deficits (Deng *et al*., 2003a). Plants have a different adaptive capacity at different water stress levels and drought tolerance is a complex trait at plant level with a range of adaptive pathways and physiological mechanisms (Deng *et al*., 2006).

Water deficit affects physiological processes of plants and cell expansion is one of the processes sensitive to water deficits. Leaves are very sensitive to water shortage and a reduction in leaf area is one of the key ways in which a plant adjusts its water use (Passioura, 2002). Deng *et al*. (2006) indicated that reduced cell expansion also has an effect on the development of yield components such as inflorescence or tiller initials, leading to potential low reproductive growth.

There is a positive relationship between photosynthesis and transpiration: transpiration increases as photosynthesis increases, however, it continues to increase after photosynthesis has reached a maximum (Wang & Liu, 2003). If soil water content drops below a certain level, stomata closure is induced to reduce water loss, prohibiting photosynthesis (Hoff *et al*., 2002). Soil water availability is highly correlated to rooting depth (Nijland *et al*., 2010).

WUE, the instantaneous ratio of leaf net carbon assimilation over transpiration rate, varies among plants with different photosynthetic pathways (C3, C4 and CAM) (Marshall & Zhang, 1994). It also varies for plants growing in different habitats (Ehleringer & Cooper, 1988; Garten & Taylor, 1992), plants possessing different leaf types (Marshall & Zhang, 1994; Damesin *et al*., 1997), different plant organs (Comstock & Ehleringer, 1992) and plants of different ages (Cavender-Bares & Bazzaz, 2000). The intrinsic water use efficiency (IWUE) is defined as the ratio of net assimilation rate to stomatal conductance. Unlike WUE, it is thought to be less tightly coupled to the instantaneous environmental temperature and atmospheric humidity and more closely reflects plant physiological properties (Comstock & Ehleringer, 1992).

Water use efficiency at the community level depends on the WUE of species and hence on species composition. Species composition is a measure of ecosystem structure and is largely affected by the successional status and level of disturbance of the ecosystem (Redmann *et al*., 1995) and thus the degradation state of the site should be considered an important variable when determining WUE at the community or ecosystem level. According to Yu *et al*. (2005), the photosynthetic pathway is an important determinant of IWUE at the species level. It has been reported that IWUE for C4 species is double that of C3 species (Yu *et al*., 2005; Marshall & Zhang, 1994). The vegetation type and habitat degradation status significantly affect species IWUE, indicating that there is a relationship between species IWUE and its microhabitat (Ehleringer & Cooper, 1988). Yu *et al*. (2005) attributed the difference in IWUE among vegetation types to differences in species composition and to the occurrence of species with different carbon pathways.

The timing of rainfall influences water availability in soil, and thus water fluxes between soil and plants, and vegetation growth (De Michele *et al*., 2008). Zhang & Schilling (2006) indicated that vegetation has effects on evapotranspiration (ET) and groundwater recharge. A low water table is likely to decrease soil evapotranspiration due to capillary rise, as well as water availability in the upper soil horizons, where most plant roots occur (Cooper *et al*., 2006). This could trigger changes in plant species composition and because ET occurs largely through transpiration, changes in plant species composition or plant cover could change long-term ET rates (Scott *et al*., 1999).

Vegetation adapts to water stress in various ways. Drought-tolerant plant species may survive under conditions of a declining water table with only reduced leaf area (Cooper *et al*., 2003). Cooper (2005) indicated that other plants might experience a canopy dieback or death. Some plant species could grow roots to access deeper water tables (Sorenson *et al*., 1991), but in cases of substantial hydrologic changes, the entire plant community can change from phreatophytes or facultative phreatophytes to plants with no dependency on the water table (Merritt & Cooper, 2000).

The defining characteristics of water-limited ecosystems are the intensity, frequency and duration of water stress periods (Fernandez-Illescas & Rodriguez-Iturbe, 2004). Spatio-temporal variation in soil water distribution and plant-available water, the dominant factors in terrestrial ecosystem dynamics, are strongly influenced by vegetation cover. Conversely, changes in soil water regime can alter the vegetation cover of terrestrial ecosystems (Wang *et al.*, 2009).

#### 2.3.1.1.3 *Relationship between soil properties and rangeland water dynamics*

In water-limited ecosystems, vegetation dynamics are influenced by water stored in the soil layer occupied by roots. The timing of rainfall influences the water availability in soil, and thus water fluxes between soil and plants, and vegetation growth (De Michele *et al*., 2008). Water-limited ecosystems offer a particular rich example of space-time species dynamics due to the complex temporal variability present in interannual precipitation (Fernandez-Illescas & Rodriguez-Iturbe, 2004). Soils influence hydrologic processes by providing the medium for the capture, storage and release of water (Whisenant, 1999). The flow of soil and water through rangeland ecosystems are related, because flow of water can cause soil erosion. Soil and water are two critical resources for agricultural production. There is, therefore, an urgent and ongoing need for research to devise ways to manage soil and water resources in a sustainable manner, especially in the rangelands (Sarangi *et al*., 2004).

The retention of water by the soil is tentative, relying on the attractive forces between water and soil particles to act against gravity. Little can be done to prevent the movement of water, least of all in the semi-arid areas where the hostile environmental conditions present a strong resistance to the retention of water in surface bodies, soil or plants.

The long-term difference between evapotranspiration (ET) and rainfall/precipitation (P) is particularly relevant because it indicates to what extent water is retained and used for primary production. In the case where P is greater than ET, water losses through runoff or deep drainage are likely to be important, land condition can be expected to be poor and associated processes such as soil erosion may be active. However, where P is less than ET, water inputs by overland or sub-surface flow can be expected to outweigh the losses by runoff and deep drainage (Domingo *et al*., 2001).

Soil water repellency (SWR) is affected by various biotic and abiotic factors. Biotic factors include the presence of hydrophobic organic compounds released by roots and plant tissues, fungal activity, and mineralization/humification rates (Doerr *et al*., 1998; Jex *et al*., 1985; McGhie & Posner, 1981). Abiotic factors that affect soil water repellency include wild fires, soil texture, temperature and soil moisture (Doerr *et al*., 2000). Some of the consequences of SWR are reduced soil infiltration rates, enhanced overland flow, soil erosion and non-uniform wetting fronts with fingered flow (Ritsema *et al.,* 1993; Jordán *et al.,* 2008). The occurrence of SWR is often linked to wildfires. The degree of repellency varies with land use or vegetation types (Lorena *et al.,* 2009). Plant litter is considered to be a source of hydrophobic substances. SWR is related to plant roots activity (Doerr *et al.,* 1998). Certain evergreen trees such as eucalyptus and conifers are associated with SWR (Mataix-Solera & Doerr, 2004). Water repellency in soils is believed to be caused by coatings of hydrophobic organic substances on soil particles. Therefore, soils with a low specific surface area should be more susceptible to SWR (Roberts & Carbon, 1972).

#### 2.3.1.1.4 *Grazing practices and water dynamics in rangelands*

In arid and semi-arid areas, shallow groundwater circulates within a system that is replenished by high intensity precipitation events. This shallow groundwater serves as the main source of water for grazing and daily nomadic life (Tsujimura *et al.,* 2006). Grazing activities affect the soil surface condition and should have a large influence on surface-atmosphere interactions (Sugita *et al.,* 2007). Grazing activities reduce soil vegetation coverage and thus make the soils more vulnerable to erosion.

Forage production that determines animal production is controlled primarily by precipitation (Diaz-Solis *et al*., 2006). According to the livestock water productivity (LWP) framework, there are nine strategies to increase LWP. These include water management, feed type selection, improving feed quality, improving feed water productivity, grazing management, increasing animal productivity, improving animal health, supportive institutions and enabling policies (Descheemaeker *et al*., 2010). The strategies directed at the biophysical components of the farming systems are grouped into three categories related to feed management (improving feed quality, improving feed water productivity, feed type selection, grazing management), water management and animal management (increasing animal productivity, improving animal health) (Descheemaeker *et al*., 2010).

Livestock keeping and feeding are important components of agricultural water use in sub-Saharan Africa and other parts of the world (Harrington *et al.,* 2009). Livestock convert water resources into high value goods and services. Animals derive their water from different sources (Sileshi *et al*., 2003; McGregor, 2004), such as water directly consumed by drinking and water consumption through feed intake. The amount of drinking water used varies from 20 l to 50 l $day^{-1}$ per Tropical Livestock Unit (TLU, 250 kg bodyweight), and depends on various factors related to the animal, feed and environmental conditions (Gigar-Reverdin & Gihad, 1991).

Water required for feed production is generally about 50-100 times more than the amount needed for drinking. This relates to the major water depletion by livestock (Peden *et al.,* 2007; Gebreselassie *et al*., 2009). Livestock keeping has important impacts on water resources at the watershed and landscape scales (Ameda *et al*., 2009). Livestock grazing affects the hydrological response of pastures and rangelands and may result in soil and vegetation degradation (Descheemaeker *et al.*, 2006). Grazing pressure on vegetation and the trampling effect of livestock are especially notable around watering points, where land degradation can be severe (Brits *et al.*, 2002).

The importance of precipitation is highlighted by the introduction of water use efficiency as a unifying concept in the ecology of semi-arid areas (Le Houerou, 1984). Snyman (2005) and Oba *et al*. (2000) define water use efficiency as the quantity of above-ground phytomass produced per unit of water evapo-transpired. Water use efficiency (WUE) in rangeland management relates to the condition of the rangeland: regardless of the amount of rainfall, rangeland in poor condition has low water use efficiency. Water use efficiency is related to infiltration, runoff and soil water storage (Fischer & Turner, 1978).

Water productivity is generally defined as the ratio of agricultural outputs to the amount of water consumed. It provides a robust measure of the ability of agricultural systems to convert water into food (Kijne *et al.,* 2003). Livestock water productivity (LWP) is the ratio of net livestock-related benefits, including both products and services, to the water depleted and degraded in producing these (Peden *et al*., 2007).

Water is used for biomass production, drinking, processing, and servicing. It allows the system to produce animal outputs which contribute to livelihoods and environmental services (Descheemaeker *et al*., 2010). Livestock outputs comprise many different products varying from food items such as meat, fibre and milk, and secondary product such as manure, draught power and transport, and services such as nutrient cycling, risks spreading and socio-cultural roles (Descheemaeker *et al.,* 2010).

#### 2.3.1.1.5 *Rangeland degradation and water dynamics*

Rangeland degradation is not only accompanied by a decrease in biological productivity, but also reduced water use efficiency (Snyman, 1999). When rangelands are in poor condition, water use efficiency is low, regardless of soil water content. Perennial aerial biomass, ground cover and rain use efficiency (RUE) are substantially lower in degraded ecosystems (Le Houérou, 1984). Le Houérou (1984), Snyman (1999) and Snyman & Fouché (1991) have indicated that the significant decrease in primary production with rangeland condition deterioration is a function of WUE and stability of the different species within a plant community. Abel (1993), O’Connor & Roux (1995) and Snyman & Van Rensburg (1990) demonstrated that variation in rainfall between years is a cause of variation in the abundance of species. Behnke & Scoones (1993), Roux (1996) and O’Connor (1985) suggested that rainfall variability rather than grazing is the major determinant of species change in semi-arid areas.

Degraded rangelands experience an increasing intensity and frequency of droughts, which is normal in semi-arid areas (Snyman, 2005). Degraded rangelands also expereience higher runoff. Snyman (1998) suggested that the contribution of evaporation (Es) to rangeland condition in semi-arid areas may be much more with degradation.

#### 2.3.1.1.6 *Managing rangelands for water conservation*

Soil and water are the two critical resources for agricultural production and thus there is an urgent and ongoing need for research to devise ways to manage soil and water resources in a more sustainable manner (National Research Council, 1992). In the context of agricultural production in drylands, soil and water conservation practices such as rainwater harvesting (RWH) provide an opportunity to stabilise agricultural landscapes in semi-arid regions and make them more productive and resilient towards climate change (Wallace, 2000). Stabilization of the agricultural landscape includes the restoration of degraded cultivated and/or natural grazing lands (Vohland & Barry, 2009). There are many marginal water sources that could be used more efficiently, such as road and land runoffs which are normally lost through erosion processes (Prinz & Malik, 2002). RWH practices refer to all practices whereby rainwater is collected artificially to make it available for cropping or domestic purposes (Ngigi, 2003). Rainwater is collected from fields, roofs and streets and stored in underground tanks or open ponds. *In situ* RWH practices refer to micro-catchments at field level (Prinz & Malik, 2002). These practices are primarily used to help overcome dry spells, as the soil, which is the main storage site of *in situ* RWH practices, serves as a storage system for only a few days or weeks. (Falkenmark *et al*., 2001).

Integrated watershed management (IWM) is a vital approach for sustainable development as the watershed is the hydrogeological unit that harbours natural resources. IWM can be defined as a multidisciplinary, holistic way of protecting and managing a watershed’s natural resources to enhance biomass production in an eco-friendly manner (Sarangi *et al*., 2004). The watershed is viewed as a hydrogeological complex and dynamic ecosystem in which natural and anthropogenic processes occur and interact, and gives rise to runoff at the watershed outlet. Rainfall use efficiency is a derivative of rainfall and biomass production. It is linearly correlated with a rainfall gradient varying from very arid sites to the sub-humid savanna (Oba *et al.*, 2000).

Rangeland ecosystems have served as productive systems for animal production for a long time especially in the arid and semi-arid environments. Their management has been mostly attributed to the grazing management for sustainability of forage production. Less attention has been paid to the water dynamics within the rangeland ecosystems. One of the major questions should be: Could the water-saving agricultural system apply in the rangeland management system? The water-saving agricultural system refers to integrated farming practices that are able to efficiently use natural rainfall and irrigation facilities for improved water use efficiency (Shan, 2002).

In practice there are several requirements for the successful implementation water-saving agricultural systems:

- the quantity, quality, spatial and temporal distribution of water resources need to be taken into account;
- cultivation practices aimed at reducing water consumption need to be introduced taking into account the current distribution pattern of water resources;
- provision of sufficient manpower and equipment for research, development, production, supply and maintenance of water-saving materials, spare parts, instruments and facilities; and

- relevant laws and statutes concerning water management need to be enacted, formulated and perfected and a special campaign launched to enhance the public's water-saving awareness (Deng *et al.*, 2003a).

One of the challenges facing rangeland management research in water saving and utilization is how to improve water utilization rate and water use efficiency in order to maximize rainfall use efficiency (Deng *et al.*, 2006). This could be achieved by maximizing the following hydro-pedagogical and plant parameters: soil-stored water content / precipitation volume; water consumption / soil storage of water; transpiration / water consumption; biomass yield / transpiration and economic benefits / biomass yield (Deng *et al.*, 2006).

Most interventions in water management merely modify the flow so that this scarce resource can be channelled towards the desired target, which may be people, livestock or crops. Water harvesting techniques can be divided into five basic methods:

- vegetation management,
- natural impervious surface,
- land alteration,
- chemical treatment of soil, and
- ground covers.

These methods have a wide range of costs, performance and durability, which can limit the potential applicability of a treatment (Frasier, 1975).

2.3.1.1.7 *Rangeland vegetation restoration and water recharge, storage and discharge*

In arid and semi-arid regions vegetation dynamics depend on soil water availability, which, in turn, results from a number of complex and mutually interacting hydrologic processes (Porporato *et al.*, 2002). Vegetation restoration, therefore, requires that the soil water dynamics be considered in both time and space. Soil water dynamics are affected by a number of factors including topography, soil properties, land cover, water routing processes, depth of water table and/or meteorological conditions (Beate & Haberlandt, 2002). The relationship between vegetation and soil moisture varies with region (Domingo *et al.*, 2001; Kerkhoff *et al.*, 2004). Choosing suitable species with respect to soil water balance is crucial for vegetation restoration, especially where water shortage is a limiting factor. Other factors controlling plant growth include temperature and nutrient availability. However, when these are not the controlling factors, soil moisture becomes the key controlling variable (Daly *et al.*, 2004). Vegetation restoration in arid and semi-arid regions must take into consideration that rainfall is the only source of water recharge to sustain plant growth (Chen *et al.*, 2007).

Chen *et al.* (2007) discovered that semi-natural grassland had higher soil moisture content than sloping cropland. However, they noted that average soil moisture content varied between vegetation types and periods of observation and attributed this to the difference in plant transpiration in different time periods. Such temporal dynamics are pronounced in water-limited ecosystems (Tinley, 1982). Chen *et al.* (2007) also observed that the difference in soil moisture content among different vegetation types decreased with increasing soil depth.

Vegetation has a strong effect on surface runoff. In addition rainfall intensity and amount, evaporation, antecedent soil moisture, topography and soil hydraulic characteristics also influence surface runoff (Gautam *et al.,* 2000).

#### 2.3.1.2 Rangeland vegetation restoration

##### 2.3.1.2.1 *Role of management on rangeland restoration*

Management of land degradation can be divided into preventative and restoration measures. Answers to preventative measures can often be found within the causes of land degradation. In view of the massive scale of land degradation that has already occurred in parts of southern Africa's communal rangelands, restoration is of significant importance to land owners.

The fast rate at which natural ecosystems are degraded and decline in areas occupied by intact ecosystems worthy of protection, has emphasized the importance of ecological restoration to maintain the earth's natural capital (Young, 2000). In order to restore degraded ecosystems it is crucial to identify which ecosystem functions should be restored first. It is, therefore, important to define the functional status of the ecosystem beforehand. It is also important to establish the relationship between ecosystem structure and functioning, and to assess the potential for ecosystem restoration (Cortina *et al*., 2006).

##### 2.3.1.2.2 *Theories, paradigms and models describing rangeland dynamics*

There are a large number of conceptual models that have been developed by restoration ecologists to describe how ecosystem structure and functioning are related (Cortina *et al*., 2006). Bradshaw (1984) developed a model for the reclamation of derelict land, which was later termed the Linear structure vs. Function model (LSF). This model assumes a linear increase in ecosystem function with an increase in complexity of its structure (Cortina *et al*., 2006). According to this model, restoration is defined as the simultaneous increase in structure and function promoted by human intervention, paralleling changes occuring during secondary succession. Although the LSF model has a strong heuristic value and has successfully captured the essence of ecological restoration, it fails to reflect many real situations, and it may lead to excessively narrow definitions of reference ecosystems, and to erroneous estimations of the effort needed to restore degraded ecosystems (Cortina *et al*., 2006).

The major assumption of the LSF model is the linear and positive relationship between ecosystem structure and function. However, Hooper *et al*. (2005) suggested that the relationship between community composition and ecosystem functioning does not form a straightforward universal relationship between both sets. The negative relationship between biodiversity and productivity (Bakker & Berendse, 1999) is an example of the inconsistency of the LSF model. Furthermore, the introduction of a new species does not always translate into measurable changes in ecosystem function (Cortina *et al.,* 2006). Species differ in their impact on ecosystem function and the effect of a particular species on ecosystem function may be low (Hulbert, 1997). In the same vein, species loss does not always directly relate to functional decline (Smith & Knapp, 2003). The LSF model is implicit in that the notion of linear trajectory and a single final ecosystem state follow Clementsian successional tractories (Cortina *et al*., 2006).

Hobbs & Norton (1996) reported the altenative meta-stable states in the structure-function space, which was the basis for state and transition models. State and transition models recognize that multiple successional trajectories are possible, and that altenative meta-stable states can exist under the same environment (Hobbs & Norton, 1996). Different states represent areas of higher probability in the structure-function space and may result from gradual or sudden changes in the ecosystem structure and function. Altenative states can be targeted as reference ecosystems for restoration, provided that a particular combination of both sets of variables suits society interest (Hobbs & Norton, 1996).

State and transition models can help define transitions that are feasible and those that are not, and may help to identify restoration techniques needed to bring the ecosystem to a desired state (Cortina *et al*., 2006). The existence of irriversible transitions and hysteretical dynamics has major consequences for ecological restoration. When aggradative and degradative trajectories differ, restoration may need to use bypasses to reach a particular reference ecosystem, and thus additional efforts may be required (Cortina *et al.*, 2006). Restoration may not need to follow the entire sequence of degradation stages to reach the target ecosystem, but may 'jump' over partially degraded ones. The state and transition model and its derivative, the rangeland health model, can be used to characterize the conditions of different vegetation states (Westoby *et al*., 1989), which feature high vegetation cover turnover (Noy-Meir, 1973).

Walker (1980) defined three concepts that have to do with system dynamics, *viz.* stability, resilience and a system's domain of attraction. He describes a stable system as one which when subjected to outside stress (e.g. drought or grazing) changes little in composition and production. A resilient system may or may not be stable, but remains attracted towards its equilibrium. A domain of attraction is described as that region of a system's state-space within which the system is attracted towards an equilibrium. According to Walker (1980), in a resilient system the domain of attraction is usually large. If a stable system changes to such an extent that it falls outside the domain of attraction, the amounts of the variables will then either change to a different equilibrium, or they will go to zero (extinction).

Equilibrium (based on range succession) and non-equilibrium grazing models (such as state and transition, rangeland health, climate-plant-herbivory models) have influenced rangeland policy and management widely (Oba *et al.,* 2000). Fernandez-Gimenez & Allen-Diaz (1999) also attested that the two equilibrium based ecological models have dominated conventional range science and management, e.g. the Clementsian successional model of vegetation change (Clements, 1916; Ellison, 1960) and the classical model of plant-herbivore population dynamics (Caughley, 1979). Equilibrium and non-equilibrium models differ in their characterization of range ecology, grazing systems and development (Oba *et al.,* 2000). Both models possess tightly coupled relationships between the abundance of herbivores and the productivity and species composition of plants (Fernandez-Gimenez & Allen-Diaz, 1999).

The range condition (RC) model of vegetation dynamics has been established on the basis of a presumed relationship between grazing intensity and vegetation (Dyksterhuis, 1949). The RC model predicts that as herbivore numbers increase, plant biomass and cover decline and species composition shift from dominance by perennial grasses and forbs towards dominance by unpalatable forbs and weedy annuals (Oba *et al*., 2000). When grazing is reduced or stopped, biomass and cover are predicted to increase and species composition shifts back towards late-successional stages.

Classical rangeland theory has portrayed traditional, communal rangeland management as an unproductive and unsustainable form of land use, invariably leading to irreversible rangeland degradation (Abel, 1993). However, recently the traditional pastoral systems have highlighted their compatibility with prevailing uncertainty of the physical, social and economic climate under which they opperate (Ellis *et al.,* 1993). Equilibrium based theoretical models and the resource management measures based on them are purported to have failed to predict successfully the behaviour of complex natural systems (May, 1977; Connell & Sousa, 1983).

There are number of alternative models proposed for addressing rangeland dynamics, these include the state and transition (Walker & Noy-Meir, 1989; Allen-Diaz & Bartolome, 1998), threshold (Friedel, 1991; Laycock, 1991) and catastrophe (Lockwood & Lockwood, 1993) models. These models are closely related and they focus on describing quasi-stable vegetation states, predicting the circumstances that trigger transitions to specific different states, and modelling these changes. They emphasize the non-linearity of vegetation responses to grazing and other environmental perturbations (Fernandez-Gimenez & Allen-Diaz, 1999).

The non-equilibrium persistent (NEP) model of rangeland dynamics (Ellis & Swift, 1988; Behnke & Scoones, 1993) focusses on the effects of abiotic factors on plant community and herbivore population dynamics. Ellis & Swift (1988) proposed that many rangeland ecosystems are dominated by density independent and abiotic factors, rather than density dependent and biological interactions. Furthermore, Oba *et al*. (2000) highlighted some ecological characteristics of a non-equilibrium system, which are generally inverse to the characteristics of an equilibrium system, *viz.* climatic variability, variability of primary productivity, livestock population is controlled by density independent factors and livestock track unpredictable forage production. Vegetation cover and plant productivity in the arid and semi-arid rangelands may be regulated by rainfall variabilty rather than herbivore density (Ellis & Swift, 1988).

The NEP model predicts that in arid and highly variable ecosystems abiotic factors such as precipitation have a greater influence on vegatation biomass and species composition than grazing (Fernandez-Gimenez & Allen-Diaz, 1999). The model also predicts that in moist and constant environments, grazing plays a greater role in regulating vegetation productivity and composition.

The climate-plant-herbivory interactive model is one of the new models in rangeland management and contributes to an improved understanding of the dynamics of sub-Saharan rangelands. Most importantly this model provides an opportunity to interpret more effectively the causes of land degradation in arid zones (Oba *et al*., 2000). The linkages between climate, plants and herbivory serve as ecological drivers that influence the dynamics of sub-Saharan rangelands (Oba *et al.*, 2000). The principal driver is the climate with its variability having a direct impact on the variability of plant cover and biomass. However, herbivory influence biomass, species diversity and the efficiency with which plants use rainwater. Pickup (1994), Rietkerk *et al*. (1997) and O’Connor (1994) indicated that in the arid zones vegetation growth epends on a number of factors: soil moisture, structure, and water storage capacity; rainfall patterns over several years; amounts of effective rainfall released; and duration of rainfall and season (Ellis & Swift, 1988).

Noy-Meir (1973) explained the two synergistic effects of rainfall and grazing on plant production. Firstly, rainfall, by increasing plant growth, increases food availability to herbivores. Secondly, moderately intense herbivory promotes productivity that is higher than in the absence of grazing. Understanding the interaction among climate, plants and grazing rather than trying to separate their effects would improve understanding of the dynamics of rangelands (Oba *et al.,* 2000). The climate-plant-herbivory interactive model has the components that describe responses of the rangelands to climate and grazing, it addresses linkages between components that describe the functions of grazing ecosystems, and the components are linked through complex, interactive ecological and physiological processes that serve as diagnostic parameters for measuring and monitoring responses of plants to rainfall and grazing.

Carrying capacity (CC) has been used a tool for rangeland management purposes and is usually expressed as the number of standardized livestock units (LU) of 250 kg that can be held per unit of land area. The major flaw with this concept is that it assumes that a unique population of livestock is directly associated with a defined grazing area of homogeneous forage growth and quality (Hary *et al*., 1996). The validity of CC is based on the premise that grazing systems behave as density dependent systems, and, therefore, rangeland productivity decreases with increasing stocking rates and *vice versa*. Rangeland production under arid and semi-arid conditions is more a function of climate. The amount of forage produced varies mainly according to the amount of rainfall, whereas forage quality is also affected by the length of the growing period. It is best at the peak of the growing season and declines rapidly until the beginning of the dry season (Hary *et al*., 1996).

#### 2.3.1.2.3 *Role of vegetation on restoration of degraded rangelands*

Vegetation plays an important role in erosive dynamics control, efficiently mitigating erosion by active and passive protection (Rey *et al*., 2004). Active protection against erosive agents consists of rain drop interception (Woo *et al*., 1997) and increased water infiltration in soils, thermal regulation and soil fixation by root systems (Gyssels & Poesen, 2003). Aboveground vegetation provides passive protection, by trapping and retaining sediments inside the catchment. (Abu-Zreig, 2001). Furthermore, vegetation prevents soil erosion by reducing the velocity of runoff and providing physical protection from scouring (Schwab *et al.,* 1993).

Protective soil cover can be installed efficiently on eroded lands using bioengineering works, based on common practices of ecological engineering. These structures make use of artificial and natural vegetation dynamics. Vegetation is prefered over structural measures since concrete, masonry, wood or any other building materials are subjected to decay, whereas vegetation can thrive and improve over many years and (Sarangi *et al*., 2004). The long-term goal of the degradation interventions is to restore sustainable ecosystems, in accordance with recent considerations about ecological engineering concepts and techniques (Gattie *et al.*, 2003; Odum & Odum, 2003). Restoration is commonly considered as accelerated succession (Hilderbrand *et al.*, 2005). Restoration thresholds are the occurrences of abrupt changes in ecosystem structure and function in response to a given restoration effort (Cortina *et al.*, 2006).

#### 2.3.1.2.4 *Rangeland restoration techniques*

Methods used for rangeland restoration consist of biological and mechanical approaches. The biological approach includes seed planting methods with manure, gravel and straw. The mechanical approach includes the use of farm implements to disturb the soil (Van der Merwe, 1997). The use of organic mulch to improve establishment of oversown grass seeds in degraded rangelands has been recommended. (Ricket, 1970; Winkel *et al*., 1991; Jordaan & Rautenbach, 1996).

The main objective of vegetation restoration is to create favourable micro-sites to enable seeds to germinate and establish themselves more successfully (Gebremeskel & Pieterse, 2008). Revegetation techniques are normally introduced when insufficient desirable forage plants remain on the rangelands (Vallentine, 1989) and when sound rangeland management practices cannot restore it to its original grazing potential (West *et al*., 1989; Jordaan, 1997). Hyder *et al*. (1971) and Stoddart *et al.* (1975) indicated that natural revegetation of perennial grasses is slow in many areas and, therefore, the introduction of species adapted to sowing is often desirable.

Revegetation methods have improved with the development of better techniques for seedbed preparation and planting methods to increase seed germination rate and establishment (Gebremeskel & Pieterse, 2008). Seed germination and establishment in natural and artificial revegetation is a result of the number of seeds in favourable micro-sites or 'safe sites' in the seedbed rather than the total number of available seeds (Harper *et al.*, 1965).

## 2.4 SUMMARY AND CONCLUSIONS

From the foregoing discussion on water harvesting techniques it is clear that the purpose of micro-catchments, both in croplands and rangelands, is to trap water for direct use by plant roots. The use of either mulch in croplands or brush in rangelands ensures that the trapped water is retained longer in the soil, reducing evapotranspiration. In rangelands brush has the added advantage of reducing defoliation of seedlings. Furthermore, the use of micro-catchments, brush or mulch reduces soil erosion.

Water harvesting techniques have been employed in arid areas of the world for many years to maximize the use of limited and erratic rainfall, and are particularly well documented for Sub-Saharan African, North African and West Asian countries. For example, the comprehensive review by Oweis *et al*. (2004) documents in detail the indigenous water harvesting systems found in Tunisia, Jordan, Morocco, Syria, Libya, Iraq, Egypt, Yemen and Pakistan, many of which have been in use for centuries. However, there appear to have been relatively few research studies conducted to quantify the effectiveness and sustainability of these techniques. Of the studies that have been done, some have concentrated on water harvesting for supplemental irrigation and domestic use, leaving very few which have focused on rangeland productivity techniques *per se*.

In South Africa water harvesting systems, especially indigenous ones have been in use for many years. Generally speaking, instances of implementation have been isolated, and, until recently, not well documented. The importance of water harvesting in South Africa has increased over the past few years and more interest has been shown as the technology has received greater attention. Denison & Wotshela (2009) reviewed indigenous water harvesting and conservation techniques in South Africa and found that the use of *Gelesha* (hoeing or tilling of soil after crop harvest) is not confined to the Eastern Cape, but is also found in other areas of the country. They also reported that *Saaidamme* (planting dams) are mainly used in the Northern Cape.

By far the most detailed research has been conducted by Hensley *et al.* (2000) and Botha *et al.* (2003a) on the in-field rainwater harvesting technique. *IRWH* has been implemented with great success by smallholder farmers on marginal clay soils in the Free State Province, where it has proven to be agronomically sustainable (higher crop yields), to reduce the risk of crop failures, to conserve the natural resources (no soil erosion), and to be economically viable and socially acceptable. Botha *et al.* (2003a) claim that the *IRWH* technique is a tool to empower people to fight food insecurity and poverty, and with this in mind it was decided to extend it to the Eastern Cape Province. However, given the fact that water conservation techniques are ecotope specific, and the limited extent of proven research studies on the suitability of the *IRWH* technique under different conditions, it will be necessary to evaluate its performance under the semi-arid conditions of the Eastern Cape.

Rainwater harvesting in rangelands is vital. Veld in good condition has a dense basal cover which ensures efficient harvesting and utilization of rainwater. Good basal cover also ensures that soil is protected against the erosive effect of rain. While basal cover is regarded as the basic measurement, it is also worth noting that canopy cover also plays an important role in reducing the direct impact of rain drops on the bare soil. Smallholder farmers should be encouraged to apply a camping system to enable part of the grazing area to rest for use during periods of feed shortages.

# 3 SOCIO-ECONOMIC AND BIOPHYSICAL BASELINE ANALYSIS OF THE TARGET AREA

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## 3.1 INTRODUCTION

The aim of this chapter is to present a situation analysis of the study area. The purpose of the situation analysis was to provide baseline information in terms of socio-economic and biophysical issues that could be used to plan the water harvesting project at selected sites in Alice. This chapter presents information on rural livelihoods and information systems, degree of poverty, government and organizations, long-term climatic description, veld and rangeland condition assessments and soil descriptions and analyses. A background description of the target area and the selected communities is provided as well as details on the methodology used to collect data.

## 3.2 BACKGROUND DESCRIPTION OF THE CENTRAL EASTERN CAPE PROVINCE

According to Van Averbeke (2000), the central Eastern Cape (Figure 3.1) covers an area of about 18 024 km$^2$, and incorporates 14 Magisterial Districts situated in two historical regions, namely the Border region, and the former Ciskei. The six districts situated in the Border region cover an area of 9 924 km$^2$, and the eight in former Ciskei 8 100 km$^2$. Agro-ecologically, the central Eastern Cape can be subdivided into five major entities. Four of these are encountered when travelling from the coast in a northerly direction, namely the Coastal Belt, the Coastal Plateau, the Amatola Mountains and the Midland Plateau. The valleys of the three major river systems that cut through all or some of the other four agro-ecological entities make up the fifth entity.

Stretching about 30-40 km inland, the Coastal Belt rises rapidly from sea level to an altitude of about 100 m and, thereafter, gradually to an altitude of about 300 m at the boundary with the Coastal Plateau. It is dissected by numerous steeply incised river valleys causing intense relief at local level. The mean annual rainfall increases from 600 mm in the southwest to about 850 mm in the northeast. The Coastal Belt receives most of its rain during summer, but the influence of cold fronts sweeping the southern edge of the continent, predominantly a winter phenomenon, causes approximately 40% of the rain to fall in winter. Moderated by the Indian Ocean, the climate is virtually frost-free, making it suitable for year-round production of a range of crops. These include selected sub-tropical fruits, of which pineapples are the most important economically. Soils are generally shallow and often prone to waterlogging, especially those situated on the level crests of the plateau. They usually show evidence of leaching, and have an acid reaction. This appears to provide them with a fair degree of resistance against erosion, and enables their cultivation on slopes exceeding 20% without excessive loss of soil, at least during the initial years. Cultivation occurs mainly on sloping land because of the waterlogged conditions that prevail on the level crests. The natural vegetation is dominated by Coastal Mixed Grassveld and Acacia Savanna, and the numerous steeply sloping river valleys are covered with Valley Bushveld. Natural vegetation is used for grazing for dairy farming around East London and beef production in areas away from this urban centre.

Geomorphologically, the Coastal Plateau is a continuation of the Coastal Belt, rising gradually from an altitude of 300 m in the south, and reaching an altitude ranging between 700 and 900 m at the edge of the Amatola-Winterberg mountain range. Climatically, the plateau differs considerably from the Coastal Belt. Compared with the Coastal Belt, the influence of the Indian Ocean is less distinct. It is hotter in summer and colder in winter and the proportion of rain falling in winter is typically between 20 and 30%. The rainfall pattern can be described as bimodal, because a mid-summer dry period separates the spring and autumn maxima. Generally, the climate is dry in the west, where the mean annual rainfall is about 500 mm, and gets wetter towards the east, where the mean annual rainfall may reach about 750 mm. Frost occurs throughout the winter, and the frost period increases from about 30 days in the south to 60 days in the north. As a result, the plateau has two growing seasons, namely a summer season during which crops sensitive to frost can be grown, and a winter season for frost-resistant crops. However, because of the bimodal rainfall distribution both summer and winter crops rely on stored soil water during some part of their growing cycle. As a result, successful cropping relies heavily on the adequacy of the water holding capacity of the soils being used. The natural vegetation is dominated by Acacia Savanna in the dry parts, and Dohne Sourveld in areas that are more humid. Soils react more or less neutral in the dry areas, and slightly too moderately acid in the wet parts. The general absence of deep and adequately drained soils causes the area of land suited to crop production to be limited to about 10% of the total area. Red soils of the Shortlands and Hutton type are the most productive. Derived from dolerite, they are usually deep, resistant to erosion, and chemically fertile. Most of the land is best suited to extensive livestock production, involving a combination of goats and cattle on Acacia Savanna, and cattle or sheep on Dohne Sourveld.

The Amatola Mountains run east to west, at a distance of about 70 km from the coast in the eastern part of the central Eastern Cape and about 120 km in the west. Rising sharply from the Coastal Plateau to an altitude ranging between 1500 and 2000 m, the southern slopes of the mountain range appear as a green forested belt. The sudden increase in altitude causes orographic rain, explaining why the southern slopes and mountain peaks enjoy a mean annual rainfall that is much higher than on the Coastal Plateau. A large portion of the mountain range, which has a width of only about 10-15 km, is under mature Afromontane forest, pine plantation, or wattle. The rest is covered with Dohne Sourveld, fynbos or scrub. The climate in the mountains is considerably cooler than on the Coastal Plateau, and misty conditions prevail during much of the year. Snow falls regularly during the winter, especially on the high peaks, but it seldom lasts longer than a few days. Rock outcrop and stony soils are found on the steep slopes, but pockets of deep Clovelly and Hutton type soils occur on gentler slopes. Due to the high rainfall, leaching conditions prevail, explaining why most soils react acid throughout their solum. Soils at the southern foot of the mountains are usually deep, lateritic, and often susceptible to erosion. The mountain range is the source and main catchment area of three important river systems, namely the Kat River, the Keiskamma and Tyhume Rivers, and the Buffalo River. Economically, the mountain range is well suited for forestation, but is also used for the production of cattle, goats and sheep. Cultivation is very limited, but climatically the area is suited for a range of high-value niche crops, such as seed-potatoes, cherries and proteas.

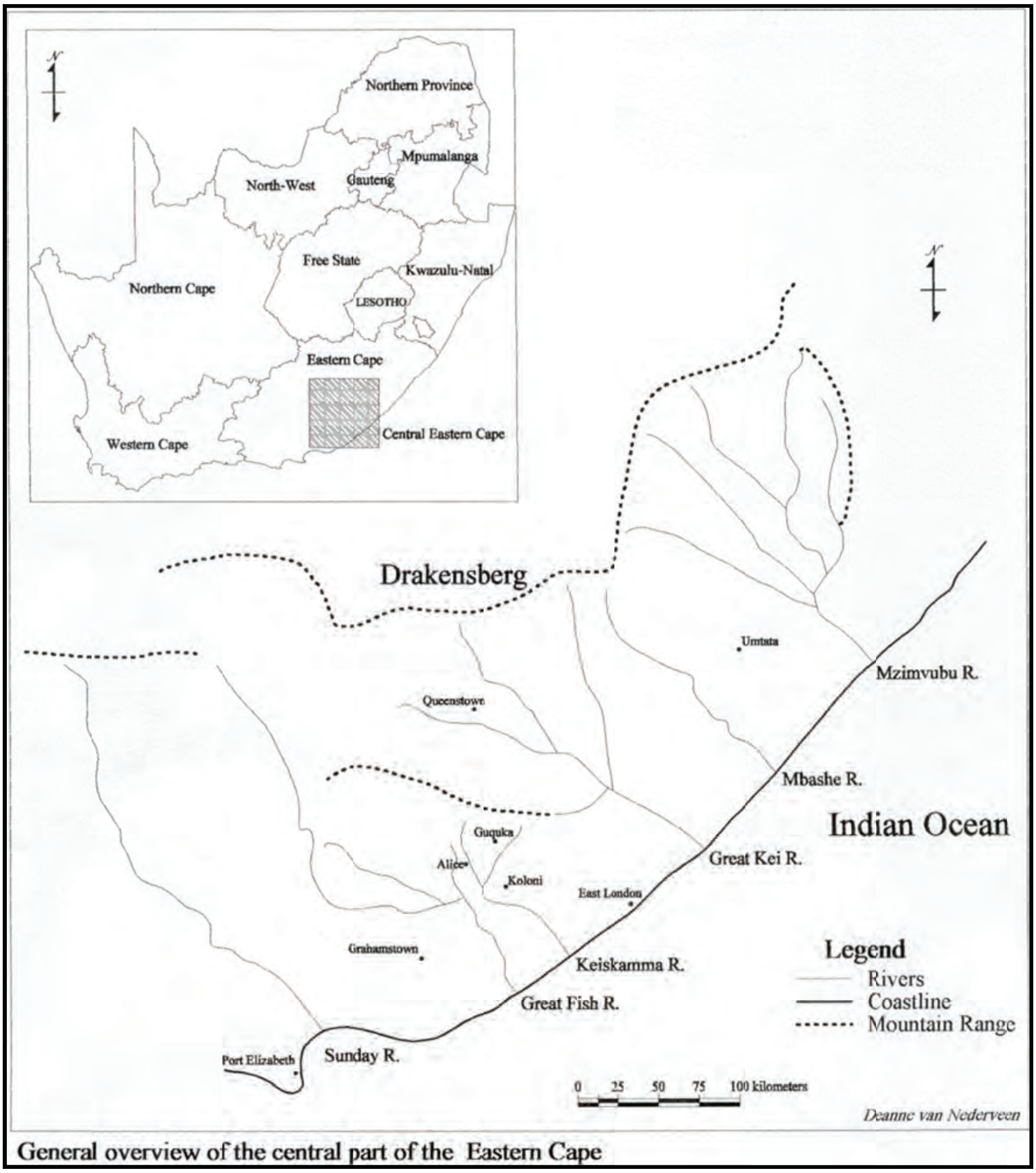


**Figure 3.1** General overview of the central part of the Eastern Cape (after Van Averbeke, 2000).

The study had several objectives. These were to:

1) identify existing livelihoods and farming systems,
2) analyse the degree of poverty in the area,
3) conduct veld condition assessment, and
4) analyse soils and climate.

## 3.3 MATERIAL AND METHODS

### 3.3.1 Selected communities

The area under investigation was the Tyhume Valley, which is located about 30 km north of Alice in the Nkonkobe Local Municipality, central Eastern Cape Province. The valley, which is traversed by the Tyhume River, is the home of the AmaKhuze Tribal Authority under Chief Mqalo. Within the Tyhume Valley the two villages Khayalethu and Guquka were selected for focussed attention. The villages lie just below the escarpment of the Amatola Mountains with the upper Tyhume River flowing past them. The Tyhume River acts as a border between Guquka and Khayalethu villages, which are home to 233 households and 220 households, respectively. Figure 3.2 shows the homesteads and landscape of the study area (Khayalethu in the foreground and Guquka on the upper slope).


**Figure 3.2** Homesteads and landscape of Khayalethu and Guquka.

Climatically, the area in which these villages lie can be described as semi-arid to sub-humid. The mean annual rainfall on the rangelands, which are situated on the mountains, ranges between 700 and 800 mm, making rainfed crop production possible. The villages lie in a veld type known as the Dohne Sourveld of the Eastern Cape. Sourveld is not well suited to livestock production as it is nutritionally deficient during the winter months and does not generally tolerate high grazing pressures. Although the mean annual rainfall seem to be sufficient to sustain the rangelands, the winter period is generally dry, with June and July being the driest months. Only 7% of the total annual rainfall occurs in these months, compared to roughly 70% in the months of October through March (Bennet, 2003). It becomes much drier towards the croplands and homesteads.

One of the reasons these villages were selected for the present study is that a lot of work has already been done by Agricultural and Rural Development Research Institute (ARDRI) researchers at the University of Fort Hare (UFH), who thus possess a great deal of socio-economic contextual understanding of the sites. Recent work showed, for example, that local households rely on external economic activities or sources of income, especially state grants, for more than 90% of their income (Monde, 2003; Monde *et al.*, 2005). However, the contributions of these external economic activities and sources do not ensure that rural households escape poverty. There is a high level of poverty in the area, with more than 80%

of households in the two villages having incomes that are below the poverty line, with some being so far below as to be categorized as 'ultra-poor' (i.e. those whose incomes fall below half the poverty line).

Among local economic activities, farming has traditionally been the most important. However, as in many other rural areas of the Eastern Cape, farming in Tyhume Valley has declined over time to where it presently consists primarily of home garden production. Home gardens are food plots within the boundaries of people's residential sites. In the study area, the average size of these gardens is about 300 $m^2$, ranging from 50 $m^2$ to 1500 $m^2$ depending on the size of the residential site. Home gardening contributes little to the overall diet of these people relative to food purchased from shops and supermarkets (Monde, 2003). However, this is not is not only due to the small size of the gardens, but also to the seasonal rainfall pattern, which means that food gardening is effectively limited to the rainy season. The challenge, therefore, is to improve community members' access to water as a means of improving their overall livelihoods. In principle, this would be of particular importance to poorer households for whom lack of own production during dry periods contributes to absolute deprivation.

One attempt to respond to this need came in the form of a water harvesting project that was initiated, managed and funded by the WRC and conducted by the ARC-ISCW together with the UFH. According to Duveskog (2001), 'water harvesting' is a term describing methods of collecting and concentrating various forms of runoff. In the case at hand, the technology that was introduced was *IRWH,* which consists of promoting rainfall runoff on a 2-m wide strip between alternate crop rows, and storing the runoff water in a basin. Water collected this way can infiltrate deep into the soil below the surface layer from which evaporation takes place. After the basins have been constructed, conservation tillage is applied to the land as a whole. *IRWH* has the potential to reduce total runoff to zero and thus make more water available to plants, resulting in improved yields. The technique was initially introduced in two households in each village, who volunteered to make their gardens available for use as demonstration plots. However, during the three-year period since the *IRWH* project was initiated, a number of other households have adopted the technology as well. By November 2010 there were 34 and 26 households in Guquka and Khayalethu, respectively that had implemented the technique in their gardens.

### 3.3.2 Socio-economic and farming system survey

A socio-economic survey was conducted during the period December 2004 to January 2005. The survey sought information on demography, income, expenditure and farming systems used farmers in Guquka and Khayalethu. An interview schedule (questionnaire) containing structured questions was used as the data collection instrument. A copy of the questionnaire is presented in Appendix 12. The unit of analysis was a household. Interviews were carried out with the heads of the households. If the head of a household was absent at the time of the interview, other senior members of the household were interviewed. Using a systematic sampling technique, a sample size of 105 households (59 in Khayalethu and 46 in Guquka) was selected.

Monde *et al*. (2000) and Fraser *et al*. (2003) analyzed the poverty status of households in two settlements in the central Eastern Cape, Guquka being one of the villages that was included in the analysis. Their method involved a comparison of the adult equivalent income of households with an absolute poverty line developed for the rural areas of South Africa by Carter & May (1999). In 1999, this poverty line was R476.30 per adult equivalent (AE) per month. Households with an AE income in excess of the poverty line were categorized as non-poor, and those with an AE income equal or less than half the poverty line (R238.15) as ultra-poor. Households with an AE income ranging between R238.15 and R476.30 were categorized as poor. The use of AE income removes the influence of household size and composition on the adequacy of a household income. The number of adult equivalents in a household is calculated as follows:

Number of AE per household = $(\frac{1}{2} \times \text{no of children} + \text{no of adults})^{0.9}$ ,whereby a child is a person aged 14 years old or less and an adult is a person aged 15 years or older.

To analyze the poverty status of households in Guquka and Khayalethu in 2005, the 1999 poverty line was adjusted using the CPI, which was achieved by multiplying the 1999 poverty line by a factor of 1.32, yielding a poverty line for January 2005 of R628.72.

### 3.3.3 Veld condition survey

The veld condition assessment was conducted on a total of fifteen sites, thirteen in Guquka and two in Khayalethu. The sites were selected according to five homogenous vegetation units, identified at both Khayalethu and Guquka. The homogenous vegetation units included grasslands occurring on plains, the bottom, middle, and upper slopes, and on open mountains. A species survey was conducted in each of the selected sample sites. The technique used for assessing condition of the grass sward is based a method developed by Trollope *et al.* (1992). The assessment of the condition of the herbaceous layer was based on its botanical composition and the basal cover of the grass sward. A point quadrat survey was conducted along two transects (located 25 m apart) at each of the sample sites to determine the botanical composition and basal cover of the grass sward. The relative frequency of the different herbaceous plants and the basal cover were recorded using 100 randomly placed points in each sample site, using a sharp stick that was placed every two steps along each transect (i.e. two rows of 50 points). The nearest rooted plant to each point and the number of strikes of living rooted plant material were recorded. The height of the standing crop was determined using a disc pasture meter.

The veld condition data was analysed using the method of Trollope *et al.* (1992). The benchmark site (BM) for the Dohne Sourveld area and its associated botanical composition was used to calculate of the grazing capacity and the veld condition score (VCS) of the sample sites in both communities. A special score sheet developed by Berkeling *et al.* (1995) was used to record the percentage frequency of each of the key grass species identified during botanical survey. The percentage of each key grass species was then multiplied with the coefficients to determine the forage score. The sum of different Decreaser and Increaser categories was determined. The veld condition score calculated using the formula: FS Site (A)/FS BM) x 100 = X, and the grazing capacity was determined using the formula: (FS BM/ FS Site (A)) x GC BM (Ha/AU) = X. The standing crop of grass was estimated using the regression of Trollope (1983).

### 3.3.4 Soil survey

Based on an earlier soil investigation by Hill Kaplan Scott & Partners (1976), on a scale of 1: 50 000, a general overview was obtained of the soils in the area. With the aim to elaborate and improve on this, over 200 holes were drilled with a hand auger and described within a 200-400 m distance distribution over the main study area. After this, a more detailed map with improved descriptions based on the later edition of the classification system (Soil Classification Working Group, 1991) could be compiled. Interpretations and interpolations were used to address the grazing areas, as described earlier.

Samples of topsoil and subsoil were taken and were analysed for clay percentage, exchangeable cations, cation exchange capacity (CEC), pH ($H_2O$ & KCl), organic carbon and P (Bray 1) (The Non-Affiliated Soil Analysis Work Committee, 1990). The sample sites are shown on the map in Appendix 5.

### 3.3.5 Climate survey

A homogeneous climate zone (HCZ) is defined as an area of homogeneity as far as climate factors such as topography and climate elements such as rainfall are concerned. The study area is covered by climate zones as defined by Dent *et al*. (1988) (HCZ 165) and Ehlers (undated) (67/25 and 57/14) (Figure 3.3). According to the Köppen climate classification the study area is classified as humid subtropical with the warmest month below 22ºC (Thackrah *et al*., 2002).

The ARC-ISCW Agro-climatology Databank was used to find the long-term climate data representative of the HCZ of the study area. This databank contains data collected by organizations including ARC-ISCW and the South African Weather Service (SAWS). One rainfall and one climate station were chosen to represent the area. The rainfall station Pleasant View (11106) best represents the study area with rainfall data for 39 years, from 1928 until 1968. Pleasant View is located at 32.67ºS and 26.9ºE at an altitude of 701 m above sea level and is 3 km west southwest from the study area. The weather station that best represents these climate zones is Keiskammahoek (30380), climate data of 9 years, from 1999-2008. It is located at 32.68ºS and 27.13ºE with an altitude 668 m above sea level, and is 19 km to the east of the study area (Figure 3.3).

The ARC-ISCW developed climate surfaces for South Africa with a grid resolution of 1 x 1 km. The surfaces were found to be accurate to within 1ºC for temperature and 10 mm for rainfall. They include maximum, minimum and average temperature, rainfall and sunshine hours surfaces on a 10-daily, monthly and annual basis. These climate surfaces were used to give a spatial representation of the study area.

3.4 RESULTS OF THE SITUATION ANALYSIS

### 3.4.1 Socio-economic description

3.4.1.1 Major land use categories in the study area

The land associated with these communities is generally divided into three major, relatively discrete categories, namely arable land, residential land and communal rangeland. These land categories are discussed separately below.

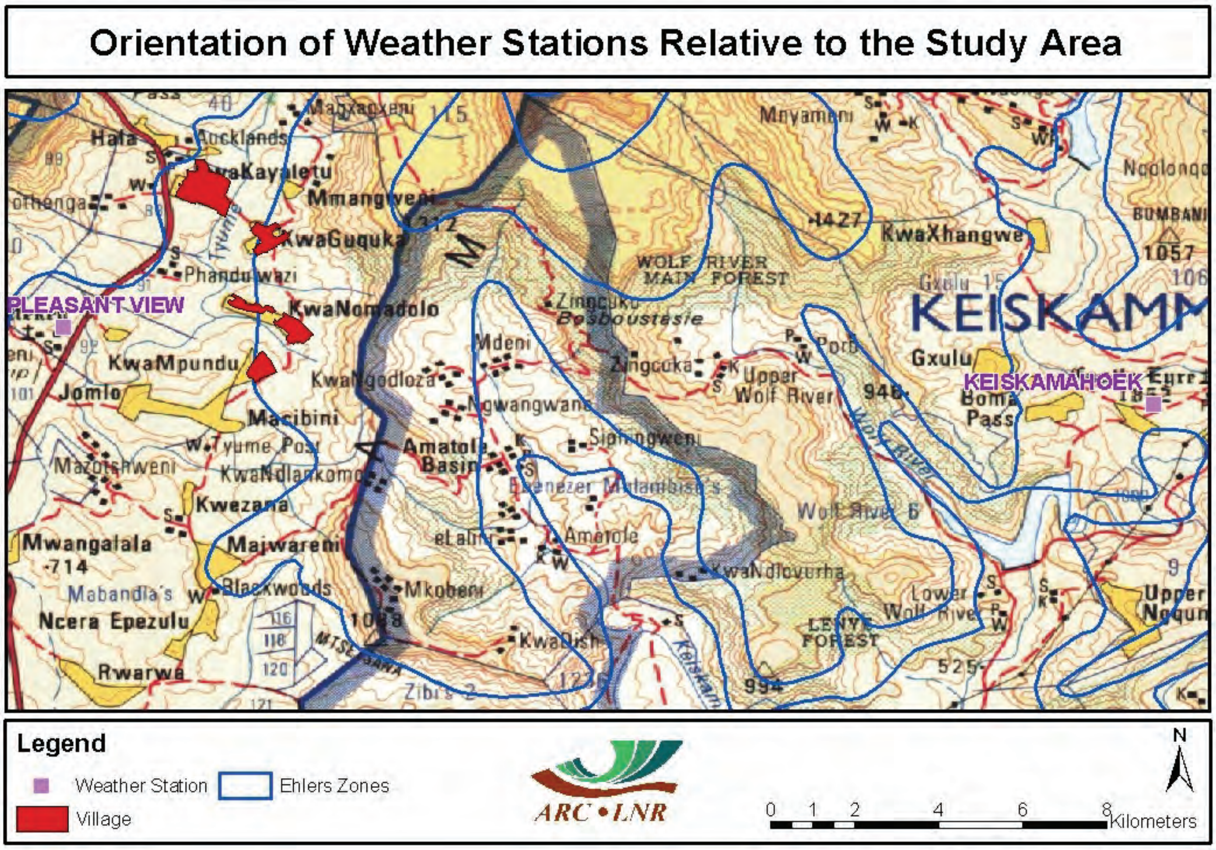


**Figure 3.3** Orientation of weather stations relative to the study area.

3.4.1.1.1 *Arable land*

The residents of Khayalethu do not own nor have access to arable land. In Guquka, arable land is estimated to cover an area of 160 ha divided into 41 individual fields. The sizes of fields range from 1-4.2 ha with a mean size of 3 ha. Crops grown in the fields are mainly grains (with maize as the main crop) and pulses. Field activities such as ploughing and planting are mainly done by a tractor hired from local tractor owners. Crop production is a rainfed system. Although agro-ecological conditions in Guquka favour rainfed maize crop production, only 10% of arable land was actually cropped during the 1997/98 cropping season (Bennet, 2003).

3.4.1.1.2 *Residential land*

Residential land (home gardens) was estimated to be 34 ha and 26 ha in Guquka and Khayalethu, respectively. Home gardens are food plots located within the boundaries of residential areas. The size of these plots ranges between 117 and 1500 $m^2$ with a mean of 392 $m^2$. Households grew both crops and vegetables in their gardens. These include maize, potatoes, pumpkins, cabbages, tomatoes, carrot, beet, onions, butternuts, beans, peas and spinach. Households showed a preference for maize and potatoes, allocating large plots to these crops. Potatoes were favoured because they are easily incorporated in a wide range of meals. Home gardening was a rainfed production system. However, some households do supplement water during drought periods from stock dams. Some also harvest rainwater for use in gardens. Figure 3.4 shows the type of water harvesting used in the area.

**Figure 3.4** Small dam constructed from soil, and lined with cement provides irrigation for home gardening.

3.4.1.2 Land tenure system in Guquka

Land at Guquka is held by means of ‘Permission to Occupy’ (PTO). In 1997 the PTO register in the Magistrates Court in Alice contained 59 registrations of residential sites, 1/8 morgen in size (Holbrook, 1998). In the same year 121 residential sites were counted in Guquka, leaving 62 unaccounted for in the register. In addition, only 41 individual fields were counted, meaning that 80 households did not own fields. Interviews with landowners and landless residents suggested that landless people could gain access arable land in one way only, namely through share-cropping. The local arrangement adhered to by land right holders demanded that share-croppers carry all production costs and handed over half of their crop yield to the land owner in return the use of their land. This share-cropping arrangement caused resentment on the part of past and potentially new share-croppers. Without exception they considered it unreasonable and said they would not enter or re-enter share-cropping agreements unless the terms were substantially revised. Most favoured a long lease (a minimum of 3-5 years) against payment of a pre-determined fee. Land right holders were not entirely against renting out their land, but they favoured a one-year arrangement, motivated it seemed by a fear of losing control over their land should they enter leases of longer duration. One of the important challenges to rural development in the region is to find out if enhancing the security of tenure in the PTO system can rally such fears and lead to an increase in exchanges of arable land.

#### 3.4.1.3 Physical capital

Guquka and Khayalethu are accessible by relatively good road systems. The settlements are within an hour's drive of centres with shops and financial and administrative services, most of this journey being on tarred roads. Residents make use of taxis that operate from locations about 5 km away from Guquka and 1 km away from Khayalethu. Each village has a primary school and secondary level education is available nearby. Similarly, residents have access to clinics in nearby locations (Gilton). At Khayalethu, there is a shop, but there only spaza shops in Guquka. The majority of residents make use of supermarkets in Alice. However, some make use of local shops in nearby villages. Almost all residents of both communities benefit from electrification although most use this principally as a source of lighting. A telephone service is available in both communities, but is not widespread. Guquka residents make use of water from the Tyhume River by fetching it or by using it at the river's edge. However, the installation of a set of stand-pipes in the centre of the village in 1998 has brought water closer to the residents of Guquka. Also, several small dams exist, which are used by both animals and residents.

#### 3.4.1.4 Governance and institutions

Governance at both villages appeared to have been transformed fundamentally. Under the previous Tribal Authority system, Guquka and Khayalethu were governed by a headman who was responsible for decisions at the village level. He in turn was responsible to the chief of the local Tribal Authority, who reported to the local magistrate. With the collapse of the Ciskei homeland system in the early 1990s, democratic structures of civil governance were adopted in most villages. A civil and elected body dominated by the younger generation replaced the headman and Tribal Authority. Members of the village leadership appeared to have been elected for their skills and ability to communicate and operate in the new political and administrative environment that was created in South Africa after 1994. The Residents Association (RA) makes decisions on village matters. People living in the village, or maintaining a home there, were eligible for membership of the RA. There is no evidence of any age or gender restrictions on membership. The Guquka RA holds its meetings on a weekly basis while such meetings in Khayalethu appear to be irregular and less frequent. The RA is led by a five-member 'Residents Committee', which is elected annually. Similar committees operate in Sompondo, Gilton and Mpundu, the three neighbouring villages of Guquka. These committees are represented on a combined ‘umbrella’ body. This body maintains direct contact with the Transitional Rural Council (TRC) of Victoria East, and represents the interests of the five settlements on the TRC. This model of village governance and the way in which it is linked with local government appears to be working quite well. It has been instrumental in bringing new developments to the five settlements, such as the installation of a windmill at Guquka in 1998, to pump groundwater from the valley to a central stand-pipe in the village.

3.4.1.5 Demographic characteristics

3.4.1.5.1 *Size and composition of households at Guquka and Khayalethu*

The size of households and the age of members of households surveyed in 2005 are presented in Table 3.1 for Guquka and Table 3.3 for Khayalethu. The mean household size at Khayalethu (6.6) was slightly larger than the mean at Guquka (5.7), but the difference was not statistically significant. The most important difference between the two settlements was that in Guquka the majority of households (76 %) were headed by males, whereas in Khayalethu the most (64 %) were headed by females. No child-headed households were encountered in either of the two villages. Another important fact was that the composition of households in both settlements did not conform to the conventional two adults and three children used by many researchers. Instead there was a predominance of adult members and a relative absence of children.

**Table 3.1** Size of households and age distribution of household members at Guquka (2005; n = 46)

| **Variable** | **Mean** | **Range** | **95% conf. interval** |
|---|---|---|---|
| Household size | 5.7 | 1-12 | 5.0-6.4 |
| Number of household members aged 65 or older | 0.5 | 0-1 | 0.3-0.7 |
| Number of household members aged 15 to 64 | 4.2 | 1-9 | 3.6-4.8 |
| Number of household members aged less than 15 | 1.0 | 0-6 | 0.7-1.3 |

**Table 3.2** Size of households and age distribution of household members at Khayalethu (2005; n = 59)

| **Variable** | **Mean** | **Range** | **95% conf. interval** |
|---|---|---|---|
| Household size | 6.6 | 1-13 | 5.8-7.4 |
| Number of household members aged 65 or older | 0.6 | 0-2 | 0.4-0.8 |
| Number of household members aged 15 to 64 | 4.6 | 1-11 | 4.0-5.2 |
| Number of household members aged less than 15 | 1.4 | 0-7 | 0.9-1.8 |

3.4.1.5.2 *Employment status of household members at Guquka and Khayalethu*

Table 3.3 shows the employment status of the heads of households at Guquka and Khayalethu. In both settlements five to six out of every ten households were headed by a retired person, and one to two out of ten by an unemployed person. Households headed by a person in formal employment constituted only 13% of the total number at Guquka and 19% at Khayalethu. The employment status of household members in the two villages is presented in Table 3.4. In Guquka, about one-third of the people were still at school (30%) and one-third were unemployed (29%). The remainder consisted mainly of people in formal employment

(18%) and retired people (13%). At Khayalethu the proportion of people that were employed was somewhat higher (23%) than in Guquka, but there was little difference between the two villages in terms of unemployment.

The employment status of the economically active section of the population in the two villages is presented in Table 3.3. The economically active consisted of individuals captured by the survey that were 15-64 years old.

**Table 3.3** Employment status of heads of households in Guquka and Khayalethu (2005)

| **Employment status** | **Guquka** | | **Khayalethu** | | **All** | |
|---|---|---|---|---|---|---|
| | No of households | Proportion of total (%) | No of households | Proportion of total (%) | No of households | Proportion of total (%) |
| Full-time formally employed | 4 | 8.7 | 6 | 10.2 | 10 | 9.5 |
| Part-time formally employed | 2 | 4.4 | 5 | 8.4 | 7 | 6.7 |
| Unemployed | 10 | 21.7 | 9 | 15.3 | 19 | 18.1 |
| Housewife | 5 | 10.9 | 3 | 5.1 | 8 | 7.6 |
| Retired | 24 | 52.2 | 36 | 61.0 | 60 | 57.1 |
| Scholar | 1 | 2.1 | 0 | 0.0 | 1 | 1.0 |
| **Total** | **46** | **100** | **59** | **100** | **105** | **100** |

**Table 3.4** Employment status of people in Guquka and Khayalethu (2005)

| **Employment status** | **Guquka** | | **Khayalethu** | | **All** | |
|---|---|---|---|---|---|---|
| | No of people | Proportion of total (%) | No of people | Proportion of total (%) | No of people | Proportion of total (%) |
| Full-time formally employed | 37 | 14.0 | 59 | 15.2 | 96 | 14.7 |
| Part-time formally employed | 11 | 4.2 | 31 | 8.0 | 42 | 6.4 |
| Informally employed | 1 | 0.3 | 1 | 0.2 | 2 | 0.3 |
| Unemployed | 76 | 28.8 | 121 | 31.1 | 197 | 30.2 |
| Housewife | 14 | 5.3 | 6 | 1.5 | 20 | 3.1 |
| Not working by choice | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Retired | 33 | 12.5 | 50 | 12.9 | 83 | 12.7 |
| Medically unfit | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Scholar (tertiary) | 2 | 0.8 | 2 | 0.5 | 4 | 0.6 |
| Scholar (prim. & sec.) | 77 | 29.2 | 101 | 26.0 | 178 | 27.2 |
| Pre-school | 13 | 4.9 | 17 | 4.4 | 30 | 4.6 |
| Other | 0 | 0.0 | 1 | 0.2 | 1 | 0.2 |
| **Total** | **264** | **100** | **389** | **100** | **653** | **100** |

The data presented in Table 3.5 provides evidence of the critical lack of economic development in rural settlements of the Ciskei region of the Eastern Cape. Among the economically active section of the population in both Guquka and Khayalethu, about four out of ten people were unemployed, two out of ten were still at school, one out of ten was either retired or housewife, and only three out of ten were employed. The high rate of unemployment among the economically active presents a picture of many young lives being wasted. This situation begs for development initiatives that offer scope for employment of the massive reserve of labour that exists in these settlements.

**Table 3.5** Employment status of the economically active population (aged 15 to 64) in Guquka and Khayalethu (2005)

| **Employment status** | **Guquka** | | **Khayalethu** | | **All** | |
|---|---|---|---|---|---|---|
| | No of people | Proportion of total (%) | No of people | Proportion of total (%) | No of people | Proportion of total (%) |
| Full-time formally employed | 37 | 19.1 | 59 | 21.8 | 96 | 20.6 |
| Part-time formally employed | 11 | 5.7 | 31 | 11.4 | 42 | 9.0 |
| Informally employed | 1 | 0.5 | 1 | 0.4 | 2 | 0.4 |
| Unemployed | 76 | 39.2 | 121 | 44.6 | 197 | 42.4 |
| Housewife | 14 | 7.2 | 6 | 2.2 | 20 | 4.3 |
| Not working by choice | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Retired | 11 | 5.7 | 13 | 4.8 | 24 | 5.2 |
| Medically unfit | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Scholar (tertiary) | 2 | 1.0 | 2 | 0.7 | 4 | 0.9 |
| Scholar (sec.) | 42 | 21.6 | 38 | 14.0 | 80 | 17.2 |
| **Total** | **194** | **100** | **271** | **100** | **465** | **100** |

3.4.1.6 Income of households at Guquka and Khayalethu

Mean monthly income of households in Guquka and Khayalethu and the sources from which this income was derived are presented in Table 3.6.

**Table 3.6** Mean monthly adult equivalent income of households at Guquka and Khayalethu (in cash and kind; 2005)

| **Source** | **Guquka (n = 46)** | | **Khayalethu (n = 59)** | | **All (n = 105)** | |
|---|---|---|---|---|---|---|
| | (R $month^{-1}$) | (%) | (R $month^{-1}$) | (%) | (R $month^{-1}$) | (%) |
| Remittances | 59.42 | 4.8 | 153.36 | 12.4 | 112.21 | 9.1 |
| Wages | 415.22 | 33.8 | 225.93 | 18.2 | 308.86 | 25.0 |
| Grants | 601.26 | 48.9 | 787.29 | 63.4 | 705.79 | 57.1 |
| Trade | 21.74 | 1.8 | 18.81 | 1.5 | 20.09 | 1.6 |
| Farming | 131.95 | 10.7 | 56.24 | 4.5 | 89.41 | 7.2 |
| **Total** | **1229.59** | **100** | **1241.63** | **100** | **1236.36** | **100** |

The mean monthly household income at Guquka differed little from that at Khayalethu. In both settlements social grants were the main source of income. When the data obtained in the two settlements are combined, social grants contributed nearly 60% to the mean household income. In Guquka, the contribution of grants to total income was lower (R601 and 49% of total) than in Khayalethu (R787 and 63% of total). The earning of wages or salaries in the formal sector was the second most important source of income, contributing 25% to the overall mean household income in both villages. This source was more important in Guquka (R415 and 34% of total) than in Khayalethu (R226 and 18% of total). Sales from gardening/farming by household members working elsewhere declined as a source of rural household income in the Ciskei during the last quarter of the 20th century. This corresponds to the establishment of a homeland administration and the implementation of a regional economic development policy. In 2005 gardening/farming contributed only 9% to the overall total income of households in Guquka and Khayalethu.

The data presented in Table 3.7 enables assessment of household income trends over the past eight years in Guquka. The 1997 and 1999 income data were obtained from Van Averbeke *et al*. (1998) and Fraser *et al*. (2003), respectively, and were adjusted to 2005 Rand values using the CPI index (Statistics SA, 2005).

**Table 3.7** Changes in mean monthly income in cash and kind of households at Guquka during the period 1997 to 2005 (1997 and 1999 Rand values were converted to 2005 Rand values using the CPI index)

| **Source** | **1997 (n = 78)** | | **1999 (n = 68)** | | **2005 (n = 46)** | |
|---|---|---|---|---|---|---|
| | (R month$^{-1}$) | (%) | (R month$^{-1}$) | (%) | (R month$^{-1}$) | (%) |
| Remittances | 158.89 | 13.1 | 131.58 | 13.3 | 59.42 | 4.8 |
| Wages | 462.69 | 38.1 | 246.57 | 25.0 | 415.22 | 33.8 |
| Grants | 487.93 | 40.1 | 522.33 | 52.9 | 601.26 | 48.9 |
| Trade | 52.79 | 4.3 | 14.93 | 1.5 | 21.74 | 1.8 |
| Farming | 53.30 | 4.4 | 71.76 | 7.3 | 131.95 | 10.7 |
| **Total** | **1215.60** | **100** | **987.17** | **100** | **1229.59** | **100** |

The data presented in Table 3.7 show a decline in the mean income of households in Guquka from 1997 to 1999 and a subsequent recovery. The 1999 decline was primarily associated with a dramatic reduction in the contribution of wages to mean household income, which was associated with retrenchment of service workers by the University of Fort Hare, one of the major employers in the area. From 1999 to 2005 there was a continued decline in the relative and absolute contribution of remittances to household income, and an increase in the relative and absolute contributions by wages and agriculture. The increase in mean total household income since 1999 did not trigger a recovery in village trade to the 1997 level, indicating that most households continue to purchase their food and other goods outside the village, as was the case in 1999 (Monde, 2003).

The contribution of a particular source to mean total household income is the product of the mean absolute value of the contribution of that source per household deriving income from that source and the number of households that derive income from that source. In Table 3.8 and Table 3.9 the contributions of the different sources to mean household income are analyzed in terms of these two components.

**Table 3.8** Number of households deriving income in cash or kind from different sources at Guquka and Khayalethu (2005)

| Source | Guquka (n = 46) | | Khayalethu (n = 59) | | All (n = 105) | |
|---|---|---|---|---|---|---|
| | Number of households | (%) | Number of households | (%) | Number of households | (%) |
| Remittances | 13 | 28 | 36 | 61 | 49 | 47 |
| Wages | 10 | 22 | 11 | 19 | 21 | 20 |
| Grants | 34 | 74 | 49 | 83 | 83 | 79 |
| Trade | 2 | 4 | 4 | 7 | 6 | 6 |
| Farming | 45 | 98 | 52 | 88 | 97 | 92 |

The data presented in Table 3.8 clearly show that among the different sources of rural household income, farming was the most important in terms of frequency, closely followed by social grants. In both settlements nearly all households (at least nine out of ten) derived income from farming, underlining the importance of this activity in the livelihoods of rural people. The proportion of households deriving income from social grants was also considerable (seven to eight out of ten). Remittances were the third most important source of income in terms of frequency, with nearly five out of ten households deriving income from this source in the two villages combined, but with marked differences between the two villages. Remittances to the rural homestead by members working elsewhere indicate the maintenance of relationships to the rural homestead and its members. Guquka dates back to the 19th century, and is much older than Khayalethu, which was established after 1950. Therefore, one would expect remittances to play a more important role in Guquka than Khayalethu, but this was not the case. A possible explanation may be that in Khayalethu the majority of homesteads are headed by (old) women, whereas in Guquka they are headed by (old) men, and that migrants are more likely to support their mothers than fathers. Fourth in line in terms of frequency were wages, with two out of ten households deriving income from paid employment, and last was trade, with less than one out of ten households deriving income from selling goods.

Table 3.9 provides insight into the livelihood orientation of rural people in South Africa, who typically consider ‘getting a job’ as the preferred livelihood option.

**Table 3.9** Mean monthly income in cash or kind derived from different sources by households deriving incomes from these sources at Guquka and Khayalethu (2005)

| Source | Guquka (n = 46) | Khayalethu (n = 59) | All (n = 105) |
|---|---|---|---|
| | (R per household) | (R per household) | (R per household) |
| Remittances | 210.26 | 251.34 | 240.44 |
| Wages | 1910.00 | 1211.82 | 1544.29 |
| Grants | 813.47 | 947.96 | 892.87 |
| Trade | 500.00 | 277.50 | 351.67 |
| Agriculture | 134.89 | 63.81 | 96.79 |

Note: Table 3.6 shows average monthly adult equivalent income while Table 3.9 shows average income per household. This means that incomes in Table 3.6 have been divided by the number of adult equivalents as opposed to number of households in Table 3.9, hence content is different

The data clearly show that for rural people wages earned through being employed is the most effective way to escape poverty. On average, for the two villages combined, income earned as wages was almost twice as high as income derived from social grants, which was second largest in terms of monetary value. Compared to mean monthly monetary value of wages and social grants, trade and remittances were a distant third and fourth, and mean monetary value derived from farming was least of all.

The analysis of the survey data presented in Table 3.1 through to Table 3.9 provided useful insights into the structure of the livelihoods of rural homesteads in the study area. In both villages, the dominant way in which these livelihoods were structured was to supplement monetary income from social grants with farming on a small scale. Urban migration of household members in search of employment provided another source of income through remittances, which were particularly important in terms of frequency in Khayalethu. A minority of rural households, about one in five, structured their livelihood around paid employment, again supplemented by farming. Indications were that these were the richest among the population. In the next section the relationships between livelihoods and poverty status of households in the study area are explored in more detail.

#### 3.4.1.7 Poverty status of households in Guquka and Khayalethu

For the analysis of poverty status, the size and composition of households were redefined as a function of consumption. All members of a household, who spent at least one night at home every week, were considered part of the consumptive unit and were considered to take part in the consumption of the income available to the rural homestead, irrespective of the number of nights they spent at the homestead. Members of households, who were at home less frequently once per week, were not considered to be part of the consumptive unit. In Table 3.10 and Table 3.11 the mean size of the consumptive units is compared with the mean size of the households for Guquka and Khayalethu, respectively.

**Table 3.10** Comparison between mean size of households and mean size of households as consumptive units at Guquka (2005; n = 46)

| Variable | Mean household size | Mean size of consumptive unit | Members living elsewhere |
|---|---|---|---|
| Household size | 5.7 | 4.9 | 0.8 |
| Number of household members aged 65 or older | 0.5 | 0.5 | 0.0 |
| Number of household members aged 15 to 64 | 4.2 | 3.4 | 0.8 |
| Number of household members aged less than 15 | 1.0 | 1.0 | 0.0 |

**Table 3.11** Comparison between mean size of households and mean size of households as consumptive units at Khayalethu (2005; n = 59)

| Variable | Mean household size | Mean size of consumptive unit | Members living elsewhere |
|---|---|---|---|
| Household size | 6.6 | 5.5 | 1.1 |
| Number of household members aged 65 or older | 0.6 | 0.6 | 0.0 |
| Number of household members aged 15 to 64 | 4.6 | 3.6 | 1.0 |
| Number of household members aged less than 15 | 1.4 | 1.3 | 0.1 |

In both villages the mean size of households, when defined as a consumptive unit, was smaller than the mean household size, by 0.8 members in Guquka and by 1.1 members in Khayalethu. The results presented in Table 3.10 and Table 3.11 also shows that it was primarily the adult members of households who lived elsewhere. When defined as consumptive units, the mean number of adult equivalents per homestead was 3.43 in Guquka, and 3.58 in Khayalethu.

In Table 3.12 information on the adult equivalent (AE) incomes of households, defined as consumptive units, are presented for Guquka and Khayalethu. The households have been subdivided into the three poverty categories as defined earlier.

In Guquka, where the mean monthly AE income in 2005 was R414.75, 20% of households were categorized as non-poor, 35% as poor, and 45% as ultra-poor. In Khayalethu, where the mean monthly AE income in 2005 was R390.79, 10% of households were categorized as non-poor, 34% as poor, and 56 % as ultra-poor. It follows that at the time of the survey the poverty rate was 80% in Guquka and 90% in Khayalethu.

**Table 3.12** Adult equivalent incomes of households, defined as consumptive units, for Guquka and Khayalethu in 2005 according to poverty status

| | Non-poor | Poor | Ultra-poor | All |
|---|---|---|---|---|
| | **Guquka** | | | |
| Frequency | 9(20%) | 16(35%) | 21(45%) | 46 |
| Mean AE (R $month^{-1}$) | 934.61 | 411.84 | 194.17 | 414.75 |
| Highest AE (R $month^{-1}$) | 1894.14 | 578.34 | 291.31 | 1894.14 |
| Lowest AE (R $month^{-1}$) | 660.45 | 316.69 | 47.77 | 47.77 |
| | **Khayalethu** | | | |
| Frequency | 6(10%) | 20(34%) | 33(56%) | 59 |
| Mean AE (R $month^{-1}$) | 1206.05 | 429.39 | 219.17 | 390.79 |
| Highest AE (R $month^{-1}$) | 2268.16 | 570.31 | 313.54 | 2268.16 |
| Lowest AE (R $month^{-1}$) | 671.33 | 319.30 | 63.40 | 63.40 |

3.4.1.8 Poverty status and expenditure patterns among households in Guquka and Khayalethu

Overall mean total monthly expenditure per AE of households exceeded mean monthly total income by R67.80 (16%) in Guquka and by R40.01 (10%) in Khayalethu. When estimating household income, expenditure data are usually a more reliable indicator than income. Since the difference between income and expenditure was important, the categorization of the poverty status of households was repeated, using mean monthly total expenditure per adult equivalent. The results of this analysis are presented in Table 3.13. Table 3.13 shows that the use of expenditure data to categorize households into poverty categories did not affect poverty rate in either of the villages, but it did reduce the depth of poverty. Compared to the analysis based on income data, the use of expenditure data resulted in a larger number of households being categorized as poor rather than ultra-poor in both settlements. The rate of ultra-poverty was reduced from 46% to 30% in Guquka, and from 56% to 37% in Khayalethu.

**Table 3.13** Comparison of the frequency of households at Guquka and Khayalethu in different poverty categories when using adult equivalent income and adult equivalent expenditure (2005)

| | **Non-poor** | **Poor** | **Ultra-poor** | **All** |
|---|---|---|---|---|
| | **Guquka** | | | |
| Frequency based on income | 9 | 16 | 21 | 46 |
| Frequency based on expenditure | 9 | 23 | 14 | 46 |
| | **Khayalethu** | | | |
| Frequency based on income | 6 | 20 | 33 | 59 |
| Frequency based on expenditure | 6 | 31 | 22 | 59 |

Expenditure of households in the three poverty categories is shown in Table 3.14 for Guquka and Table 3.15 for Khayalethu.

Expenditure on purchased food was calculated from expenditure on groceries. Previous work in the area had shown that households were able to accurately recall their expenditure on groceries, as in most cases groceries were purchased once a month. Work by Monde (2003) showed that groceries consisted of food and items used in cleaning and personal hygiene. She monitored grocery purchases of a selection of households in Guquka and Khayalethu and determined the proportion of the value of grocery purchases that was spent on food and non-food items in each poverty category. These results were used in a report on expenditure patterns of households by Fraser *et al*. (2003). In the 2005 analysis of expenditure patterns of households in Guquka and Khayalethu, the food/non-food ratios that applied to the three poverty categories in Guquka and Khayalethu combined, were used to calculate grocery expenditure on food and on items used for cleaning and personal hygiene.

The analysis of the relationship between poverty status and household expenditure pattern presented here differs from that by Fraser *et al*. (2003) in that farm produce that was consumed by the producer households was added to expenditure. This means that the total value of produce obtained by farming was taken as income, and that farming contributed in two ways to expenditure, *viz.* as food consumed and as money spent on agricultural inputs. In this way expenditure on food, which is of primary concern to the water harvesting project, was estimated more accurately.

**Table 3.14** Mean monthly expenditure per adult equivalent of households in the three poverty categories at Guquka (2005)

| Expenditure | Non-poor (n = 9) | Poor (n = 23) | Ultra-poor (n = 14) | All (n = 46) |
|---|---|---|---|---|
| | (R $month^{-1}$ $AE^{-1}$) | | | |
| Purchased food | 232.45 | 134.02 | 90.25 | 139.96 |
| Own food consumption | 97.27 | 78.71 | 43.95 | 71.76 |
| Energy | 54.61 | 36.40 | 20.15 | 35.01 |
| Education | 73.87 | 19.35 | 10.28 | 27.25 |
| Health | 41.27 | 27.34 | 5.54 | 23.43 |
| Cleaning & personal hygiene | 23.13 | 9.76 | 5.75 | 11.15 |
| Agriculture | 10.35 | 2.91 | 0.28 | 3.56 |
| Labour | 15.98 | 0.00 | 0.00 | 3.13 |
| Transport | 47.55 | 12.49 | 5.19 | 17.12 |
| Telecommunication | 23.49 | 9.08 | 1.01 | 9.45 |
| Clothing | 51.67 | 31.20 | 9.32 | 28.54 |
| Furniture | 43.71 | 14.08 | 3.99 | 16.80 |
| Maintenance | 47.33 | 7.51 | 0.60 | 13.20 |
| Church | 30.90 | 3.78 | 1.57 | 8.41 |
| Subscriptions | 15.68 | 2.85 | 2.90 | 5.37 |
| Entertainment | 28.96 | 7.12 | 2.33 | 9.94 |
| Interest | 11.91 | 0.00 | 0.00 | 2.33 |
| Savings | 177.46 | 38.82 | 6.61 | 56.14 |
| **Total** | **1027.59** | **435.42** | **209.72** | **482.55** |

**Table 3.15** Mean monthly expenditure per adult equivalent of households in the three poverty categories in Khayalethu (2005)

| Expenditure | Non-poor (n = 6) | Poor (n = 31) | Ultra-poor (n = 22) | All (n = 59) |
|---|---|---|---|---|
| | (R $month^{-1}$ $AE^{-1}$) | | | |
| Food purchases | 288.43 | 125.95 | 98.71 | 132.32 |
| Own food production | 76.69 | 50.95 | 25.07 | 43.92 |
| Energy | 81.05 | 32.29 | 19.23 | 32.38 |
| Education | 9.08 | 13.78 | 4.99 | 10.02 |
| Health | 66.20 | 17.82 | 5.54 | 18.16 |
| Cleaning & personal hygiene | 28.70 | 9.17 | 6.28 | 10.07 |
| Agriculture | 19.67 | 3.66 | 0.86 | 4.25 |
| Labour | 46.56 | 7.01 | 0.00 | 8.42 |
| Transport | 41.56 | 13.78 | 6.44 | 13.87 |
| Telecommunication | 46.45 | 10.92 | 4.25 | 12.05 |
| Clothing | 121.45 | 32.53 | 9.45 | 32.97 |
| Furniture | 1.40 | 27.05 | 0.00 | 14.35 |
| Maintenance | 36.03 | 4.77 | 2.26 | 7.01 |
| Church | 25.34 | 13.80 | 4.94 | 11.67 |
| Subscriptions | 0.00 | 2.39 | 1.54 | 1.83 |
| Entertainment | 51.35 | 12.66 | 3.35 | 13.12 |
| Interest | 0.00 | 1.50 | 1.17 | 1.23 |
| Savings | 333.30 | 45.28 | 14.71 | 63.17 |
| **Total** | **1273.26** | **425.31** | **208.79** | **430.81** |

The results presented in Table 3.14 and Table 3.15 show the effects of poverty on the quality of life of rural households. Poor households spent on average 40-60% more money on food purchases than non-poor households and between 34 and 39% more ultra-poor households. Monde (2003) showed that differences in expenditure on food among households in the three poverty categories were closely associated with differences in the nutritional adequacy of the diets. Typically, the food intake of the ultra-poor was deficient in fats, proteins, and in some cases even in energy. Other indicators of the close relationship between poverty and quality of life were reductions in the amount of money spent on education, health, maintenance and durables and semi-durables with increasing depth of poverty.

The results also show that vulnerability to stresses and shocks increases with depth of poverty. Saving is an important way to protect a household against stresses and shocks. On average non-poor households in Guquka allocated 17% of their expenditure to savings, and in Khayalethu 26%. In the case of poor households this allocation was reduced to 9% in Guquka and 11% in Khayalethu. For ultra-poor households the allocation to saving was 3% in Guquka and 7% in Khayalethu. Non-poor households, and to a lesser extent poor households, made use of a variety of saving vehicles, both formal and informal. Ultra-poor households limited their savings to particular vehicles. This was particularly striking in the case of Guquka, where without exception the only vehicle used by ultra-poor households to save was burial clubs. These clubs only provide financial assistance to members in cases of bereavements, and do not offer protection against any other stresses or shocks.

3.4.1.9 Agriculture and food acquisition in Guquka and Khayalethu

Maize is popular as a vegetable (green mealies) and also as grain when it is dry. Dry maize is usually stored in old rainwater tanks (Figure 3.5). When dry it is processed into samp (broken grain) or meal. Households produce their own maize samp by crushing dry maize grain in a wooden mortar using a metal pestle (Figure 3.6). They obtain maize meal using the milling machine of the Phandulwazi Agricultural High School, which is situated across the Tyhume River from Guquka and adjacent to Khayalethu.

**Figure 3.5** An old rainwater tank is used to store maize.

**Figure 3.6** Woman processing maize into samp at home.

The data presented in Table 3.14 and Table 3.15 underline the importance of agriculture in the food security of households in both villages.

In Guquka, 34% of total mean monthly household expenditure on food was attributable to own production. The absolute value of the contribution of own food production to total expenditure on food declined with depth of poverty from a mean of R97.27 per AE per month among the non-poor, to R78.71 among the poor and R43.95 among the ultra-poor. In relative terms this contribution was highest among the poor (37%), followed by the ultra-poor (33%) and lowest among the non-poor (30%).

Own production of food was less important in Khayalethu than in Guquka, forming only 25% of total household expenditure. The difference in the contribution of own food production between the two villages is most probably linked to differences in access to land. Khayalethu has neither rangeland nor arable land designated specifically for use by its inhabitants. In Guquka both these land resources are available. As was the case in Guquka, the absolute value of the contribution of own production to total mean expenditure on food declined with depth of poverty, from R76.69 in the case of non-poor households to R50.95 among poor households and R25.07 among the ultra-poor. In relative terms this contribution was highest among the poor (29%), followed by the non-poor (21%) and lowest among the ultra-poor (20%).

### 3.4.2 Biophysical description

#### 3.4.2.1 Climate

In order to characterize climate in Guquka and Phandulwazi; two weather stations (Pleasant View and Keiskammahoek) were used. Maritz (2004) reported that the long-term climate data indicates that the area is semi-arid with an aridity index of 0.35. The mean annual precipitation for the study area is 607 mm. The study area receives 69% of its annual rainfall between October and March. Error bars in Figure 3.7, which indicate the standard deviation of monthly rainfall, show that the area will receive rainfall 68% of the time (2 out of 3 years) between these values. Rainfall for December, for example, will be between 23.5 and 115.8 mm in 2 out of 3 years. Rainfall will be below (or above) the standard deviation 16% of the time (3 out of 20 years). Hailstorms normally occur during the late afternoon and early evening, when hard hail is more common. Over this region there are on average, at any one given point, two hail events a year. (Schulze, 1997). They usually occur during late spring

(November), when the lapse rates are steep and temperatures high. The lapse rate is the rate at which temperature falls with increasing height (Preston-Whyte & Tyson, 1988). The mean annual temperature is 15.6ºC, with the maximum peaking in February at 30ºC and a minimum of 5.6ºC in July. A frost day is defined as a day with temperatures below 0ºC. The average length of the frost season is 124 days, starting on 13 June and lasting until 15 October. The earliest date and latest dates on which frost was recorded were 2 June and 14 November respectively. On average 6 frost days occur per season, mainly in July.

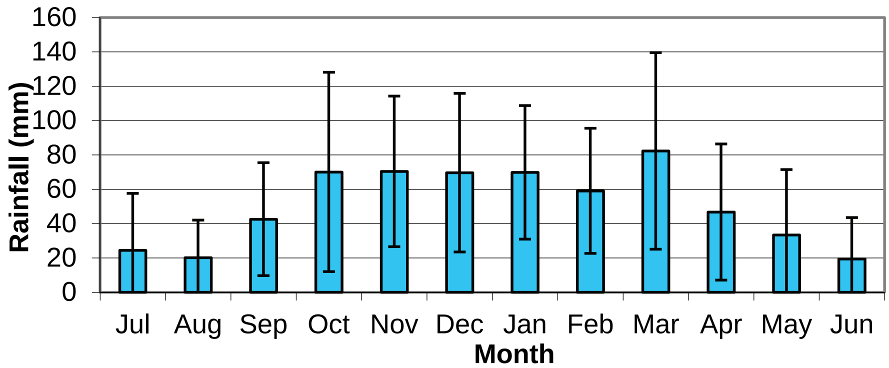


**Figure 3.7** Average and standard deviation of monthly rainfall for the study area.

3.4.2.2 The condition of the rangeland

The study area falls within the Amakuze Tribal Authority (ATA) area which was established in the late 1890s and the villages within this tribal area share the rangelands of approximately 400 ha (Van Averbeke *et al.*, 1998). Administratively, the ATA falls within the boundaries of Amatole District Municipality (Hebinck, 2007). These villages were subjected to limited betterment planning during the early 1960s to the extent that rangeland and arable land were fenced off from the residential section of the village.

Livestock grazing at the ATA is described as open-access with little institutional control on the rangeland area (Bennett & Barrett, 2007). During summer months animals free-range to the upper reaches of the rangeland and are rarely kraaled; however, small stock are kraaled at night to prevent predation and theft.

Some efforts are made to reserve available forage on arable lands for livestock during the dry season (Bennett & Barrett, 2007). Decisions to open and close the arable lands for grazing by livestock are taken democratically on a community basis through a meeting of the RA, which is composed of all adult members of the community and is responsible for key decisions concerning resource management (Bennett & Barrett, 2007).

The communal grazing land in Guquka and Khayalethu is shared among community participants and to a lesser extent with other nearby communities. The total area is estimated to cover an area of 578 ha. The boundaries of the community grazing land are well defined in relation to residential and arable blocks, but the high elevation grazing land shared by several communities is not well defined. Cattle may be found at or around the summits of the mountain terrain at 1600-1650 m, but much of this formerly valuable high elevation grazing resource has been lost or degraded.

Apart from nearby indigenous forest, two major vegetation units occur, namely, mixed grassland and Karoo shrubs on the bottomlands and lower slopes, and grassland on the mid- to upper slopes. The grazing area is managed as one camp. The local veld type is a combination of Dohne and Highland Sourveld (Acocks, 1988). These sour veld types are not well suited to livestock production, as they are nutritionally deficient during the winter months and do not generally tolerate high grazing pressures. Both cattle and sheep are forced to compete for available forage on the arable lands during the winter. Preferred grazing resources such as crop residues are quickly exhausted and thereafter shortage of adequate winter forage becomes a real problem in the village. The lack of central control over grazing exacerbates the problem and has, in many cases, forced livestock production efforts to devolve to the individual level. Under current constraints this seems likely to continue.

In terms of forage production potential the condition of the veld in Guquka can be regarded as fair as indicated by an average veld condition score of 66%. This was translated to a mean grazing capacity of 3 ha $AU^{-1}$ (based on a grazing area of approximately 400 ha). The recommended stock number is therefore 133 AU. Both veld condition score and grazing capacity are very good compared to the veld condition score of 51% and the grazing capacity of 6 ha $AU^{-1}$ observed by ARDRI researchers in 1996. Good veld condition was also indicated by the higher percentage of Decreaser species at 31%, while the presence of abundant Increaser II species was a slight indication of over-utilization of the grazing area. Overstocking of this area can be attributed to the fact that this grazing area is shared with the neighbouring communities. However, the level of overstocking may be reduced by as much as half if livestock range substantially further than the indicated area. A very high stocking rate is reflected in the poor condition of the range. There are a large number of Increaser species including large quantities of the unpalatable Karoo shrub *Chrysocoma tennuifolia,* which is a widely accepted indicator of overgrazed veld (Trollope, 1986). This undesirable species dominated on the bottom lands and lower slopes, and grassland on the middle and upper slopes at higher altitudes.

The basal cover, which is an indicator of resistance to soil erosion, was excellent in this area as the average distance from the recording point to the nearest tuft was less than 0.5 cm. This is also an indication of excellent protection against soil erosion through reduced runoff. It should be noted that the dense basal cover can be attributed to the presence of *Richardia humistrata*, probably induced by a heavy grazing pressure as the plant is not utilized by livestock. Canopy cover was not at its best due to continuous utilization of the grass sward by livestock, as no veld management practices are used in the area. The average height of the grass sward was slightly more than 3.5 cm indicating a closely grazed and a short stand of grass. The standing crop of grass this was estimated at an average of about 1700 kg $ha^{-1}$ using the regression of Trollope (1983). This biomass yield did not vary a great deal and ranged from 1200 to 1800 kg $ha^{-1}$. However, much of this biomass (up to 35% on average) is contributed by the Karoo shrub.

The two sites that were surveyed in Khayalethu were in a better veld condition than Guquka with an average veld condition score of 86% and a mean grazing capacity of 2.3 ha $AU^{-1}$. At Khayalethu the basal cover was also better, with an average distance from the recording point to the nearest tuft estimated at less than 0.2 cm. It must be noted that the percentage of the herbaceous species *R. humistrata* was even higher at Khayalethu at 21% compared to 11% at

Guquka. This may be responsible for the better basal cover. The higher occurrence of *R.humistrata* can be attributed to the fact that even though this community has no grazing area of its own, a large number of animal are owned by the villagers. The height of the standing crop of grass was on average 3.3 cm, which was comparable to Guquka.

#### 3.4.2.3 Soils

##### 3.4.2.3.1 *Introduction*

Soils found in the study area were not easy to classify according to the classification system of Soil Classification Working Group (1991) for a number of reasons set out below.

Firstly, there was a large colour variation between the moist and dry state of the top soils, and, more importantly, the sub-soils, that were encountered over most of the study area. The colour tends to be very dark greyish in the moist state, especially when augured, but after drying out, it changes in some cases to the bleached grey colour that forms the overall impression of the soils of the area. All of the inspection holes produced soil in the moist condition and understandably, it was neither practical nor feasible to wait for the drying out process in every case. This sometimes impeded decision making regarding the choice between two possible horizons in the subsoil, namely E or B. The colour of the soils is therefore described in the moist state, as was encountered when augured.

Secondly, the second and third layers found in a large number of the augured holes contained large amounts of fragments termed concretions, which it was suspected were not derived from wet conditions in the soil profile as is normally the case, but can rather be attributed to previous geological events in historical times. In some locations these concretions were cemented together, but not always in an unbreakable form, a requirement of the classification system in order to diagnostically classify it as a ferricrete or hard plinthite. In some cases it was breakable by hand, even though a cementing agent was noticeable. This soil also did not fit the requirements for hard plinthite and no provision is made for it elsewhere in the classification system.

Lastly it was difficult to estimate clay content due to the high silt content in all these soils. However, based on experience with the soils of the Transkei and soil analysis data in Appendices 9-10, the field estimations are assumed to be correct.

With this in mind, the following soils were found to dominate the study area: Cartref (**Cf**), Wasbank (**Wa**), Vilafontes (**Vf**), Oakleaf (**Oa**) and Longlands (**Lo**). Due to only small variations in colour that place a soil either just inside or outside a requirement, some of the above-mentioned soil forms are actually closely related (see discussion of each soil association unit below). All these soil forms, together with sub-dominant soil forms, were described and mapped into ten soil association units. Three further land classes were encountered. All the units and land classes are represented on the accompanying map and a description of each is contained in the map legend.

**Table 3.16** Long-term monthly and annual climate data from Keiskammahoek (1999-2008) and Pleasant View* (1928-1968)

| Element | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain | 70 | 59 | 82 | 47 | 33 | 19 | 24 | 20 | 43 | 70 | 70 | 70 | 607 |
| T * | 20 | 20 | 19 | 16 | 14 | 12 | 12 | 13 | 14 | 16 | 17 | 19 | 190 |
| Rs | 23 | 21 | 18 | 15 | 12 | 11 | 12 | 15 | 18 | 20 | 23 | 24 | 212 |
| U2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| RH * | 73 | 73 | 72 | 70 | 62 | 58 | 52 | 56 | 62 | 66 | 70 | 70 | 784 |
| Tx | 27 | 28 | 27 | 23 | 22 | 20 | 20 | 20 | 22 | 23 | 25 | 26 | 284 |
| Tn | 15 | 15 | 13 | 10 | 7 | 5 | 4 | 5 | 7 | 9 | 12 | 14 | 114 |
| RHx | 92 | 92 | 91 | 92 | 88 | 85 | 82 | 86 | 89 | 89 | 91 | 91 | 1067 |
| RHn | 46 | 45 | 43 | 40 | 32 | 29 | 26 | 29 | 33 | 38 | 40 | 43 | 445 |
| HU | 240 | 251 | 220 | 160 | 113 | 85 | 92 | 103 | 117 | 150 | 182 | 216 | 1930 |
| CU | -477 | -486 | -404 | -181 | 12 | 124 | 89 | 69 | 21 | -125 | -253 | -398 | -2009 |
| DPCU | 0.87 | 0.76 | 1.64 | 4.03 | 7.52 | 9.85 | 8.94 | 8.9 | 7.63 | 4.86 | 3.24 | 1.71 | 60 |
| ET0 | 168 | 141 | 136 | 104 | 94 | 82 | 94 | 110 | 123 | 143 | 156 | 172 | 1522 |
| AI | 0.45 | 0.40 | 0.55 | 0.46 | 0.29 | 0.16 | 0.21 | 0.41 | 0.41 | 0.29 | 0.41 | 0.38 | 0.38 |

| | | | | | |
|---|---|---|---|---|---|
| Rain | Average total rainfall | (mm) | T* | Average daily temperature (calculated from hourly values) | (°C) |
| A-Pan | Average daily evaporation [Class A pan] | (mm) | U2 | Average daily wind speed | ($km.day^{-1}$) |
| AI | Aridity Index | | HU | Heat units | (ºC) |
| RHx | Average daily maximum relative humidity | (%) | CU | Cold units | (ºC) |
| RHn | Average daily minimum relative humidity | (%) | DPCU | Daily positive chilling units | (ºC) |
| RH* | Average daily relative humidity (calculated from hourly values) | (%) | | | |
| Rs | Average total radiation | ($MJ\ m^{-2}$) | | | |
| Tn | Average daily minimum temperature | (°C) | | | |
| Tx | Average daily maximum temperature | (°C) | | | |

* Record from Pleasant View weather station

3.4.2.3.2 *Description and evaluation of the soil units*

The distribution of the soil units can be seen on the soil map presented in Appendix 5.

3.4.2.3.3 *The Cf/Wa unit*

In this unit the Cartref (**Cf**) and Wasbank (**Wa**) forms dominate and are closely related to each other, with the only difference being the bottom layer. In the **Cf** form it is the lithocutanic B-horizon as described previously, while in the **Wa** form it is a cemented concretion layer (ferricrete/hard plinthite), and as already mentioned, only weakly cemented in some profiles. In places, this hard plinthite outcrops at the surface.

Looking from the top of a typical **Cf** or **Wa** profile, there is a dark brown to dark greyish-brown (bleached in the dry state) surface layer that overlies the very dark to dark greyish-brown (bleached in the dry state) second layer (E-horizon). Both layers have clay content in the order of 15-20%. Depth to the bottom layer varies between 400-600 mm depending on the position in the landscape, although on occasion, depths of >900 mm occur. The general rule is that the steeper the slope, the shallower the soil becomes.

More concretions were more often found in the E-horizon of the **Cf** form than in the E horizon of the **Wa** form. In the lithocutanic B-horizon of the **Cf** form, concretions also occurred in places.

*Capability for crop production*

Both the bottom layers of the dominant soils in this unit can be regarded as limiting. Because these soils have a shallow to moderate soil depth before the limiting layer is encountered, they are not recommended for serious crop production. However, in the case of subsistence farming, for crop production with limited soil depth requirements could be considered.

3.4.2.3.4 *The Lo/We unit*

This unit occurs in two different locations, both of which are near to the Tyhume River. It displays characteristics of periodic wet conditions (hydromorphic properties) in the profile, as is usually the case with soils close to natural drainage courses.

In the dominant Longlands (**Lo**) soil form, brown to dark brown (bleached when dry), structureless, loam to silty loam topsoil overlies a very dark to dark greyish-brown (bleached when dry), structureless, loam to silty loam subsoil (E-horizon), containing variable amounts of concretions. It varies in depth from 450-600 mm before it reaches the bottom layer. The bottom layer is dark grey to greyish-brown with yellow, and sometimes red mottles, which are an indication of periodic water saturation. It is also weakly structured with a loam to clay loam texture. In the case of the Westleigh (**We**) soil form, the mottled layer occurs in the second horizon position, limiting the useable root depth to the depth of the topsoil, which varies from 200-300 mm. Mainly weathered, mottled rock material was found to occur underneath.

3.4.2.3.5 *The Lo/Ka unit*

As with the **Lo**/**We** unit, this unit is also associated with the presence of drainage courses occurs in narrow flatter strips next to the riverbanks. It thus resembles the soils of the **Lo**/**We** unit and differs from it only in the second horizon, where the period of water saturation is different, showing a more irregular mottling pattern (G-horizon). The **Ka** form is waterlogged for much longer periods than the **We** form, thus rendering it even less suitable for crop production than the **We** soil form. However, on the **Ka** form found in this unit, a sandy overburden lying on top of the A-horizon is present in some occasions, increasing the soil depth before the saturated G-horizon is encountered. On occasion, deep E-horizons (over 1 m) were encountered in the **Lo** form, but in general the depth varied between 350-600 mm before reaching the hydromorphic B-horizon.

*Capability for crop production*

Due to sporadically wet conditions in the soil profiles of the **Lo**, **Ka** and **We** forms, none of these soils are recommended for crops that have a susceptibility to excessive water presence, which often occurs in the subsoil and bottom layers during the rainy season. However, it can still be a viable option for crops with shallow root systems as long as the water-affected zone begins below the rooting depth.

3.4.2.3.6 *The Vf/Oa unit*

This unit is also located on the banks of the Tyhume, but is wider than the **Lo**/**Ka** unit extending further away the riverbank. Therefore, the dominant soils here do not display signs of wetness as the greater part of this unit occurs further away from the river. However, closer to the riverbanks, hydromorphic soils do occur.

The same dark greyish-brown to dark brown (bleached when dry) topsoil occurs in Vilafontes (**Vf**) form and overlies a very dark greyish-brown (bleached when dry), structureless, loam to silty loam subsoil. The bottom soil consists of very dark greyish-brown, weakly structured; loam to clay loam with recognizable cutans (variable coloured smooth surfaces) caused by clay accumulation or disintegrated rock fragments. This same layer occurs as the second horizon in the Oakleaf (**Oa**) form and then overlies a third layer consisting dominantly of unconsolidated material. Depth of the Vilafontes form in most of the inspection holes drilled was over 1 m, making this one of the better units regarding root penetrable depth.

*Capability for crop production*

Favourable physical conditions of the dominant soils in this unit, including sufficient depth, loamy texture and no signs of wetness, lend it a high capability for crop production. Bear in mind though that hydromorphic soils (showing signs of wetness) will occur close to the Tyhume River. Furthermore, due to its proximity to the river and flat topography, this unit may be submitted to sporadic floods.

3.4.2.3.7 *The Se/Va unit*

It is suspected that dolerite had an influence on the origin of the soils of this small unit that occurs on the banks of the Tyhume River. The topography is generally flat with undulating terrain in places. Due to the dolerite influence, the soils are structured and contain more than

30% clay from the second horizon onwards. Both topsoil and subsoil horizons are dark in colour (moist state) and the third layer is a dark coloured material in an unconsolidated state (C-horizon), displaying signs of wetness where the Sepane (**Se**) soil form was found. The Valsrivier (**Va**) form is constituted of exactly the same topsoil and subsoil horizons, the only difference lying in the bottom layer (C horizon), which does not display signs of wetness in this layer of unconsolidated material. Thickness of the topsoil varies from 150-200 mm with clay content of 20-25%. Depth down to the C-horizon of both soil forms varies between 600-800 mm.

*Capability for crop production*

Soil structure can impede root penetration as well as slow down water infiltration, but this is dependent on the grade and size of the structure. In this unit, fine-sized peds of a moderate grade were often found. Therefore, utilization of these soils for crop production is advised, only after the necessary precautions have been taken. The hydromorphic properties of the C-horizon of the **Se** soil form should also be taken into account.

#### 3.4.2.3.8 *The Sw/Oa unit*

This unit lies on a slope. The presence of dolerite is obvious, leading to the conclusion that it was the dominant soil forming factor. A brown to dark brown (moist state), structured topsoil with a loam to silty loam texture (20% clay content) occurs down to 200 mm, and overlies a dark brown (moist state), strongly (but finely) structured clay loam to silty clay loam subsoil, where the dominant Swartland (**Sw**) form was found. A third layer, beginning at a depth 500-700 mm and which is in essence very weathered rock (called saprolite), sometimes showed a reddish-brown colour and occurred beneath the subsoil. It often contained some concretions as well as rock fragments.

Subdominant is the Oakleaf (**Oa**) form with a brownish, structureless, loam to silty loam topsoil that changes after a depth of 200 mm to weakly structured, silty loam subsoil with a darkish brown colour, underlain by unconsolidated material. Depths to the third layer are in the order of 600 mm.

*Capability for crop production*

The same recommendations apply as those for the **Se/Va** unit, but a root depth of up to 600 mm to the weathered material (C-horizon), is available for the **Oa** form.

### 3.4.2.4 Soils within the villages

#### 3.4.2.4.1 *Overview*

In addition to the establishment of the soil units as described above, several inspection holes were augured inside the villages in order to support decision-making for the water-harvesting project with regard to the utilization of the soils found within the village boundaries.

More subdominant soils were found in the units where the villages are located. Therefore, it was decided to list the site descriptions exactly as they were recorded, to narrow down the clay percentages and depth ranges in relation to the more dominant ones given in the legend.

These descriptions are listed in Appendix 1 and Appendix 3and each site is numbered and indicated on the accompanying map (Appendix 5). Included with the descriptions are the analytical results of the holes that were sampled and analysed (all those indicated with a C number). Note that the given clay percentages are just field estimations, except where the field estimation was corrected using the analytical data.

3.4.2.4.2 *Analytical results for the sample sites in the villages*

Silt content in most of the samples was generally very high (33-53%). This was to be expected from soils derived from the dominant mudstone. The high silt content is probably responsible for the soil's hardness in the dry state because the fine particles become densely compacted when the soil is drying out.

The pH value of a soil gives an indication of its acid or alkaline status. Values were mostly found to vary between slightly acid and neutral (pH ($H_2O$) 5.9-6.7). An exception is in Khayalethu at sample site **C14** (pH 5.4).

For most of the samples, base cation values (sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg)) appear normal (FSSA, 2007). On occasion though, Ca/Mg imbalances occur (FSSA, 2007), such as at two locations in Khayalethu (**C13** B and **C14** B2). In the case of **C14,** the Mg value is higher than the Ca value in the B2-horizon, which could lead to instability in that part of the soil profile, especially when water is applied. Further investigation is recommended if this piece of land should be considered for cultivation purposes. At **C13**, the Ca/Mg ratio fell far outside the recommended ratio of 1.5-4.5 (FSSA, 2007).

From of all the analytical results for phosphate status, only two fall within the range of 8-35 ppm (parts per million) recommended for grain crops by the FSSA (2007). The rest are below this requirement, some even very close to zero. With regard to the recommended requirement for vegetables (15-50 ppm), only the figure for the A-horizon sample taken at site **C11** in Guquka is sufficient, where fertilizer was probably applied.

3.4.2.5 Soils in the cultivated fields of the villages

3.4.2.5.1 *Overview*

One of the aims of this survey was to obtain more detail on the soils of the recently and currently cultivated fields. The only available aerial photos of the study area were taken in 1985 and show that most of the open areas around the villages were used for cultivation. However, during the survey it was found that less than 20% of this area is still in use today. Around Guquka fields are more clustered over a larger area than in 1985 but they are still cut up into small pieces owned by different households. The residents of Khayalethu do not own or have access to arable land.

In most cases, the soils encountered in the fields compared well to the soil units in which they occur. Only on occasion were subdominant soils encountered. Even so, in order to get more accurate depth and clay values of each cultivated area, soil descriptions of each site are given in Appendix 1 and Appendix 3. Location coordinates for each site are also included. For those starting with a **C symbol,** analytical results are available. Each site is also indicated and numbered on the accompanying map.

#### 3.4.2.6 Soils of the grazing areas

##### 3.4.2.6.1 *Around Khayalethu*

This area is mainly occupied by the Oakleaf (**Oa**) soil form alternating with Cartref (**Cf)** and Wasbank (**Wa**) forms. Properties of **Oa** are similar to those found at the sites in the village of Khayalethu, i.e. soils containing loam to clay loam horizons and ranging in depth from 500-1000 mm. The **Cf** and **Wa** forms have similar properties to those described in the **Cf/Wa** unit in the map legend.

##### 3.4.2.6.2 *East of the main road*

Where flatter areas occur below the steep slopes of the mountains, dominant soils of the Cartref (**Cf)**, Vilafontes (**Vf)**, and Wasbank **Wa** forms are encountered with the same properties as those of the **Vf/Cf** an **Cf/Wa** units described in the map legend. As slopes become progressively steeper, soils become more shallow and rocky, and soils mainly of the Glenrosa (**Gs**) and Cartref (**Cf**) forms are found. **Gs** is similar to the Cf form, but without the E-horizon. Around the small drainage courses, the Longlands (**Lo**) form is dominant.

#### 3.4.2.7 Soil erosion

Soil erosion caused by human activities occurred mostly on the slopes (indicated by **S, E** or **S/E** on the soil map). On slopes of between 10-15%, cultivation took place previously, but has now been abandoned. Here, dongas and landslides with some gully erosion now prevail.

A few steeper slopes (20-30%) were encountered in Guquka and the neighbouring communities of Gilton and Mpundu, mostly with rock outcrops and loose rock on the surface. Here, landslides and sheet erosion was observed. It is suspected that this was caused by too little vegetation cover, probably due to overgrazing, and tracks made by human movement.

Where current cultivation takes place on slopes, and is maintained, no or little erosion was encountered. Erosion was seen in watercourses, which could be due to cattle movement for their drinking needs.

Therefore, the soils show susceptibility to erosion on slopes greater than 10% where human interference through grazing, cultivation or footpaths took place. Therefore, cultivation on slopes greater than 10% is not recommended. Even on flatter slopes (5-10%), soil conservation measures such as contour banks are recommended for cultivation purposes.

## 3.5 SUMMARY AND CONCLUSIONS

The results of the 2005 survey confirmed earlier studies conducted in the area that poverty and unemployment are important problems. Social grants obtained by claiming against the state are now the most important source of income. Finding formal employment was shown to be the most effective way to escape poverty, but few households had members who were formally employed. To augment their income the large majority of households engaged in agriculture. The contribution by agriculture to the livelihoods of rural homesteads was mainly in the form of food for own consumption. The scope to further increase the contribution farming makes in the food acquisition of households in the study area was deemed to exist, especially among the ultra-poor where this contribution was least in absolute terms.

Implementation of the water harvesting project needs to pay attention to the diversity of livelihoods encountered in the two villages, and focus its attention on households that are most vulnerable to food insecurity, i.e. those falling in the category of the ultra-poor.

Land suitable for rainwater harvesting requires veld in good condition, accompanied by a dense basal cover, to ensure efficient harvesting and utilization of rainwater, as well as resistance to soil erosion. Basal cover as an indicator of resistance to soil erosion and is measured as the average distance from the measuring point to the nearest species in centimetres. This is based on the assumption that the shorter the distance, the closer the plants are to one another, and the better is the soil protected against the erosive effect of rain. While basal cover is regarded as the basic measurement it is also worth noting that canopy cover also plays an important role in reducing the direct impact of rain drops on the bare soil. The two target areas had good veld condition, both in terms of forage production potential and resistance to soil erosion. Basal cover was excellent in all the selected sample sites, indicating good soil protection, better harvesting of rainwater and efficient use of such water through good plant growth.

Although the selected sample sites showed that the areas are in good condition in terms of protection against soil erosion and runoff, one of the major impediments would seem to be inability of the two communities to apply veld management practices. The adverse effects of this inability to apply these important practices can be observed from the poor height of the standing crops. This, therefore, implies a significant need for smallholder farmers in Guquka to be encouraged to apply a camping system, in order to rest some of the grazing area for the periods of feed shortages (rotational grazing).

There was no clearly no preferred rainwater harvesting and conservation technique in use to ensure that there was always good basal cover. This was also the general opinion of pasture scientists working in the area. Therefore, where bare patches occur like in the northern side of Guquka, it is recommended that stone belts (where soil has been eroded) should be built and grass should be planted.

It was also recommended that those grazing areas that were found to be dominated by Karoo shrubs should be burnt and closed to grazing (Trollope, 2005; personal communication). This will encourage the growth of more desirable grass species (Decreaser species).

# 4 STAKEHOLDER INCEPTION WORKSHOP

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## 4.1 INTRODUCTION

Insufficient water is a major constraint for the country's vision of sustainable agriculture and rural development. Ideally, sustainable dryland farming systems should be conducive to soil and water conservation, counteract and reverse land degradation, and reduce the need for external inputs to improve and sustain soil fertility and soil productivity. The stark realities facing South Africa are, however, that 33% of the total population living in the communal areas, as well as more than 40% of populations living in densely populated, informal tenancy and mission settlements, are progressively experiencing food insecurity, while natural resources are being exploited at an alarming rate. It is against this background that the water harvesting project was implemented in the study area.

The Eastern Cape Province has medium-potential agricultural land, but arable soils are limited because steep, undulating mountains make such soils highly erodible. The soils are also shallow. In addition, it has a semi-arid climate with variable and unreliable rainfall, the evapotranspiration rate is high, and an unacceptably high percentage of water is lost by runoff, *in situ* evaporation and deep drainage. The emphasis of this project is, therefore, on the wise use of water to reduce food insecurity and the vulnerability of particularly the poor. There are, obviously, many different water and conservation technologies noted in literature – the *Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa* (2003) being a compendium. Water harvesting and conservation technologies are, however, agro-ecosystem specific, dictating that technologies and innovations need to complement the biophysical and socio-economic conditions of a target area. Therefore, in accordance with the terms of reference of this project, a formal, project specific workshop was held to share and capture available knowledge on rainwater harvesting and conservation technologies and obtain endorsement of stakeholders in the selected study area to conduct field trials.

## 4.2 WORKSHOP OBJECTIVES

The objectives of the workshop were to:

1) Share and capture available knowledge and experience on rainwater harvesting and conservation technologies suitable for the ecosystems of the Alice area.
2) Deliberate on the most suitable rainwater harvesting and conservation technologies for sustainable and profitable agricultural production in the target villages. Agricultural production, for the purpose of this objective, included field cropping and husbandry, pasture production and veld management.
3) Get relevant stakeholders from different levels together to introduce the project.

4) Obtain an endorsement from stakeholders in the selected study area to conduct the project.
5) Draw up a MoU with the stakeholders.

## 4.3 PROCEDURE

### 4.3.1 Organizing the workshop and identification of relevant stakeholders

It was decided that the workshop would take place from 22-24 November 2004 at the University of Fort Hare. The UFH is situated close to the selected villages and most of the stakeholders are also based in the Eastern Cape. It was decided to arrange a field excursion to the selected areas during the workshop. All relevant stakeholders were invited to the workshop. The target group included national and provincial Departments of Agriculture, other state departments, local government, agricultural researchers, socio-economists and extension officers, universities, WRC Steering Committee members, Non-Governmental Organizations (NGOs), farmer unions/associations, the agricultural production sector. Five representatives from each village were also invited to attend the workshop. This group included homestead, small-scale and emerging farmers. Experts on rainwater harvesting and conservation technologies were invited to give presentations at the workshop to share and capture their knowledge.

### 4.3.2 Stakeholder process

Stakeholder endorsement followed a facilitated participatory approach based on a log frame analysis, with questions being posed by the facilitator, Prof. R. Barnard from ARC-ISCW. An extension officer of the Eastern Cape Department of Agriculture (ECDA), Mr. A. Phillip, excelled as interpreter.

### 4.3.3 Memorandum of Understanding (MoU)

After the relevant stakeholders had indicated their willingness to participate in the project, a MoU was drafted.

### 4.3.4 Participants

Participants totalled 63, including representatives from the five target villages, researchers, extension officers and socio-economists from the ECDA, the UFH and University of KwaZulu-Natal (UKZN), the WRC, an NGO, Nkonkobe Municipality, Buffalo City Municipality and the ARC. Village farmers represented 40% (25 delegates) of the participants. (Figure 4.1).

**Figure 4.1** Workshop participants.

## 4.4 FIELD EXCURSION

The afternoon before the workshop, participants were taken to the target area to get a better understanding of what they are dealing with, and to familiarize themselves with the lay of the land. They were provided with background information on the villages in the area, and an overview on the predominant soils in the various villages, the geomorphological attributes of specific areas/landscapes, as well as prevailing climatic factors to highlight the importance of ecosystem specifics.

The workshop participants were shown a roof water harvesting system (Figure 4.2 and Figure 4.3). They were also rather excited at witnessing an example of road water harvesting for the first time (Figure 4.4). The farmer concerned diverts runoff from a dirt road via a terraced channel (to break the velocity of the water) into a pit, from which he siphons the water out to irrigate his vegetable and citrus crops. They were particularly impressed by the turnout and enthusiasm of the village farmers.

The field excursion contributed to fostering team spirit and to bonding between workshop participants and this contributed significantly to the success of the goal-directed workshop.

**Figure 4.2** Roof rainwater harvesting.

**Figure 4.3** Rainwater tank.

**Figure 4.4** Road water harvesting redirected into a pit.

## 4.5 WORKSHOP, STAKEHOLDER ENDORSEMENT AND MEMORANDUM OF UNDERSTANDING

Mr. Allwood, Chief Director of the ECDA, presented the opening address on the first day of the formal workshop. Dr. Botha (ARC-ISCW) introduced the projects and Dr. Monde (UFH) gave more background on two of the villages in the study area, Khayalethu and Guquka. This was followed by a presentation from Mr. Du Toit (UKZN) on rangeland and veld management. Dr. Auerbach (Rainman LandCare Foundation) presented various in- and ex-field water harvesting technologies followed by Mr. Fowler with a presentation on water conservation techniques. Dr. Beukes (ARC-ISCW) gave a presentation on sustainable land management practices and Ms. Maritz (ARC-ISCW) gave an overview on the climate in the villages. Mr. Carstens (ARC-ISCW) delivered the last formal presentation on the socio-economic and farming conditions in the three neighbouring villages in the study area, Sompondo, Gilton and Mpundu.

The rest of the day was facilitated by Prof. Barnard and dealt with the identification of project specific stakeholders and the assignment of responsibilities to these stakeholders. Following a participatory stakeholder analysis based on log frame analysis, the following people/organizations were identified as direct/major stakeholders: the WRC, UFH, ARC-ISCW, management of the ECDA, researchers and extension officers of the ECDA, the five communities, farmers associations, traditional leaders, counsellors, Department of Health, schools, Department of Education, Department of Water Affairs, Department of Social Development, Department of Public Works, Expanded public works programme, Amathole District Council and the Department of Safety and Security.

It was decided that the responsibilities of the major role players would be as follows:

- The WRC, which initiated the project, would manage and fund the project and ensure that the project objectives are achieved in accordance with the contract and on budget. They would also assist in the facilitation to see that the project succeeded.
- The UFH would manage the project and also execute the project to achieve the objectives and lead the socio-economic and rangeland/veld aspects of the project.
- The ARC-ISCW would introduce and manage RWH techniques in the croplands and homesteads. The project would be executed in a participatory way and all the activities would be done together with the village members and extension personnel. They would lead the technical and biophysical aspects of the project.
- The ECDA extension services would work closely with the project team and they will continue with the project once the ARC and the UFH withdraw from the selected villages. They would demonstrate techniques and motivate and support the village members. The researchers would act in an advisory capacity, especially in the fields of pastures and crops, and would have a hands-on approach towards the project.
- The representatives of the communities indicated that each village would provide three backyards where demonstration/training plots could possibly be laid out. They would also provide a piece of cropland for demonstration/training purposes. They also indicated that they would provide manpower, mobilize others in the village to become part of the project, promote working together in the village and in the surrounding villages and teach, and educate others about the *IRWH* technique.

The second day of the workshop was also facilitated by Prof. Barnard and focussed on the drafting of the MoU between the various stakeholders. All the stakeholders agreed that they would work together on the rainwater harvesting project and committed to ensure that all objectives are reached within the budget and terms of reference.

## 4.6 MOTIVATION FOR THE USE OF DIFFERENT WATER HARVESTING TECHNIQUES IN THE EASTERN CAPE

Village members from Guquka and Khayalethu, near Alice in the Eastern Cape, indicated at a project planning workshop that they would like to be introduced to the *IRWH* technique and to implement it at their homesteads as the first step to increasing crop yields (De Villiers *et al.*, 2005). It was decided that *IRWH* in the homesteads would be the departure point of the project and that the second step would be to combine *IRWH* with other rainwater harvesting techniques.

### 4.6.1 *IRWH* with a cover crop or mulch

The villages of Guquka and Khayalethu are located on steep slopes and the rainfall is higher than in the Thaba Nchu area of the Free State Province where the *IRWH* technique was previously successfully implemented. The Eastern Cape Province has medium-potential agricultural land, but arable soils are limited and in a poor condition because steep, undulating mountains make such soils highly erodible. The soils are also shallow and very low in organic carbon content. The rainfall is seasonal and unreliable, evapotranspiration rate is high, and an unacceptably high percentage of water is lost by runoff, *in situ* evaporation and deep drainage. In all farming systems mixed farming occurs where crops as well as livestock are part of the system. In most cases the livestock grazed the croplands after the crops were harvested. Not only is crop production very low, but feed for livestock is also in short supply.

The *IRWH* technique promotes rainfall runoff on 2 m wide strips between crop rows and storing the runoff in 1 m wide storage basins. The application of the *IRWH* in this higher rainfall area has a number of potential advantages. The conservation of rainwater may make it possible for a cover crop on the runoff area to succeed because more water will be available to sustain both crops. The cover crop on the runoff area will also decrease higher amounts of runoff directed towards the basins and combat possible erosion that might take place on the runoff area and prevent damage to storage basins. Cover crops are important as animal feed (cut and carry system). If the cover crops are legumes they have the benefit of adding much needed protein to the animal diets, particularly in winter. Poor crop residues can be mixed with legume residues for use in dry season feeding. Cover crops can further stabilize the whole crop-livestock system by preventing erosion, and contributing to soil organic material and carbon content. It was, therefore, suggested that the runoff area of the *IRWH* technique be covered by crops. Mr. Conradie of ECDA suggested green leaf desmodium (*Desmodium intortum*) as a cover crop, and it was also decided to make use of lucerne (*Sisyrinchium angustifolium*) and vetiver grass (*Chrysopogon zizanioides*). Due to the success with mulches on the runoff area in the Free State, it was decided to also compare the effect of mulch with that of a cover crop. At the project planning workshop it was agreed to investigate the effects of a cover crop on the runoff area of the *IRWH* system on the cropland of the village of Guquka and by means of an on-station experimental trial (De Villiers *et al.*, 2005).

### 4.6.2 Roof water harvesting

The average long-term rainfall data (over a period of 39 years) indicates that very low rainfall occurs during the winter (April to August) in the Alice area Maritz (2004), which makes crop production during the winter very difficult. Monde (2003) also indicated that food shortages are highly evident during the winter months, as the food produced during the summer is not available during the winter due to a lack of adequate storage facilities. Another problem that occurs in these villages is that there is not always sufficient water available for domestic purposes, especially during the winter. The implementation of roof water harvesting and rainwater storage in tanks could overcome this problem. At the project planning workshop it was therefore decided to implement roof water harvesting in combination with *IRWH* (De Villiers *et al.*, 2005). It is hoped that the introduction of this combination of techniques will improve water use efficiency, especially during the winter, as only the crops (vegetables) in targeted areas will receive supplementary irrigation instead of whole areas being irrigates as is the case with conventional tillage.

### 4.6.3 Road water harvesting

The roads in the villages of Guquka and Khayalethu are in a very poor condition especially due to ex-field runoff water that washes away the roads after every storm event. By redirecting this storm water into pits or dams in the homesteads, the velocity of the runoff will be reduced and damage to the roads, as well as erosion down slope, will be minimized. In addition to these conservation benefits the storm water could be used more productively to produce food and for other purposes at the homestead. Rainwater harvested from the roads and channelled into pits could be used as supplementary irrigation in combination with the *IRWH* technique, which will allow people in these two villages to produce food during the winter. This would also mean that there would be more clean water available in rainwater storage tanks, for domestic consumption. At the project planning workshop the village members indicated that the road water harvesting technique could be used, especially in combination with *IRWH* (De Villiers *et al.*, 2005). However, concerns were raised about the safety issues of open tanks or pits, especially for small children, and so attention should be given to this aspect when the technique is implemented.

#### 4.6.4 Strip cropping / Runoff strips

One of the disadvantages of the *IRWH* technique is that it is difficult to incorporate small grain crops like wheat and barley into the system. Hensley *et al.* (2000) recommended that the *IRWH* technique not be used for small grains as it concentrates rainwater on a 1-m wide basin area while using a 2-m wide runoff strip. This uneven distribution of water suits widely spaced row crops such as maize which can be planted next to the basin area and gain maximum benefit from the available soil water. In the case of wheat, however, some rows will benefit from water stored in the basins while others growing on the runoff area, will depend largely on the previous summer's rainfall stored in the root zone. To plant wheat in the normal way would mean destroying the basins and then reconstructing them after harvest, which makes the *IRWH* technique very labour intensive and expensive. The strip cropping or runoff strip technique, on the other hand, will allow farmers to plant small grains in a downstream strip adjacent to an upstream catchment strip during the winter when food for humans and animals is scarce. This technique could also be implemented on abandoned croplands.

### 4.7 EXPECTATIONS OF VILLAGERS

The villagers' expectation where many; the key ones include the following:

- They expect increased yields from use of water harvesting techniques. They would like to produce enough food for consumption and excess for marketing to generate income. Through improved food production and ability to generate income they expect to eradicate poverty in their households.
- The use of home gardens will allow them to grow nutritious vegetables and other crops and they therefore expect household health to improve through a healthy diet of home grown foods. Villagers contend that the use of the *IRWH* techniques as outlined will have the potential to curb soil erosion in their fields and the use of brush in rangelands will reduce bush encroachment in higher lying areas.

### 4.8 SUMMARY AND CONCLUSIONS

The Stakeholder Workshop was a very rewarding and highly successful event characterized by enthusiasm, team spirit and the lively participation of all delegates in achieving the objectives of the workshop. As it was aimed at discussing the successful application of technologies suitable for the target agro-ecosystems, the workshop symbolized a learning curve for all involved. The field excursion was a notable experience, highlighted by the demonstration of a successful roadside water harvesting technique perfected by one of the village farmers.

The plan of action agreed on by team members and the subsequent MoU which was drawn up reflected a desire to achieve the project objectives and paved the way for the successful implementation of the project.

It was unfortunate that representatives from the following government and provincial departments (i.e. Provincial Departments of Water Affairs, Education, Environment, Health, Social Development, Public Works, Agriculture and the South African Police Service) did not attend the workshop, although they were invited. Another limitation was the absence of farmer associations and suppliers who could have contributed towards the projects in kind. This limitation/shortcoming was successfully abridged by project team members undertaking to get the commitment and involvement of parties concerned, as stipulated in the detailed responsibilities.

Workshop resolutions were that:

- Project participants from the five villages would work together as a team, supporting each other across village borders;
- A combination of RWH&C technologies would be applied to ensure the maximum water available in backyards, but farmers would prefer to start with *IRWH*. The point of departure would be backyard gardens and also school food gardens. Participants would endorse the MoU, should they agree to the responsibilities allocated, and would then comply with the stipulations of the MoU.

# 5 EVALUATION OF THE AGRONOMIC PERFORMANCE OF VARIOUS RAINWATER HARVESTING AND CONSERVATION TECHNIQUES

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## 5.1 INTRODUCTION

The Eastern Cape Province has medium-potential agricultural land, but arable soils are limited because steep, undulating mountains making such soils highly erodible. In addition to land being marginal for food production, rainfall is seasonal and unreliable, evapotranspiration rate is high, and an unacceptably high percentage of water is lost by runoff, *in situ* evaporation and deep drainage.

In the semi-arid crop production areas of South Africa, the problem of low and erratic rainfall is exacerbated by two major unproductive soil water losses, *viz*. runoff (R) and evaporation (Es). These losses hamper the efficient use of available water for crop production. These losses must be minimized in order to optimize crop yield and improve rainwater productivity (RWP). An improved soil water regime can be achieved by increasing the amount of water stored in the root zone by reducing losses through Es, R, and deep drainage (D). The latter is generally negligible on duplex and clay soils and all coarser textured soils underlain by an impermeable layer within the root zone. The two main losses are therefore Es and R. Various South African researchers have found the loss of R to be between 6 and 30% of the annual rainfall on various soils under conventional tillage conditions (Haylett, 1960; Du Plessis & Mostert, 1965; Bennie *et al.*, 1998). Runoff from croplands is usually associated with water induced soil erosion. Between 50 and 75% of annual precipitation is lost through Es (Bennie & Hensley, 2001). Water loss by Es is severe, especially during long fallow periods (Unger & Stewart, 1983; Hensley, 1986). This is the main cause of low RWP.

Dryland agriculture depends heavily upon the climate, especially rainfall/precipitation (P). Low and erratic P is the single most important climatic factor that limits crop yields in semi-arid regions. A high evaporative demand (Eo), so typical of southern Africa, is a powerful exacerbating factor. The farmer does not have much control over unfavourable climatic conditions, but at least he/she can implement crop production techniques that minimize the risk of total crop failures. Two practices that have a major impact on soil and water conservation are crop residue management and tillage. Stroosnijder (2003) stated that water conservation practices reduce erosion, improve soil qualities and increase RWP.

Various water conservation techniques, among them rainwater harvesting, are seen as having the potential for increasing available water for successful crop production in semi-arid areas. One of the rainwater harvesting techniques is the *IRWH* technique developed by a group of researchers from the ARC-ISCW (Hensley *et al.,* 2000). The *IRWH* technique combines the advantages of a number of water conservation techniques like water harvesting, no-till, basin tillage and mulching in order to reduced R and Es. The technique consists of promoting runoff on a 2-m wide strip between alternate crop rows, and storing the runoff water in basins. The ex-field runoff from a land is reduced to zero, and soil loss from the land is also prevented. Soil movement from the runoff strip into the basins, however, may be a problem in the long-term in relation to sustainable crop production. To control this mulch can be applied in the basin and/or runoff area; or cover crops can be planted on the runoff area. Cover crops have the advantage of suppressing evaporation.

Most soil conservation methods, such as strip cropping, contour ploughing and terracing aim at reducing runoff, and are therefore also effective in increasing the amount of water that is stored in the soil (Arnon & Gupta, 1995). Mulches are used for various reasons, but water conservation and erosion control are undoubtedly the most important objectives of this practice in dryland cropping in semi-arid and arid regions. While the effectiveness of mulches for water conservation is variable, mulches when properly managed are definitely effective for wind and water erosion control (Unger, 1995). Many soil properties and conditions are affected by mulches, either directly or indirectly. Among these are improved soil water content through runoff control, increased infiltration, decreased evaporation, weed control, ameliorated soil temperature through radiation shielding, improved soil fertility and soil structure, improved biological regime and root distribution through organic matter additions, and in some cases decreased soil salinity through leaching and evaporation control (Unger, 1995).

Cover crops are crops planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases and biodiversity (Lu *et al.*, 2000). Cover crops are of interest in sustainable agriculture as many of them improve the sustainability of agro-ecosystem attributes and may also indirectly improve qualities of neighbouring natural ecosystems (Snapp *et al.*, 2005). Growing green manure legume cover crops as part of the smallholder cropping system can play an important role in improving soil fertility, reducing soil erosion and controlling weeds (Kimemia, 1998). Integration of high yielding green manure legumes can increase plant nutrient supply in the soil, especially nitrogen, and improve soil physical properties (Mureithi *et al.*, 2003). Legumes can also provide good ground cover minimizing soil erosion by reducing raindrop impact and runoff (Gachene & Haru, 1997). Some green manure legume cover crops are a source of food (Versteeg *et al.*, 1998) and fodder (Njarui *et al.*, 2000), an important attribute especially in the high population density areas with zero grazing dairy production systems (Ngugi & Kabutha, 1989). Maina *et al.* (2006) found that legumes established good crop cover and crop biomass and offer an effective method of weed control. Legumes such as green leaf desmodium, silver leaf desmodium, and Lablab which established good crop cover and biomass, were effective in weed control and can be used as forage by the farmers to supplement feed for their livestock. Lemunyon (2006) claimed that cover crops are suited for use in any cropping system where there is opportunity for ample vegetated development, and where the establishment of canopy and roots before cold or dry weather – protects the soil surface from the detachment of soil particles by erosion or runoff. Lemunyon (2006) recommends that caution should be used in situations where cover crop vegetation could deplete soil moisture prior to seeding of the succeeding crop.

The questions that need to be answered are as follows:

- Could an appropriate production technique be developed which can a) reduce R and Es; b) increase crop water use, crop growth and crop yields; and c) increase RWP?
- Will the crop yield from cover crops be sufficient to supplement livestock feeding? It was hypothesized that *IRWH* is a sustainable crop production technique that could increase crop yields by minimizing unproductive water losses (Es and R) and maximizing RWP in semi-arid areas.

The general objective of this chapter is to evaluate the agronomic performance of various rainwater harvesting and conservation tillage techniques in terms of their ability to convert water into food in a sustainable manner.

## 5.2 MATERIAL AND METHODS

Various treatments were applied to the runoff area of the *IRWH* system. The indicators of crop response to the various treatments were grain yield, dry matter production, harvest index, transpiration and rainwater productivity. On-station and on-farm field experiments were conducted in order to test RWH&C techniques. The on-station field experiments were conducted at the Research Farm at the University of Fort Hare over a period of four seasons (2004/05-2007/08). An additional on-station field experiment was conducted at Phandulwazi Agricultural School next to Guquka village during the last two seasons (2006/07 and 2007/08). This experiment, funded by the ARC-ISCW, was not initially part of the project. It was included as an extra field experiment because it is situated closer to Guquka and is more representative of the targeted area. The on-farm field demonstration experiment was conducted on a farmer's field in Guquka village over a period of four seasons (2004/05-2007/08).

### 5.2.1 Experimental plan

On-station experimental plots were laid out at the Research Farm at the UFH. A fully randomized statistical design with seven treatments and three replications was employed. The size of the experimental block was 46 x 48 m and comprised 21 plots, each 6 x 9 m in size (Figure 5.1). The different treatments were as follows:

- In-field rainwater harvesting (*IRWH*) with a bare runoff area and bare basin area ($IRWH_{Bare}$)
- *IRWH* with organic mulch both on the runoff area and basin area ($IRWH_{Mulch}$)
- *IRWH* with lucerne as a cover crop on the runoff area ($IRWH_{Lucerne}$)
- *IRWH* with green leaf desmodium as a cover crop on the runoff area ($IRWH_{GLDM}$)
- *IRWH* with vetiver as a cover crop on the runoff area ($IRWH_{Vet}$)
- Strip cropping (*STRIP*)
- Conventional tillage (*CON*)

The motivations for the different treatments are presented in section 4.6.

| | 6 m | 6 m | 6 m | 6 m | 6 m | 6 m | 6 m | |
|---|---|---|---|---|---|---|---|---|
| 9 m | ***CON*** | ***STRIP*** | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | $IRWH_{Lucerne}$ | $IRWH_{GLDM}$ | $IRWH_{Vet}$ | Rep 1 |
| 9 m | ***STRIP*** | $IRWH_{Bare}$ | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Mulch}$ | ***CON*** | Rep 2 |
| 9 m | ***CON*** | $IRWH_{Vet}$ | $IRWH_{Mulch}$ | $IRWH_{Bare}$ | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | ***STRIP*** | Rep 3 |

**Figure 5.1** Layout of the experimental plot at the Fort Hare/Oakleaf – Ritchie ecotope.

On-station experimental plots were laid out from 2006 at Phandulwazi Agricultural School. A fully randomized statistical design with seven treatments and three replications was employed. The size of the experimental block was 46 x 48 m and comprised 21 plots, each 6 x 9 m in size (Figure 5.2). The different treatments were as follows:

- $IRWH_{Bare}$
- $IRWH_{Mulch}$
- $IRWH_{Vet}$
- $IRWH_{Lucerne}$
- $IRWH_{GLDM}$
- *STRIP*
- *CON*

| | 6 m | 6 m | 6 m | 6 m | 6 m | 6 m | 6 m | |
|---|---|---|---|---|---|---|---|---|
| 9 m | ***CON*** | ***STRIP*** | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | $IRWH_{Lucerne}$ | $IRWH_{GLDM}$ | $IRWH_{Vet}$ | Rep 1 |
| 9 m | ***STRIP*** | $IRWH_{Bare}$ | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Mulch}$ | ***CON*** | Rep 2 |
| 9 m | ***CON*** | $IRWH_{Vet}$ | $IRWH_{Mulch}$ | $IRWH_{Bare}$ | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | ***STRIP*** | Rep 3 |

**Figure 5.2** Layout of the experimental plot at the Phandulwazi/Westleigh ecotope.

An on-farm demonstration plot was laid out on a cropland at Guquka. A partially randomized statistical design with six treatments was employed (Figure 5.3). The different treatments are as follows:

- *IRWH*$_{\text{Bare}}$
- *IRWH*$_{\text{Mulch}}$
- *IRWH*$_{\text{Vet}}$
- *IRWH*$_{\text{GLDM}}$
- *STRIP*
- *CON*

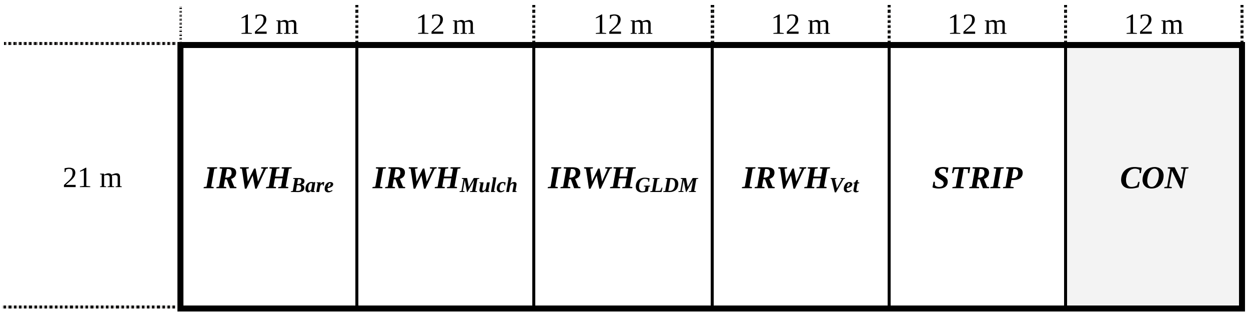


**Figure 5.3** Layout of the demonstration trial at the Guquka/Cartref ecotope.

### 5.2.2 Agronomic information and activities

A tractor was used to prepare the land and spades and rakes were used to construct the basins on the experimental and demonstration plots. Chemicals were used to control weeds on the runoff area. Planting was done by hand in all cases. Since planting of maize was done by hand, 32.5 g of fertilizer mixture 3:2:3 (22) + 0.5% Zn Profert fertilizer was applied per maize plant to supply 60 kg N ha$^{-1}$, 40 kg P ha$^{-1}$ and 60 kg K ha$^{-1}$ during planting. No top-dressing was done during the growing season. Maize crop details for the Fort Hare/Oakleaf ecotope (2004/05-2007/08), Phandulwazi/Westleigh ecotope (2006/07-2007/08) and Guquka/Cartref ecotope (2004/05-2007/08) are presented in Table 5.1.

**Table 5.1** Maize details during the different growing seasons on the Fort Hare/Oakleaf (2004/05-2007/08), Phandulwazi/Westleigh (2006/07-2007/08) and Guquka/Cartref (2004/05-2007/08) ecotopes

| Ecotope | Season | Cultivar | Plant population (plants ha$^{-1}$) | Planting date | Harvest date |
|---|---|---|---|---|---|
| Fort Hare/Oakleaf | 2004/05 | PAN6480 | 22 000 | 19/01/2005 | 22/06/2005 |
| | 2005/06 | PAN6480 | 22 000 | 22/11/2005 | 25/04/2006 |
| | 2006/07 | PAN6480 | 22 000 | 11/01/2007 | 03/07/2007 |
| | 2007/08 | PAN6480 | 22 000 | 06/12/2007 | 07/05/2008 |
| Phandulwazi/Westleigh | 2006/07 | PAN6480 | 22 000 | 22/11/2006 | 08/05/2007 |
| | 2007/08 | PAN6480 | 22 000 | 17/11/2007 | 09/05/2008 |
| Guquka/Cartref | 2004/05 | PAN6480 | 22 000 | 18/01/2005 | 09/06/2005 |
| | 2005/06 | PAN6480 | 22 000 | 26/11/2005 | 20/04/2006 |
| | 2006/07 | PAN6480 | 22 000 | 23/11/2006 | 10/05/2007 |
| | 2007/08 | PAN6480 | 22 000 | 11/12/2007 | 10/05/2008 |

### 5.2.3 Ecotope characterization

The term ecotope can be defined as three-dimensional representations of the soil-plant-atmosphere continuum (SPAC) in which the natural resources that influence yield (climate, topography, and soil) are reasonably homogeneous (MacVicar *et al.,* 1974). The characteristics, productivity and stability of the SPAC system depend on these natural resource factors. The boundaries of such a system are determined by points in the landscape at which the characteristics of one or more of the factors (climate, topography and soil) change significantly (Hensley, 1995).

According to Hensley *et al.* (2000), it is not possible to do detailed research work on every ecotope used for crop production in a country. Therefore, it is desirable that the main ecotope characteristics that affect productivity are characterized in detail to ensure correct extrapolation of results to all other similar ecotopes (i.e. pedotransfer functions) (Hensley *et al.,* 2000). This implies that wherever similar ecotopes occur, the same production potential can be expected.

The Fort Hare/Oakleaf, Guquka/Cartref and Phandulwazi/Westleigh ecotopes were described using the following factors:

#### 5.2.3.1 Climate

Long-term climate data from nearby weather stations were used to characterize the climate. For the Fort Hare/Oakleaf ecotope, the Alice weather station which is located 500 m north of the study area, was used Rainfall, class A-pan evaporation**,** relative humidity, sunshine hours, temperature and wind speed data have been recorded for 30 years (1979-2009). For the Guquka/Cartref and Phandulwazi/Westleigh ecotopes, rainfall data was obtained from the Pleasant View weather station (1928-1968), located 32.67ºS and 26.9ºE at an altitude of 701 m above sea level and 3 km west southwest of the study area Climate data (1999-2008) was obtained from the Keiskammahoek weather station, located 19 km to the east of the study area with geographical coordinates 32.68ºS and 27.13ºE and an altitude 668 m above sea level.

The Alice weather station was used to monitor the meteorological conditions for the Fort Hare/Oakleaf ecotope during the duration of the project. When the project started there was no weather station at Guquka. A manual rain gauge was installed at the demonstration plot and at the homestead of the cropland owner, who was asked the monitor the rainfall. During May 2005 an automatic weather station was installed at the school in Guquka to measure air temperature, solar radiation, wind speed and direction, and rainfall. Reference crop evaporation (ETo) was determined with the FAO-56 Penman-Monteith equation. A rain gauge was used to measure rainfall at Phandulwazi Agricultural School.

#### 5.2.3.2 Topography

Land type data was used to characterize the macro-topography of the various selected sites. The slope at the University of Fort Hare/Oakleaf ecotope was determined by using a dumpy level. The slope of the Guquka/Cartref and Phandulwazi/Westleigh ecotopes was determined by using a Global Positioning System (GPS).

5.2.3.3 Soil classification

A profile pit was dug at each ecotope. The profiles were morphologically described in detail according to the Soil Classification Working Group (1991). The soil colour was read by using a Munsell Colour Chart. Soil samples were taken from each diagnostic horizon. Soil analyses were done at the ARC-ISCW laboratory in Pretoria, according to The Non-Affiliated Soil Analysis Work Committee (1990).

### 5.2.4 Soil measurements

The six water balance processes identified in Equation 1 (Bennie *et al.*, 1994) play an important role in the functioning, productivity and stability of the SPAC. In order to develop technological options for sustainable management of soil and water resources, it is necessary to have a good understanding of these processes. To monitor these processes, soil, plant and climate measurements were taken regularly during the growing season at the on-station experiments.

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

$$Ev = (P \pm \Delta S) - (Es \pm R + D) \qquad \textbf{(Equation 1)}$$

where:

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

5.2.4.1 Soil water content of the root zone

To monitor the soil water content of the root zone (θr) at the on-station experimental plots, neutron water meter (NWM) access tubes were installed to a depth of 1.2 m, i.e. to a greater depth than that of the root zone. NWM access tubes (A and C) were installed as shown in Figure 5.4.

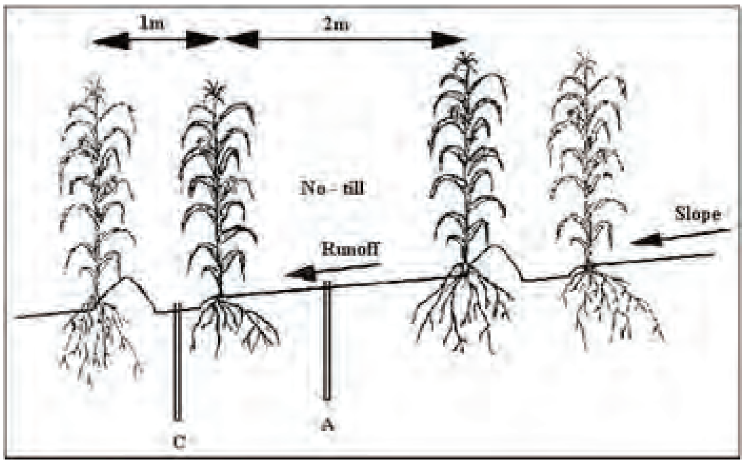


**Figure 5.4** The distribution of NWM access tubes (A and C) in the experimental plots at the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes.

Measurements of θr at Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes were taken during the fallow period, at planting and during the growing season at 300 mm depth intervals, starting at 150 mm. This procedure ensured that the different pedological layers in the soil were adequately represented. A Campbell Pacific 503 DR NWM was used. 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 were made under wet and dry conditions, and at the same time samples for θm determinations were taken close to the NWM access tubes. The θm values for each soil layer were multiplied with the appropriate bulk density value to give the volumetric soil water content (θv) of that soil layer. The linear relationship between NWM counts and the θv values provided the calibration equation. This procedure is described in detail by Hensley *et al.* (2000) and Botha (2006).

At Guquka, gravimetric water content measurements were taken at planting, flowering and at harvest for four layers, *viz.* 0-300 mm, 300-600 mm, 600-900 mm and 900-1200 mm. The values were multiplied by the bulk density values of each layer to obtain volumetric water content.

5.2.4.2 Drained upper limit of available water

Drained upper limit (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 0.1-0.2% per day (Ratliff *et al.*, 1983). An internal drainage experiment was conducted on an area of 4 x 4 m. The area was levelled and a low earth wall coupled with zinc plates was made around the area to prevent runoff water from entering. Five NWM access tubes spaced at about 0.75 m from one another were installed to a depth of 1350 mm in the middle of the area.

The drainage plot was filled with water until NWM readings showed that the transition zone of infiltration had reached about 1200 mm, the bottom of the root zone. Addition of water was discontinued when there were no more changes in the readings at 1050 mm depth. The plot was then covered with a plastic sheet to prevent rainwater from entering. Silicon was used to ensure that there was good seal around the protruding access tubes and the plastic to prevent wetting by rain. The time when the last surface water had infiltrated into the soil was recorded, and the water content of the whole profile was then measured with a NWM. Soil water content measurements were taken at 300 mm intervals at depths of 150, 450, 750 and 1050 mm. The water content of the root zone plotted against time after saturation describes the drainage curve.

Previous research has shown that at saturation, percentage of porosity filled with water ranges between 75 and 95% for sandy to clay soils, respectively (Hensley, 2006; personal communication). The theoretical saturation point (TSP) was calculated by using Equation 2. The procedure was followed for all soil layers and the root zone. This procedure was followed because the soil was too wet to take initial gravimetric soil water content samples.

$$\text{TSP (mm)} = \frac{1 - BD}{2.64} \times 0.9 \times layer \qquad \textbf{(Equation 2)}$$

where: BD represents bulk density and layer represents the depth of different layers from 300-1200 mm.

5.2.4.3 Lower limit of plant-available water

Lower limit (LL) is the lowest field-measured water content of a soil after plants are no longer 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. LL was taken as the lowest NWM reading for each soil layer for the specific chosen crop measured during this study.

5.2.4.4 Bulk density

The bulk density (BD) of each soil layer in the root zone was measured using a core sampler (Blake & Hartge, 1986). Detailed measurements for the root zone were carried out at 300 mm depth intervals. Three replications from each depth were taken. BD can also give an indication of any soil compaction in the root zone.

5.2.4.5 Runoff

Runoff (R) was measured from separate plots, 3 m wide and 2 m long. These were only laid out at the Fort Hare/Oakleaf ecotope during the experimental period. The R areas of these plots were prepared in the same way as in the different treatments of the field experiment. The runoff plots were replicated twice. The R plots were demarcated by corrugated iron sheet borders with a trough at the lower end to collect the R and channel it to the automatic tipping bucket through a 110 mm plastic UV resistant pipe. The corrugated iron borders extended 200 mm above the soil surface and were inserted to a depth of 200 mm into the soil. During the course of the experiment, growth of weeds within the plots was chemically controlled by spraying with Roundup®. The tipping bucket-measuring device discards the R after each 3.5 litres of water (representing one "tip") collected in the bucket. The number of tips is recorded by an electronic counter device. The R volume divided by the area of the plot was used to calculate the millimetres of R from each P event. Unfortunately, due to the malfunctioning of the electronic recording tipping bucket devices, R data was only collected for seven P events.

The extent of R during a growing season has an important influence on the water conservation advantage of *IRWH* techniques or water loss disadvantage of *CON* and *STRIP*. Runoff is a complex dynamic process that requires a dynamic, process based model for reliable simulation. Runoff is influenced by rainfall intensity ($P_i$), final infiltration rate of the soil; surface storage, which depends on the surface roughness; and the speed and degree of crust formation. Long-term $P_i$ values are generally not available for many weather stations in South Africa. Hensley *et al*. (2000) developed a procedure to predict R from daily rainfall data on a clayey soil in the Bloemfontein region. Their empirical equation was based on R measured from 20-m long runoff plots. Because of the influence of the overland flow process on R, the amount recorded from a particular storm from a 20-m long plot cannot be expected to be the same as that from a 2-m long plot. Anderson (2007) adjusted the Hensley *et al.* (2000) results from the 20-m long runoff plots to provide meaningful values for 2-m long plots. The statistical R prediction equations (Equations 3, 4 & 5) from various surface treatments for P events > 8 mm suggested by Anderson (2007) were used to calculate runoff.

Due to the fact that only a very limited number of runoff events were recorded it was not possible to obtain the measured runoff for each growing season. Instead the Anderson (2007) equation was used to predict the R from each P event during the growing season, as the physical and chemical conditions of the ecotopes he used to develop the equations were very similar to that of the ecotope where the on-station experiments were conducted. The Willmott (1982) statistical test parameters for R from the various treatments and surfaces gave the following acceptable results: D-index = 0.41; $R^2$ = 0.01; RMSEu/RMSE = 0.83. The predicted R was very close to that of the seven events where R was measured.

*CON*: ($R^2$ = 0.69; n = 36) (**Equation 3**)

$IRWH_{Bare}$: ($R^2$ = 0.68; n = 135) (**Equation 4**)

$IRWH_{Mulch}$: ($R^2$ = 0.21; n = 83) (**Equation 5**)

#### 5.2.4.6 Deep drainage

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

#### 5.2.4.7 Determination of Es

The procedure proposed by Tanner & Sinclair (1983) was used to separate ET into its two components, Ev and Es. Biomass was used to determine transpiration (Ev) using the procedure proposed by Tanner & Sinclair (1983), including their transpiration efficiency coefficient (k) for maize of 9.5 g $m^{-2}$ $mm^{-1}$, and the factor they proposed to make allowance for root mass, i.e. total biomass = 1.2 x above-ground biomass. To implement the procedure the mean saturation deficit during daylight hours for each growing season was determined from data obtained from the automatic weather station. It was possible to estimate evapotranspiration (ET = Ev + Es) by employing a simplified water balance equation suitable for semi-arid conditions (Equation 1) and thereafter ET was divided into its two components.

### 5.2.5 Plant measurements

#### 5.2.5.1 Biomass

Biomass ($Y_b$) was determined by cutting twelve plants per replication in each treatment just above the soil surface at flowering and harvesting to determine the final above-ground biomass for each replication treatment. Since the roots were not sampled, the biomass represents only the above-ground component. The plants were chopped and then put in an oven at 65°C for 14 days. Biomass was expressed as oven dry material in kg $ha^{-1}$.

#### 5.2.5.2 Grain yield

Grain yield (Yg) was determined by harvesting 6 plant rows each 4 m in length. The grain was weighed, oven-dried and adapted to 13% moisture content and expressed as kg $ha^{-1}$.

5.2.5.3 Harvest index

The harvest index (HI) was calculated as the ratio of grain yield to the total above-ground biomass yield (Bennie *et al*., 1998).

$$HI = \frac{Yg}{Yb}$$ **(Equation 6)**

where:

HI = harvest index

Yb = total above-ground biomass (kg $ha^{-1}$)

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

5.2.5.4 Rainwater productivity

Botha (2006) concluded that the most reliable, appropriate and acceptable way to describe the effectiveness with which rainwater is converted into grain or seed by different treatments, is by using the parameter rainwater productivity (RWP). RWP was calculated for both on-station and on-farm trials.

$$RWP_n = \frac{\sum Yg_n}{\sum P_n}$$ (**Equation 7**)

where:

$RWP_n$ = rainwater productivity over a period of n consecutive years (kg $ha^{-1}mm^{-1}$)

$\sum Yg_n$ = total grain yield over n consecutive years (kg $ha^{-1}$)

$\sum P_n$ = total precipitation over n consecutive years (mm)

5.2.5.5 Plant-available water

Plant-available water was calculated as the difference between soil water content measured and lower limit of plant-available water.

### 5.2.6 Climatic variables

At the Fort Hare/Oakleaf ecotope weather parameters, namely air temperature, relative humidity, wind speed and direction, sunshine hours, rainfall and A-pan evaporation, were determined with a manual weather station. When the project started there was no weather station at Guquka. A manual rain gauge was installed at the demonstration plot and at the homestead of the cropland owner, who was asked the monitor the rainfall. During May 2005 an automatic weather station was installed at the school in Guquka to measure air temperature, solar radiation, wind speed and direction, and rainfall. Reference crop evaporation (ETo) was determined with the FAO-56 Penman-Monteith equation (Allen *et al.*, 1998). A rain gauge was used to measure rainfall at Phandulwazi Agricultural School.

### 5.2.7 Statistical analyses

Analysis of variance was done on the results of the different treatments using the statistical software NCSS 6.0.21, 1996 for Windows (Hintze, 1996). Means were compared using the Tukey Kramer test ($P \leq 0.05$).

### 5.2.8 Agronomic sustainability

A number of RWH&C technologies that have shown great potential for decreasing poverty and food insecurity have been developed through research over the years. Unfortunately, low adoption of these techniques occurs in rural communities. Botha (2006) claims that low adoption rates are directly as the result of not investigating the five pillars of sustainability. Sustainability involves the appropriate use of crop systems and agricultural inputs supporting those activities that maintain economic and social viability while preserving the productivity of land. The requirements for sustainable crop production according to Smyth & Dumanski (1993) are improvement in agronomic productivity, reduction in production risk, conservation of the natural resource base, economic viability and social acceptability. Only agronomic productivity, reduction in production risk and conservation of the natural resource base are discussed under agronomic sustainability whereas economic viability and social acceptability are discussed in Chapters 7 and 9, respectively.

#### 5.2.8.1 Agronomic productivity

Agronomic productivity for crop production was measured by maize grain yields obtained from on-station (Research Farm at the University of Fort Hare: 2004/05-2007/08 and Phandulwazi Agricultural School: 2006/07 and 2007/08) and on-farm (Guquka: 2004/05-2007/08) trials. $RWP_{1979/80-2009/10}$ and $RWP_{1999/00-2007/08}$ were calculated from simulated long-term maize yield data for the different production techniques on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes with the crop model, Crop Yield Predictor for Semi-Arid Areas (CYP-SA), and long-term rainfall data over 31 and 9 consecutive years, respectively.

#### 5.2.8.2 Reduction in risk

A valuable feature of models is their ability to utilize long-term climate data to provide long-term yield simulations, which can serve to quantify risk of crop production. Models utilize long-term climate data to provide long-term yield simulations, which can serve to quantify production risk especially in semi-arid areas where rainfall is marginal and erratic with regard to amount, distribution and intensity. 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 use of crop models and long-term climate data to achieve this objective has been widely used in agriculture for more than a decade. However, the application of this approach for the production techniques used in this study required more than standard crop modelling procedures. Because of these considerations the empirical crop water stress model termed “Crop Yield Predictor for Semi-Arid Areas” (CYP-SA) was used, which is described in detail by Botha *et al.* (2003c) and Botha (2006). The model was created to cater specifically for the following production techniques: *CON*; $IRWH_{Bare}$; *IRWH* technique with organic mulch in the basins and bare runoff area (ObBr); *IRWH* technique with organic mulch in the basins and stones on the runoff area (ObSr); $IRWH_{Mulch}$; *IRWH* technique with stones in the basins and organic mulch on the runoff area (SbOr); and *IRWH* technique with stones in the basins and stones on the runoff area (SbSr). CYP-SA was developed to serve as a tool for decision-making regarding crop water management, especially in the field of *IRWH*. The inputs required by the model are crop modified upper limit of available water (CMUL), drained upper limit of available water (DUL), lower limit of available water (LL), rainfall (P), evaporative demand ($E_o$) and soil water content at planting ($\theta_p$).

To be able to simulate maize yields from $IRWH_{Lucerne}$, $IRWH_{GLDM}$ and $IRWH_{Vet}$, adaption was made to the yield of $IRWH_{Bare}$. The next step was the validation of the CYP-SA model. Model reliability tests were done by using the procedure of Willmott (1981). Willmott (1982) points out that in an accurate model the systematic root mean square error ($RMSE_s$) should approach zero, while the index of agreement (D-index) should approach one. The difference between the unsystematic root mean square error ($RMSE_u$) and $RMSE_s$ is a measure of the potential accuracy of the model. The $RMSE_s$ should be as small as possible; large $RMSE_s$ indicates bias. The $RMSE_u$ should be as close as possible to the root mean square error (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.

Validation was accomplished using measured yield data from all the treatments on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes. Risk assessment was achieved by developing long-term cumulative probability functions (CPFs) of maize yields. The crop model CYP-SA (Botha *et al.*, 2003c; Botha, 2006), and long-term climate data (31-year period (1979/80-2009/10) for Fort Hare/Oakleaf and 9 years (1999/2000-2007/08) for Phandulwazi/Westleigh ecotope) were used to provide long-term yield simulations. CPFs were developed of simulated long-term yields for maize on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes planted in a ½ full profile on 17 December.

#### 5.2.8.3 Conservation of the natural resource base

The organic carbon content of the top 150 mm soil layer was used as one of the indicators for the conservation of the natural resources. Soil samples at the Guquka/Cartref ecotope were taken prior to the start of the 2004/05 growing season (beginning of experiment) as well as at the beginning of the 2007/08 season (final season of experiment). Soil samples at the Fort Hare/Oakleaf ecotope were only taken at the beginning of the 2007/08 season (beginning of final season). Unfortunately the soil samples taken at the beginning of the field experiments at Fort Hare/Oakleaf ecotope got lost. Therefore no initial C content results were available for that ecotope. The soil samples were analysed at the ARC-ISCW laboratories in Pretoria using standard procedures.

$RWP_n$ with maize obtained from on-station and on-farm trials was calculated from short-term field experiments that were conducted over periods from two to four years as described in Section 5.2.5.4.

## 5.3 ON-STATION EXPERIMENTAL PLOT: UFH

### 5.3.1 Ecotope characterization

#### 5.3.1.1 Climate

The long-term (LT) mean annual rainfall recorded from 1979 to 2009 indicates that the study area receives on average 590 mm per annum (Table 5.2), with November receiving the highest rainfall (87 mm) followed by December (72 mm). Both these months are suitable for planting, but it must also be noted that December has the highest evaporation. Rainfall peaks occur during spring and early autumn with severe water deficits occurring during summer, especially in January. Low temperatures (5°C) and rainfall (18 mm) are experienced in July during the winter season., The climate of the study area is classified as semi-arid due to high evaporative demand and low rainfall, which results in an aridity index (AI) of 0.35. Unfavourable conditions for summer crop production may occur between October and March when the evaporative demand is twice the rainfall and the average AI is 0.41, The area receives 70% of its rainfall from October to March. July receives the lowest amount of rainfall (17 mm). Low temperatures are experienced during the winter coupled with very little rain.

**Table 5.2** Long-term (1979-2009) monthly and annual climate data from Alice meteorological station

| Element | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rain** | 64 | 68 | 65 | 49 | 21 | 21 | 17 | 33 | 35 | 61 | 85 | 73 | 590 |
| **UTot** | 105 | 99 | 84 | 80 | 92 | 102 | 113 | 122 | 122 | 122 | 120 | 113 | 1275 |
| **Tx** | 28 | 29 | 27 | 25 | 23 | 21 | 21 | 22 | 23 | 24 | 25 | 27 | 295 |
| **Tn** | 16 | 17 | 15 | 12 | 8 | 5 | 5 | 7 | 9 | 11 | 13 | 15 | 133 |
| **RHx** | 90 | 91 | 92 | 89 | 86 | 84 | 80 | 82 | 85 | 87 | 89 | 90 | 1046 |
| **RHn** | 41 | 42 | 41 | 37 | 31 | 31 | 28 | 31 | 32 | 37 | 40 | 40 | 431 |
| **A-pan** | 196 | 162 | 141 | 110 | 99 | 89 | 107 | 118 | 135 | 157 | 169 | 197 | 1678 |
| **AI** | 0.33 | 0.42 | 0.46 | 0.44 | 0.21 | 0.23 | 0.16 | 0.28 | 0.26 | 0.39 | 0.50 | 0.37 | 4 |

| | | |
|---|---|---|
| Rain | Average total rainfall | (mm) |
| UTot | Average daily wind speed | (km $day^{-1}$) |
| Tx | Average daily maximum temperature | (°C) |
| Tn | Average daily minimum temperature | (°C) |
| RHx | Average daily maximum relative humidity | (%) |
| RHn | Average daily minimum relative humidity | (°C) |
| A-Pan | Average daily evaporation [Class A pan] | (mm) |
| AI | Aridity Index | |

#### 5.3.1.2 Topography

The trial site is located at a foot slope with a straight 1.5% slope in a northerly direction.

5.3.1.3 Soil

A detailed soil profile description is presented in Appendix 6. Important features are summarized in Table 5.3. The soil is classified, according to the Soil Classification Working Group (1991), as belonging to the Ritchie Family of the Oakleaf form. From the soil surveys results it is clear that the Oakleaf soil form represents large parts of the study area. The colour of the soil is generally dark brown to dark yellowish-brown in the dry state. It must be noted that the profile was described up to 1000 mm since there was no evident change from 600 to 1500 mm in terms of diagnostic horizons. The soil profile is remarkably homogenous with respect to colour, texture, structure, and bulk density. The sand grade of the profile is fine and the clay content is 21% for both the topsoil and subsoil. The bulk density varies from 1.6 g $cm^{-3}$ in the topsoil to an average of 1.5 g $cm^{-3}$ in the subsoil. The sum of the exchangeable cations (S-value) varies from 10 cmol (+) $kg^{-1}$ soil in the topsoil to 11 cmol (+) $kg^{-1}$ soil in the subsoil (Appendix 9).

**Table 5.3** The soil component of the Fort Hare/Oakleaf – Ritchie ecotope

| **Profile detail** | | | | | **Soil water extraction properties (mm)** | | |
|---|---|---|---|---|---|---|---|
| Diagnostic horizon | Depth (mm) | Colour (Dry) | Clay (%) | BD (g $cm^{-3}$) | DUL | LL (Maize) | TESW[*1] |
| Orthic A | 0-300 | Dark brown | 21 | 1.6 | 75 | 39 | 36 |
| Neocutanic B | 300-600 | Very dark greyish brown | 22 | 1.6 | 60 | 38 | 22 |
| Neocutanic B | 600-900 | Dark yellowish brown | 24 | 1.4 | 67 | 39 | 28 |
| Neocutanic B | 900-1200 | Reddish brown | 21 | 1.5 | 60 | 40 | 20 |
| TOTAL | | | | | 256 | 156 | 100 |

[*1]TESW = Total extractable soil water

5.3.1.3.1 *Drainage characteristics*

The volumetric soil water content (θ) time series graphs for the different B-horizon layers are presented in Figure 5.5.

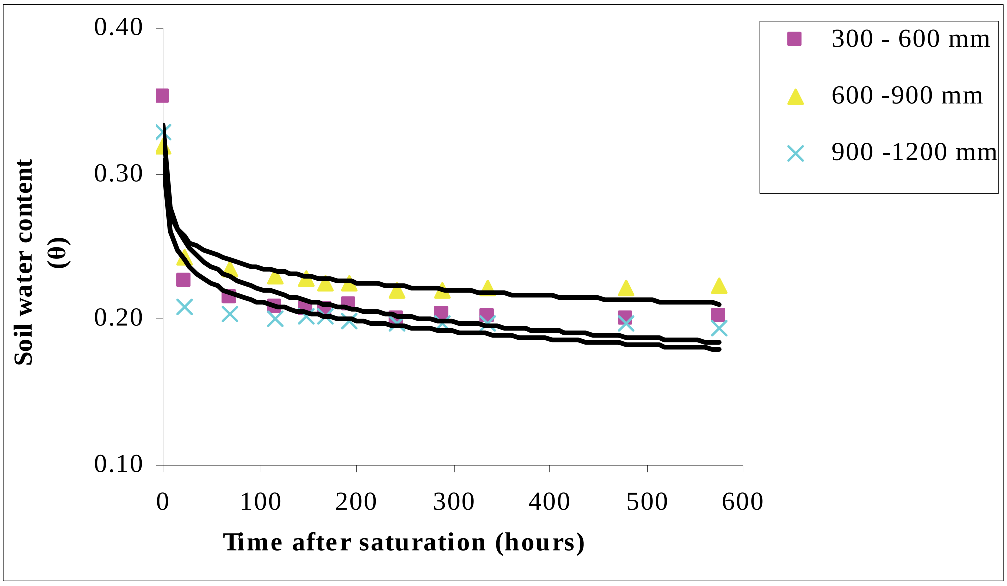


**Figure 5.5** Drainage curves of various layers on Fort Hare/Oakleaf ecotope.

Firstly, it is clear from the graphs in Figure 5.5 and Figure 5.6 that the profile was uniformly wetted at the onset of the experiment. Secondly, the shape of the curves reflects the internal drainage process, which seems remarkably similar amongst layers. The wetness diminishes approximately at the same rate over the measurement period of 25 days (600 hours). This can be attributed to the homogeneity in soil texture and bulk density of the layers. Under such homogenous conditions it is possible to obtain a depth-average soil water content (mean of B-horizons) – time relationship by fitting the data to a mathematical function depicted in Equation 9. The internal drainage process of the A-horizon was also characterized and plotted in Figure 5.6. The $r^2$ of both functions justifies the application of Equation 8.

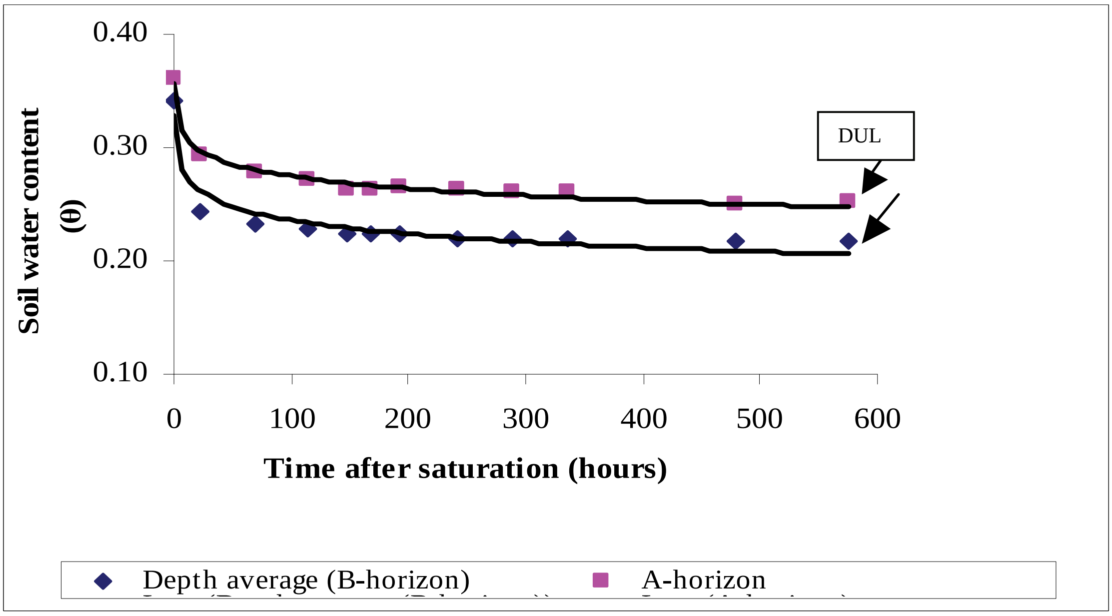


**Figure 5.6** θ-time relationship of the B-horizon and A-horizon during the internal drainage on the Fort Hare/Oakleaf ecotope.

$$\theta_A = -0.02Ln(t) + 0.35 \qquad (R^2 = 0.99) \qquad \textbf{(Equation 8)}$$

$$\theta_B = -0.02Ln(t) + 0.32 \qquad (R^2 = 0.93) \qquad \textbf{(Equation 9)}$$

where:

θ = soil water content depth average of B-horizon (subscript B) and A-horizon (subscript A)
t = time (hours) after field saturation

On the other hand, downward flux ($q_b$), in mm hour$^{-1}$, through any plane at depth $z_b$ can be calculated with the following equation:

$$q_b = \frac{dw}{dt} = -z_b \frac{d\theta}{dt} \qquad \textbf{(Equation 10)}$$

Equation 10 was used to calculate q values for a range of θ values at 1-day intervals. Following the suggestion of Hillel (2004), that under internal drainage conditions for homogenous deep soil, hydraulic conductivity (K) equals the downward flux (Equation 11), Equation 12 was derived from Equation 11 assuming that the matrix suction gradient () is negligible, leaving the gravitational force () to be the main driver in the internal drainage process.

$$q = \frac{-K(\theta)(\partial(-\varphi - z)}{\partial z} \qquad \textbf{(Equation 11)}$$

$$q = K(\theta) \qquad \textbf{(Equation 12)}$$

Equation 12 indicates that K relates to q at a given soil water content. By using Equation 10 it is possible to calculate K at daily time interval drainage by applying the θ-time related functions (Equations 8 & 9). The corresponding K-θ values for depth average B-horizon and A-horizon are plotted in Figure 5.7. The functions are presented in Equation 13 and Equation 14 for the B-horizon and A-horizon, respectively.


**Figure 5.7** Relationship between hydraulic conductivity and θ between field saturation and the DUL of both A and B-horizons.

$K_B = 10^{10} \times \theta^{18}$ ($R^2 = 0.99$) (**Equation 13**)

$K_A = 6 \times 10^7 \times \theta^{14.6}$ ($R^2 = 1.00$) (**Equation 14**)

Figure 5.7 represents soil water content between field saturation and DUL. When Equation 12 is applied to the field, it is possible to calculate the daily percolation from the depth-average soil water content, if the soil water content is above the DUL. According to Ratliff *et al.* (1983) DUL can be taken at any point where the internal drainage becomes negligibly low *viz.* 0.1-0.2% lower than initial K. The θ points were chosen to be 0.25 and 0.22 for the A- and B-horizons, respectively. Using Equation 14 and Equation 13 the corresponding K-values for A and B-horizons were 0.09 and 0.14 mm day$^{-1}$, respectively. Taking into account the thickness of the pedological layers, the DUL for the A-horizon and the three successive B-horizons is 75, 60, 66 and 57 mm per 300 mm, respectively. Hence, the amount of water stored in the profile to a depth of 1200 mm is 258 mm (Joseph, 2007).

5.3.1.3.2 *Conservation of natural resources*

Two indicators of sustainability of conservation of natural resources for crop production were used, namely organic carbon (C) content and RWP.

The organic carbon content of the top 150 mm soil layer was used as the first indicator of sustainability. Soil samples at the Guquka/Cartref ecotope were taken prior to the start of the 2004/05 growing season (beginning of experiment) as well as at the beginning of the 2007/08 season (final season of experiment). Soil samples at the Fort Hare/Oakleaf ecotope were only taken at the beginning of the 2007/08 season (beginning of final season). Unfortunately the soil samples taken at the beginning of the field experiments at Fort Hare/Oakleaf ecotope got lost. Therefore no initial C content results were available for that ecotope. The soil samples were analysed at the ARC-ISCW laboratories in Pretoria using standard procedures.

$RWP_n$ with maize on the Fort Hare/Oakleaf, Phandulwazi/Westleigh and Guquka/Cartref ecotopes was calculated from short-term field experiments that were conducted over periods from two to four years as described above.

### 5.3.2 Results: Agronomic impact

The on-station and on-farm crop production field experiments focussed on the effect of different treatments on maize production and not on the cover crops. Therefore, the growth and production of the cover crops were not taken into consideration. $IRWH_{GLDM}$ was ignored during the discussion of the results because of the poor establishment of green leaf desmodium on the runoff area at the Fort Hare/Oakleaf ecotope. It was replanted every year, but without any success. Therefore, the discussions of the results for the Fort Hare/Oakleaf ecotope will only deal with *STRIP*, *CON*, $IRWH_{Bare}$, $IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{Lucerne}$.

5.3.2.1 Meteorological conditions

To characterize the climatic conditions during the four seasons they were each sub-divided into five periods, *viz*. (i) the fallow period ($F_p$), which extended 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; (iii) the reproductive period ($R_p$), which represents the time from flowering until harvest; (iv) the growing period ($G_p$), which represents the time from planting until harvest; and (v) the production period ($P_p$), which include $F_p$, $V_p$ and $R_p$. The results are presented in Table 5.4.

**Table 5.4** Precipitation (P), potential evaporation (ETo) and aridity index (AI) for the 2004/05, 2005/06, 2006/07 and 2007/08 production seasons

| Parameter | Season | Period | | | | |
|---|---|---|---|---|---|---|
| | | $F_p$ | $V_p$ | $R_p$ | $G_p$ | $P_p$ |
| P (mm) | 2004/05 | - | 174 | 82 | 256 | - |
| | 2005/06 | 246 | 174 | 170 | 344 | 589 |
| | 2006/07 | 545 | 190 | 120 | 310 | 855 |
| | 2007/08 | 161 | 234 | 179 | 413 | 574 |
| | **Mean** | **317** | **193** | **138** | **331** | **673** |
| | **LT mean** | **276** | **164** | **131** | **295** | **571** |
| ETo (mm) | 2004/05 | - | 386 | 252 | 638 | - |
| | 2005/06 | 669 | 464 | 306 | 770 | 1439 |
| | 2006/07 | 658 | 412 | 359 | 771 | 1429 |
| | 2007/08 | 724 | 309 | 228 | 537 | 1261 |
| | **Mean** | **684** | **393** | **286** | **679** | **1376** |
| | **LT mean** | **844** | **445** | **317** | **762** | **1606** |
| AI | 2004/05 | | 0.45 | 0.33 | 0.40 | |
| | 2005/06 | 0.37 | 0.38 | 0.56 | 0.45 | 0.41 |
| | 2006/07 | 0.83 | 0.46 | 0.33 | 0.40 | 0.60 |
| | 2007/08 | 0.22 | 0.76 | 0.79 | 0.77 | 0.46 |
| | **Mean** | **0.46** | **0.49** | **0.48** | **0.49** | **0.49** |
| | **LT mean** | **0.33** | **0.37** | **0.41** | **0.39** | **0.36** |

During the 2004/05 season, water shortages occurred mostly in the reproductive period due to very low rainfall. This is reflected in the low AI value and also contributed to a relatively low AI value during the growing period. The 2005/06 season was characterized by a just below average vegetative period, while the very good climatic conditions which prevailed during the reproductive period may have contributed to higher yields. The 2006/07 season started very well with above-normal rain during the fallow period but as the season progressed the climatic conditions turned out to be very unfavourable for crop production. Low rainfall occurred during the reproductive period and above-normal potential evaporation occurred during the vegetative and reproductive period (growing period), contributing to below-normal AI values for the growing period, but especially for the critical reproductive period. The 2007/08 season was the opposite of the 2006/07 season. It started off with very unfavourable climatic condition during the fallow period, but as the season progressed climatic conditions became very favourable for crop production. Rainfall was much higher than normal, while potential evaporation was much lower than normal which contributed towards very high and favourable AI values during the vegetative and reproductive periods. The Fort Hare/Oakleaf ecotope received a total of 413 mm during the 2007/08 growing season, of which 42% occurred during the critical reproduction stage and could have had a positive effect on grain yield. The 2007/08 season had the most favourable climatic conditions for crop production followed by the 2005/06 season. The 2004/05 and 2006/07 seasons had unfavourable conditions for crop production.

### 5.3.2.2 Water balance components

#### 5.3.2.2.1 *Soil water content*

Conservation of water during the fallow period is essential in semi-arid environments to give a higher pre-plant water advantage. The plant-available water at planting ($PAW_p$), tasseling ($PAW_T$), and harvesting ($PAW_H$) values for each treatment are summarized in Table 5.5.

The yellow maize cultivar (PAN 6480) that was used during this experiment is a medium-long growing season cultivar, i.e. ± 155 days from planting to maturity. This implies a fallow period of 7 months.

In the 2004/05 growing season there was no fallow period because the field was ploughed and basins were constructed just before planting. The *IRWH* treatments, therefore, did not have any time to collect runoff water during the fallow period of the 2004/05 season, and consequently *IRWH*$_{Bare}$ did not have a pre-plant water advantage above the *CON* and *STRIP* cropping treatments. All treatments started the 2004/05 season with almost the same soil water content. During the first growing season (2004/05) the cover crops were still not well established and the cover crops did not extract much water from the soil profile. However, from the 2005/06 season very strong trends were observed in the PAW water patterns of the different treatments at $PAW_p$, $PAW_T$ and $PAW_H$. *IRWH*$_{Mulch}$ had the highest PAW at planting, tasseling and harvest followed by *IRWH*$_{Bare}$ > *STRIP* > *CON* > *IRWH*$_{Vet}$ > *IRWH*$_{Lucerne,}$ with the exception of *IRWH*$_{Lucerne}$ which had a higher $PAW_H$ than *IRWH*$_{Vet}$. *IRWH*$_{Mulch}$ showed considerably higher PAWp, $PAW_T$ and $PAW_H$ than the other treatments during all seasons.

*IRWH*$_{Mulch}$ induced mean pre-plant water advantages at planting of 20 and 40 mm above the means of *STRIP* and *CON* and *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$, respectively and $PAW_T$ advantages of 25 and 47 mm, respectively. *IRWH*$_{Mulch}$ induced mean PAW advantages at harvest of 12 and 36 mm above the means of *STRIP* and *CON* and *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$, respectively. The reason for this is that no runoff occurred from the land and the mulch on the runoff and basin areas minimized water losses through evaporation from the soil surface. This resulted in *IRWH*$_{Mulch}$ starting and ending the growing season with a much higher pre-plant water advantage in comparison to all the other treatments.

The mean PAWp, $PAW_T$ and $PAW_H$ of *IRWH*$_{Bare}$ induced slightly higher PAW at planting, tasseling and harvest than *STRIP* and *CON*. The reason for this may have been the total stoppage of ex-field runoff by the *IRWH* technique. *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$ induced the lowest mean $PAW_p$, $PAW_T$ and $PAW_H$. This is because the cover crops (lucerne and vetiver) are perennial crops and extract water throughout the year. *IRWH*$_{Lucerne}$ had the lowest mean PAWp and $PAW_T$ probably due to deeper root system of lucerne. In general *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ induced the highest mean $PAW_p$, $PAW_T$ and $PAW_H$ followed by *STRIP* and *CON* and then by *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$.

**Table 5.5** Plant-available water (mm) at planting ($PAW_p$), tasseling ($PAW_T$) and harvesting ($PAW_H$) for the root zone (0-1200 mm) on the different treatments during the four growing seasons at the Fort Hare/Oakleaf ecotope

| Water content | Season | Treatment | | | | | | Mean *CON*+ STRIP | Mean Lucerne +Vet | Mean Bare + Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | *IRWH* Lucerne | *IRWH* Vet | *IRWH* Bare | *IRWH* Mulch | | | |
| $PAW_p$ (mm) | 04/05 | $55^{a}$ | $57^{a}$ | $61^{a}$ | $59^{a}$ | $48^{a}$ | $71^{a}$ | 56 | 60 | 60 |
| | 05/06 | $77^{b}$ | $93^{b}$ | $84^{b}$ | $88^{b}$ | $91^{b}$ | $116^{a}$ | 85 | 86 | 104 |
| | 06/07 | $94^{a}$ | $102^{a}$ | $52^{a}$ | $65^{a}$ | $102^{a}$ | $107^{a}$ | 98 | 59 | 105 |
| | 07/08 | $76^{b}$ | $72^{ab}$ | $17^{c}$ | $38^{c}$ | $87^{a}$ | $99^{a}$ | 74 | 28 | 93 |
| | **Mean** | **76** | **81** | **54** | **63** | **82** | **98** | **78** | **58** | **90** |
| $PAW_T$ (mm) | 04/05 | $34^{a}$ | $52^{a}$ | $46^{a}$ | $42^{a}$ | $35^{a}$ | $53^{a}$ | 43 | 44 | 44 |
| | 05/06 | $41^{b}$ | $40^{b}$ | $22^{b}$ | $18^{b}$ | $40^{b}$ | $69^{b}$ | 41 | 20 | 55 |
| | 06/07 | $64^{b}$ | $65^{a}$ | $9^{c}$ | $22^{c}$ | $65^{b}$ | $83^{a}$ | 65 | 16 | 74 |
| | 07/08 | $57^{c}$ | $67^{bc}$ | $42^{c}$ | $44^{c}$ | $90^{ab}$ | $106^{a}$ | 62 | 43 | 98 |
| | **Mean** | **49** | **56** | **30** | **32** | **58** | **78** | **53** | **31** | **68** |
| $PAW_H$ (mm) | 04/05 | $19^{a}$ | $28^{a}$ | $25^{a}$ | $20^{a}$ | $20^{a}$ | $41^{a}$ | 24 | 23 | 31 |
| | 05/06 | $31^{b}$ | $34^{ab}$ | $20^{bc}$ | $13^{c}$ | $34^{ab}$ | $49^{a}$ | 33 | 17 | 42 |
| | 06/07 | $83^{b}$ | $91^{ab}$ | $40^{bc}$ | $33^{c}$ | $98^{ab}$ | $87^{a}$ | 87 | 37 | 93 |
| | 07/08 | $43^{b}$ | $49^{ab}$ | $18^{c}$ | $21^{c}$ | $60^{a}$ | $61^{a}$ | 46 | 20 | 61 |
| | **Mean** | **44** | **51** | **26** | **22** | **53** | **60** | **47** | **24** | **56** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

Statistical analyses of the $PAW_p$ values indicated that cover crops significantly affected $PAW_p$ during the 2007/08 season. *IRWH* treatments without cover crops had $PAW_p$ values that were significantly higher than *IRWH* treatments with cover crops during the 2007/08 season. *IRWH*$_{Mulch}$ had $PAW_p$ values that were significantly higher than all the other treatments during the 2005/06 season and significantly higher than *CON*, *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$ during the 2007/08 season ($P \leq 0.05$). The *IRWH* treatments without cover crops started the growing seasons with a mean of 12 and 32 mm pre-plant water advantage above *CON* and *STRIP*, and *IRWH* treatments with cover crops, respectively. In semi-arid areas pre-plant water advantage is a critical factor in crop growth, especially during dry seasons. The $PAW_T$ value of *IRWH*$_{Mulch}$ was significantly higher than all the other treatments in three of the four years, except for *IRWH*$_{Bare}$ during the 2007/08 season. *IRWH* treatments without cover crops had significantly higher $PAW_T$ values than *IRWH* treatments with cover crops in two of the four years. These results clearly demonstrate the build-up of available water in the root zone on the *IRWH* plots compared to *CON*, *STRIP*, *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$. This advantage at the critical tasseling stage is of particular significance for promoting better yields. *IRWH*$_{Mulch}$ had $PAW_H$ values that were significantly higher than *CON*, *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$ during three of the four seasons ($P \leq 0.05$).

#### 5.3.2.2.2 *Soil water extraction*

Figure 5.8 illustrates the measured changes in soil water content in the root zone during all growing seasons; these values help to explain yield and soil water balance relationship. Lines represent the mean of three replicates. The water management boundaries of plant-available water (PAW), DUL and LL are also included in the graphs.

*Vegetative period ($V_p$):*

During the vegetative period yield potential is determined. A favourable vegetative period will result in large strong plants (factories) with a high yield potential. During unfavourable conditions small weak plants will develop with a limited yield potential. The vegetative periods during the four seasons revealed that the 2005/06, 2006/07 and 2007/08 seasons, in all cases (except for $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$ in 2006/07 and 2007/08) had considerably higher $PAW_p$ than in the first season (2004/05). This may have been due to the lack of a proper fallow period prior to implementation in the first season, rather than an unfavourable $V_p$. Apart from the 2004/05 season, which did not have a fallow period, only the 2007/08 season was characterized by an unfavourable fallow period. The only season that was characterized by an unfavourable $V_p$ in comparison to the other seasons was 2005/06, which is also reflected in an AI value of 0.38 (Table 5.4) which was more the result of very high potential evaporation rather than low rainfall.

During the $V_p$ of the first growing season (2004/05) the cover crops (lucerne and vetiver) were not well established and did not extract much water from the soil profile. After the cover crops were well established they extracted a lot more water from the soil profile. There were clear trends in the soil water content patterns of the different treatments during the vegetative $V_p$ of the last three seasons: $IRWH_{\text{Mulch}}$ > $IRWH_{\text{Bare}}$ > *STRIP* > *CON* > $IRWH_{\text{Vet}}$ > $IRWH_{\text{Lucerne}}$. According to the DUL and CMUL limits, no significant drainage could have occurred during the vegetative period in any of the seasons.

During the 2004/05 season, 86 mm of rain (Figure 5.8) occurred between planting and days after planting (DAP) 29. The soil water content (SWC) of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ increased by 24 and 40 mm, respectively, during the same period. This may have been because more runoff that was generated from the bare runoff area than the runoff area covered with organic mulch.

Botha (2006) found in runoff studies that the treatment of the runoff area has a major influence on runoff and, therefore, water harvesting. He found on the Glen/Bonheim and Glen/Swartland ecotopes that the bare treatments had the highest runoff of 43% and 39%, respectively. He also found that the use of organic mulch on the runoff area clearly suppressed runoff and enhanced infiltration. Between DAP 20 and 40 the SWC of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ decreased by 24 and 31 mm, respectively. That the SWC of $IRWH_{\text{Bare}}$ decreased more than $IRWH_{\text{Mulch}}$ during this period may have been due to soil water lost to Es from the bare runoff and basin areas of $IRWH_{\text{Bare}}$ rather than to the runoff and basin areas of $IRWH_{\text{Mulch}}$ which were covered with organic mulch.

Botha (2006) has shown that evaporation from the soil surface can be reduced by between 8 and 20% using different mulches over long periods. He further stated that the effect over the short-term (8-16 days after saturation) is much greater and varied between 28 and 72%. He claimed that this could give crop roots time to extract a greater portion of the rainwater and use it more productively through transpiration. This would lead to less water being lost by evaporation. Similar results were found by Botha *et al*. (2003c) who studied the effect of mulches on evaporation from the soil surface on the Glen/Bonheim ecotope and found that organic mulch reduced Es from the runoff area. Rainfall during the Vp of the 2004/05 season was well distributed.

During the 2005/06 season, the SWC of $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$ decreased on average by 55 mm between DAP 0 and 85 (Figure 5.8) while the SWC of $IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$, *STRIP* and

*CON* decreased on average by 40 mm. This difference of 15 mm may have been due to the cover crops that competed with the maize crop for available water and extracted a lot of the water from the soil profile.

During the 2006/07 season maize emerged very poorly because of dry and very warm conditions after planting, but mainly due to bird damage. The effect of the cover crops can be seen between DAP 0 and 118 where the SWC of $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$ decreased on average by 43 mm, while the SWC of $IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$, *STRIP* and *CON* decreased on average by 35 mm. Rainfall during the $V_p$ of the 2007/08 season was not well distributed. Very good rain occurred between DAP 40 and 54.

During the 2007/08 season it can clearly be seen that the treatments with cover crops, ($IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$) and *CON* and *STRIP*, had lower soil water contents than the $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$. $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ had higher soil water contents than all the treatments.

*Reproductive period ($R_p$):*

The potential yield that was determined during $V_p$, is either realized or minimized during the critical $R_{\text{p}}$, depending on climatic conditions and soil water content. Climatic conditions during $R_p$ of the 2004/05 and 2006/07 seasons were unfavourable for crop production, while the $R_p$ of the 2005/06 and 2007/08 seasons was very favourable for crop production. As is often the case in a semi-arid environment, climatic conditions can change dramatically in a short time. For example, during the 2006/07 season there was a change from favourable conditions during the $V_p$ period (DAP 40-54) to very unfavourable in the $R_p$ after DAP 70. The crop received 120 mm of rain during $R_p$, while the corresponding Eo amounted to 359 mm. Twenty-two rainfall events occurred with none larger than 17 mm. Due to unfavourable rainfall conditions during the $R_p$ of the 2004/05 and 2006/07 seasons, the crop depended heavily on water stored in the soil profile to maintain the crop water demand. Another example of a dramatic change in climatic conditions occurred in the 2005/06 season when there was a change from unfavourable conditions during the $V_p$ period to very favourable in the $R_p$ after DAP 70. The crop received 170 mm of rain during $R_p$, while the corresponding Eo amounted to 306 mm and resulted in an AI value of 0.56. The 2007/08 season was an exception, characterized by a good $V_p$ and $R_p$ period.

During the 2004/05 season between DAP 75 and 89 (Figure 5.8), 39 mm of rain occurred and the SWC of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ increased by 23 and 18 mm, respectively, an indication that the SWC of $IRWH_{\text{Bare}}$ responded better than $IRWH_{\text{Mulch}}$. Once again this may have been due to more runoff being generated from the bare runoff area than from the runoff area covered with organic mulch. Between DAP 110 and 138 the SWC of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ decreased by 9 and 13 mm, respectively. The SWC of $IRWH_{\text{Bare}}$ decreased more than $IRWH_{\text{Mulch}}$ which might once again be due to more soil water lost to Es from the bare runoff and basin areas of $IRWH_{\text{Bare}}$ as compared to the runoff and basin areas of $IRWH_{\text{Mulch}}$ that are covered with organic mulch.

During the 2007/08 season 91 mm of rain occurred between DAP 80-100. The SWC of all the *IRWH* treatments ($IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$, $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$) responded and rose sharply with an average increase in SWC of 30 mm. The SWC of *STRIP* and *CON* did not respond that well and only increased by 6 mm each. The difference between the *IRWH* treatments and *STRIP* and *CON* is no ex-field runoff occurred from the *IRWH* treatments. Runoff for *STRIP* and *CON* was estimated to be 36 mm for the period DAP 80-100. Although

*CON* and *STRIP* lost large amounts of rainwater to ex-field runoff during the growing season, they still had higher SWC than $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$. This is due to the fact that cover crops (lucerne and vetiver) are perennial crops and extract water throughout the year. $IRWH_{\text{Lucerne}}$ had the lowest soil water content at the beginning of the season probably due to deeper root system of lucerne. $IRWH_{\text{Mulch}}$ outperformed all the other treatments in terms of SWC throughout the production period.

In general the soil water content of $IRWH_{\text{Mulch}}$ remained significantly higher than all the other treatments during the last three growing seasons, followed by $IRWH_{\text{Bare}}$ > *STRIP* > *CON* > $IRWH_{\text{Vet}}$ > $IRWH_{\text{Lucerne.}}$

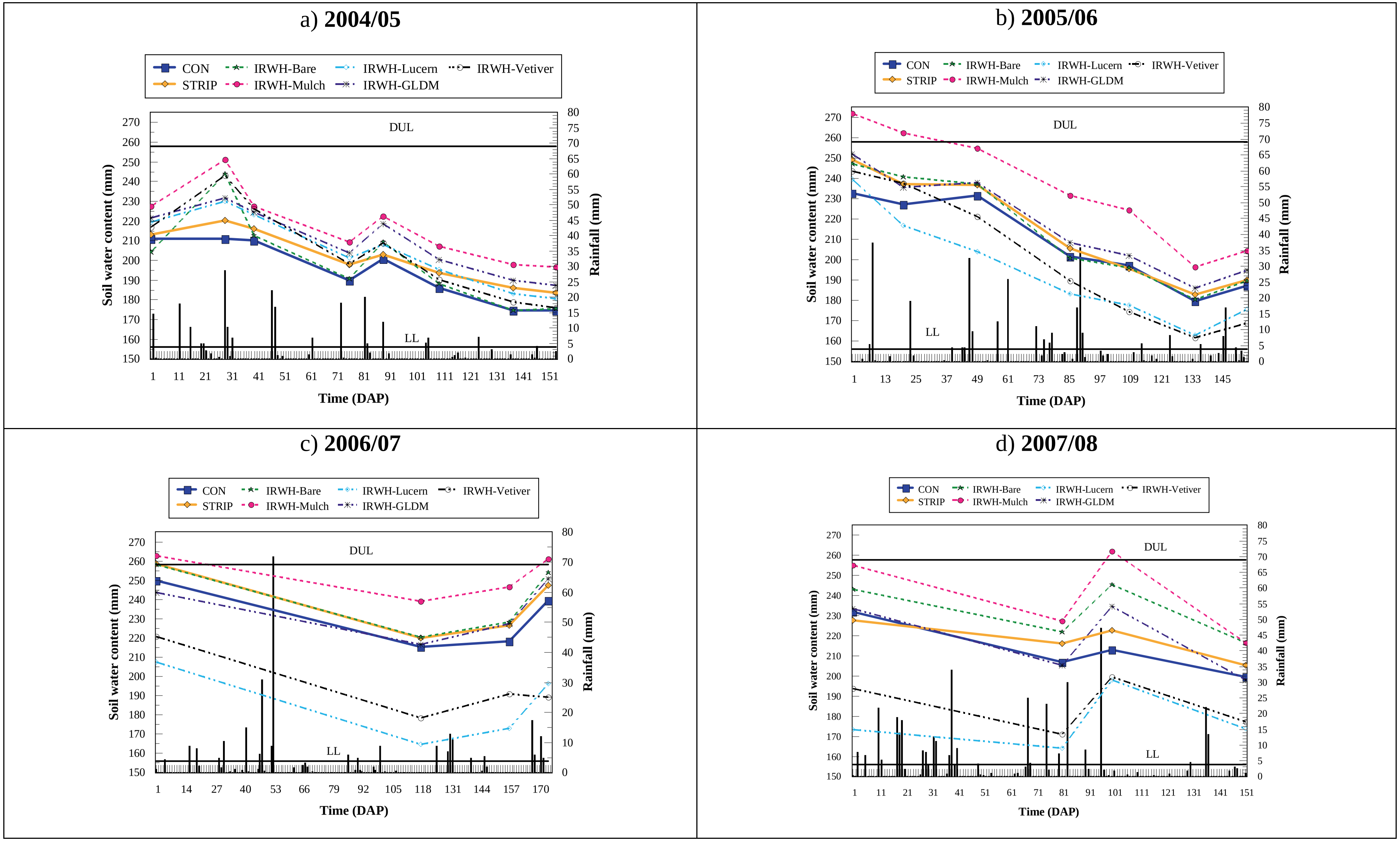


**Figure 5.8** Change in the soil water content of the maize root zone (0-1200 mm) during the 2004/2005, 2005/2006, 2006/2007 and 2007/2008 seasons at Fort Hare/Oakleaf-Ritchie ecotope.

#### 5.3.2.2.3 *Evapotranspiration*

Es, ET and Ev results for the four seasons are presented in Table 5.6. These provide the opportunity to analyse the general effect of the different treatments on ET, Ev and Es, the effect of mulch placement in the *IRWH* system, as well as the effect of cover crops on the runoff area. It should be kept in mind that the cover crops contributed towards higher ET and Ev as well as lower Es values. Therefore *CON*, *STRIP*, $IRWH_{Mulch}$ and $IRWH_{Bare}$ will first be discussed.

**Table 5.6** Evapotranspiration (ET = Ev+Es), evaporation from the soil surface (Es) and maize transpiration (Ev) during the growing period for the four seasons for the different treatments

| Parameters | Growing season | Treatment | | | | | | Mean *CON* +SC | Mean Luc+ Vet | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| Ev (mm) | 2004/05 | $70^{a}$ | $55^{a}$ | $77^{a}$ | $78^{a}$ | $80^{a}$ | $74^{a}$ | 63 | 78 | 77 |
| | 2005/06 | $127^{b}$ | $112^{c}$ | $59^{e}$ | $93^{d}$ | $137^{ab}$ | $150^{a}$ | 120 | 76 | 144 |
| | 2006/07 | $41^{b}$ | $45^{ab}$ | $15^{c}$ | $15^{c}$ | $55^{a}$ | $55^{a}$ | 43 | 15 | 55 |
| | 2007/08 | $131^{b}$ | $123^{b}$ | $68^{c}$ | $79^{c}$ | $138^{ab}$ | $175^{a}$ | 127 | 74 | 157 |
| | **Mean** | **92** | **84** | **55** | **66** | **103** | **114** | **88** | **61** | **108** |
| Es (mm) | 2004/05 | $163^{a}$ | $169^{a}$ | $215^{b}$ | $217^{b}$ | $204^{b}$ | $212^{b}$ | 166 | 216 | 208 |
| | 2005/06 | $173^{a}$ | $202^{b}$ | $348^{e}$ | $325^{d}$ | $264^{c}$ | $262^{c}$ | 188 | 337 | 263 |
| | 2006/07 | $196^{a}$ | $193^{a}$ | $306^{b}$ | $327^{b}$ | $259^{b}$ | $275^{b}$ | 195 | 317 | 267 |
| | 2007/08 | $250^{a}$ | $247^{a}$ | $346^{cd}$ | $352^{d}$ | $303^{c}$ | $277^{b}$ | 249 | 349 | 290 |
| | **Mean** | **196** | **203** | **304** | **305** | **258** | **257** | **199** | **305** | **257** |
| ET (mm) | 2004/05 | $233^{b}$ | $224^{b}$ | $293^{a}$ | $295^{a}$ | $284^{a}$ | $286^{a}$ | 229 | 294 | 285 |
| | 2005/06 | $300^{d}$ | $314^{c}$ | $407^{ab}$ | $418^{a}$ | $401^{b}$ | $411^{ab}$ | 307 | 413 | 406 |
| | 2006/07 | $237^{c}$ | $238^{c}$ | $321^{ab}$ | $342^{a}$ | $314^{b}$ | $330^{ab}$ | 238 | 332 | 322 |
| | 2007/08 | $370^{d}$ | $380^{d}$ | $413^{c}$ | $430^{b}$ | $440^{ab}$ | $452^{a}$ | 375 | 422 | 446 |
| | **Mean** | **285** | **289** | **359** | **371** | **360** | **370** | **287** | **365** | **365** |
| Es/ET (%) | 2004/05 | $70^{a}$ | $75^{a}$ | $73^{a}$ | $74^{a}$ | $72^{a}$ | $74^{a}$ | 73 | 73 | 73 |
| | 2005/06 | $58^{a}$ | $64^{a}$ | $86^{b}$ | $78^{b}$ | $66^{a}$ | $64^{a}$ | 61 | 82 | 65 |
| | 2006/07 | $83^{a}$ | $81^{a}$ | $95^{b}$ | $96^{b}$ | $82^{a}$ | $83^{a}$ | 82 | 95 | 83 |
| | 2007/08 | $68^{a}$ | $65^{a}$ | $84^{b}$ | $82^{b}$ | $69^{a}$ | $61^{a}$ | 66 | 83 | 65 |
| | **Mean** | **69** | **71** | **85** | **82** | **72** | **69** | **70** | **83** | **71** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

*CON* and *STRIP* gave similar results and, therefore, for the purposes of this discussion the mean of the two treatments was used. The mean ET during all four seasons was higher for $IRWH_{Mulch}$ and $IRWH_{Bare}$ treatments than *CON* and *STRIP*. The mean increase was about 27%. Differentiation of ET into its components suggests that the mean increase in ET for *IRWH* can be attributed towards higher Ev and Es during the growing seasons. The mean Ev and Es results of $IRWH_{Mulch,}$ and $IRWH_{Bare}$ treatments were 23 and 29% higher than those of *CON* and *STRIP*. The mean increase is about 20% also. It should be kept in mind that $IRWH_{Mulch}$ and $IRWH_{Bare}$ treatments were constantly wetter than *CON* and *STRIP* and therefore it is to be expected that Es from the wetter *IRWH* treatments would be higher than from *CON* and *STRIP*. Es from $IRWH_{Mulch}$ and $IRWH_{Bare}$ treatments were significantly higher than *CON* and *STRIP* during all four seasons. ET from all the *IRWH* treatments was significantly higher than *CON* and *STRIP* during all four seasons. Es/ET is an indication of the portion of ET that was unproductively lost to Es. The mean Es/ET results for maize on the *CON*, *STRIP*, $IRWH_{Mulch}$ and $IRWH_{Bare}$ were 69, 71, 69 and 72%, respectively. This shows that *CON*, *STRIP*, $IRWH_{Mulch}$ and $IRWH_{Bare}$ lost similar portions of ET to Es In other words these treatments performed equally in minimizing the unproductive loss of water through Es. This was confirmed by a statistical analysis which showed no significant difference in Es/ET values between *CON*, *STRIP*, $IRWH_{Mulch}$ and $IRWH_{Bare}$.

Botha (2006) indicated that Es can be reduced through mulching if the drying period is no longer than approximately 16 days. $IRWH_{Mulch,}$ with mulch on the basin and runoff areas, in comparison with $IRWH_{Bare}$ suppressed Es significantly in only one of the four years (2007/08). During the 2007/08 season seven rain events, which were larger than 20 mm and well-distributed, occurred during the growing season, of which three were during the vegetative period and four during the reproductive period. Season 2004/05 received two such events, the 2005/06 season four and 2006/07 received two. This may have been the reason why $IRWH_{Mulch}$ only managed to significantly suppress Es during the 2007/08 season compared to $IRWH_{Bare}$. Mulch placement in the *IRWH* systems showed that both *IRWH* treatments were very similar in suppressing Es. A comparison of the portion of ET lost to Es, also confirmed that both *IRWH* treatments were very similar in suppressing Es. The mean Es/ET of $IRWH_{Mulch}$ and $IRWH_{Bare}$ showed that $IRWH_{Mulch}$ was slightly more successful (3%) than $IRWH_{Bare.}$

Comparing the effect of cover crops on the runoff area on Ev and Es for ($IRWH_{Vet}$ and $IRWH_{Lucerne}$) with ($IRWH_{Mulch}$ and $IRWH_{Bare)}$ was very complicated, as Es is a derived value. These values are not a true reflection of the real situation where the crop is produced together with a cover crop. If the Ev of the cover crops is not taken into consideration it may appear as if $IRWH_{Vet}$ and $IRWH_{Lucerne}$ lost most of their ET to Es. If Ev is expressed for only one crop, then the assumption is made that all other water lost from the system is due to Es. However, the cover crops also use water through the process of transpiration and this loss should be subtracted to get a better indication of Es. Currently the treatments with aggressive growing cover crops (vetiver grass and lucerne) indicate the highest mean Es values. This was contradictory to what was expected as the cover crops covered almost the whole soil surface and protected the soil surface from water losses through Es. The mean ET of $IRWH_{Vet}$ was similar to $IRWH_{Mulch}$ while the mean ET of $IRWH_{Lucerne}$ was similar to $IRWH_{Bare}$, therefore the mean ET of cover crops was equal to the mean ET of $IRWH_{Mulch}$ and $IRWH_{Bare.}$ The problem is to separate ET into Ev not only for maize, but also the cover crops and Es. In order to separate ET for maize the procedure proposed by Tanner & Sinclair (1983) using a transpiration efficiency coefficient (k) was used, but it was difficult to find a k value for lucerne and vetiver. Another problem that occurred was that some of the lucerne and vetiver cuttings used for biomass measurement were lost and therefore biomass data were missing. Therefore it was decided to make use of the following assumptions:

1) Mulch cover on the runoff area and the canopy of the cover crops were similar.
2) Es for $IRWH_{Vet}$, $IRWH_{Lucerne}$, $IRWH_{Mulch}$ and $IRWH_{Bare}$ were the same.

ET, Ev and Es results for $IRWH_{Vet}$ and $IRWH_{Lucerne}$ which take the above mentioned assumptions in consideration, are given in Table 5.7. It should be mentioned that Ev for the cover crops may be under-estimated resulting in the over-estimation of Es. This was especially true during the 2006/07 season where poor emergence of the maize occurred and much more water was extracted by the cover. As it was assumed that Es of $IRWH_{Vet}$ and $IRWH_{Lucerne}$ are the same as for $IRWH_{Mulch}$ and $IRWH_{Bare}$ only Ev will be discussed. By taking the estimated Ev of the cover crops into consideration the total Ev for $IRWH_{Lucerne}$ and $IRWH_{Vet}$ increased on average by 47 and 49 mm, respectively, over the four seasons. Therefore, the mean Ev values for the maize and the cover crops ($IRWH_{Lucerne}$ and $IRWH_{Vet}$)

compare very well with the mean Ev values of $IRWH_{Mulch}$ and $IRWH_{Bare}$ (Table 5.6). Taking the estimated mean Ev values of the cover crops into consideration the Es/ET values of $IRWH_{Lucerne}$ and $IRWH_{Vet}$ decreased from 85% and 82% to 72% and 69%, respectively, with an average decrease of 13%. This is an indication that cover crops on the runoff areas were just as successful as all the other treatments in minimizing the portion of ET lost to Es.

**Table 5.7** Total evapotranspiration (ET = Ev + Es), evaporation from the soil surface (Es) and total transpiration (Ev) during the growing period for the four seasons for the cover crop treatments

| | Growing season | Treatment | | | | | | Mean Maize | Mean Cover crop | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $IRWH_{Lucerne}$ | | | $IRWH_{Vet}$ | | | | | |
| | | Maize | Lucerne | Maize and Lucerne | Maize | Vetiver | Maize and Vetiver | | | |
| Ev (mm) | 2004/05 | $77^{a}$ | $4^{AA}$ | $81^{A}$ | $78^{a}$ | $5^{AA}$ | $83^{A}$ | **78** | **5** | **82** |
| | 2005/06 | $59^{a}$ | $86^{AA}$ | $145^{A}$ | $93^{b}$ | $63^{AA}$ | $156^{A}$ | **76** | **75** | **151** |
| | 2006/07 | $15^{a}$ | $31^{AA}$ | $46^{A}$ | $15^{a}$ | $52^{AA}$ | $67^{A}$ | **15** | **42** | **57** |
| | 2007/08 | $68^{a}$ | $68^{AA}$ | $136^{A}$ | $79^{a}$ | $74^{AA}$ | $153^{A}$ | **74** | **71** | **145** |
| | **Mean** | **55** | **47** | **102** | **66** | **49** | **115** | **61** | **48** | **109** |
| Es (mm) | 2004/05 | 212 | | | 212 | | | 212 | | |
| | 2005/06 | 262 | | | 262 | | | 262 | | |
| | 2006/07 | 275 | | | 275 | | | 275 | | |
| | 2007/08 | 277 | | | 277 | | | 277 | | |
| | **Mean** | **257** | | | **257** | | | **257** | | |
| ET (mm) | 2004/05 | 293 | | | 295 | | | 294 | | |
| | 2005/06 | 407 | | | 418 | | | 413 | | |
| | 2006/07 | 321 | | | 342 | | | 332 | | |
| | 2007/08 | 413 | | | 430 | | | 422 | | |
| | **Mean** | **359** | | | **371** | | | **365** | | |
| Es/ET (%) | 2004/05 | 72 | | | 72 | | | 72 | | |
| | 2005/06 | 64 | | | 63 | | | 64 | | |
| | 2006/07 | 86 | | | 80 | | | 83 | | |
| | 2007/08 | 67 | | | 64 | | | 66 | | |
| | **Mean** | **72** | | | **69** | | | **70** | | |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$). Upper case superscripts are used to compare cover crops and lower case superscripts to compare maize

The mean ET for $IRWH_{Vet}$ and $IRWH_{Lucerne}$ (maize + cover crop) (Table 5.7) are the same as the mean ET for $IRWH_{Mulch}$ and $IRWH_{Bare}$ (Table 5.6). The difference is that maize only used 56% of the mean Ev, while cover crops used the rest (44%). Expressed differently, cover crops used 13% of ET for Ev, whereas maize used 17%. A lot of valuable rainwater was used by the cover crops for producing biomass instead of for producing maize, negatively influencing crop yield in $IRWH_{Vet}$ and $IRWH_{Lucerne}$ (Table 5.9). It is crucial in semi-arid areas to conserve as much rainwater as possible in order for the crop to use it for Ev. The rainfall in this area is just too low (LT mean P and AI are 295 mm and 0.39, respectively, for the growing seasons – Table 5.4) to make use of cover crops, especially vetiver which is not palatable. Lucerne at least adds value since, apart from contributing to soil conservation as was the case in this project; it can be used as fodder for animals. Vetiver is mainly used for soil conservation purposes in order to minimize erosion on steep slopes and; cuttings can also be used as a mulch. Ev values did not differ significantly for the different cover crops over the four years. Total Ev values of maize and cover crops for $IRWH_{Lucerne}$ and $IRWH_{Vet}$ also did not differ significantly during any of the four years.

These results show that the evaporation process dominates all the other water processes. The water loss through evaporation was higher than the rainfall received during the growing period. This clearly indicates the importance of minimizing water losses. This experiment clearly demonstrates the importance of studying Es, especially during the crop growing period. Separating ET into Es and Ev is complicated and procedures need to be improved before the actual contribution of ES can be truly quantified.

5.3.2.2.4 *Runoff*

To quantify ex-field runoff ($R_{Ex}$) from *CON* and *STRIP* each seasons was sub-divided into the following five periods as presented in section 5.3.2.1, *viz*. (i) $F_p$; (ii) $V_p$; (iii) $R_p$; (iv) $G_p$; (v) $P_p$. No $R_{Ex}$ occurred from any of the *IRWH* treatments, therefore, only runoff from *CON* and *STRIP* is reported. The procedure used to calculate $R_{Ex}$ is described in Section 5.2.4.5.

**Table 5.8** Ex-field runoff ($R_{Ex}$) from *CON* and *STRIP* for subdivisions of the four seasons for maize on the Fort Hare/Oakleaf ecotope

| Parameter | Season | Period | | | | |
|---|---|---|---|---|---|---|
| | | $F_p$ | $V_p$ | $R_p$ | $G_p$ | $P_p$ |
| $R_{Ex}$(mm) | 2004/05 | - | 17 | 4 | 21 | - |
| | 2005/06 | 33 | 22 | 11 | 33 | 67 |
| | 2006/07 | 58 | 24 | 4 | 29 | 86 |
| | 2007/08 | 5 | 21 | 24 | 45 | 50 |
| | **Mean** | **32** | **21** | **11** | **32** | **67** |
| $R_{Ex}$/P (%) | 2004/05 | | 10 | 4 | 8 | |
| | 2005/06 | 13 | 13 | 7 | 10 | 11 |
| | 2006/07 | 11 | 13 | 4 | 9 | 10 |
| | 2007/08 | 3 | 9 | 13 | 11 | 9 |
| | **Mean** | **9** | **11** | **7** | **9** | **10** |

During the 2004/05, 2005/06, 2006/07 and 2007/08 seasons $G_p$ *CON* and *STRIP* lost 21, 33, 29 and 45 mm of rainwater to $R_{Ex}$, respectively, which is a mean loss of 9% of the total rainfall over the four growing periods. The mean $R_{Ex}$ during the four seasons for $F_p$, $V_p$, $R_p$, $G_p$, and $P_p$ periods were 32, 21, 11, 32 and 67 mm, respectively. Severe water losses due to $R_{Ex}$, with a mean of 11 mm, occurred during the critical $R_p$ period. These unproductive losses could have seriously hampered maize yields. $R_{Ex}$ (mm and % of P) differs between the various seasons and depends most of all on the rainfall characteristics.

5.3.2.2.5 *Drainage*

There was no significant amount of deep drainage occurred during the 2004/05, 2006/07 and 2007/08 seasons, this is clearly shown by the root zone water content (θr) results presented in Figure 5.8. Deep drainage can only be expected when θr exceeds DUL and the crop modified upper limit. Only during the beginning of 2005/06 was the θr of $IRWH_{Mulch}$ above DUL for about 21 days. However, since no measurements were taken beyond a depth of 1200 mm at Fort.

5.3.2.3 Yield

Grain and biomass yields and the harvest index for the different treatments are summarized in Table 5.9. Over the four years grain yields of individual treatments varied between 461 and 6658 kg ha$^{-1}$ with a very strong yield trend of $IRWH_{\text{Mulch}}$ > $IRWH_{\text{Bare}}$ > *CON* > *STRIP* > $IRWH_{\text{Vet}}$ > $IRWH_{\text{Lucerne}}$. The grain yields of all the *IRWH* treatments were only significantly higher ($P \leq 0.05$) than *CON* and *STRIP* during the first season (2004/05). The reason for this was that the cover crops were not well established and therefore did not compete with the maize for water. The grain yields of $IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$, *CON* and *STRIP* were significantly higher than $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$ during two seasons (2005/06 and 2007/08). This was expected, as the soil water content of $IRWH_{\text{Vet}}$ and $IRWH_{\text{Lucerne}}$ were always lower than that of $IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$, *CON* and *STRIP* throughout the three last seasons (Figure 5.8).

$IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$ and *CON* only induced significantly higher maize yields than *STRIP* during the 2005/06 season. Apart from the 2004/05 season, $IRWH_{\text{Mulch}}$, $IRWH_{\text{Bare}}$ and *CON* did not differ significantly.

**Table 5.9** Maize grain and biomass yields and harvest index for the different treatments during four seasons on the Fort Hare/Oakleaf ecotope

| Parameter | Season | Treatment | | | | | | Mean CON +SC | Mean Luc+ Vet | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | $IRWH_{\text{Lucerne}}$ | $IRWH_{\text{Vet}}$ | $IRWH_{\text{Bare}}$ | $IRWH_{\text{Mulch}}$ | | | |
| Grain (kg ha$^{-1}$) | 2004/05 | $2066^{bc}$ | $1643^{c}$ | $2689^{ab}$ | $2680^{ab}$ | $2611^{ab}$ | $2775^{a}$ | 1855 | 2685 | 2693 |
| | 2005/06 | $3952^{a}$ | $3274^{b}$ | $983^{c}$ | $2292^{c}$ | $4177^{a}$ | $4373^{a}$ | 3613 | 1638 | 4275 |
| | 2006/07 | $1467^{a}$ | $1327^{a}$ | $461^{a}$ | $486^{a}$ | $1595^{a}$ | $1412^{a}$ | 1397 | 474 | 1504 |
| | 2007/08 | $5583^{a}$ | $5281^{ab}$ | $2997^{c}$ | $3461^{bc}$ | $6326^{a}$ | $6658^{a}$ | 5432 | 3229 | 6492 |
| | **Mean** | **3267** | **2881** | **1783** | **2230** | **3677** | **3805** | **3074** | **2006** | **3741** |
| Biomass (kg ha$^{-1}$) | 2004/05 | $5528^{a}$ | $4379^{a}$ | $6103^{a}$ | $6165^{a}$ | $6323^{a}$ | $5883^{a}$ | 4954 | 6134 | 6103 |
| | 2005/06 | $7676^{b}$ | $6755^{c}$ | $3559^{e}$ | $5633^{d}$ | $8289^{ab}$ | $8996^{a}$ | 7216 | 4596 | 8643 |
| | 2006/07 | $3277^{b}$ | $3573^{ab}$ | $1196^{c}$ | $677^{c}$ | $4348^{a}$ | $4332^{a}$ | 3425 | 937 | 4340 |
| | 2007/08 | $9919^{b}$ | $9767^{b}$ | $5349^{c}$ | $6235^{c}$ | $10913^{a}$ | $13852^{a}$ | 9843 | 5792 | 12383 |
| | **Mean** | **6600** | **6119** | **4052** | **4678** | **7468** | **8266** | **6359** | **4365** | **7867** |
| Harvest index | 2004/05 | $0.37^{c}$ | $0.38^{c}$ | $0.44^{ab}$ | $0.43^{ab}$ | $0.41^{bc}$ | $0.47^{a}$ | 0.38 | 0.44 | 0.44 |
| | 2005/06 | $0.52^{a}$ | $0.49^{a}$ | $0.28^{c}$ | $0.41^{b}$ | $0.5^{a}$ | $0.49^{a}$ | 0.51 | 0.35 | 0.50 |
| | 2006/07 | $0.45^{a}$ | $0.37^{a}$ | $0.39^{a}$ | $0.72^{a}$ | $0.37^{a}$ | $0.33^{a}$ | 0.41 | 0.56 | 0.35 |
| | 2007/08 | $0.56^{a}$ | $0.54^{a}$ | $0.56^{a}$ | $0.56^{a}$ | $0.51^{a}$ | $0.48^{a}$ | 0.55 | 0.56 | 0.50 |
| | **Mean** | **0.48** | **0.45** | **0.42** | **0.53** | **0.45** | **0.44** | **0.46** | **0.47** | **0.45** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

The mean grain yield of $IRWH_{\text{Mulch}}$ was only a 3% higher than that of $IRWH_{\text{Bare}}$. The mean grain yields of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ were 16 and 13% higher than *CON* and 32 and 28% higher than *STRIP*. Mean grain yields of *IRWH* treatments without cover crops were on average 22% higher than those of *CON* and *STRIP*, indicating that $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ were superior to *CON* and *STRIP* maize production under semi-arid conditions.

On the other hand the mean *CON* grain yield was 13% higher than *STRIP*. This may have been due to the fact that more ex-field runoff occurred from *STRIP*, especially at the beginning of the growing season. This is an indication that *STRIP* cropping should rather be used for a fodder crop which is cultivated on a wider area than maize.

A comparison of mean grain yields of *IRWH* treatments without cover crops ($IRWH_{Mulch}$ and $IRWH_{Bare}$) with those of *IRWH* treatments with cover crops ($IRWH_{Vet}$ and $IRWH_{Lucerne}$), indicate that *IRWH* treatments without cover crops on a semi-arid ecotope like that of Fort Hare/Oakleaf , totally outperformed *IRWH* treatments with cover crops with an 86% increase in mean grain yield. The vetiver and lucerne cover crops competed with the maize crop for the available water and that led to a drastic reduction in crop yield. It seems that rainfall in the semi-arid areas is just too low to sustain two crops simultaneously. If the intention of small-scale farmers is to produce only a well-balanced fodder in bulk for their animals, or fodder for their animals as well as food for the household, then the *IRWH* treatments with cover crops may be the best option.

Cover crop yields determined from *IRWH* treatments with cover crops ($IRWH_{Vet}$ and $IRWH_{Lucerne}$) are presented in Table 5.10. Cover crop yields (biomass) are expressed in kg $ha^{-1}$, even though it was only produced on two thirds (2-m wide runoff strip) of the field. Lucerne and vetiver had mean cover crop yields of 1053 and 1562 kg $ha^{-1}$ per annum. This is an indication that there is a trade-off between low maize yields and additional cover crop yield. Although maize yields were low on $IRWH_{Vet}$ and $IRWH_{Lucerne}$ at least additional biomass was produced that could be used for fodder in the case of lucerne and as organic mulch in the case of vetiver. $IRWH_{Lucerne}$ had a mean maize grain yield of 1783 kg $ha^{-1}$ and a lucerne yield of 1053 kg $ha^{-1}$, which might be ideal for mixed farming. However, where the intention is purely to produce food for household consumption one would prefer an option that produces a vigorous, lush growing crop with a big photosynthesis factory. Employing the *IRWH* system and applying mulches to the soil surface can achieve this.

Biomass yields over the four years varied between 677 and 13 852 kg $ha^{-1}$, in a pattern similar to that of the grain yields, *viz.* $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{Vet}$ > $IRWH_{Lucerne}$. The biomass yields of $IRWH_{Mulch}$ were significantly higher ($P \leq 0.05$) than *CON* and *STRIP* during the last three seasons (2005/06, 2006/07 and 2007/08). The biomass yields for $IRWH_{Bare}$ increased more than *CON* and *STRIP* during 2006/07. The biomass yields of $IRWH_{Mulch}$, $IRWH_{Bare}$, *CON* and *STRIP* were significantly higher than $IRWH_{Vet}$ and $IRWH_{Lucerne}$ during the last three seasons (2005/06, 2006/07 and 2007/08).

The harvest index of treatment options varied between 0.28 and 0.56 during the four seasons. Values for the 2004/05 and 2006/07 seasons were lower than the other two seasons.

The highest mean grain and biomass yields were produced during the climatically favourable 2007/08 season followed by the 2005/06, 2004/05 and 2006/07 seasons. This corresponds with the climate data as presented in Table 5.4.

**Table 5.10** Cover crop yields during four seasons on the Fort Hare/Oakleaf ecotope

| Year | Cover crop (kg $ha^{-1}$) | |
|---|---|---|
| | Lucerne | Vetiver |
| 2006 | 835 | 2058 |
| 2007 | 1108 | 1293 |
| 2008 | 1218 | 1333 |
| **Mean** | **1053** | **1562** |

According to Dickinson *et al.* (1990) crop yields of 4000-7000 kg $ha^{-1}$ of dry matter lucerne can be achieved in areas with 500-600 mm rainfall under dryland conditions. The results in Table 5.11 indicate that indicate that these yields were not achieved and this can be attributed to the fact that the lucerne was used as a cover crop and not as a stand-alone crop. Other factors which may have contributed to low yield are number of cuttings (once per year), fertilization (only at planting) and the planted area (two-thirds of the area). It is well known that decreasing number of cuttings per year decreases production of lucerne. Dickinson *et al.* (1990) claimed that it is possible for 1 hectare of lucerne to feed ten ewes and lambs per growing season. Although low yields were achieved, this could be a beneficial crop for livestock in the villages. Nutritionally, lucerne has crude protein between 22 and 25% and total digestible nutrients of between 67 and 72%.

#### 5.3.2.4 Rainwater productivity

Rainwater productivity (RWP) data for the Fort Hare/Oakleaf ecotope was determined over a period of four growing seasons. The results are presented in Table 5.11. RWP is probably the simplest and most comprehensive way of expressing the productivity of converting rainwater into seed yield.

**Table 5.11** Rainwater productivity data (kg $ha^{-1}$ $mm^{-1}$) for maize on the different treatments during the four seasons for Fort Hare/Oakleaf ecotope

| $RWP_{04/05-07/08}$ | Treatment | | | | | | Mean *CON* +SC | Mean Luc+ Vet | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|
| | *CON* | *STRIP* | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| | $10^{ab}$ | $9^{b}$ | $5^{c}$ | $7^{c}$ | $11^{a}$ | $12^{a}$ | 10 | 6 | 12 |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

$RWP_{04/05-07/08}$ varied between 5 and 12 kg seed $ha^{-1}$ $mm^{-1}$ rain. A common trend of $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ was observed during the experimental period. $IRWH_{Mulch}$ and $IRWH_{Bare}$ produced significantly higher $RWP_{04/05-07/08}$ values compared to *STRIP*. $IRWH_{Mulch}$, $IRWH_{Bare}$, *CON* and *STRIP* produced significantly higher $RWP_{04/05-07/08}$ values compared to $IRWH_{Vet}$ and $IRWH_{Lucerne}$. $IRWH_{Mulch}$ produced 9, 10, 33, 71 and 140% higher $RWP_{04/05-07/08}$ values compared to $IRWH_{Bare}$, *CON*, *STRIP*, $IRWH_{Vet}$ and $IRWH_{Lucerne}$, respectively. The superiority of $IRWH_{Mulch}$ and $IRWH_{Bare}$ is the result of their ability to prevent $R_{Ex}$ completely and induce in-field runoff ($R_{In}$. $RWP_{04/05-07/08}$ values results show that *IRWH* treatments without cover crops were on average a 100% more successful than *IRWH* treatments with cover crops in converting rainwater into food effectively. $RWP_{04/05-07/08}$ values also showed that *IRWH* treatments without cover crops were on average 20% more successful than *CON* and *STRIP* in converting rainwater into food effectively.

$RWP_{04/05-07/08}$ data for cover crops on the Fort Hare/Oakleaf ecotope were determined over four seasons and are presented in Table 5.12. Results indicate that vetiver was more efficient in converting rainwater into biomass than lucerne. When the $RWP_{04/05-07/08}$ of maize on $IRWH_{Vet}$ and $IRWH_{Lucerne}$ were added to the $RWP_{04/05-07/08}$ values of vetiver and lucerne, respectively, the results indicate total $RWP_{04/05-07/08}$ values of 9.57 and 6.65 kg $ha^{-1}$ $mm^{-1}$ rain for $IRWH_{Vet}$ and $IRWH_{Lucerne}$, respectively. These results confirm that the rainfall in the semi-arid areas is just too low to sustain two crops simultaneously.

**Table 5.12** Rainwater productivity data (kg $ha^{-1}$ $mm^{-1}$) for cover crops on the Fort Hare/Oakleaf ecotope

| $RWP_{04/05-07/08}$ | Treatment | |
|---|---|---|
| | *Lucerne* | *Vetiver* |
| | 1.55 | 2.57 |

$RWP_{05/06-07/08}$ data for the production of maize and cover crops on the Fort Hare/Oakleaf ecotope were determined over three seasons and expressed in terms of biomass are presented in Table 5.13. The biomass of maize and the cover crops grown during the first growing season were ignored because the cover crops were not yet established It was decided to use biomass in order to compare like with like. $RWP_{05/06-07/08}$ results, expressed in terms of biomass, varied between 7.48 and 15.33 kg seed $ha^{-1}$ $mm^{-1}$ rain. A common trend of $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ was observed during the experimental period. $IRWH_{Vet}$ had a significantly higher $RWP_{05/06-07/08}$ than $IRWH_{Lucerne}$, while the RWP05$_{/06-07/08\ for}$ IRWHLucerne was significantly lower than all the other treatments.

**Table 5.13** Rainwater productivity data (kg $ha^{-1}$ $mm^{-1}$) expressed in terms of biomass production for maize and cover crops on the Fort Hare/Oakleaf ecotope

| $RWP_{05/06-07/08}$ | Treatment | | | | | | Mean *CON* +SC | Mean Luc+ Vet | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|
| | *CON* | *STRIP* | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| | $11.77^{c}$ | $11.33^{c}$ | $7.48^{e}$ | $9.72^{d}$ | $13.28^{b}$ | $15.33^{a}$ | 11.55 | 8.60 | 14.31 |

5.4 ON-STATION EXPERIMENTAL PLOT: PHANDULWAZI

This experimental site was initially not included in the project, but was later included as an extra experimental site as it was closer to the on-farm experimental activities and therefore more representative of the communities.

### 5.4.1 Ecotope characterization

5.4.1.1 Climate

Long-term climate for the Phandulwazi/Westleigh ecotope is described in section 3.4.2.1.

5.4.1.2 Topography

The slope at Phandulwazi is about 3% in an easterly direction.

5.4.1.3 Soil

A detailed soil profile description is presented in Appendix 7. Important soil characteristics of the Phandulwazi/Westleigh-Helena ecotope are summarized in Table 5.14. The soil analytical data provided in Appendix 10.

**Table 5.14** Selected physical properties of Phandulwazi/Westleigh-Helena ecotope

| Profile detail | | | | | Soil water extraction properties (mm) | | |
|---|---|---|---|---|---|---|---|
| Diagnostic horizon | Depth (mm) | Colour | Clay (%) | BD (g $cm^{-3}$) | DUL | LL | *1TESW |
| Orthic A | 400 | Dark greyish brown | 26.6 | 1.61 | 121 | 65 | 56 |
| Soft plinthic B | 700 | Yellowish red | 17 | 1.71 | 83 | 50 | 33 |
| Soft plinthic B | 1100 | Red | 17.6 | 1.75 | 131 | 65 | 66 |
| TOTAL | | | | | 335 | 180 | 155 |

*1TESW = Total extractable soil water

The soil is classified, according to the Soil Classification Working Group (1991), as belonging to the Helena family of the Westleigh form. It has a dark greyish brown, poorly structured, loam orthic A-horizon overlying a yellowish red soft plinthic B-horizon at a depth of 400 mm. The bulk density ranges from 1.6 g $cm^{-3}$ in the topsoil to 1.75 g $cm^{-3}$ in the subsoil. The effective rooting depth is down to about 1 m. The clay content decreases with depth from 26% in the topsoil to 17% in the subsoil.

5.4.1.3.1 *Drainage characteristics*

A drainage curve was not constructed for Phandulwazi/Westleigh ecotope. DUL was estimated to be 85% of porosity. The LL was taken as the lowest soil water content of each layer for the duration of the study period.

### 5.4.2 Results: agronomic impact

5.4.2.1 Meteorological conditions

To characterize the climatic conditions the season was sub-divided into the five periods described in section 5.3.2.1, *viz*. (i) $F_p$; (ii) $V_p$; (iii) $R_p$; (iv) $G_p$; (v) $P_p$. (Table 5.15).

**Table 5.15** Precipitation (P), potential evaporation (ETo) and aridity index (AI) values for subdivisions of the two seasons in relation to long-term (LT) means for maize on the Phandulwazi/Westleigh ecotope

| Parameter | Season | Period | | | | |
|---|---|---|---|---|---|---|
| | | $F_p$ | $V_p$ | $R_p$ | $G_p$ | $P_p$ |
| P (mm) | 2006/07 | - | 121 | 189 | 310 | - |
| | 2007/08 | 299 | 206 | 140 | 346 | 645 |
| | **Mean** | **299** | **164** | **165** | **329** | **645** |
| | **LT mean** | **301** | **169** | **157** | **326** | **627** |
| ETo (mm) | 2006/07 | - | 383 | 391 | 774 | - |
| | 2007/08 | 757 | 380 | 384 | 764 | 1521 |
| | **Mean** | **757** | **382** | **387** | **769** | **1521** |
| | **LT mean** | **733** | **344** | **266** | **610** | **1343** |
| AI | 2006/07 | - | 0.32 | 0.48 | 0.40 | - |
| | 2007/08 | 0.39 | 0.54 | 0.36 | 0.45 | 0.42 |
| | **Mean** | **0.39** | **0.43** | **0.43** | **0.43** | **0.42** |
| | **LT mean** | **0.41** | **0.49** | **0.59** | **0.53** | **0.47** |

In order to characterize these parameters the weather station for the Guquka/Cartref-Frosterley ecotope was used. During both growing periods rainfall was typical or even greater than the long-term mean (LT-mean) for a semi-arid ecotope. Rainfall lower than the LT-mean only occurred during the Vp (2006/07) and $R_p$ (2007/08) seasons. Potential evaporation was higher than the LT-mean throughout the experiment. This resulted in AI values of below the LT-mean except during $V_p$ in the 2007/08 season.

The 2006/07 season began without a fallow period due to the implementation of the experiment. A very unfavourable $V_p$ during the same season was the result of rainfall that was 28% below the LT-mean and an ETo that was 11% higher than the LT-mean. This resulted in an AI that was 35% lower than the LT-term mean. These unfavourable climatic conditions may have influenced crop growth negatively and could have resulted in smaller plants with a lower yield potential. During the critical $R_{p,}$ 20% more rain than the LT-mean occurred, but ETo for the same period was 47% higher than the LT-mean, which resulted in an AI 19% lower than the LT-mean. In general 2006/7 was an unfavourable season for crop production as unfavourable climatic conditions also occurred during $G_{p.}$

In the 2007/08 season $F_p$ was characterized by rainfall, ETo and AI values that are typical of this ecotope. Twenty percent more rain than the LT-mean occurred during $V_p$ with ETo only 10% more than the LT-mean. This resulted in a very favourable $V_p$ with an AI value 10% higher than the LT-mean. This may have resulted in large strong plants with a high yield potential. As is the case in a semi-arid area, climatic conditions can change rapidly. The 2007/08 season was characterized by an unfavourable $R_p$ with rainfall 11% lower than LT-mean and ETo 44% higher than LT-mean. This resulted in an AI value of 39% lower than the LT-mean, which may have influenced yields negatively.

5.4.2.2 Water balance components

5.4.2.2.1 *Soil water content*

The plant-available water at planting ($PAW_p$), tasseling ($PAW_T$), and harvesting ($PAW_H$) values for each treatment are summarized in Table 5.16.

**Table 5.16** Plant-available water (mm) at planting ($PAW_p$), flowering ($PAW_T$) and harvesting ($PAW_H$) for the root zone (0-1200 mm) on the different treatments during the four growing seasons at Phandulwazi/Westleigh ecotope

| Water content (mm) | Season | Treatment | | | | | | | Mean CON + SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | *IRWH* GLDM | *IRWH* Lucerne | *IRWH* Vet | *IRWH* Bare | *IRWH* Mulch | | | |
| $PAW_p$ (mm) | 2006/07 | 110[a] | 106[a] | 107[a] | 106[a] | 105[a] | 112[a] | 111[a] | 108 | 106 | 112 |
| | 2007/08 | 80[a] | 60[a] | 70[a] | 50[a] | 55[a] | 75[a] | 99[a] | 70 | 58 | 87 |
| | **Mean** | **95** | **83** | **89** | **78** | **80** | **94** | **105** | **89** | **82** | **99** |
| $PAW_T$ (mm) | 2006/07 | 200[a] | 194[a] | 176[a] | 190[a] | 164[a] | 204[a] | 195[a] | 197 | 177 | 200 |
| | 2007/08 | 83[a] | 77[a] | 81[a] | 68[a] | 69[a] | 74[a] | 80[a] | 80 | 73 | 77 |
| | **Mean** | **66** | **65** | **56** | **56** | **57** | **81** | **77** | **66** | **56** | **79** |
| $PAW_H$ (mm) | 2006/07 | 56[a] | 43[a] | 47[a] | 32[a] | 21[a] | 60[a] | 63[a] | 50 | 33 | 62 |
| | 2007/08 | 68[a] | 64[a] | 53[a] | 46[a] | 39[a] | 63[a] | 75[a] | 66 | 46 | 69 |
| | **Mean** | **62** | **54** | **50** | **39** | **30** | **62** | **69** | **58** | **40** | **65** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

The 2006/07 growing season did not have a preceding fallow period since the field was ploughed and basins were constructed close to planting. Therefore no runoff was collected prior to implementation of the project and there were no significant differences in $PAW_p$ between the different treatments as they all started the 2006/07 season with almost the same soil water content. During the 2006/07 growing season cover crops were not well established and, therefore, did not extract much water from the soil profile. In the 2007/08 season cover crops were well established and extracted more water.

Strong trends were observed in mean $PAW_p$, $PAW_T$ and $PAW_H$, *viz.* $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{GLDM}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$. Mean $PAW_p$, $PAW_T$ and $PAW_H$, results for *IRWH* without cover crops ($IRWH_{Mulch}$ and $IRWH_{Bare}$), were considerably higher than those of *CON* and *STRIP*; followed by *IRWH* with cover crops ($IRWH_{GLDM}$, $IRWH_{Vet}$, and $IRWH_{Lucerne}$). This may have been due to; a) the ability of *IRWH* techniques to prevent ex-field runoff, and b) the presence of cover crops, which extract additional water and compete with the main crop for valuable rainwater. No significant PAW differences were observed during either of the two years.

5.4.2.2.2 *Soil water extraction*

Figure 5.9 illustrates changes in soil water content in the root zone during all growing seasons, and can be used to explain yield and water balance data. Lines represent the mean of three replicates. The water management boundaries of PAW, DUL and LL are also included in the graphs.

*Vegetative period ($V_P$):*

A comparison of VP during the two growing seasons showed that 2006/07 was less favourable than 2007/08 for crop production as it had a lower rainfall (85 mm less). This forced the crops to rely more on water from the soil profile. The water contents at tasseling were considerably lower than at planting for all treatments during the 2006/07 season. This indicated that rainfall was insufficient to maintain the crop water demand, and the crop had to rely on the soil water to supply the water deficit. Fortunately, the water supply from rainfall and soil water together was enough to protect the crop from severe water stress. During the 2006/7 season $IRWH_{\text{Vet}}$, and $IRWH_{\text{Lucerne}}$ extracted more water during the $V_P$ than the other treatments, probably due to the cover crops extracting additional water.

The 2007/08 season had relatively favourable cropping conditions, the high rainfall with good distribution and relative low Eo conditions during $V_p$ resulted in better yield. All the *IRWH* treatments with cover crops had lower soil water contents during the 2007/08 $V_p$ as compared to the *IRWH* treatments without cover crops and *CON* and *STRIP*. For the greater part of 2007/08, $V_p$ $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ managed to maintain the highest soil water contents, followed by *CON* and *STRIP* and then the *IRWH* treatments with cover crops.

*Reproductive period ($R_p$):*

Climatic conditions during $R_p$ either realize or minimize the potential crop yield determined during $V_p$, depending on the climatic conditions and the soil water content. Climatic conditions during $R_p$ of the both seasons were unfavourable for crop production and the crop depended heavily on rainfall and water stored in the soil profile to maintain the crop water demand. In the 2006/07 season almost 80% of the total available water had been extracted towards the end of the growing season (Figure 5.9a). The crop received 184 mm of rain from a number of rain events during DAP 63 and 105 of the 2006/07 season, causing the root zone water content of all the treatments to rise sharply. The response of IRWHBare was by far the best, followed by *CON* and *STRIP* and then the *IRWH* treatments with cover crops. If it had not been for the good rains during this period, maize yields would have been very low as there was very little rain during the remainder of the season (Figure 5.9a).

As is often the case in a semi-arid environment, climatic conditions can change dramatically in a short time. For example, during the 2007/08 season favourable conditions during $V_p$ became unfavourable during $R_p$. The crop received 140 mm of rain during $R_p$, while the corresponding Eo amounted to 384 mm, resulting in an AI value of 0.36. If good rains had not occurred during $V_{p,}$ maize yields would have been very low. *IRWH* treatments with cover crops had the lowest soil water content during the 2007/08 season and $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ had the highest.

In general the soil water content of $IRWH_{\text{Mulch}}$ remained significantly higher than the other treatments followed by $IRWH_{\text{Bare}}$ > *CON* > *STRIP* > $IRWH_{\text{GLDM}}$ > $IRWH_{\text{Lucerne}}$ > $IRWH_{\text{Vet}}$ during both seasons.

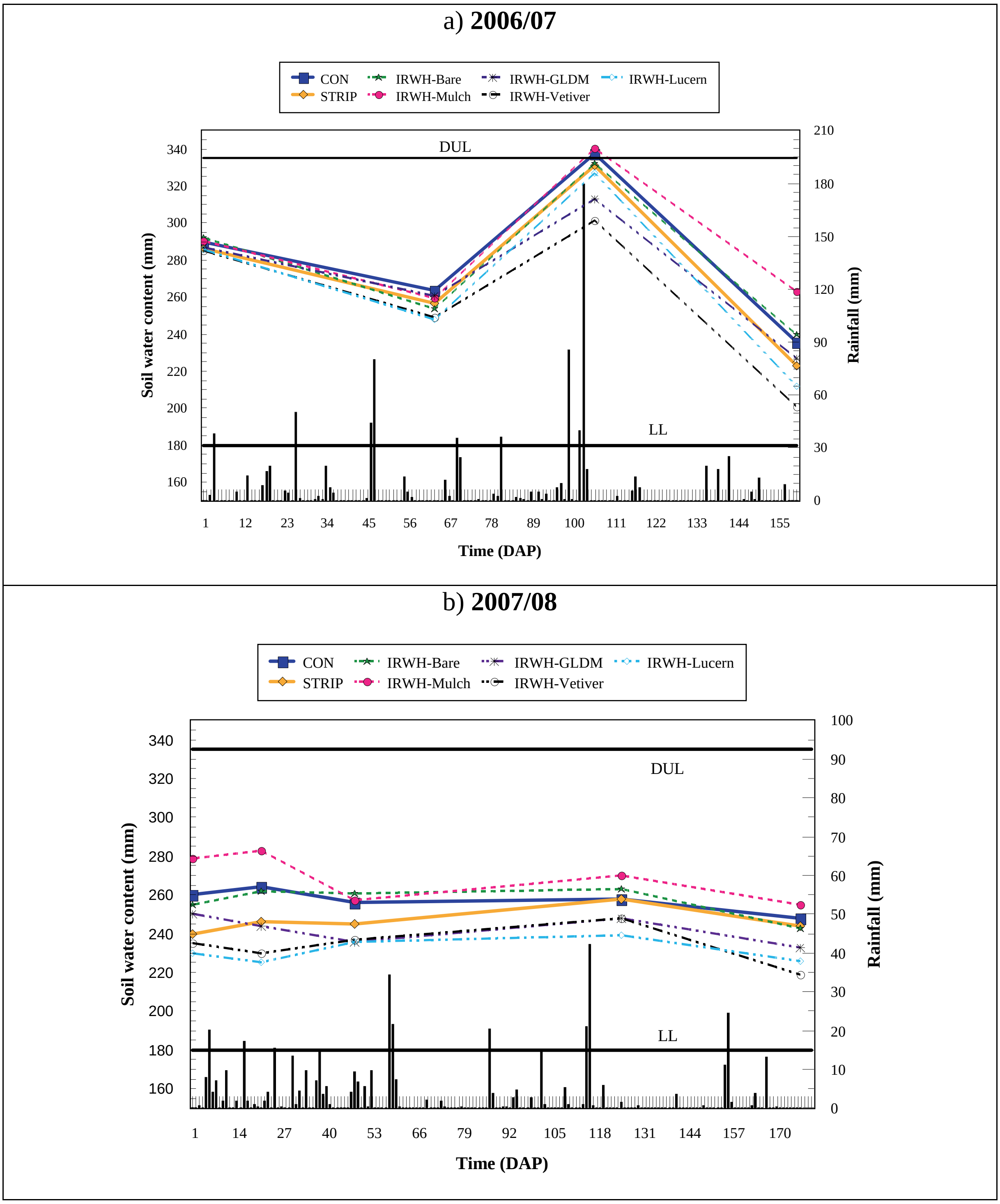


**Figure 5.9** Change in the soil water content of the maize root zone (0-1200 mm) during a) 2006/07 and b) 2007/08 seasons at Phandulwazi/Westleigh ecotope.

5.4.2.2.3 *Evapotranspiration*

ET, Ev and Es and results for the two growing seasons are presented in Table 5.17. $IRWH_{Mulch}$ induced a higher mean ET and Ev as well as a lower mean Es than $IRWH_{Bare}$. This is an indication that mulch on the runoff and basin area contributed towards higher Ev values and, therefore, indirectly to better crop growth. Results also indicate that $IRWH_{Mulch}$ was 6% more successful than *IRWH*$_{Bare}$ in minimizing Es. *IRWH*$_{Mulch}$ only induced significantly higher Ev values than *IRWH*$_{Bare}$ during 07/08.

*CON* and *STRIP* were very similar and gave similar ET, Ev and Es results and will, therefore, be discussed as a mean. *IRWH*$_{Mulch}$ induced higher ET and Ev values than *CON* and *STRIP* during both seasons. The average increase was 21 and 25%, respectively. Es results indicate that *IRWH*$_{Mulch}$ induced a 26% higher Es than *CON* and *STRIP*. The reason for this may have been that *IRWH*$_{Mulch}$ treatments were constantly wetter than *CON* and *STRIP* and, therefore, one would expect it to have a higher Es. Es/ET results indicate that *CON*, *STRIP* and *IRWH*$_{Mulch}$ lost the same portion of ET to Es. The mean Es/ET results for maize on the *CON*, *STRIP*, and *IRWH*$_{Mulch}$ were 73, 73 and 74%, respectively. This shows that *CON*, *STRIP*, *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ lost similar portions of ET to Es. In other words these treatments performed equally in minimizing the unproductive loss of water through Es. *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ induced significantly higher ET values during both seasons, while *IRWH*$_{Mulch}$ induced a significantly higher Ev during 2007/08 than *CON* and *STRIP*. The Es of *CON* and *STRIP* was only significantly lower than *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ during 2007/08.

A comparison of average ET and Ev values for *CON* and *STRIP* with the average of *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ clearly shows that *IRWH* treatments without cover crops induced higher average ET and Ev values. The results also indicate that *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ lost on average more water to Es and slightly more of ET to Es than the average of *CON* and *STRIP*.

Comparing *IRWH* with cover crops on the runoff area (*IRWH*$_{GLDM}$, *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$) with *IRWH* without cover crops (*IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$) is very complicated. The values for *IRWH* with cover crops presented in Table 5.17 are not a true reflection of the real situation because the crop is produced together with a cover crop. The same procedure described in section 5.3.2.2.3 was followed to estimate Ev for cover crops. It seems, unfortunately, that this procedure under-estimate the Ev of cover crops and, therefore, over-estimates Es. Table 5.18 presents adapted ET, Ev and Es results for *IRWH* treatments with cover crops. Because of the assumptions made, Es for *IRWH* treatments with and without cover crops are the same. *IRWH* treatments with cover crops showed a slightly higher ET than *IRWH* treatments without cover crops. This was to be expected as the maize together with the perennial cover crops extracted more water from the soil profile than maize mono-cropping. The average Ev (maize and cover crops) results indicate that maize was responsible for 60% of Ev, while cover crops were on average responsible for 40%. Expressed differently, cover crops used on average 10% of ET for Ev, while maize used on average 15% of ET for Ev. Es/ET results indicate that *IRWH* treatments with cover crops were as successful as *IRWH*$_{Mulch}$, *CON* and *STRIP* in suppressing Es.

More research needs to be directed into the separation of ET into Es and Ev, not only for mono-cropping but also for intercropping which is more complicated. Only then will it be possible to draw proper conclusions and make recommendations regarding ET, Ev and Es.

**Table 5.17** Evapotranspiration (ET = Ev + Es), evaporation from the soil surface (Es) and transpiration (Ev) during the growing period for the two seasons for the different treatments on the Phandulwazi/Westleigh ecotope.

| | Growing season | Treatment | | | | | | | Mean *CON* +SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | *IRWH*$_{GLDM}$ | *IRWH*$_{Lucerne}$ | IRWH$_{Vet}$ | *IRWH*$_{Bare}$ | *IRWH*$_{Mulch}$ | | | |
| Ev (mm) | 2006/07 | $79^{a}$ | $81^{a}$ | $57^{b}$ | $80^{a}$ | $80^{a}$ | $80^{a}$ | $95^{a}$ | 80 | 72 | 88 |
| | 2007/08 | $104^{b}$ | $100^{b}$ | $60^{c}$ | $57^{c}$ | $57^{c}$ | $75^{bc}$ | $127^{a}$ | 102 | 58 | 101 |
| | **Mean** | **92** | **91** | **59** | **69** | **69** | **78** | **111** | **91** | **65** | **94** |
| Es (mm) | 2006/07 | $209^{a}$ | $217^{a}$ | $316^{c}$ | $294^{bc}$ | $301^{bc}$ | $263^{ab}$ | $286^{ab}$ | 213 | 304 | 275 |
| | 2007/08 | $287^{a}$ | $277^{a}$ | $407^{c}$ | $393^{bc}$ | $393^{bc}$ | $396^{b}$ | $340^{b}$ | 282 | 398 | 368 |
| | **Mean** | **248** | **247** | **362** | **344** | **347** | **330** | **313** | **248** | **351** | **321** |
| ET (mm) | 2006/07 | $288^{b}$ | $298^{b}$ | $373^{a}$ | $374^{a}$ | $381^{a}$ | $343^{a}$ | $381^{a}$ | 293 | 376 | 362 |
| | 2007/08 | $391^{b}$ | $377^{b}$ | $467^{a}$ | $450^{a}$ | $450^{a}$ | $471^{a}$ | $467^{a}$ | 384 | 456 | 469 |
| | **Mean** | **340** | **338** | **420** | **412** | **416** | **407** | **424** | **339** | **416** | **416** |
| Es/ET (%) | 2006/07 | $73^{a}$ | $73^{a}$ | $85^{c}$ | $79^{ab}$ | $79^{ab}$ | $77^{ab}$ | $75^{ab}$ | 73 | 81 | 76 |
| | 2007/08 | $73^{a}$ | $73^{a}$ | $87^{b}$ | $87^{b}$ | $87^{b}$ | $84^{ab}$ | $73^{a}$ | 73 | 87 | 78 |
| | **Mean** | **73** | **73** | **86** | **83** | **83** | **80** | **74** | **73** | **84** | **77** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

**Table 5.18** Evapotranspiration (ET = Ev + Es), evaporation from the soil surface (Es) and transpiration (Ev) during the growing period for the two seasons for the cover crop treatments on the Phandulwazi/Westleigh ecotope

| | Growing season | Treatment | | | | | | | | | Mean Maize | Mean Cover crops | Mean all |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *IRWH*$_{GLDM}$ | | | *IRWH*$_{Lucerne}$ | | | *IRWH*$_{Vet}$ | | | | | |
| | | Maize | GLDM | Maize + GLDM | Maize | Lucerne | Maize + Lucerne | Maize | Vetiver | Maize + Vetiver | | | |
| Ev | 2006/07 | $57^a$ | $29^A$ | $86^{AA}$ | $80^a$ | $0^A$ | $80^{AA}$ | $80^a$ | $5^A$ | $85^{AA}$ | 72 | 11 | 84 |
| | 2007/08 | $60^a$ | $61^A$ | $121^{AA}$ | $57^a$ | $78^A$ | $135^{AA}$ | $57^a$ | $88^A$ | $145^{AA}$ | 58 | 76 | 134 |
| | **Mean** | **59** | **45** | **104** | **69** | **39** | **108** | **69** | **47** | **115** | **65** | **44** | **109** |
| Es | 2006/07 | $388^a$ | | | $381^a$ | | | $388^a$ | | | 386 | | |
| | 2007/08 | $248^a$ | | | $248^a$ | | | $248^a$ | | | 248 | | |
| | **Mean** | **318** | | | **315** | | | **318** | | | **317** | | |
| ET | 2006/07 | $474^a$ | | | $461^a$ | | | $473^a$ | | | 469 | | |
| | 2007/08 | $369^a$ | | | $383^a$ | | | $393^a$ | | | 382 | | |
| | **Mean** | **422** | | | **422** | | | **433** | | | **426** | | |
| Es/ET (%) | 2006/07 | $82^a$ | | | $83^a$ | | | $82^a$ | | | 82 | | |
| | 2007/08 | $67^a$ | | | $65^a$ | | | $63^a$ | | | 65 | | |
| | **Mean** | **75** | | | **74** | | | **73** | | | **74** | | |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

5.4.2.2.4 *Runoff*

Runoff was calculated as described in Section 5.2.4.5. Ex-field runoff ($R_{Ex}$) for maize from *CON* and *STRIP* for subdivisions the 2006/07 and 2007/08 growing seasons on the Phandulwazi/Westleigh ecotope are presented in Table 5.19. During these seasons $G_p$ *CON* and *STRIP* lost 32 and 41 mm of rainwater to $R_{Ex}$, respectively, which is a mean loss of 11% of the total rainfall over the two growing periods. The mean $R_{Ex}$ during the two seasons for $F_p$, $V_p$, $R_p$, $G_p$, and $P_p$ periods were 5, 12, 24, 37 and 46 mm, respectively. Severe water losses due to $R_{Ex}$, with a mean of 24 mm, occurred during the critical $R_p$ period. These unproductive losses could seriously hamper maize yields. $R_{Ex}$ (mm and % of P) differs between the various seasons and depends mainly on rainfall characteristics.

**Table 5.19** Ex-field runoff ($R_{Ex}$) from the *CON* treatment for subdivisions of the two seasons for maize on the Phandulwazi/Westleigh ecotope

| Parameter | Season | Period | | | | |
|---|---|---|---|---|---|---|
| | | $F_p$ | $V_p$ | $R_p$ | $G_p$ | $P_p$ |
| R (mm) | 2006/07 | - | 5 | 27 | 32 | - |
| | 2007/08 | 5 | 20 | 22 | 41 | 46 |
| | **Mean** | **5** | **12** | **24** | **37** | **46** |
| R/P (%) | 2006/07 | - | 4 | 14 | 10 | - |
| | 2007/08 | 2 | 9 | 16 | 12 | 7 |
| | **Mean** | **2** | **7** | **15** | **11** | **7** |

5.4.2.2.5 *Drainage*

At DAP 106 in the 2006/07 season the soil water content of some of the treatments was at DUL. It was estimated that no significant drainage took place during this period.

5.4.2.3 Yield

Grain yield, and biomass yield and the harvest index are summarized in Table 5.20.

Over the two seasons grain yields varied between 1955 and 5002 kg ha$^{-1}$ with a very strong mean yield trend of $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *STRIP* > *CON* > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ > $IRWH_{GLDM}$. No significant differences in grain yield occurred during the first season (2006/07). The grain yield of $IRWH_{Mulch}$ was significantly higher than *CON* and *STRIP* during the 2007/08 season. The grain yields of $IRWH_{Mulch}$, $IRWH_{Bare}$, *CON* and *STRIP* were significantly higher than $IRWH_{GLDM}$, $IRWH_{Vet}$ and $IRWH_{Lucerne}$ during the last season (2007/08). This was expected, as the soil water content of $IRWH_{GLDM}$, $IRWH_{Vet}$ and $IRWH_{Lucerne}$ was lower than that of $IRWH_{Mulch}$, $IRWH_{Bare}$, *CON* and *STRIP* throughout the last season (Figure 5.9). $IRWH_{Mulch}$ only induced significantly higher maize yields than *CON* and *STRIP* during the 2007/08 season.

$IRWH_{Mulch}$, which had the advantage of having mulch on the runoff and basins areas to minimize Es as well as enhance infiltration, induced on average a 15% higher grain yield than $IRWH_{Bare}$ during the both seasons. $IRWH_{Mulch}$ and $IRWH_{Bare}$ had a grain yield advantage over *CON* of 36 and 16%, respectively, and a 24 and 8% advantage over *STRIP*. *IRWH* treatments without cover crops (*IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$) had on average a grain yield advantage of 20% above the average of *CON* and *STRIP*. This is an indication that *IRWH* treatments without cover crops are by far superior to *CON* and *STRIP* for grain crop production in semi-arid areas.

A comparison of mean grain yields of *IRWH* treatments without cover crops with mean grain yields of *IRWH* treatments with cover crops showed that *IRWH* treatments without cover crops are on average 63% more successful in producing high maize yields. This is clearly an indication that if the sole purpose of farming is maize production, then intercropping with cover crops on the runoff area in order to stabilize the *IRWH* system on steeper slopes in semi-arid climates is not the answer. The cover crops competed too much with the maize crop for water and nutrients. Cover crops should be properly managed within the system because without proper management the maize grain yield could decline. A comparison of mean grain yields in *IRWH* treatments with cover crops indicated that *IRWH*$_{Vet}$ had the highest grain yield followed by *IRWH*$_{Lucerne}$ and then *IRWH*$_{GLDM}$.

Biomass yields of individual treatments varied between 4099 and 8849 kg $ha^{-1}$ for the two years, with a pattern similar to the grain yields, *viz.* *IRWH*$_{Mulch}$ > *IRWH*$_{Bare}$ > *STRIP* > *CON* > *IRWH*$_{Vet}$ > *IRWH*$_{Lucerne}$ > *IRWH*$_{GLDM}$. No significant difference in biomass yield occurred during the first season (2006/07). The biomass yield of *IRWH*$_{Mulch}$ was significantly higher than that of *CON* and *STRIP* during the 2007/08 season. The biomass yields of *IRWH*$_{Mulch}$, *IRWH*$_{Bare}$, *CON* and *STRIP* were significantly higher than *IRWH*$_{GLDM}$, *IRWH*$_{Vet}$ and *IRWH*$_{Lucerne}$ during 2007/08.

**Table 5.20** Maize grain and biomass yields and harvest index for the different treatments during the 2006/2007 and 2007/2008 seasons on the Phandulwazi/Westleigh ecotope

| Parameter | Season | Treatment | | | | | | | Mean *CON* +SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | *IRWH*$_{GLDM}$ | *IRWH*$_{Lucerne}$ | IRWH$_{Vet}$ | *IRWH*$_{Bare}$ | *IRWH*$_{Mulch}$ | | | |
| Grain (kg ha$^{-1}$) | 2006/07 | 2381$^{a}$ | 2647$^{a}$ | 2020$^{a}$ | 2670$^{a}$ | 2581$^{a}$ | 2864$^{a}$ | 3012$^{a}$ | 2514 | 2424 | 2938 |
| | 2007/08 | 3636$^{b}$ | 3796$^{b}$ | 1955$^{c}$ | 1984$^{c}$ | 2616$^{c}$ | 4124$^{ab}$ | 5002$^{a}$ | 3716 | 2185 | 4563 |
| | **Mean** | **3009** | **3222** | **1988** | **2327** | **2599** | **3494** | **4007** | **3115** | **2304** | **3751** |
| Biomass (kg ha$^{-1}$) | 2006/07 | 5646$^{a}$ | 5856$^{a}$ | 4099$^{a}$ | 5771$^{a}$ | 5787$^{a}$ | 6862$^{a}$ | 6992$^{a}$ | 5751 | 5219 | 6927 |
| | 2007/08 | 7354$^{b}$ | 7327$^{b}$ | 4287$^{c}$ | 4120$^{c}$ | 5377$^{bc}$ | 7845$^{ab}$ | 8849$^{a}$ | 7341 | 4595 | 8347 |
| | **Mean** | **6500** | **6592** | **4193** | **4946** | **5582** | **7354** | **7921** | **6546** | **4907** | **7637** |
| Harvest index | 2006/07 | 0.42$^{a}$ | 0.45$^{a}$ | 0.49$^{a}$ | 0.46$^{a}$ | 0.45$^{a}$ | 0.42$^{a}$ | 0.43$^{a}$ | 0.44 | 0.47 | 0.42 |
| | 2007/08 | 0.49$^{a}$ | 0.52$^{a}$ | 0.46$^{a}$ | 0.48$^{a}$ | 0.49$^{a}$ | 0.53$^{a}$ | 0.57$^{a}$ | 0.51 | 0.47 | 0.55 |
| | **Mean** | **0.46** | **0.49** | **0.47** | **0.47** | **0.47** | **0.47** | **0.50** | **0.47** | **0.47** | **0.48** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

5.4.2.4 Rainwater productivity

Rainwater productivity results (RWP) for a two-year period (2006/07-2007/08) are presented in Table 5.21.

**Table 5.21** RWP data (kg $ha^{-1}$ $mm^{-1}$) for maize on the different treatments over a two-season period for Phandulwazi/Westleigh ecotope

| RWP 06/07-07/08 | Treatment | | | | | | | Mean *CON* + SC | Mean Cover crops | Mean Bare + Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | *CON* | *STRIP* | *IRWH* GLDM | *IRWH* Lucerne | *IRWH* Vet | *IRWH* Bare | *IRWH* Mulch | | | |
| | $8^b$ | $8^b$ | $5^d$ | $6^{cd}$ | $7^c$ | $9^a$ | $10^a$ | 8 | 6 | 10 |

Different superscripts within a row indicate a significant difference (P ≤ 0.05); values with the same superscripts are not significantly different (P ≤ 0.05)

$RWP_{06/07-07/08}$ results show a common trend for the treatments, *viz*. $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *STRIP* > *CON* > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ > $IRWH_{GLDM}$. All the *IRWH* treatments without a cover crop produced significantly better $RWP_{06/07-07/08}$ values than *STRIP* and *CON*. $RWP_{06/07-07/08}$ results indicated that the *IRWH* treatments without a cover crop were on average 25% more efficient than *STRIP* and *CON* in converting rainwater into grain yield. The significantly higher productivity of the *IRWH* treatments without a cover crop in relation to *STRIP* and *CON* can be attributed to the total stoppage of $R_{Ex}$ and a minimization i the portion of ET lost to Es. *IRWH* treatments without cover crops produced significantly better $RWP_{06/07-07/08}$ values than *IRWH* treatments with cover crops. $RWP_{06/07-07/08}$ results also indicated that *IRWH* treatments without cover crops were on average 67% more efficient than the average of *IRWH* treatments with cover crops in converting rainwater into grain yield. The significantly higher productivity of the *IRWH* treatments without cover crops can be attributed to the effect of cover crops which compete with the maize crop for water and nutrients.

## 5.5 ON-FARM DEMONSTRATION TRIAL: GUQUKA

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 (Bembridge, 1991). One of the key areas identified for rectifying problems experienced in the small-scale farming sector, is the development of appropriate technology for improving small-scale farming systems (FAO, 1993). A demonstration was conducted on a cropland in Guquka village. The main aims of the demonstration trial were to (i) demonstrate the benefits of rainwater harvesting techniques over *CON* tillage; (ii) disseminate agronomic information on *IRWH* to farmers and extension personnel; and (iii) gather more crop yield information in order to compare different techniques. This section will only report on the yields of the various treatments which were demonstrated.

### 5.5.1 Ecotope characterization

5.5.1.1 Climate

Long-term climate for the Guquka/Cartref ecotope is described in section 3.4.2.1.

#### 5.5.1.2 Topography

The on-farm demonstration plot was located on an upper mid-slope terrain unit with a concave, 4% slope in a northerly direction.

#### 5.5.1.3 Soil

The soils in Guquka are dominantly brown in colour overlying iron concretions, which in turn overly weathered rock. The soils are very shallow with maximum depth of about 600 mm. The dominant soil forms are Cartref, Westleigh and Oakleaf (Potgieter, 2005). A detailed soil profile description is presented in Appendix 8. Bulk density samples were taken with a core sampler. The bulk density ranges from 1.9 g $cm^{-3}$ in the topsoil to 2.2 g $cm^{-3}$ in the subsoil. The clay content increases from 12.7% in the topsoil to 15.1% in the subsoil. Selected physical properties of the Guquka/Cartref – Frosterley ecotope are presented in Table 5.22. The analytical data is presented in Appendix 11.

**Table 5.22** Selected physical properties of Guquka/Cartref – Frosterley ecotope

| Profile detail | | | | |
|---|---|---|---|---|
| Diagnostic horizon | Depth (mm) | Colour | Clay (%) | BD (g $cm^{-3}$) |
| Orthic A | 330 | Yellowish brown | 12.7 | 1.87 |
| E-horizon | 600 | Dark grey | 15.1 | 2.17 |
| Lithocutanic | 1200 | Yellowish brown | 28.6 | 2.09 |
| TOTAL | | | | |

### 5.5.2 Results: Agronomic impact

#### 5.5.2.1 Meteorological conditions

To characterize the climatic conditions which occurred during trial, the two growing seasons were each sub-divided into five periods as described in section 5.3.2.1, *viz*. (i) $F_p$; (ii) $V_p$; (iii) $R_p$; (iv) $G_p$; (v) $P_p$. The results are presented in Table 5.23.

The mean rainfall received during the different growing periods was typical of the long-term mean (LT-mean) for this semi-arid ecotope. A higher mean ETo than the LT-mean occurred, which resulted in a slightly lower mean AI than the LT-mean.

Favourable climatic conditions for crop production occurred during $V_p$ of the 2004/05 season. During the same season 27% lower rainfall than the LT-mean occurred during the critical $R_p$ period, which resulted in an AI value 10% lower than the LT-mean. These unfavourable climatic conditions during $R_p$ may have affected crop yields negatively. The fact that the treatments did not have a fallow period prior to the trial in which to conserve rainwater in the soil may have exacerbated the situation.

**Table 5.23** Precipitation (P), potential evaporation (ETo) and aridity index (AI) for the 2004/05, 2005/06, 2006/07 and 2007/08 production seasons on the Guquka/Cartref ecotope, where Fp = fallow period, Vp = vegetative period, Rp = reproductive period, Gp = crop growing period and Pp = production period

| Parameter | Season | Period | | | | |
|---|---|---|---|---|---|---|
| | | $F_p$ | $V_p$ | $R_p$ | $G_p$ | $P_p$ |
| P (mm) | 2004/05 | - | 195 | 114 | 309 | - |
| | 2005/06 | 279 | 130 | 158 | 288 | 567 |
| | 2006/07 | 615 | 121 | 189 | 310 | 924 |
| | 2007/08 | 284 | 216 | 160 | 376 | 660 |
| | **Mean** | **393** | **166** | **155** | **321** | **717** |
| | **LT mean** | **301** | **169** | **157** | **326** | **627** |
| ETo (mm) | 2004/05 | - | 320 | 217 | 537 | - |
| | 2005/06 | 680 | 390 | 291 | 681 | 1361 |
| | 2006/07 | 494 | 383 | 391 | 774 | 1268 |
| | 2007/08 | 807 | 365 | 351 | 716 | 1523 |
| | **Mean** | **660** | **365** | **313** | **677** | **1384** |
| | **LT mean** | **733** | **344** | **266** | **610** | **1343** |
| AI | 2004/05 | - | 0.61 | 0.53 | 0.58 | - |
| | 2005/06 | 0.41 | 0.33 | 0.54 | 0.42 | 0.42 |
| | 2006/07 | 1.24 | 0.32 | 0.48 | 0.40 | 0.73 |
| | 2007/08 | 0.35 | 0.59 | 0.46 | 0.53 | 0.43 |
| | **Mean** | **0.60** | **0.45** | **0.50** | **0.47** | **0.52** |
| | **LT mean** | **0.41** | **0.49** | **0.59** | **0.53** | **0.47** |

During Vp in 2005/06 unfavourable climatic conditions were experienced as rainfall was 23% lower than the LT-mean and ETo 13% higher contributed to an AI of 33% lower than the LT-mean, which might have affected crop growth negatively during the $V_p$. Climatic conditions typical for the ecotope occurred during the $R_p$ that might have favoured crop growth during this critical period.

The 2006/07 season started with a very favourable $F_p$ which may have benefited the crop later during the growing season. A very unfavourable 2006/07 $V_p$ was the result of 28% lower rainfall than the LT-mean and 11% higher ETo than the LT-mean. This resulted in a $V_p$ with an AI that was 35% lower than the LT-term mean. These unfavourable climatic conditions during Vp may have influenced crop growth negatively and could have result in smaller plants with a lower yield potential. During the critical $R_p$, 20% more rain than the LT-mean occurred but ETo for the same period was 47% higher than the LT-mean. This resulted in an AI 19% lower than the LT-mean. This was in general an unfavourable season for crop production due to unfavourable climatic conditions that occurred during the $G_{p.}$

In the 2007/08 season, Fp was characterized by an AI during the $G_p$ that is typical of this ecotope. Twenty-seven percent more rain than the LT-mean occurred during $V_p$ with an ETo of only 6% more than the LT-mean, resulting in a favourable AI value which was 10% higher than the LT-mean. This may have resulted in large strong plants with a high yield potential. Climatic conditions changed from favourable to unfavourable during $R_p$. The $R_p$ was characterized by unfavourable climatic conditions with rainfall typical of this ecotope, but a 32% higher ETo than the LT-mean. This resulted in an AI value 22% lower than the LT-mean and this could have influenced yields negatively if insufficient rainwater was stored in the root zone.

5.5.2.2 Yield

Results for grain and biomass yields, as well as the harvest index (HI) are summarized in Table 5.24.

Grain yields of individual treatments varied between 907 and 3318 kg $ha^{-1}$ over the four seasons. A very strong mean yield trend was established, *viz.* $IRWH_{\text{Mulch}}$ > $IRWH_{\text{Bare}}$ > *STRIP* > *CON* > $IRWH_{\text{Vet}}$ > $IRWH_{\text{GLDM}}$. The mean yields indicate that $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ produced 50 and 31% more grain, respectively, than *CON* and 42 and 24% more grain, respectively, than *STRIP*. These increases were statistically significant in three of the four seasons. $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ outperformed *STRIP* and *CON* due to the ability of the *IRWH* to stop ex-field runoff completely and also contributed to a higher Ev/ET ratio. A comparison of mean grain yields of $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ indicates that $IRWH_{\text{Mulch}}$ produced 15% more grain than $IRWH_{\text{Bare}}$ (due to the additional benefits created by mulch on the runoff and basin areas), lower Es and higher infiltration rate. These increases were not statistically significant during any of the four seasons. Comparing the grain yields of *IRWH* without cover crops ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) to *IRWH* with cover crops ($IRWH_{\text{Vet}}$ and $IRWH_{\text{GLDM}}$) indicates that cover crops competed with maize for water and nutrients and, therefore influenced its yields negatively. *IRWH* without cover crops induced on average a grain yield advantage of 46% above the average of *IRWH* with cover crops. This is also an indication that the rainfall for this semi-arid ecotope is too low to sustain two crops. *IRWH* without cover crops induced significantly higher grain yields as compared to *IRWH* with cover crops for two of the four years. $IRWH_{\text{Vet}}$ induced 11% more grain yield than $IRWH_{\text{GLDM}}$. The reason may be that $IRWH_{\text{GLDM}}$ had a deeper root system than $IRWH_{\text{Vet}}$. All the *IRWH* treatments induced a statistically higher grain yield than *STRIP* and *CON* during the 2004/05 season. *STRIP* induced slightly higher, but non-significant, grain yields than *CON* during all four seasons.

Biomass yields of individual treatments varied between 1613 and 5589 kg $ha^{-1}$ over the four seasons with a strong trend of $IRWH_{\text{Mulch}}$ > $IRWH_{\text{Bare}}$ > *STRIP* > *CON* > $IRWH_{\text{Vet}}$ > $IRWH_{\text{GLDM}}$. Statistical results revealed that $IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$ induced significantly higher biomass yields than *STRIP* and *CON* during two of the four seasons (2004/05 and 2005/06), as well as higher biomass yields than the two *IRWH* with cover crops treatments in two of the four seasons (2006/07 and 2007/08). The harvest index varied between 0.35 and 0.71 during the four seasons. Values for the 2004/05 season were lower than in other years, but can still be considered high for dryland maize. These values indicate that water supply in the $V_p$ was sufficient to meet the crop water demand; hence no severe water stress occurred.

**Table 5.24** Grain yield, biomass and harvest index for maize as affected by various water tillage treatments on the Guquka/Cartref ecotope

| Parameter | Season | Treatment | | | | | | Mean *CON* + SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | *IRWH*$_{GLDM}$ | IRWH$_{Vet}$ | *IRWH*$_{Bare}$ | *IRWH*$_{Mulch}$ | | | |
| Grain (kg ha$^{-1}$) | 2004/05 | 955$^{c}$ | 1295$^{bc}$ | 1983$^{ab}$ | 1571$^{ab}$ | 2008$^{a}$ | 2078$^{a}$ | 1125 | 1777 | 2043 |
| | 2005/06 | 1714$^{c}$ | 1799$^{c}$ | 2450$^{bc}$ | 2420$^{bc}$ | 2593$^{ab}$ | 3045$^{a}$ | 1757 | 2435 | 2819 |
| | 2006/07 | 2137$^{a}$ | 2127$^{a}$ | 907$^{b}$ | 1466$^{b}$ | 2206$^{a}$ | 2749$^{a}$ | 2132 | 1187 | 2478 |
| | 2007/08 | 2636$^{b}$ | 2646$^{b}$ | 922$^{c}$ | 1469$^{c}$ | 2966$^{ab}$ | 3318$^{a}$ | 2641 | 1196 | 3142 |
| | **Mean** | **1861** | **1967** | **1566** | **1732** | **2443** | **2798** | **1914** | **1649** | **2620** |
| Biomass (kg ha$^{-1}$) | 2004/05 | 2768$^{c}$ | 3508$^{b}$ | 4678$^{a}$ | 3668$^{ab}$ | 4655$^{a}$ | 4251$^{a}$ | 3138 | 4173 | 4453 |
| | 2005/06 | 3520$^{b}$ | 3764$^{b}$ | 4738$^{a}$ | 4989$^{a}$ | 5263$^{a}$ | 5589$^{a}$ | 3642 | 4864 | 5426 |
| | 2006/07 | 3904$^{a}$ | 3718$^{a}$ | 2351$^{b}$ | 2896$^{b}$ | 4103$^{a}$ | 4366$^{a}$ | 3811 | 2624 | 4235 |
| | 2007/08 | 4095$^{b}$ | 4435$^{ab}$ | 1613$^{d}$ | 2348$^{c}$ | 4195$^{ab}$ | 5087$^{a}$ | 4265 | 1981 | 4641 |
| | **Mean** | **3572** | **3856** | **3345** | **3475** | **4554** | **4823** | **3714** | **3410** | **4689** |
| Harvest index | 2004/05 | 0.35$^{b}$ | 0.37$^{b}$ | 0.42$^{ab}$ | 0.43$^{ab}$ | 0.43$^{ab}$ | 0.49$^{a}$ | 0.36 | 0.43 | 0.46 |
| | 2005/06 | 0.49$^{aa}$ | 0.48$^{a}$ | 0.52$^{a}$ | 0.49$^{a}$ | 0.49$^{a}$ | 0.54$^{a}$ | 0.48 | 0.50 | 0.52 |
| | 2006/07 | 0.55$^{a}$ | 0.57$^{a}$ | 0.39$^{a}$ | 0.51$^{a}$ | 0.54$^{a}$ | 0.63$^{a}$ | 0.56 | 0.45 | 0.58 |
| | 2007/08 | 0.64$^{a}$ | 0.60$^{a}$ | 0.57$^{a}$ | 0.63$^{a}$ | 0.71$^{a}$ | 0.65$^{a}$ | 0.62 | 0.60 | 0.68 |
| | **Mean** | **0.51** | **0.50** | **0.47** | **0.51** | **0.54** | **0.58** | **0.50** | **0.49** | **0.56** |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$); values with the same superscripts are not significantly different ($P \leq 0.05$)

5.5.2.3 Rainwater productivity

This is probably the simplest way of expressing the efficiency of converting rainwater into food. It is based on the principle that the system that produces 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. $RWP_{04/05-07/08}$ results are presented in Table 5.25. $RWP_{04/05-07/08}$ varied between 5 and 8 kg grain $ha^{-1}$ $mm^{-1}$ rain. A common trend of $IRWH_{Mulch}$ > $IRWH_{Bare}$ > *STRIP* > *CON* ≈ $IRWH_{Vet}$ ≈ $IRWH_{GLDM}$ was observed during the experimental period. $RWP_{04/05-07/08}$ indicated that $IRWH_{Mulch}$ was 14% more efficient than $IRWH_{Bare}$ in converting rainwater into grain. $IRWH_{Mulch}$ and $IRWH_{Bare}$ were 60 and 28%, respectively, more efficient than *CON* in converting rainwater into grain, and 33 and 16% more efficient than *STRIP* in converting rainwater into grain. *IRWH* without cover crops were on average 60% more efficient than *IRWH* with cover crops in utilizing the valuable rainwater in order to produce grain yield. $IRWH_{Mulch}$ was significantly better than all the other treatments, while $IRWH_{Bare}$ was significantly better than *CON*, $IRWH_{Vet}$ and $IRWH_{GLDM}$.

**Table 5.25** RWP data (kg $ha^{-1}$ $mm^{-1}$) for maize on the different treatments over a four season's period for the Guquka/Cartref ecotope

| $RWP_{04/05-07/08}$ | Treatment | | | | | | Mean *CON* + SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|
| | *CON* | *STRIP* | $IRWH_{GLDM}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| | $5^d$ | $6^c$ | $5^d$ | $5^d$ | $7^b$ | $8^a$ | 6 | 5 | 8 |

5.6 AGRONOMIC SUSTAINABILITY

### 5.6.1 Agronomic productivity

The agronomic results are discussed in detail within the context of the water balance components in Section 5.3.2.3, Section 5.4.2.3 and Section 5.5.2.2. A summary of the maize seed yields obtained from the on-station and on-farm trials, as affected by different treatments, are presented in Table 5.26. Generally, the results showed that the *IRWH* technique without cover crops on the runoff area increased maize yields significantly compared to *CON*, and that the *IRWH* treatments with cover crops on the runoff area gave significantly lower maize yields as compared to the *IRWH* technique without cover crops on the runoff area, *CON* and *STRIP*. The most productive treatment was $IRWH_{Mulch}$. Comparing the *IRWH* techniques revealed that there is a consistent trend in grain yield during the experimental period, *viz*. $IRWH_{Mulch}$ > $IRWH_{Bare}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ > $IRWH_{GLDM}$. It was concluded that the subsistence farmers in the semi-arid area in Nkonkobe Municipality could improve maize yields considerably by replacing the *CON* practices with *IRWH* without cover crops on the runoff area.

**Table 5.26** Maize grain yields as affected by different treatments

| Locality | Season | Treatment | | | | | | | Mean Con +SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *CON* | *STRIP* | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| Fort Hare/Oakleaf (kg ha$^{-1}$) | 04/05 | $2066^{bc}$ | $1643^{c}$ | | $2689^{ab}$ | $2680^{ab}$ | $2611^{ab}$ | $2775^{a}$ | 1855 | 2685 | 2693 |
| | 05/06 | $3952^{a}$ | $3274^{b}$ | | $983^{c}$ | $2292^{c}$ | $4177^{a}$ | $4373^{a}$ | 3613 | 1638 | 4275 |
| | 06/07 | $1467^{a}$ | $1327^{a}$ | | $461^{a}$ | $486^{a}$ | $1595^{a}$ | $1412^{a}$ | 1397 | 474 | 1504 |
| | 07/08 | $5583^{a}$ | $5281^{ab}$ | | $2997^{c}$ | $3461^{bc}$ | $6326^{a}$ | $6658^{a}$ | 5432 | 3229 | 6492 |
| | **Mean** | **3267** | **2881** | | **1783** | **2230** | **3677** | **3805** | **3074** | **2007** | **3741** |
| Phandulwazi/Westleigh (kg ha$^{-1}$) | 06/07 | $2381^{a}$ | $2647^{a}$ | $2020^{a}$ | $2670^{a}$ | $2581^{a}$ | $2864^{a}$ | $3012^{a}$ | 2514 | 2424 | 2938 |
| | 07/08 | $3636^{b}$ | $3796^{b}$ | $1955^{c}$ | $1984^{c}$ | $2616^{c}$ | $4124^{ab}$ | $5002^{a}$ | 3716 | 2185 | 4563 |
| | **Mean** | **3009** | **3222** | **1988** | **2327** | **2599** | **3494** | **4007** | **3116** | **2305** | **3751** |
| Guquka/Cartref (kg ha$^{-1}$) | 04/05 | $955^{c}$ | $1295^{bc}$ | $1983^{ab}$ | | $1571^{ab}$ | $2008^{a}$ | $2078^{a}$ | 1125 | 1777 | 2043 |
| | 05/06 | $1714^{c}$ | $1799^{c}$ | $2450^{bc}$ | | $2420^{bc}$ | $2593^{ab}$ | $3045^{a}$ | 1757 | 2435 | 2819 |
| | 06/07 | $2137^{a}$ | $2127^{a}$ | $907^{b}$ | | $1466^{b}$ | $2206^{a}$ | $2749^{a}$ | 2132 | 1187 | 2478 |
| | 07/08 | $2636^{b}$ | $2646^{b}$ | $922^{c}$ | | $1469^{c}$ | $2966^{ab}$ | $3318^{a}$ | 2641 | 1196 | 3142 |
| | **Mean** | **1861** | **1967** | **1566** | | **1732** | **2443** | **2798** | **1914** | **1649** | **2621** |
| **MEAN** | | **2653** | **2584** | **1706** | **1964** | **2104** | **3147** | **3442** | **2618** | **1925** | **3295** |
| **Advantage above *CON* (%)** | | | -2.61 | -35.68 | -25.96 | -20.68 | 18.63 | 29.76 | | -26.48 | 25.84 |

Different superscripts within a row indicate a significant difference ($P \leq 0.05$)

$RWP_{1979/80-2009/10}$ and $RWP_{1999/00-2007/08}$ calculated from simulated yields for the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes, respectively, are presented in Table 5.27. Mean long-term RWP varied between 2.39 and 5.76 kg seed ha$^{-1}$ mm$^{-1}$ rain for maize. The mean RWP value for the *IRWH* treatments without cover crops on the runoff area ($IRWH_{Mulch}$ and $IRWH_{Bare}$) was 44 and 100% higher than *CON* and *IRWH* treatments with cover crops on the runoff areas ($IRWH_{Vet}$, $IRWH_{Lucerne}$ and $IRWH_{GLDM}$), respectively. These are indications that for every 1 mm of rain that occurred, the *IRWH* treatments without cover crops on the runoff area produced 1.68 kg of maize grain yield per hectare and 2.78 kg of maize grain yield per hectare more than the *CON* and *IRWH* treatments with cover crops on the runoff areas, respectively. This is a remarkable difference, especially in a semi-arid environment where every drop of rainwater must be utilized to produce food. The superiority of the *IRWH* treatments without cover crops on the runoff area is the result of their ability to stop $R_{Ex}$ completely and induce in-field runoff ($R_{In}$) within the system and therefore utilize every drop of rainwater far better than *CON*. Comparing $IRWH_{Mulch}$ and $IRWH_{Bare}$ indicates that it is more advantageous to apply mulches in the basin and on the runoff areas of the *IRWH* technique.

**Table 5.27** $RWP_{1979/80-2009/10}$ and $RWP_{1999/00-2007/08}$ data (kg ha$^{-1}$ mm$^{-1}$) for maize from the different treatments on Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes, respectively

| Locality | Treatment | | | | | | *CON* | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|
| | *CON* | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| $RWP_{1979/80-2009/10}$ Fort Hare/Oakleaf (kg ha$^{-1}$ mm$^{-1}$) | 3.09 | 1.99 | 2.28 | 2.67 | 4.44 | 4.82 | 3.09 | 2.31 | 4.63 |
| $RWP_{1999/00-2007/08}$ Phandulwazi/Westleigh (kg ha$^{-1}$ mm$^{-1}$) | 4.67 | 2.78 | 3.19 | 3.74 | 6.28 | 6.70 | 4.67 | 3.24 | 6.49 |
| **MEAN** | **3.88** | **2.39** | **2.74** | **3.21** | **5.36** | **5.76** | **3.88** | **2.78** | **5.56** |

### 5.6.2 Reduction in risk

The CYP-SA model tends to over-predict lower yields and under-predict higher yields. Results of model reliability tests using the procedure of Willmott (1981) are presented in Figure 5.10. The D-index and $r^2$ values were good at 0.81 and 0.57, respectively, which indicates reasonable agreement. CYP-SA was thus suitable for making long-term maize yield predictions with long-term climate data.

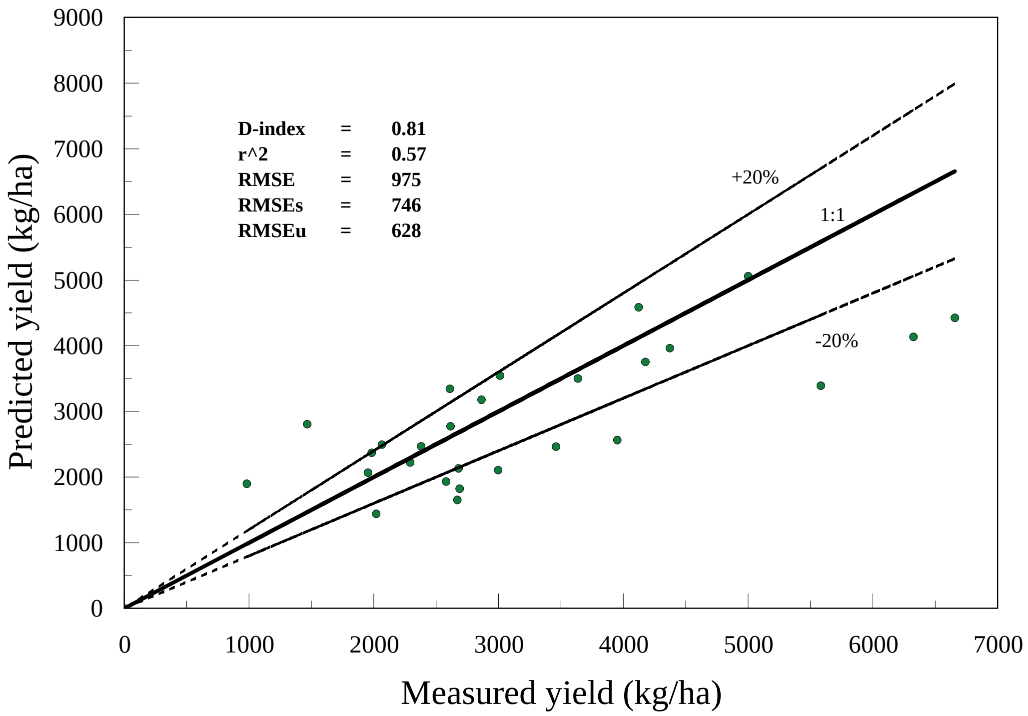


**Figure 5.10** Measured and predicted maize grain yields for the validation dataset on the Fort Hare/Oakleaf and Phundulwazi/Westleigh ecotopes.

The cumulative probability functions of maize yields simulated with CYP-SA on the Fort Hare/Oakleaf ecotope using the proposed production techniques are depicted in Figure 5.11.

The probability presented in the figure is that of non-exceedance of the specified yield intercept on the graph. The closer the graph is to the right-hand bottom corner of the figure, the higher is the potential of the production strategy. Figure 5.11 shows clearly that the *IRWH* treatments without cover crops on the runoff area ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) performed significantly better ($P \leq 0.01$) at any risk level than the *CON* and the *IRWH* treatments with cover crops on the runoff areas ($IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$). The graphs predict that at a very low level of risk, i.e. for an 80% chance of exceedance, when starting with a half-full profile, the $IRWH_{\text{GLDM}}$, $IRWH_{\text{Lucerne}}$, *CON*, $IRWH_{\text{Vet}}$, $IRWH_{\text{Bare}}$ and $IRWH_{\text{Mulch}}$ treatments will produce 961, 1103, 1254, 1291, 2123 and 2396 kg grain $ha^{-1}$, respectively. At this level of risk the $IRWH_{\text{Bare}}$ treatment, which will be the departure point for any farmer, yielded 869 kg $ha^{-1}$ higher than the *CON* treatment. The *IRWH* treatments without cover crops on the runoff area ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) produced on average 1118 and 1006 kg $ha^{-1}$ higher maize yields than the *IRWH* treatments with cover crops on the runoff areas ($IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$) and the *CON* treatment, respectively. CYP-SA indicates that maize yields will increase by 69% through changing from *CON* to $IRWH_{\text{Bare}}$ and by another 13% when changing from $IRWH_{\text{Bare}}$ to $IRWH_{\text{Mulch}}$. Steyn (2003; personal communication) has found in the Eastern Cape Province of South Africa that a household of between 6 and 10 members need, as staple food, between 1000 and 1500 kg maize per annum. With the *IRWH*$_{Mulch}$, *IRWH*$_{Bare}$, *CON*, *IRWH*$_{Vet}$, *IRWH*$_{Lucerne}$ and *IRWH*$_{GLDM}$ treatments the risk of failing, not harvesting ±1500 kg ha$^{-1}$ is only 6.5%, 8.5%, 28%, 30%, 39% and 60%, respectively. With the *IRWH* treatments without cover crops on the runoff area (*IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$) a household would have a 92% probability of realizing a yield of 1500 kg ha$^{-1}$. This is a very low and acceptable risk. The risk of failing with the *IRWH*$_{Bare}$ treatment compared to the *CON* treatment is more than triple. It is clear that the *IRWH* techniques without cover crops on the runoff area (*IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$) decrease the risk of crop failure tremendously.

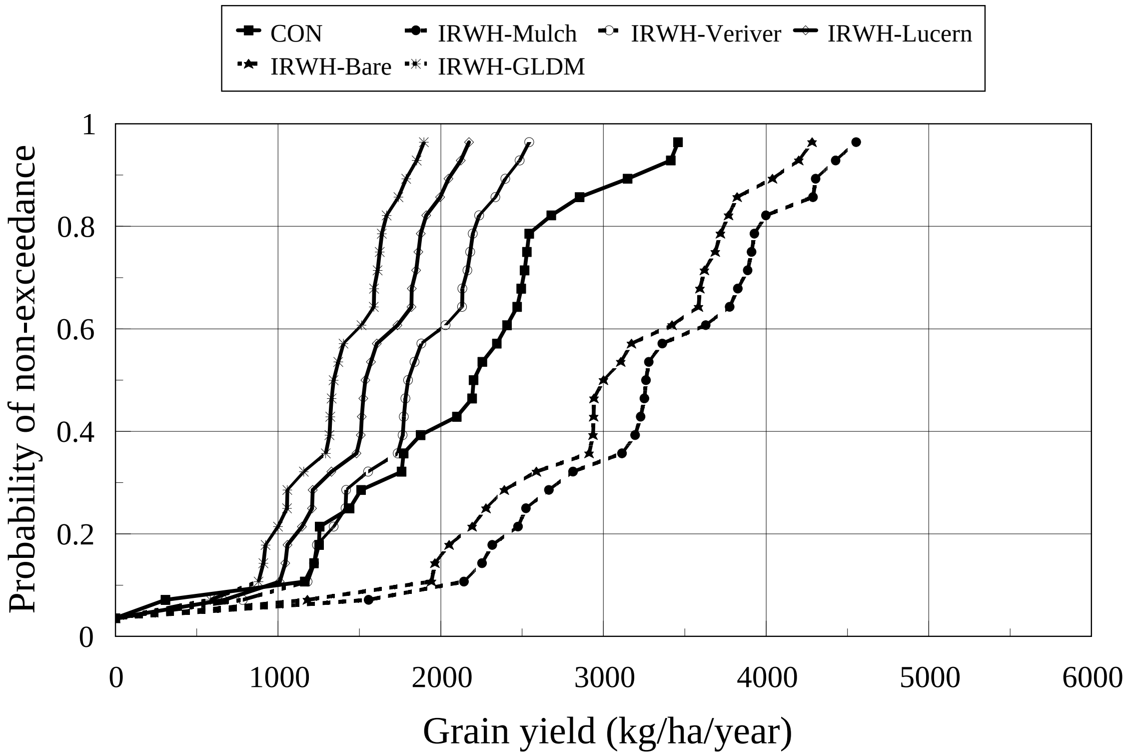


**Figure 5.11** Cumulative distribution functions of yield for maize planted in a ½ full profile on 17 December at the Fort Hare/Oakleaf ecotope.

CPFs of long-term maize yields on the Phandulwazi/Westleigh ecotope simulated with CYP-SA using different production techniques are presented in Figure 5.12. The superiority of the *IRWH* treatments without cover crops on the runoff area (*IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$) over the *CON* treatment and *IRWH* treatments with cover crops on the runoff areas (*IRWH*$_{Vet}$, *IRWH*$_{Lucerne}$ and *IRWH*$_{GLDM}$) for all risk levels is clearly shown. Even at the low level of risk, i.e. 80% chance of success, the *IRWH*$_{Bare}$ yielded 39% more than the *CON* treatment. *IRWH*$_{Mulch}$ produced a 13% higher maize yield than *IRWH*$_{Bare}$, presumably due to the suppressing effect of the organic mulch in the basins and runoff area on Es, especially during the vegetative stage. All the treatments with cover crops on the runoff areas (*IRWH*$_{Vet}$, *IRWH*$_{Lucerne}$ and *IRWH*$_{GLDM}$) yielded (80% chance) on average 1560 kg ha$^{-1}$ less than the *IRWH*$_{Bare}$ treatment, presumably due to the extra competition for water and nutrition from the cover crops on the maize. These results draw attention to the importance of water harvesting as well as water conservation on the runoff area, in addition to that which takes place in the basins.

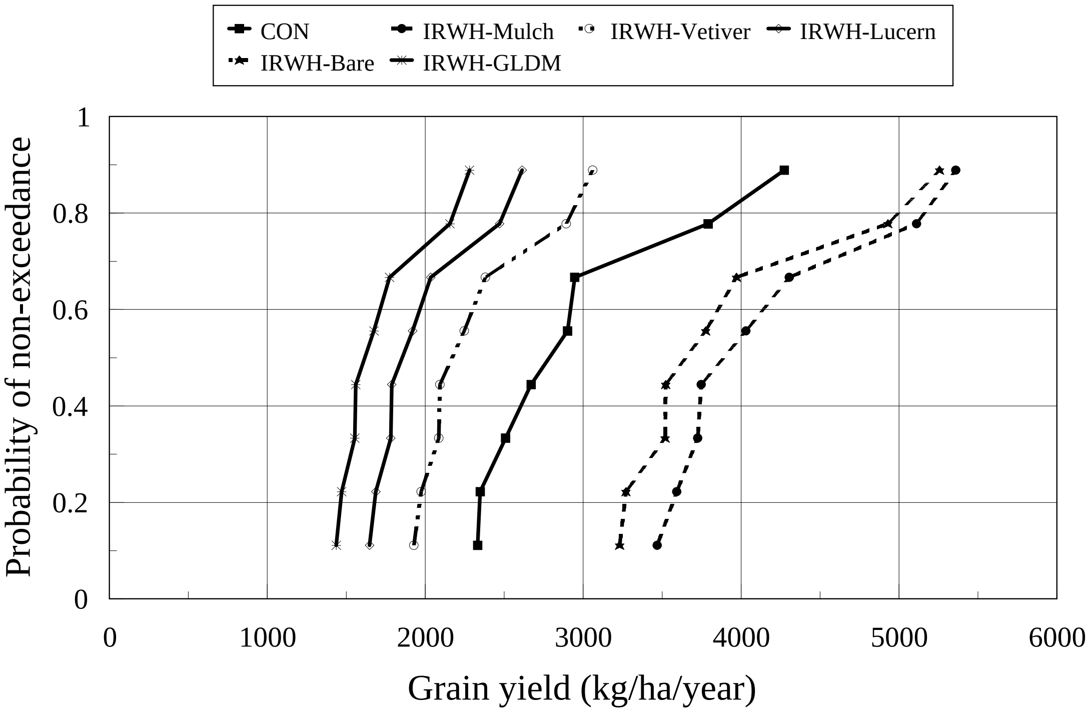


**Figure 5.12** Cumulative distribution functions of yield for maize planted in a ½ full profile on 17 December at the Phundulwazi/Westleigh ecotope.

### 5.6.3 Conservation of natural resource base

$RWP_n$ values for the different treatments obtained over various growing seasons with maize on the Fort Hare/Oakleaf, Phandulwazi/Westleigh and Guquka/Cartref ecotopes are presented in Table 5.28 .

Mean $RWP_n$ for the different ecotopes indicated that *IRWH* without cover crops on the runoff areas ($IRWH_{Mulch}$ and $IRWH_{Bare}$) induced significantly higher $RWP_n$ values as compared to all the other treatments, followed by *CON* > *STRIP* > $IRWH_{Lucerne} \approx IRWH_{Vet} > IRWH_{GLDM}$. This result clearly demonstrates the superiority of *IRWH* without cover crops on the runoff areas for growing maize as well as the productive use of rainwater on this area and similar ecotopes.

**Table 5.28** RWP data (kg $ha^{-1}$ $mm^{-1}$) for the different treatments obtained over various growing seasons with maize

| Locality | Treatment | | | | | | | Mean *CON* +SC | Mean Cover crops | Mean Bare+ Mulch |
|---|---|---|---|---|---|---|---|---|---|---|
| | *CON* | *STRIP* | $IRWH_{GLDM}$ | $IRWH_{Lucerne}$ | $IRWH_{Vet}$ | $IRWH_{Bare}$ | $IRWH_{Mulch}$ | | | |
| $RWP_{04/05-07/08}$ Fort Hare/Oakleaf (kg $ha^{-1}$ $mm^{-1}$) | $10^{ab}$ | $9^{b}$ | - | $5^{c}$ | $7^{c}$ | $11^{a}$ | $12^{a}$ | 10 | 6 | 11 |
| $RWP_{06/07-07/08}$ Phandulwazi/Westleigh (kg $ha^{-1}$ $mm^{-1}$) | $8^{b}$ | $8^{b}$ | $5^{d}$ | $6^{cd}$ | $7^{c}$ | $9^{a}$ | $10^{a}$ | 8 | 6 | 9 |
| $RWP_{04/05-07/08}$ Guquka/Cartref (kg $ha^{-1}$ $mm^{-1}$) | $5^{d}$ | $6^{c}$ | $5^{d}$ | | $5^{d}$ | $7^{b}$ | $8^{a}$ | 6 | 5 | 7 |
| **MEAN** | **8** | **8** | **5** | **6** | **6** | **9** | **10** | **8** | **6** | **9** |

The change in percentage carbon for the 0-150 mm soil layer over the period from 2005 to 2008 as affected by different treatments on the Guquka/Cartref ecotope is presented in Figure 5.13. The carbon cycle processes in the soil are drastically influenced by tillage, and the systems responded accordingly, with the carbon content decreasing towards a lower equilibrium. This was to be expected as the cropland, which was cultivated during the previous years, was ploughed before the treatments were implemented. However, the carbon trends predict that short-term data carbon losses from the no-till *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) were lower than from the *CON* treatment. It is also believed that the carbon content might stabilize at a relatively higher rate for the *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) than the *CON* treatment. Carbon declined by 41% over the period 2005-2008 for the *CON* treatment and by 35% for the *IRWH* treatments. The highest carbon loss occurred on the *CON* treatment and the lowest on $IRWH_{GLDM}$.

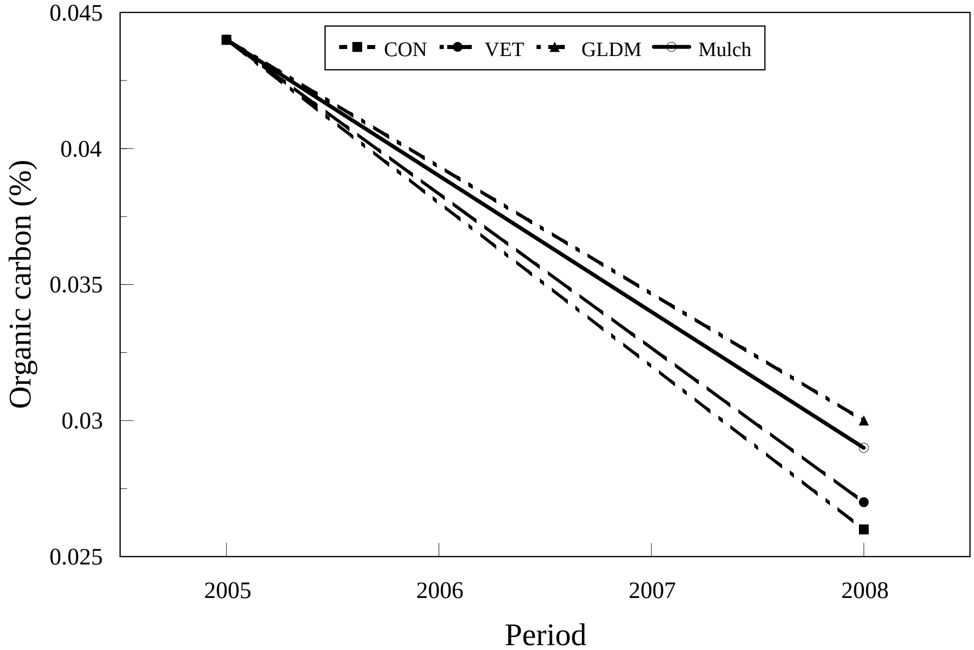


**Figure 5.13** Carbon decline in the Guquka/Cartref ecotope as affected by *IRWH* and *CON* treatments.

The carbon content at the end of the field experiment on the Fort Hare/Oakleaf ecotope is presented in Figure 5.14. Unfortunately, no initial C content results were available at Fort Hare/Oakleaf ecotope in order to demonstrate the decline in carbon content over time. *STRIP* was treated the same as *CON*, therefore no *STRIP* appears in the figure. $IRWH_{GLDM}$ was ignored during the discussions of the results because of the poor establishment of green leaf desmodium on the runoff area at the Fort Hare/Oakleaf ecotope. The results presented in Figure 5.14 are an indication of where the carbon content ended at the end of the field experiments, especially if assumed that all of these treatments started with similar carbon content. The *CON* treatment ended with a carbon content of 6, 12, 25 and 38% lower than $IRWH_{Vet}$, $IRWH_{Bare}$, $IRWH_{Lucerne}$ and $IRWH_{Mulch}$, respectively. Once again this is an indication that lower carbon content losses occurred from the *IRWH* treatments as compared to the *CON* treatment.

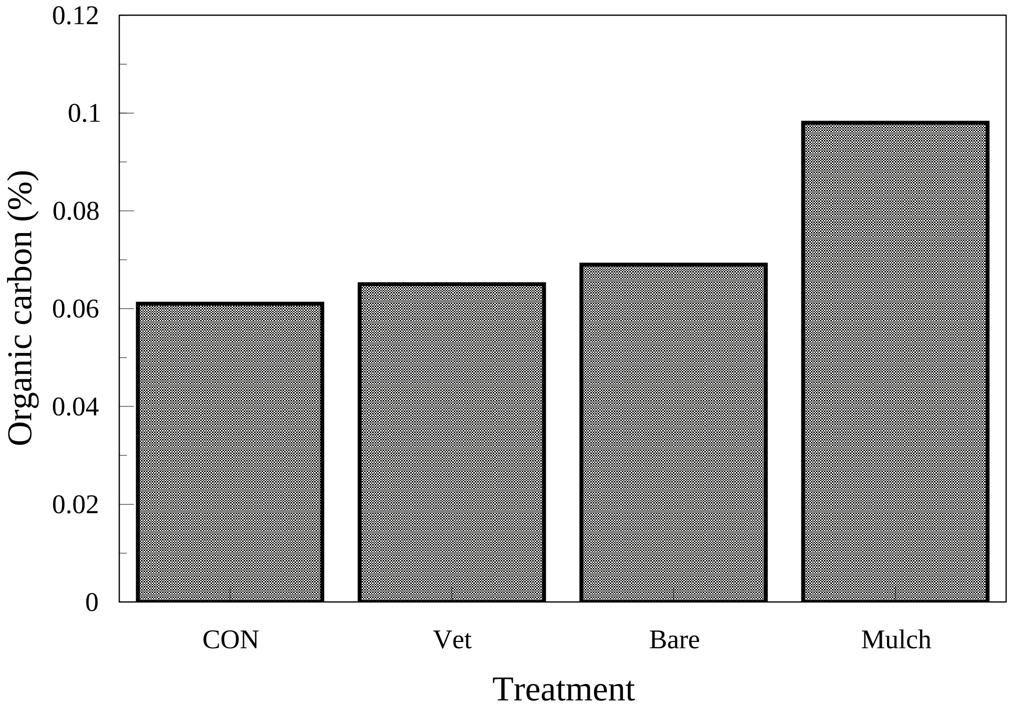


**Figure 5.14** Carbon contents at the end of the field experiment on the Fort Hare/Oakleaf ecotope.

Since changes in C% are generally not sensitive over the short-term, verification of these results will require testing over a longer period.

## 5.7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The general objective of this chapter was to evaluate the agronomic sustainability of rainwater harvesting and conservation (RWH&C) techniques in terms of their ability to convert rainwater into maize grain and biomass yield in a sustainable manner by minimizing the unproductive rainwater losses, through evaporation from the soil surface (Es) and ex-field runoff ($R_{Ex}$), and maximizing the very important parameter of rainwater productivity (RWP).

On-station and on-farm field experiments were conducted in order to test RWH&C techniques. The on-station field experiments were conducted at the UFH Research Farm over a period of four seasons (2004/05-2007/08). An additional on-station field experiment, funded by the ARC, was conducted at Phandulwazi Agricultural School next to the village of Guquka during two seasons (2006/07 and 2007/08). This experiment was not initially part of the project; because it situated closer to Guquka and is more representative of the targeted area it was included and funded by the ARC-ISCW. An on-farm field demonstration experiment was conducted on a farmer's cropland in the village of Guquka over a period of four seasons (2004/05-2007/08).

Normal conventional tillage (*CON*) was compared with strip cropping (*STRIP*) and various in-field rainwater harvesting (*IRWH*) treatments on three ecotopes, *viz*. Fort Hare/Oakleaf; Phandulwazi/Westleigh and Guquka/Cartref. The treatments were *CON*; *STRIP*; *IRWH* with a bare runoff area and bare basin area ($IRWH_{Bare}$); *IRWH* with organic mulch both on the runoff area and basin area ($IRWH_{Mulch}$); *IRWH* with lucerne as a cover crop on the runoff area

(*IRWH*$_{Lucerne}$); *IRWH* with green leaf desmodium as a cover crop on the runoff area (*IRWH*$_{GLDM}$) and *IRWH* with vetiver as a cover crop on the runoff area (*IRWH*$_{Vet}$). The indicators used to show crop response to the different treatments were grain yield, dry matter production, transpiration, runoff and RWP. Detailed measurements were conducted on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes while mainly grain and biomass yield were monitored on the Guquka/Cartref ecotope.

The natural resource components (climate, topography and soil) that affect the productivity of these ecotopes were described. The experimental plots were located on upper foot slope terrain units with a 1-3% slope. The effective root zones of these ecotopes were considered to be 0-1200 mm. The soils have a loam texture. The ecotopes are situated in a semi-arid region with low and erratic rainfall, where conditions are marginal for crop production. The average long-term annual rainfall varies between 507 and 590 mm per annum.

Rainfall records revealed that the rainfall seasons were normal, below- and above-normal with ample opportunities to harvest water in the basins. Plant-available water at planting ($PAW_p$) indicated that both *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ conserved more rainwater during the fallow period than *CON* and *STRIP*. This gave *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ a significantly higher $PAW_p$, or pre-plant water advantage than *CON* and *STRIP*. *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ also induced the highest $PAW_T$ and $PAW_H$ values. The *IRWH* treatments with cover crops on the runoff areas (*IRWH*$_{GLDM}$; *IRWH*$_{Vet}$; *IRWH*$_{Lucerne}$) induced the lowest $PAW_p$ values. The reason for this may have been that the cover crops extracted water during the fallow period. The *IRWH* treatments with cover crops on the runoff areas also induced the lowest plant-available water at tasseling ($PAW_T$) and harvesting ($PAW_H$) values followed by *CON* and *STRIP*. This can be attributed to the cover crops that extracted water from soil during the growing period.

Ex-field runoff was zero for all the *IRWH* treatments during all seasons, while *CON* and *STRIP* treatments lost on average 10% of P to $R_{Ex}$. When the average long-term annual rainfall that varies between 507 and 590 mm is taken in consideration it indicates that *CON* and *STRIP* lost on average between 50 and 59 mm of the valuable rainwater to $R_{Ex}$. This amount of rainwater lost unproductively to $R_{Ex}$ is critical in a semi-arid environment where every drop of rainwater is precious.

Evaporation from soil surface results indicated that all the *IRWH* treatments lost more water to evaporation from soil surface than normal conventional tillage and strip cropping. What should also be kept in mind is the fact that *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ treatments were constantly wetter than *CON* and *STRIP* and, therefore, one would expect Es from the wetter *IRWH* treatments to be higher than from *CON* and *STRIP*. Expressing Es in relation to evapotranspiration (ET) indicates that *IRWH* treatments (71-75%) induced either similar or slightly higher Es/ET values than *CON* and *STRIP* (71-72%). This is an indication that the *IRWH* treatments lost between 71-75% of ET to Es while *CON* and *STRIP* lost between 71-72% of ET to Es. CA comparison of the *IRWH* techniques revealed that *IRWH*$_{Mulch}$, and all the *IRWH* treatments with cover crops on the runoff area, were much more successful than *IRWH*$_{Bare}$ in suppressing the amount of ET lost to Es. In semi-arid areas where water is the main limiting factor, the use of mulch on the runoff area is preferred to cover crops because the latter compete with the main crop (maize) for valuable water.

The results showed that *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ significantly increased maize grain and biomass yields and RWP compared to *CON* and *STRIP* through their ability to stop $R_{Ex}$ completely. *IRWH*$_{Mulch}$ and *IRWH*$_{Bare}$ produced on average 26%, 23% and 24% higher grain yield, biomass yield and RWP values, respectively, than *CON* and *STRIP* in all three ecotopes. These results indicated clearly that $IRWH_{Mulch}$ and $IRWH_{Bare}$ are far more efficient than *CON* and *STRIP* at converting rainwater into grain yield. Results from the three ecotopes indicate that $IRWH_{Mulch}$ produced on average 31%, 28% and 30% higher grain yield, biomass yield and RWP values, respectively, compared to the average of *CON* and *STRIP*. These results confirm that $IRWH_{Mulch}$ is superior to all the other treatments tested, due to its ability to conserve rainwater better and use water more efficiently. This is important in semi-arid environments where the availability of rainwater is critical, therefore, it is recommended that $IRWH_{Bare}$ should be implemented first in order to increase maize yield and also produce enough biomass (organic material) to be used as mulch on the runoff area, and thereafter convert it to $IRWH_{Mulch}$. However, if enough organic material is available, it is recommended that $IRWH_{Mulch}$ be implemented immediately.

A comparison of the *IRWH* technique results from the three ecotopes revealed that there is a consistent trend in grain yield, biomass yield and RWP during the experimental period, *viz*. $IRWH_{Mulch}$ > $IRWH_{Bare}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$ > $IRWH_{GLDM}$. $IRWH_{Mulch}$ outperformed all the other *IRWH* treatments in all aspects. $IRWH_{Mulch}$ produced on average 9%, 9% and 11% higher grain yield, biomass yield and RWP values, respectively, compared to $IRWH_{Bare}$. *IRWH* treatments without cover crops on the runoff area ($IRWH_{Mulch}$ and $IRWH_{Bare}$) produced higher grain yield, biomass yield and RWP increases of 71%, 60% and 68%, respectively, compared to *IRWH* treatments with cover crops on the runoff area ($IRWH_{GLDM}$; $IRWH_{Vet}$; $IRWH_{Lucerne}$). *IRWH* treatments with cover crops on the runoff area gave significant lower $PAW_p$, $PAW_T$, $PAW_H$, grain yield, biomass yield and RWP as compared to *IRWH* treatments without cover crops on the runoff area. Although *IRWH* treatments with cover crops on the runoff area suppressed evaporation from the soil surface. However, because cover crops extract valuable soil water and indirectly competed with the main crop (maize) for water and nutrients, the use of the *IRWH* technique with cover crops on the runoff area is not recommended in semi-arid areas. Comparing only the maize results (seed and biomass yields and RWP), even *CON* and *STRIP* performed better than the *IRWH* treatments with cover crops on the runoff area.

Looking at the results from a different angle, *IRWH* treatments with cover crops on the runoff area, in this case $IRWH_{Lucerne}$, is competitive. Comparing the results of *CON*, *STRIP*, $IRWH_{Mulch}$, $IRWH_{Bare}$, and $IRWH_{Lucerne}$ indicates that the mean maize yields from the three ecotopes were 2653, 2584, 3442, 3147 and 1964 kg $ha^{-1}$, respectively. $IRWH_{Lucerne}$ produced on average 1054 kg $ha^{-1}$ lucerne (results from Fort Hare/Oakleaf ecotope) in addition to the maize yield. According to Fourie (2011; personal communication) the prices of maize and lucerne are R1500 $ton^{-1}$ and R1300 $ton^{-1}$, respectively. Thus the Rand values of *CON*, *STRIP*. $IRWH_{Mulch}$, $IRWH_{Bare}$, and $IRWH_{Lucerne}$ were R3979 $ha^{-1}$, R3875 $ha^{-1}$, R5163 $ha^{-1}$, R4721 $ha^{-1}$ and R4316 $ha^{-1}$, respectively. This is an indication that the Rand value for $IRWH_{Lucerne}$ was R337 $ha^{-1}$ and R441 $ha^{-1}$ higher than *CON* and *STRIP*, respectively, and R405 $ha^{-1}$ and R848 $ha^{-1}$ lower than $IRWH_{Bare}$, and $IRWH_{Mulch}$, respectively.

Overall it was found that $IRWH_{Mulch}$ outperformed all the other treatments followed by $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{GLDM}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$. It can be concluded that subsistence farmers in semi-arid areas could improve maize yields considerably by replacing *CON* practices with *IRWH* without cover crops and, if possible, applying mulch on the basin and runoff areas. This would improve their level of food security. *IRWH* without cover crops is agronomically more sustainable than *CON*. If the intention of small-scale farmers is to only produce a well-balanced fodder in bulk for their animals, or fodder for their animals as well as food for the household, then the *IRWH* treatments with cover crops may be a good option. Use of cover crops is vital for small-scale mixed farmers even though there is a clear decline in the yields as a consequence of cover cropping. The economics of this decline should be viewed in terms of the positive impact on the livestock sector. Indicators that one could look at include the role extra nutrition from cover crops will have on weaning weights, calving intervals, body condition score and incidence and nutrition induced diseases. There is no doubt that cover crops should be properly managed within the system, as without proper management maize grain yield could decline further.

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) from a biophysical point of view are described as follows:

*Agronomic productivity (improved production)*: The short-term field experiments (on-station and on-farm experiments) and long-term RWP results show that *IRWH* treatments without cover crops on the runoff area ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) significantly increased crop yields and RWP compared to *CON*, *STRIP* and *IRWH* treatments with cover crops on the runoff areas ($IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$). Results also indicated that $IRWH_{\text{Mulch}}$ is the most productive treatment followed by $IRWH_{\text{Bare}}$, *CON*, *STRIP*, $IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$.

*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 with maize on the Fort Hare/Oakleaf and Phandulwazi/Westleigh ecotopes using different production techniques. Results obtained from simulations done with CYP-SA indicate that maize yields could be increased on average by 54% by changing from *CON* to $IRWH_{\text{Bare}}$, and by another 13% by changing to $IRWH_{\text{Mulch}}$. Results indicate that $IRWH_{\text{Mulch}}$ was the best treatment in terms of risk reduction, followed by $IRWH_{\text{Bare}}$, *CON*, $IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$.

*Conservation techniques (conservation of natural resources)*: The carbon cycle processes in the soil were drastically influenced by tillage, and the system responds accordingly, with the carbon content tending towards a lower equilibrium with long-term cultivation. Carbon trends predict that short-term data carbon losses from the no-till *IRWH* treatments ($IRWH_{\text{Mulch}}$, $IRWH_{\text{Vet}}$ and $IRWH_{\text{GLDM}}$) were lower than from the *CON* treatment. It is also believed that the carbon content might stabilize at a relatively higher C content for the *IRWH* treatments ($IRWH_{\text{Mulch}}$, $IRWH_{\text{Vet}}$ and $IRWH_{\text{GLDM}}$) than the *CON* treatment. The highest carbon loss occurred on the *CON* treatment and the lowest on $IRWH_{\text{GLDM}}$.

Mean $RWP_n$ for the different ecotopes indicated that *IRWH* without cover crops on the runoff areas ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) induced significantly higher $RWP_n$ values as compare to all the other treatments, followed by $CON > STRIP > IRWH_{\text{Lucerne}} \approx IRWH_{\text{Vet}} > IRWH_{\text{GLDM}}$. This result clearly demonstrates the superiority of *IRWH* without cover crops on the runoff areas for growing maize as well as the productive use of rainwater on these and similar ecotopes.

Short-term data indicate *IRWH* without cover crops on the runoff areas ($IRWH_{\text{Mulch}}$ and $IRWH_{\text{Bare}}$) is far more agronomic sustainable than *CON* and *IRWH* treatments with cover crops on the runoff areas ($IRWH_{\text{Vet}}$, $IRWH_{\text{Lucerne}}$ and $IRWH_{\text{GLDM}}$) for this specific study area. Of all the techniques tested, $IRWH_{\text{Mulch}}$ was shown to be the best, followed by $IRWH_{\text{Bare}}$. However, in general, evaluation of the project in terms of the different sustainability criteria really needs to be done over the long-term.

# 6 TESTING AND EVALUATION OF RWH&C TECHNIQUES: RANGELAND/LIVESTOCK PRODUCTION

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## 6.1 INTRODUCTION

Communal rangelands are used primarily as a source of feed for livestock, and other secondary resources such as firewood, wild foods, medicinal plants and water. Land degradation is the major challenge in the communal rangelands of the Eastern Cape (Palmer *et al*., 1997) because it reduces rangeland primary productivity and soil protection, both major ecosystem functions. Abel & Behnke (1996) defined rangeland degradation as an effectively permanent decline in the rate at which land produces forage for a given input of rainfall under a given system of management, while Hahn *et al*. (2005) defined land degradation as the reduction or loss of biological and economic productivity arising from inappropriate land use practices.

Rangeland degradation results in declining functional capacity, increased poverty and food insecurity. Major changes in rangeland surface morphology and soil characteristics have a drastic effect on the primary productivity of the rangeland ecosystem, and in turn on livestock production. This suggests that there is a need for interventions to halt land degradation and improve the functional capacity of communal rangelands.

There are a large number of conceptual models that have been developed by restoration ecologists to describe how ecosystem structure and function are related (Cortina *et al*., 2006). Bradshaw (1984) developed a model for the reclamation of derelict land, which was later referred to as the Linear structure vs. Function model (LSF). The model assumes a linear increase in ecosystem function with an increase in complexity of its structure (Cortina *et al*., 2006). According to this model, restoration is defined as the simultaneous increase in structure and function promoted by human intervention, paralleling changes occurring during secondary succession.

Management of land degradation can be divided into preventative and restoration measures. Answers to preventative measures can often be found within the causes of land degradation. In view of the massive scale of land degradation that has already occurred in parts of southern Africa's communal rangelands, restoration is of significant importance to land owners.

In arid and semi-arid ecosystems, water is the major limiting factor (Chen *et al*., 2007). Performance of landscape functions relies heavily on the availability of water (Vohland & Barry, 2009). In southern Africa, a number of studies in rangeland ecology have been conducted, but most of them have been limited to traditional disciplines such as grazing management, fire ecology and vegetation characteristics. The rangeland environment generally consists of abiotic components, such as soil and climate parameters, and biotic communities, including plants and animals. Processes such as photosynthesis, hydrological cycle, respiration and many others explain the interaction between the biotic and abiotic components of the ecosystems. Therefore, there is a need for a fuller understanding of the complex nature of rangeland environment and of the various interactions and feedbacks between the different processes. The objective of this study was to evaluate rangeland restoration and rainwater harvesting techniques and practices in communal grazing areas of the Eastern Cape Province of South Africa.

## 6.2 MATERIAL AND METHODS

### 6.2.1 Restoration and water harvesting techniques

The grass species, *Themeda triandra* and *Paspalum dilatatum*, were collected from sites that were not degraded within the Amakuze Tribal Authority (ATA) in order to use local ecotypes. The grasses were separated into single tillers and propagated in the nursery with growing medium (Hygromix and pine buck) for four weeks at Fort Cox College of Agriculture and Forestry. The grass seedlings were taken to the fields for transplanting. Seeds of the grass species *Panicum maximum, Digitaria erientha* and *Eragrostis curvular* were bought from commercial seed producers (South African ecotypes). One degraded site (100 x 100 m) was selected based on visual degradation indicators such as the presence of gullies, rills, pedestals, armour layer, solution notches, plant root exposures and sediment accumulation. Twenty-four plots each 30 x 10.25 m in size were laid out and marked with 60 cm wooden pegs.

There were thirteen treatments, each replicated twice:

1) Brush pack (BP) (this is brush that is laid out over micro-catchments in rangelands to reduce evaporation and protect seedlings from grazing – they serve a similar purpose to that of mulch in cropping systems)
2) Brush pack/minimum soil disturbance/*Panicum maximum*/seeds (BP/MSD/PaMa/SD)
3) Minimum soil disturbance/*Eragrostis curvula*/seeds (MSD/ErCu/SD)
4) Minimum soil disturbance/*P. maximum*/seeds (MSD/PaMa/SD)
5) Micro-catchment/brush pack/*Digitaria erientha*/seeds (MC/BP/DiEr/SD)
6) Micro-catchment/brush pack/*P. maximum*/seeds (MC/BP/PaMa/SD)
7) Micro-catchment/brush pack/*Paspalum dilatatum*/seedlings (MC/BP/PaDi/SL)
8) Micro-catchment/brush pack/*Themeda triandra*/seedlings (MC/BP/ThTr/SL)
9) Micro-catchment/*E. curvula*/seeds (MC/ErCu/SD)
10) Micro-catchment/*P. dilatatum*/seedlings (MC/PaDi/SL)
11) Micro-catchment/*T. triandra*/seedlings (MC/ThTr/SL)
12) Water spreading system
13) Control

Twelve sub-plots (1 x 1 m) were established for a variety of treatments: brush pack (piling of brush randomly on the ground), micro-catchments, and other combinations. Micro-catchment systems are those in which surface runoff water is collected from a small catchment area, transferred over a short distance and applied to an adjacent area, where it is either stored in the root zone and used directly by plants or retained in a small reservoir for later use (Oweis *et al*., 2001). The *IRWH* techniques used on the croplands and homestead gardens fall within the micro-catchment systems category. In rangelands semi-circular bands are the most commonly used micro-catchment technique for *IRWH*. This technique is totally unrelated to the micro-catchments techniques used in croplands, but serve a similar function. It is usually used in combination with brush packs.

The plots for minimum soil disturbance with grass seeds were planted as a whole and later subdivided with a 1 x 1 m quadrat for measuring. Twelve water-spreading furrows (10 x 0.20 m) were developed in each of the water spreading system plots. On the plots where the seedlings were used, ten seedlings were planted at 12 cm inter- and intra-line spacing. Measurements included tiller and leaf number, flowering and mortality rate from six permanent tufts, at intervals of 4 weeks for 16 weeks. Other plant species that geminated were also counted. The grass seeds were planted according to the producer's recommendations for specific grass species. Biomass production was harvested in all the seed and seedling plots after 16 weeks. Soil samples were collected at intervals of 2 weeks and gravimetric soil moisture content was determined for all the plots.

### 6.2.2 Determination of soil seed bank on degraded and non-degraded rangelands

Five sites (100 x 100 m each) were selected at ATA (degraded) and at Phandulwazi Agricultural High School (non-degraded). At each site three line-transects (100 m) were randomly selected. Three surface soil samples were randomly collected along each line transect. The soil samples were collected at a depth of 3 cm on a 0.25 $m^2$ area. A total of 90 soil seed bank samples were collected: 45 cores from degraded sites and 45 cores from non-degraded sites. The samples were placed in plastic bags for immediate transportation to the greenhouse for germination. Soil seed bank samples were collected at the end of the growing season (September-October) after seed production (Solomon e*t al*., 2006).

In the greenhouse, labelled plastic pots with a 21 cm depth and 24 cm diameter were filled with a pine buck growing media to a depth of 17 cm. The soil was thoroughly mixed after removal of all root and plant fragments. Soil samples were spread over the pine buck in each plastic pot to a depth of 2 cm. The pots were placed at random in the greenhouse. The temperature in greenhouse was kept between 19 and 22$^oC$ during the day, and 10 and 12$^oC$ during the night, throughout the experimental period of eight weeks.

### 6.2.3 Data analysis

The quantitative data was analysed with ANOVA (SPSS, 1999) and the means were separated with least significant difference (LSD). Differences between the treatments for restoration, water harvesting and soil seed bank were considered significant at $p < 0.05$.

## 6.3 RESULTS AND DISCUSSION

### 6.3.1 Restoration of rangeland vegetation using micro-catchments and brush packs with grass seedlings

The tiller number was significantly ($p < 0.05$) different between the observation dates (Table 6.1). The tiller number increased with subsequent observation intervals (time), thus it was lowest in the fourth week (4.4), and increasing through the eighth (6.6) and twelfth week (14.2), and was highest during the sixteenth week (16.6). The leaf number also increased significantly ($p < 0.05$) between the fourth, eighth, twelfth and sixteenth weeks of observation (Table 6.1). The results suggest that vegetation restoration performance using grass seedlings depends on duration from establishment to observation, since the performance in terms of tiller and leaf number increases from time of establishment. This could be ascribed to the dependency of the tillering process on leaf development. These results are supported by Wolfson & Tainton (1999), who indicated that a tiller arises as a bud in the axils of a leaf and, therefore, the potential rate of tillering depends on the rate at which leaves are produced.

**Table 6.1** The performance (mean±SE) of transplanted grass seedlings at four weeks observation interval after transplanting

| Week interval | Tiller No | Leaf No | Mortality (%) | Flowering (%) | Other species | Tuft diameter |
|---|---|---|---|---|---|---|
| 4th week | 4.4±0.46$^{a}$ | 15.3±1.8$^{a}$ | 14.3±4.3$^{a}$ | - | 16.4±4.2$^{a}$ | - |
| 8th week | 6.6±0.76$^{a}$ | 27.3±3.9$^{ab}$ | 16.4±3.9$^{a}$ | 14.8±5.2$^{a}$ | 38.2±10.8$^{b}$ | - |
| 12th week | 14.2±2.1$^{b}$ | 42.5±5.8$^{b}$ | 20.9±4.7$^{a}$ | 20.9±7.4$^{a}$ | 38.0±7.7$^{b}$ | - |
| 16th week | 16.6±2.1$^{b}$ | 45.6±5.9$^{b}$ | 22.5±4.5$^{a}$ | 28.9±8.3$^{a}$ | 26.4±5.7$^{a}$ | 4.9±0.4 |

Mean values with different superscripts within the same column are significantly different.

The tiller number was significantly higher ($p < 0.05$) on micro-catchment plots with brush pack (13.1) than on micro-catchment plots without brush pack (7.2). The leaf number was also significantly higher ($p < 0.05$) on micro-catchment plots with brush pack (41.7) than on micro-catchment plots without brush pack (27.5). The results suggest that the use of micro-catchment with brush pack in vegetation restoration could support higher grass tiller and leaf development. This performance of grass seedlings on micro-catchments with brush pack could serve as an early indicator of vegetation restoration success in degraded rangelands. This could be attributed to high moisture retention under the brush pack which provides shade, reducing evaporation loss from the soil. This implies that with the use of grass seedlings, a combination of micro-catchments and brush pack could serve as an effective technique for restoring degraded rangelands.

The grass seedling mortality rates were significantly lower ($p < 0.05$) on micro-catchment plots with brush pack (10.4%) compared to micro-catchment plots without brush pack (28.7%). The flowering rate was significantly higher ($p < 0.05$) on micro-catchment plots with brush pack (21.7%) than on those without (9.4%) (Table 6.2). These results suggest that the use of brush pack with micro-catchment were effective in reducing mortality and stimulating reproductive growth. Brush pack provides shade on the micro-catchment, which results in reduced evaporation from soil and an improvement in soil moisture in terms of both amount and duration of storage. This implies that plants under micro-catchment without brush pack could have died due to soil desiccation, caused by loss of soil moisture through evaporation. The higher inflorescence production rate on plants under micro-catchment with brush pack could be ascribed to availability of moisture, and the number of leaves that the plant has before initiation of reproductive growth. This is supported by Wolfson & Tainton (1999), who indicated that there was a relationship between the number of leaves produced on a tiller and initiation of the reproductive phase, i.e. the changeover to reproductive stage does not occur until a minimum number of leaves are formed per tiller. However, this number varies with species. *Themeda triandra,* for example, will only start flowering when a minimum of nine leaves has been attained.

**Table 6.2** Effects of micro-catchment and brush packs on seedling growth (Mean±SE)

| Treatment | Tiller No | Leaf No | Mortality (%) | Flowering (%) | Other species | Tuft diameter |
|---|---|---|---|---|---|---|
| MCGS | 7.2±0.91[a] | 21.5±2.12[a] | 28.7±3.94[a] | 9.4±3.46[a] | 24.5±4.95[a] | 1.4±0.39[a] |
| MCBPGS | 13.2±1.47[b] | 41.7±4.09[b] | 10.4±1.71[b] | 21.7±5.05[a] | 33.7±5.44[a] | 1.1±0.29[a] |

Mean values with different superscripts within the same column are significantly different.
MCGS = micro-catchment with grass seedlings, MCBPGS = micro-catchment with brush pack and grass seedlings.

Tiller number was not significantly different ($p > 0.05$) between grass species. However, *Paspalum dilatatum* had a significantly lower ($p < 0.05$) leaf number (26.7) compared with *Themeda triandra* (39.7). This could be ascribed to genetic material differences between the species, which is to be expected. This implies that when vegetation restoration performance is determined by leaf development, the success of the treatment is dependent on species genetic make-up.

The mortality rate was significantly higher ($p < 0.05$) for *T. triandra* (25.2%) than *P. dilatatum* (12.2%), with a high mortality rate on the micro-catchments without brush pack (Table 6.3). This suggests that *T. triandra* is more affected by desiccation than *P. dilatatum,* and implies that the effectiveness of micro-catchment and brush pack varies with species. This could be attributed to the adaptation of grass species to low water supply, due to variation in stomatal conductance. This is in agreement with Wolfson & Tainton (1999) who indicated that the effect of moisture stress on growth and development of grass varies among different species, growth stage of the plant, duration of moisture stress period, and management prior to and during the stress period.

The rate of flowering was significantly higher ($p < 0.5$) for *P. dilatatum* (31.0%) than *T. triandra* (0.7%). This suggests that when the water harvesting technique combines micro-catchment with brush pack, *P. dilatatum* produces more flowers than *T. triandra*. This could be ascribed to genetic difference between species, because flowering is genetically induced. However, it is also induced by biochemical processes that may require a cold pre-treatment (vernalization) or a certain day length or series of day lengths (photoperiodism). *T. triandra* has been shown to be one of the species that requires over-wintering for it to flower the following spring. That could have been one of the reasons for poor flowering of *T. triandra*. Wolfson & Tainton (1999) indicated that *T. triandra* requires resting from midsummer of one year for seeding in the following spring. This implies that when flowering is considered a performance indicator for rangeland restoration, the factors that affect phenological phases of different species should be considered. Dahl (1995) alluded to the fact that floral initiation is interpreted as a biochemical process that may require a cold pre-treatment is photoperiodic, requires favourable growing conditions, and that in some plants it is genetically induced.

**Table 6.3** Performance (Mean±SE) of different grass species under micro-catchment and brush packs

| Grass species | Tiller No | Leaf No | Mortality (%) | Flowering (%) | Other species | Tuft diameter (cm) |
|---|---|---|---|---|---|---|
| *P. dilatatum* | 9. 4±0.9[a] | 26.6±2.2[a] | 12.2±2.0[a] | 31.0±5.6[a] | 29.6±4.9[a] | 1.5±0.4[a] |
| *T. triandra* | 11.8±1.7[b] | 39.0±4.8[b] | 25.3±3.7[b] | 0.7±0.3[b] | 29.5±5.8[a] | 1.0±0.3[a] |

Mean values with different superscripts within the same column are significantly different.

6.3.1.1 Rainwater harvesting techniques used in rangeland restoration practices

There was a significant difference ($F = 11.034$, $p < 0.01$) between the performance of rainwater harvesting practices. The use of brush pack alone was significantly higher ($p < 0.01$) than the control in terms of moisture retention in the soil (Figure 6.1). Plots covered with brush pack only had higher soil moisture content than those with no brush pack at all. Soil moisture retention was significantly higher ($p < 0.01$) on the plots covered with brush pack, under minimal soil disturbance and on which *P. maximum* seeds (BP/MSD/PaMa/SD) were planted, compared to the control. However, the BP/MSD/PaMa/SD was not significantly different ($p > 0.05$) from the plot that had brush pack only. Minimal soil disturbance with both *P. maximum* and *E. curvula* seeds was not significantly different ($p > 0.05$) from the control for soil moisture retention. The results suggest that the brush pack was more effective for soil water storage than minimal soil disturbance, which could be due to reduced evaporation rate from the soil resulting from shading effect of the brush pack.

Soil water retention on the plots with micro-catchment, brush pack, minimum soil disturbance and planted with *Digitaria erientha* (MC/BP/DiEr/SD) or *P. maximum* (MC/BP/PaMa/SD) were significantly higher ($p < 0.01$) than on control plots (Figure 6.1). Furthermore, the use of micro-catchment and brush pack with both *P. dilatatum* and *T. triandra* seedlings also resulted in significantly higher soil water storage ($p < 0.01$) than the control. Soil water storage was significantly higher ($p < 0.01$) on micro-catchment without brush pack planted with *E. curvular* seeds, *P. dilatatum* and *T. triandra* seedlings than the control. The use of a water spreading system also resulted in significantly better ($p < 0.01$) soil water retention than the control plots. This could be attributed to the fact that after rainfall, the micro-catchment holds rainwater within the catchment, whilst the water spreading system spreads water across the wider areas on rangelands. The results suggest that the use of micro-catchments in conjunction with brush pack and water spreading systems should be considered as water harvesting techniques and could complement the vegetation restoration methods. Both of these structures reduce water loss through runoff, and brush pack reduces water loss from evaporation.

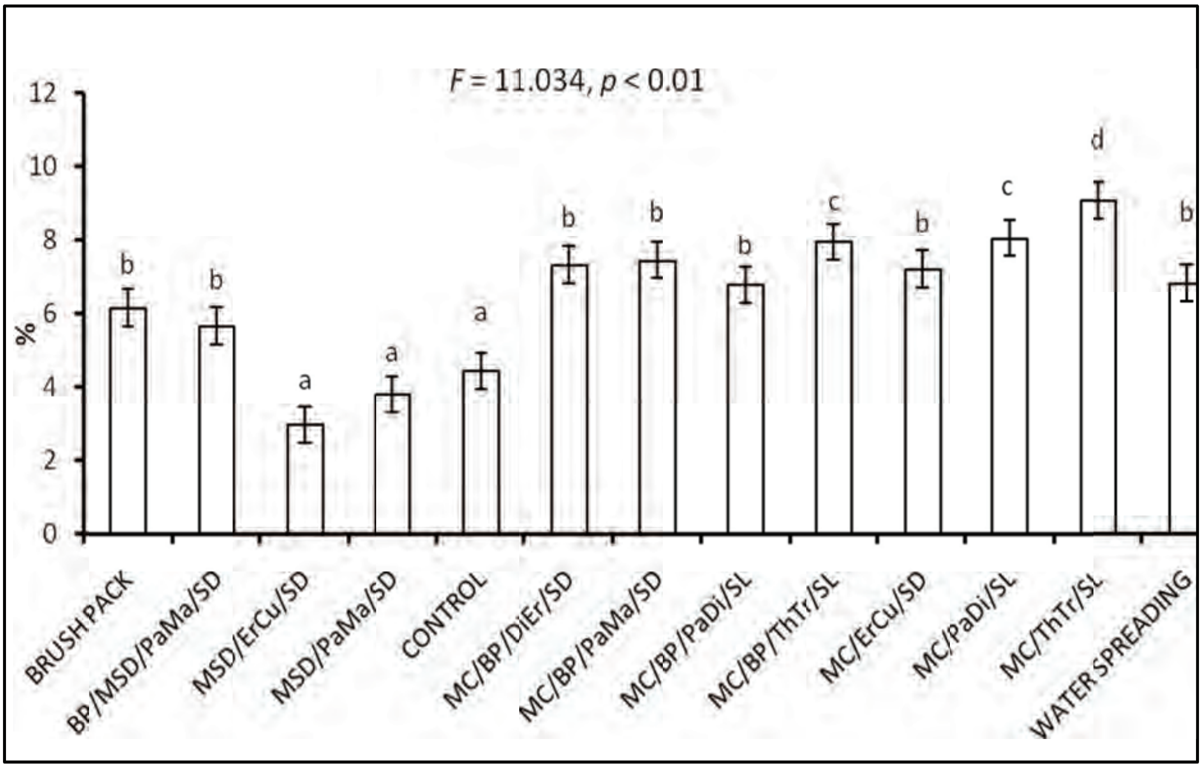


**Figure 6.1** Soil moisture content (%) under different rainwater harvesting practices in rangeland restoration.

BP = Brush pack, MSD = Minimum soil disturbance, SD = grass seeds, MC = Micro-catchment, SL = Grass seedlings, ThTr = *Themeda triandra*, ErCu = *Eragrostis curvula*, DiEr = *Digitaria erientha*, PaDi = *Paspalum dilatatum.*

### 6.3.2 Evaluation of soil seed bank on degraded rangelands

The seed bank means were significantly higher ($p < 0.01$) on degraded sites (Amakuze Tribal Authority) (5.7, SD = 4.8) than non-degraded sites (Phandulwazi High School) (1.7, SD = 1.5). The minimum seed bank at the degraded sites was 0 with a maximum of 20 while for the non-degraded sites it was 0 and 6 for the minimum and maximum, respectively (Table 6.4). The results suggest that degraded rangeland sites had higher soil seed bank compared to non-degraded sites. This could be attributed to the fact that at the non-degraded sites rotational grazing is practised instead of rotational resting, which allows grasses to produce and disperse seeds. Also, the conditions (moisture and soil) in the degraded area are not conducive for germination, so the seeds are retained in the soil. This implies degraded communal rangelands have a high seed bank, which could serve as a source of seed for re-vegetation.

There are a number of factors which could serve as barriers to natural recovery of degraded rangelands. These include soil moisture (Snyman, 1998), which is lost due to runoff and evaporation on the bare ground after rainfall; soil pH (Henig-Server *et al.*, 1996), which affects the availability of nutrients for plants; and soil temperature (Snyman, 2005), which with light serves as the important factors influencing germination. Soil seed banks indicate a potential pool of propagules for regeneration of grasses after disturbance (Bekker *et al.*, 1997), reduce the probability of population extinction of plants (Venable & Brown, 1988) and could serve as a source for establishing plant communities following environmental changes, such as rainfall (Snyman, 1993; Hayatt, 1999).

Storage of viable seeds in the soil and subsequent establishment are also functions of disturbance factors (Thompson, 1986). Drought may adversely affect the seedling recruitment of the seed bank (Kinloch & Friedel, 2005). Heavy grazing by livestock introduces a disturbance to grasslands and can negatively affect the size and composition of grasses in the seed bank (Bekker *et al.,* 1997; Solomon, 2003; Snyman, 2004). Seed germination and establishment in natural and artificial revegetation is a result of the number of seeds in favourable microsites or 'safe sites' in the seedbed, rather than the total number of available seeds (Harper *et al.,* 1965).

**Table 6.4** Soil seed bank distribution between Amakuze Tribal Authority and Phandulwazi High School

| Site | Mean | SD | Sum | Min | Max |
|---|---|---|---|---|---|
| Amakuze Tribal Authority | 5.671[a] | 4.827 | 397.0 | .0 | 20.0 |
| Phandulwazi Agricultural HS | 1.652[b] | 1.462 | 147.0 | .0 | 6.0 |

## 6.4 SUMMARY AND CONCLUSIONS

Most of the rangelands in Sub-Saharan Africa are located in areas classified as arid or semi-arid. The presence or lack of water is one of the key variables determining the fate of their ecosystems. Therefore, an understanding of the hydrologic processes is critically important. The literature review provided a description of the relationship between rangeland water movement and soil properties, vegetation characteristics, landscape formation, animal productivity, land degradation features and rangeland restoration. The rangelands are relatively homogeneous in comparison with other types of surfaces. However, they still exhibit heterogeneity resulting from, among others, topographic features and changes in dominant vegetation with horizontal scales. In order to improve our understanding and quantification of soil water-vegetation interactions and soil water carrying capacity for vegetation, it is necessary to integrate hydrological and biogeochemical processes to estimate not only water dynamics, but also its influence on vegetation density. Water use efficiency (WUE) at the community level depends on the WUE of species, and hence on species composition. The intrinsic water use efficiency (IWUE) is considered to be less tightly coupled to the instantaneous environmental temperature and atmospheric humidity, but more a reflection of plant physiological properties. Soils influence hydrologic processes by providing the medium for the capture, storage and release of water. Livestock convert water resources into high value goods and services.

Animals derive their water from different sources such as water directly consumed by drinking and water consumption through feed intake. When rangeland is in poor condition, water use efficiency is low, regardless of soil water content. Vegetation restoration requires consideration of soil water dynamics in both time and space. Soil water dynamics are affected by a number of factors such as topography, soil properties, land cover, water routing processes, and depth of water table and/or meteorological conditions. In the context of agricultural production in African dryland, soil and water conservation practices such as rainwater harvesting (RWH), provide an opportunity to stabilize agricultural landscapes in semi-arid regions and make them more productive, as well as more resilient towards climate change. There is a need for intensive research on ecosystem water relations, species water relations, plant anatomy and physiological processes in the rangelands of the southern African region to improve rangeland management and productivity.

The study was conducted at the ATA located at S32° 38´, E26°56´ with an altitude ranging from 763 m asl in low lands to 1500 m. The ATA is composed of six villages, *viz.* Makuzeni, Gomro, Mpundu, Guquka, Sompondo, and Gilton. One degraded site (100 x 100 m) was selected based on visual degradation indicators such as presence of gullies, rills, pedestals, armour layer, solution notches, plant root exposures and sediment accumulation. There were thirteen treatments, each replicated twice. The treatments for vegetation restoration and rainwater harvesting were: Brush pack, Brush pack/minimum soil disturbance/*Panicum maximum*/seeds, Minimum soil disturbance/*Eragrostis curvula*/seeds, Minimum soil disturbance/*P. maximum*/seeds, Micro-catchment/brush pack/*Digitaria erientha*/seeds, Micro-catchment/brush pack/*Panicum maximum*/seeds, Micro-catchment/brush pack/*Paspalum dilatatum*/seedlings, Micro-catchment/brush pack/*Themeda triandra*/seedlings, Micro-catchment/*E. curvula*/seeds, Micro-catchment/*P. dilatatum*/seedlings, Micro-catchment/*T. triandra*/seedlings, Water spreading system and Control. The measurements included tiller and leaf number, flowering and mortality rate from 6 permanent tufts at an interval of 4 weeks over a period of 16 weeks. Other plant species that geminated were also counted.

Five sites (100 x 100 m each) were selected at ATA (degraded) and at Phandulwazi Agricultural High School (non-degraded). At each site three line-transects (100 m) were randomly selected. Along each line transect, three surface soil samples were collected randomly. Soil seed bank samples were collected at the end of the growing season (September-October), after seed production.

Both tiller number and leaf number significantly increased with time after restoration treatment. The tillers arise as a bud in the leaf axil and, therefore, the potential rate of tillering depends on the rate of leaf development. The tiller number was higher on the plots where there was combination of micro-catchments and brush packs. The performance of grass seedlings on micro-catchments with brush pack could serve as an early indicator of vegetation restoration success in degraded rangelands.

The seedling mortality was lower on the micro-catchment and brush pack combination plots. The rate of flowering was higher on the plots covered with brush pack. Micro-catchments collect and store water and brush pack provides shade on the micro-catchment, which results in the reduced evaporation from soil and improved soil moisture in terms of both amount and duration of storage. The tiller number was not significantly different between grass species that were used as seedlings (*Paspalum dilatatum* and *Themeda triandra*). The mortality rate of *T. triandra* was higher than that of *P. dilatatum*. The flowering rate of *P. dilatatum* was higher than that of *T. triandra*.

In terms of RWH practices, the use of brush pack alone was higher than the control in soil moisture retention. The combination of brush pack, minimal soil disturbance with *Panicum maximum* seeds had the highest moisture retention. Minimal soil disturbance with both *P. maximum* and *Eragrostis curvula,* but without brush pack, was not effective for soil moisture storage. This implies that brush pack had a positive effect on soil water storage: a result of reduced evaporation rate from the soil due to the shading effect of brush pack. Soil water retention on plots with micro-catchment, brush pack, minimum soil disturbance and planted with *D. erientha* or *P. maximum* were also higher than the control.

The results suggest that a combination of micro-catchment with brush pack would benefit rangeland restoration through increased soil moisture content. Similarly it was observed in the cropland experiments that the use of micro-catchments and mulching increased soil moisture retention leading to improved yields (see chapter 5).

In conclusion, rangeland hydrology is an important aspect of the rangeland ecosystem. Therefore, when considering grazing practices, soil properties, climate, and other factors relevant to rangeland management, it is essential to have an understanding of the intrinsic water dynamics within rangelands. Research in these areas should be prioritised and be placed high on the agenda at management level and in policy formulation.

The use of micro-catchments and brush packs in rangeland restoration and rainwater harvesting has been observed to have an effect on water collection and conservation. The success of rangeland restoration depends on the identification of barriers to its natural recovery and the development of microsites, which can be used to identify and address these barriers. The barriers to natural recovery include drought, soil moisture, soil pH, soil temperature, light, soil seed bank and grazing. In the context of a crop-livestock system, as is the one found in this study area, *IRWH* techniques that can be used in both the rangeland and cropping are ideal as they reduce the learning curve for the user and enhance adoption levels: farmers are more likely to adopt a technology that they can use, with limited adjustments, for a different purpose. Micro-catchments with mulch or brush are the ideal technology for a system like the one found at Makhuzeni in the Eastern Cape of South Africa.

## 6.5 RECOMMENDATIONS

Livestock keeping and feeding are important components of agricultural water use in Sub-Saharan Africa and other parts of the world. This is because livestock convert water resources into high value goods and services. According to livestock water productivity (LWP), there are three general strategies directed to biophysical components of farming, *viz*. forage management, water management and animal husbandry. Livestock grazing affects the hydrological response of pastures and rangelands, and may result in soil and vegetation degradation.

The use of micro-catchment and brush packs in rangeland restoration and rainwater harvesting has a positive effect on water collection and conservation. The success of rangeland restoration depends on identification of barriers to natual recovery and development of microsites, which can be used to identify and address these barriers, The barriers to natural recovery or artificial restoration could include drought, soil moisture, soil pH, soil temperature, light, soil seed bank and grazing (disturbance). Introduction of seeds and seedlings could address the problem of a low soil seed bank. Exclusion of degraded sites to reduce grazing disturbance could assist in restoration of areas with high soil seed bank. Rainwater harvesting practices could provide and store water that is useful for vegetation restoration. Furthermore, the selection of grass species suitable for restoration and observation periods is essential.

While this study recommends rangeland restoration through various tested restoration and rainwater harvesting techniques, with a strong emphasis on the need to identify barriers to natural recovery, it is also recommended that a post-restoration management plan should be developed for rural communal rangelands. This will allow for the identification of major factors that influence degradation and will help in circumventing secondary degradation consequences. This will happen if the major causes are not identified and eliminated through management practices, prevention and control. It is, therefore, recommended that an adaptive management philosophy should be adopted. This entails the prior construction of a series of management related hypotheses, identification and implementation of relevant management activities, monitoring the outcome of such activities, and the evaluation of the results obtained against expectations.

Further avenues for research include:

- Intensive research on post-restoration management. Degradation may have been caused by factors not evident during restoration. These could still exist within the ecosystem, and, therefore, may still pose a threat.
- Research on rangeland water dynamics within the ecosystem, between species and within the plant. Rangeland water storage is influenced by landform, species composition, basal cover, water use efficiency of grass species available, and soil properties. More intensive research in these areas could contribute to the incorporation of rangeland hydrology into rangeland management practices.
- Long-term monitoring of restored rangelands. Restoration success may only be achieved over a long period of time and, therefore, it is important to monitor the trends of success. This will also help to determine if there is a need for follow-up restoration. Micro-catchments established across degraded sites need to be maintained, and new micro-catchments should be constructed annually in between the established ones to enhance rangeland recovery time.

# 7 INTRODUCTION, IMPLEMENTATION AND ADOPTION OF RAINWATER HARVESTING AND CONSERVATION TECHNIQUES

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## 7.1 INTRODUCTION

Many of the households in rural villages in South Africa rely mainly on governmental grants as their main source of income and are highly vulnerable to poverty and food insecurity. The Eastern Cape Province, which is regarded as the poorest province in the country, is no exception in this regard. Due to the fact that the *IRWH* technique has the potential to increase available soil water for successful crop production in semi-arid areas, the technique was introduced to village members in Guquka and Khayalethu in October 2004 in an attempt to assist them to become sustainable in the production of a variety of vegetable and cash crops in their homestead gardens.

## 7.2 MATERIAL AND METHODS

The *IRWH* technique was formally introduced to the communities of Guquka and Khayalethu in November 2004. Following the introduction, villagers were requested to make two homestead gardens in each village available for use as demonstration plots the implementation of the first *IRWH* plots began in mid-December 2004 in both villages. At the demonstration plots, village members were taught how to construct the basins and plant maize. They then duplicated the technique in their own homestead gardens. Only maize was planted at the demonstration plots, but later planting methods for a variety of vegetable crops were also demonstrated. Village members were provided with maize and vegetable seeds, fertilizers, herbicides and pesticides. The research team also provided support and assistance on all aspects related to crop production within the *IRWH* system. At an information day held in January 2005, roof and road water harvesting were introduced. Rainwater harvesting tanks funded by the Department of Agriculture were installed at seven homesteads in each village.

The research team had regular meetings with the farmers and extension officers in order to monitor their progress in the implementation of the *IRWH* technique and solve any problems which may have been encountered. Monitoring the progress of farmers entailed going to individual homestead gardens and carrying out general inspections.

On a number of occasions village members requested that the youth be involved in the *IRWH* project. Therefore, a decision was taken in 2007 to introduce the technique at six schools, where the technique was already being used in homestead gardens. The purpose of involving the schools in the *IRWH* project was to introduce scholars to the benefits of rainwater harvesting and the conservation of the natural resources, as well as encourage them to develop a love for agriculture, and its potential to address poverty and food insecurity, and improve their eating habits.

The extension officers in Alice were identified as important stakeholders in the successful execution of the project. They received theoretical and practical training in the implementation of the *IRWH* technique in the selected villages before they assisted village members.

## 7.3 TECHNOLOGY TRANSFER ACTIONS

### 7.3.1 Formal training

At the beginning of the second summer growing season (November 2005) extension officers and farmers received training on the utilization of natural resources, the role and function of *IRWH*, the application and maintenance of *IRWH*, planting of different crops, pest and weed control, communication skills and conflict resolution, the role and function of committees, marketing and value adding.

At the post-harvest festivals presentations were given on all aspects relating to crop production within the *IRWH* system. This helped the farmers to refresh their memories and prepare themselves for the upcoming growing seasons. Extension officers received rainwater harvesting manuals that could be used to advise farmers.

Needs analysis conducted during 2005 indicated that extension officers needed training on computer literacy, communication skills, data processing, project management, time management, organizational skills, conflict resolution, monitoring and evaluation, agronomic practices (fertilization, weed control, pest control, planting, irrigation, organic crop production, etc.), marketing and record keeping. Most of the extension officers had not received any training on these topics. Those who had received training on some of the topics had gained their knowledge at Agricultural Colleges more than 15 years previously. Their knowledge was thus out-dated. Training was provided on the topics listed above and, where necessary, experts in the various fields were requested to present the courses.

### 7.3.2 Informal training

The informal training of both extension officers and farmers was an on-going process. They were continually reminded of various aspects of the *IRWH* technique, e.g. planting of different vegetables, planting of maize, fertilizer application, weed control and the use of chemicals for pest control. Farmers who had already implemented the *IRWH* technique successfully mentored new farmers and technical assistants from the ARC-ISCW monitored the situation. The farmers were encouraged to work together so that they could learn from each other and whenever technical assistants or extension officers were available, farmers were provided with the necessary information and guidance.

Before the project was introduced to the communities, most of the farmers had not used herbicides and insecticides in their homestead gardens. The reasons were that they were either unaware of the extent to which weeds and insects can affect yields, or they could not afford to buy the necessary chemicals. Whenever any crop damage was observed, farmers were encouraged to apply chemicals to minimize crop losses.

Informal meetings took place monthly when technical assistants visited homestead gardens to monitor progress. Usually a general discussion was held during which the technical assistants reminded the farmers on how to construct the basins and measure correctly, as well as the importance of good weeding practices. The technical assistants would normally point out mistakes made by the farmer and provide them with the necessary guidance on how to rectify the problem.

Stakeholder meetings were held each month attended by the chairpersons of each village, ARC-ISCW representatives and extension officers from Alice. During these meetings the problems being experienced by the communities were highlighted and various degrees of advice and informal training were given.

### 7.3.3 Workshops

A number of workshops that addressed the continued expansion of the *IRWH* technique were held (20/04/2005; 17/06/2005; 09/03/2006; 29/03/2007; 27/03/2008; 24/11/2008). These workshops were attended by researchers from the ARC-ISCW and UFH, extension officers (from Alice, Bisho, Fort Beaufort, Keiskammahoek, and Middledrift), village members from Khayalethu and Guquka and other neighbouring villages where the *IRWH* technique had been implemented, and other relevant stakeholders (Department of Water Affairs and Forestry, Department of Education, Department of Social Development, Department of Health). These gatherings provided farmers with the opportunity to discuss ways of fighting poverty. In order to ensure the sustainable use of the *IRWH* technique the following topics received attention at these gatherings: increasing the numbers of the *IRWH* members, training on all aspects of *IRWH* for farmers and extension officers, support services, involvement of men and youth, expansion of *IRWH* to other villages, involvement of all relevant stakeholders, motivation and encouragement, markets and marketing, and institutional arrangements and structures.

At the workshops, presentations on relevant topics were made followed by group discussions. The farmers had to report back on what they had learned that day or the previous day on their field excursion to participating villages (where the workshop followed a pre-harvest festival). Workshops also provided an opportunity to reflect on what has been achieved and to discuss the way forward. Possible new stakeholders and funding opportunities were identified to ensure the continuation of the project and expansion to other areas. Village members were also given the opportunity to share their experiences with *IRWH* with the rest of the workshop participants. Village members received recognition certificates for their continued dedication and efforts to make use of the *IRWH* technique in their homestead gardens. Certificates of acknowledgement were also awarded to each extension officer to certify that they had participated in the implementation of *IRWH* in the rural villages in the Tyhume Valley area in the Eastern Cape Province.

At one of the workshops a **SWOT** analysis of the project was done. The findings were as follows:

- ***Strengths –*** motivated project participants; high rate of technology adoption; good support from extension services; active participation; generous funding; involvement of youth.
- ***Weaknesses –*** poor communication; insufficient extension visits; inadequate training; high level of dependency.
- ***Opportunities –*** transfer of technology; expansion; development of institutional arrangements; rediscovery of the potential of agriculture; improvement in livelihoods and food security.

- ***Threats –*** land tenure system; poor soils; small garden areas, inadequate access to water; stray animals; jealousy; old age participants; lack of tools; lack of access to financial capital; departure of key people.

### 7.3.4 Festivals

During the course of the project a number of pre- and post-harvest festivals were held. These days were attended by the participating village members, scholars and extension officers. Interested farmers from other surrounding villages were also invited to the festivals to expose them to the *IRWH* technique. At the festivals active *IRWH* farmers encouraged fellow village members to also implement the *IRWH* technique. At the pre-harvest festivals farmers also had the opportunity to display and sell their produce.

At the pre-harvest festivals (23/04/2005; 08/03/2006; 28/03/2007; 26/03/2008; 02/03/2009) outstanding homestead gardens in the participating villages were visited to learn and exchange knowledge. The aim of these visits was to show how the *IRWH* technique was being used in homestead gardens: what resources were being used; what problems had been encountered, as well as the benefits realized by project participants. These visits inspired and motivated village members to adopt the *IRWH* technique and expand it to larger areas. An on-farm demonstration plot that demonstrated the benefits of fertilizer application, weed control and insect control on crop growth and yield was also visited during the field days. This encouraged the farmers to apply these important management practices in their own homestead gardens.

The pre-harvest festival held in 2005 was even attended by some leading farmers from Thaba Nchu in the central Free State Province, where the *IRWH* crop production technique had been used with great success for the past 10 years. In March 2007 the festival was also attended by a few farmers from the North West Province who were using the *IRWH* technique to produce sunflower and cotton on a commercial scale. The attendance of these farmers provided an opportunity to share knowledge and experiences in the use of *IRWH*.

At the post-harvest festivals (23/11/2005; 07/12/2006; 22/11/2007) farmers, extension officers and researchers were brought together to exchange knowledge on the *IRWH* technique, to promote *IRWH*, and to provide each village with an opportunity to voice their opinion and share their experiences with their neighbouring villages. The main aim of these days was to uplift and encourage the farmers who had participated in the *IRWH* project during the year. Each farmer was presented with a certificate and trophies and prizes were presented to the villages that outperformed the rest in the implementation and practise of *IRWH*. The prizes included knapsack sprayers, watering cans, stationery, measuring tapes and ropes to be used during planting. Farmers and chairpersons of the rainwater harvesting committees in the participating villages were also given the opportunity to express their views as to how their livelihoods were enriched by employing the *IRWH* technique in their respective villages. It was reported that farmers gained financially by making use of the *IRWH* technique, but more important was the improvement in the nutritional status of village members who had access to a variety of crops produced in their homestead gardens. The principles of *IRWH*, maintenance of water harvesting structures, planting, weed and insect control, value adding and marketing were among the topics discussed at the post-harvest festivals in order to equip farmers with the necessary knowledge for the upcoming summer growing season. The attendance at the post-harvest festivals was lower than that at the pre-harvest festivals as preparations for the festive season and traditional ceremonies kept many village members very busy at that time of the year.

## 7.4 RESULTS: HOMESTEAD GARDENS

During the first year of implementation, communities and participants received all the necessary inputs (seeds and fertilizer) and tools (spades, rakes, knapsack sprayers) to establish the crops in their homestead gardens. Thereafter, free inputs were gradually reduced by 25% per year in order to encourage farmers to stand on their own feet. During the fourth growing season village members did not receive any free inputs and they had to buy their own seeds, fertilizers and chemicals to control weeds and insects. Lack of funds to buy inputs prevented some of the farmers from planting. However, mostly the elderly people have continued to utilize their homestead gardens to produce a variety of vegetable crops and maize, while the younger generation has fallen away. Good yields were recorded during the summer growing seasons, but during the winters only a few village members planted due to the cold and dry weather conditions. Only a few rainfall events were recorded during the winter months and the water collected in the storage tanks was used to give supplementary irrigation. After the farmers harvested their winter crops, they immediately started to maintain the basins for the next summer growing season. In most cases the farmers worked hard to keep the homestead gardens weed-free in order to ensure good yields. During the very wet seasons farmers were kept from weeding and maintaining their gardens in preparation for the next growing season. Most of the farmers were able to keep accurate records of the produce they harvested, household consumption and the amount of money they made from selling surplus produce. Examples of records kept by village members are presented in Appendix 12. After discussions with the head of the local market in Alice it was agreed that the *IRWH* farmers could sell their produce at the local market, paying 5% of their earnings to the market management. A food processing unit was built at the University of Fort Hare and *IRWH* members were invited to have their produce processed there for value adding.

Technical assistants from the ARC-ISCW held regular meetings with the farmers and extension officers to monitor their progress with the implementation of the *IRWH* technique and provide advice on problems that were encountered. Monitoring the progress of the farmers entailed visits to individual homestead gardens to do general inspections. Whenever the technical assistants noticed mistakes in the homestead gardens they corrected them and the farmer’s memory was refreshed with regard to the different aspects of the technique. Farmers were encouraged to control weeds and maintain their gardens regularly and to expand the *IRWH* technique to other homestead gardens. Farmers were also taught how to take records during harvesting. Technical assistants encouraged committee members to assist the older generation with record keeping.

The number of households that were practising *IRWH* at the end of 2008 is presented in Figure 7.1. During the first year the *IRWH* technique was demonstrated in two households in each village (total = 4). The difference between the *CON* and *IRWH* techniques was clearly visible right from the beginning of these demonstrations. These homestead owners were so encouraged by the results that they had already expanded these demonstrations by the end of the first season. They also planted vegetables with the assistance of the technical assistants. Other village members were also encouraged by the remarkable improvement in crop yield and started to implement the *IRWH* technique in their homestead gardens with assistance from other village members, technical assistants and extension officers. During the second summer growing season the use of the *IRWH* technique had already expanded to 16 homestead gardens in Khayalethu and 20 in Guquka (total = 36). During the third season the numbers increased to 24 and 34 (total = 58) in Khayalethu and Guquka, respectively. Thereafter the adoption rate was higher in Guquka than in Khayalethu. During the 2007/08 summer growing season the *IRWH* technique was in use 23 homestead gardens in Khayalethu and 40 in Guquka (total = 63). Very encouraging was the fact that the number of homestead gardens did not decrease even when people passed away or were relocated to other places.

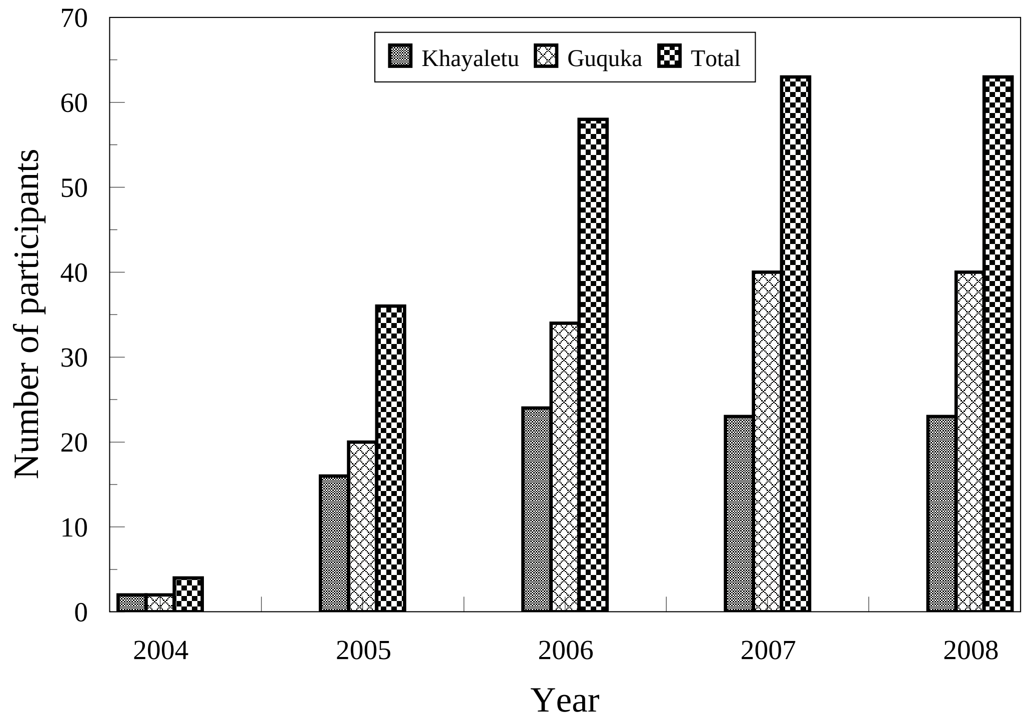


**Figure 7.1** Number of homestead gardens in Guquka and Khayalethu where *IRWH* is used.

The expansion and adoption rate of the *IRWH* technique was high and compared very well with its successful adoption in the Thaba-Nchu - Botshabelo area in the Free State Province (Botha, 2006 & Botha *et al.*, 2007)). According to these authors more than 1000 households implemented the *IRWH* technique in 42 villages, with an average of 23 households per village.

The expansion in the number of households practising *IRWH* in five villages in the Nkonkobe Municipality between 2004 and 2008 is presented in Figure 7.2. These villages included Khayalethu and Guquka and the three neighbouring villages, Gilton, Mpundo and Sompondo. The implementation of *IRWH* in these three neighbouring villages was initially funded by the Department of Agriculture (2004/05) and the Eastern Cape Department of Agriculture (2005/06). The ARC-ISCW funded the support during the period 2006-2008. During the first growing season (2004/05) 10 homestead owners were using the *IRWH* technique. In 2004/05 this number had increased to 71. By 2006/07 the number had increased further to 123 homesteads: between 20 and 34 families per village. During 2007/08 the number increased to 140. By the 2008/09 season numbers had increased further to more than 154 households: between 23 and 40 families per village, and on average 30 households per village.

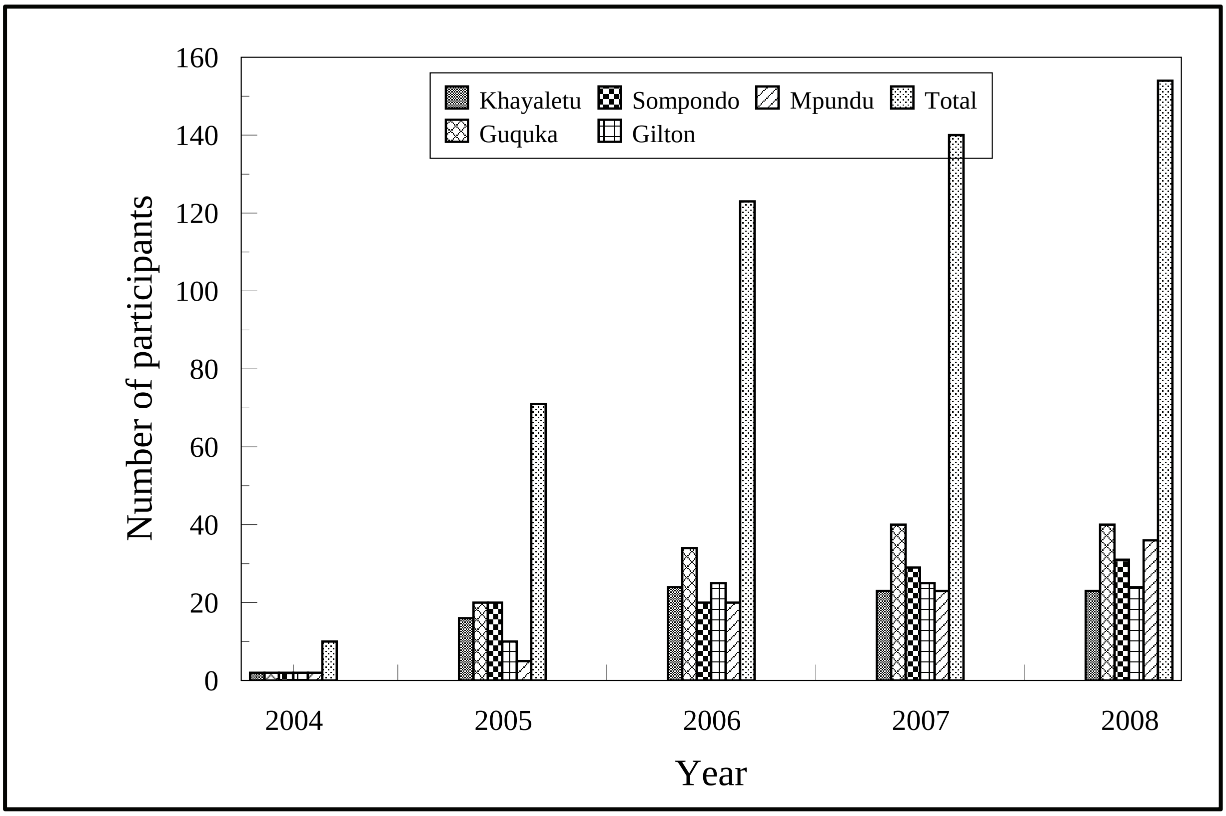


**Figure 7.2** Number of homestead gardens in five targeted villages where *IRWH* is used.

The adoption rate could have been higher if it were not for various external factors. Conflict amongst village members made it difficult to work together as a group and many decided to work on their own, using their old conventional ways of producing crops in their homestead gardens. The conflict arose from committee members keeping seeds and tools for themselves and not sharing them with the rest of the *IRWH* members. Some of the committee members did not lead by example and did not use *IRWH* in the own homestead gardens. They also did not want to give up their positions on the committees so they could be replaced with new active members. There was also an underlying fear that if they all produced good yields they would not have been able to sell their crops to their neighbours. Therefore committee members tended to keep the *IRWH* knowledge to themselves. However, members from other villages showed a lot of interest and indicated that they also wanted to use the *IRWH* crop production technique. Although more village members have joined the *IRWH* initiative the total number of households making use of this technique has not increased significantly since 2007. The reason for this is that some of the active members have passed away or obtained employed elsewhere. Some committee members have passed away and have not been replaced as there were no suitable candidates (lack of leadership). Both villages, especially Khayalethu, battled with youth involvement. There is also a large age gap in the villages between the elderly farmers and the very young. The middle generation has left the villages to look for brighter opportunities in the city. The older generation has been left to farm and the young children are often not interested in helping the elderly to maintain the homestead gardens. By the time that the research team withdrew from the project there were on average about 30 households per village practising *IRWH* in their homestead gardens.

The use of rainwater harvesting practices in Khayalethu and Guquka has contributed to food security, food diversity and income generation. Village members have benefited in various ways by making use of the *IRWH* technique. For example, a village member from

Khayalethu, Ms. Maud Petini, was found to be growing 14 different kinds of vegetables in her homestead garden. The produce she harvested was enough to feed her family and the surplus she donated to the church and school feeding schemes. By combining roof water harvesting and *IRWH* she was able to farm during both summer and winter. The rainwater collected in the tanks was used as supplementary irrigation during the hot summer days and dry spells during winter. Another example of a village member from Khayalethu, who did very well with *IRWH* was the chairperson of the *IRWH* committee, Mr. Sonjani. He was more than 80 years old but still managed to maintain and plant a variety of vegetables on a large portion of his homestead garden. He sold most of the vegetables he produced in his garden to other village members to supplement the income from his old age pension. Every week he put a notice on the gate to his premises indicating which vegetables were available and their prices. A lady from Guquka did value-adding by packaging her produce before she sold it. She produced vegetables, mainly potatoes, on an area of almost two hectares. Many village members also preserved vegetables so that they had something to eat during the winter period. People from surrounding villages, who witnessed the successful use of the *IRWH* technique in Khayalethu and Guquka, have also started to implement the technique in their homestead gardens. A lady from Mpundu, Ms. Mbotho, did so well with her garden that she received the female farmer of the year award in the Nkonkobe district. She sold her produce in a neighbouring village, Makhuzeni, on grant payment days. She managed to get a very good income and decided to apply the *IRWH* technique to every square metre in her homestead garden.

Some of the problems that the farmers encountered were water tank foundations that were beginning to crack, improperly installed water tanks and poorly constructed basins. The other problem was that cows and goats damaged the crops due to poorly fenced homestead gardens. Funds from the Comprehensive Agricultural Support Programme (CASP) were made available to buy fencing material for those homestead gardens that were not well fenced. In very wet seasons the good rains prevented the village members from controlling weeds properly. Lack of money to pay for inputs prevented some of the farmers from planting on a larger area. Other animals such as moles also damaged produce in the homestead gardens, especially carrots, and farmers were advised by the ARC-ISCW technical assistants to use chemicals to control the problem. During the 2008/09 summer growing season hail destroyed most of the crops and many farmers were still not financially strong enough to afford to replant.

In Guquka a number of farmers decided to work together as a group to make the tasks a little easier. They established a village garden where they worked together to plant beetroot and cabbage. Good progress was made until goats, which got in under the fence, destroyed it.

Theft was seen as one of the biggest problems that crippled the success of the project. Poles and fencing material were stolen from the village garden at Guquka and some of the homestead gardens in Khayalethu and Guquka. This made it easy for the animals to enter the gardens and destroy the crops. Some of the village members lost all hope when their crops were stolen after they had worked hard for many hours in their homestead gardens.

In most cases the homestead gardens were well taken care of due to the dedication of the committee members. However, farmers did make some mistakes. They battled with the measurements of the 2-m runoff strip and the 1-m basin area as well as the correct inter-row spacing. In some of the homestead gardens continuous rainfall prevented farmers from doing proper weed control and this resulted in low yields. Due to a lack of knowledge farmers planted some of the small seeded crops, like beetroot and carrots, too deeply and they did not germinate properly.

In each village a committee consisting of seven members was selected to support the rest of the village with the implementation of the *IRWH* technique. The Khayalethu committee performed very well and developed a good teamwork spirit. The committee members were all committed and responsible because their chairperson was a dedicated, experienced person. They held meetings regularly and worked well together. The committees checked on members on a regular basis and if a member was no longer active, it was the responsibility of the committee to visit the member and to try to address the problem. Most of the time the committees functioned well, but misunderstandings between the members sometimes resulted in conflict. Problems were resolved amongst the farmers themselves, but at Guquka it was necessary to elect a new committee to ensure that progress was made with the *IRWH* project. However, the new and old committee members did not see eye to eye and this made it difficult for members to work together in the homestead and village gardens and to attend meetings. The problem was addressed at a pre-harvest festival held in March 2008 and after that meetings were held on a monthly basis with the relevant stakeholders. These meetings were usually attended by the chairpersons of the water harvesting committees from each village, ARC-ISCW researchers and technical assistants and extension officers from the Department of Agriculture in Alice.

Members of the rainwater harvesting group paid monthly subscription fees that were used to buy seeds and chemicals. An umbrella body, consisting of the chairpersons of the rainwater harvesting committees in the respective villages, was established. The aim of the umbrella body was to oversee the smooth running and expansion of the *IRWH* technique in the respective villages. Initially the umbrella body came together on a regular basis to discuss and solve common problems, but after the chairperson of the committee in Khayalethu left due to old age, members representing Khayalethu did not attending these meetings. The umbrella body planned to register as a farmer’s organization in order to buy inputs in bulk collectively.

In the 2006/07 financial year water tanks were provided to some farmers in Khayalethu and Guquka. An ARC-ISCW technical assistant paid monthly visits to both villages to monitor the water usage from these tanks. Farmers who received tanks used the water collected from rooftops for household consumption (drinking, cooking, washing, etc.), drinking water for animals and as supplementary irrigation. The farmers had to give the technical assistant a detailed description of their water usage: the percentage used for household consumption and for supplemental irrigation.

The extension officers actively participated in the project and regularly attended meetings held by the farmers. Although the extension officers were very committed to the project, they did not always have enough time to focus all their attention on the rainwater harvesting project due to a heavy workload and other commitments. The extension officers have gained a lot of information through the formal and informal training. They were trained on the construction of the basins, planting of maize and vegetables, pest control and communication skills. The skills that they have acquired were used in the training of the farmers.

Village members from Khayalethu stated that the rainwater harvesting project had shown them the importance of fertilizer application, water conservation and record keeping. They also indicated that their livelihoods had improved as they are now able to eat fresh vegetables, sell some of their produce and make some money. The chairperson of the water harvesting group in Guquka, on behalf of her village, stated that *IRWH* had taught them how to conserve both soil and water. It also taught them to use water as efficiently as possible, especially in low rainfall areas. Some of the points that were highlighted were the shift from a monoculture system to a crop rotation system, the use of pesticides, weed control and record keeping of rainfall, crop yield and income. According to the village, the impact of the project was much appreciated, especially since seeds, fertilizer, chemicals, tanks and fencing material were provided free of charge.

Above all the main objective of the project was to alleviate poverty, and so far it has done a very good job in that regard.

## 7.5 RESULTS: SCHOOL GARDENS

Monthly contact sessions were held at the different schools together with the teachers and scholars. Each school was visited at least one every two months. These visits were firstly aimed at teaching the principles of *IRWH* to the teachers and scholars and secondly to create an awareness of the fragile natural resources surrounding their schools. The visits also aimed at addressing problems experienced in the application of *IRWH* in the school gardens as well as for motivational purposes. As encouragement scholars and teachers were invited to attend farmer's days and workshops.

Training material and three dimensional models were used to explain the concept of *IRWH*. The principles and role of *IRWH* were discussed as well as the methods of planting various crops within the *IRWH* system. The importance of weed and insect control was discussed on a regular basis. The teachers and scholars were also shown how to apply chemicals to control weeds and insects. Tools, such as watering cans, spades, hoes and hand spades, as well as seeds were provided.

Maize and vegetables were grown in the school gardens. A problem experienced at most of the schools was weeding. Some of the maize and vegetables were sold and the rest was consumed by the school children. The money earned from the produce was used to buy seeds, fertilizer and chemicals for pest and insect control, text books and to support the school programmes. Most of the schools managed to maintain their gardens with sufficient scholar participation. Unfortunately, due to a lack of fencing a lot of produce was lost due to stray animals feeding on the crops and this lowered the moral of the learners. None of the schools had sufficient funds to provide their own fencing.

Roof water harvesting systems were installed at the schools and rain gauges were provided. Scholars were taught how to measure the amount of rain correctly and to use the rainwater collected in the tanks as supplementary irrigation for the crops grown in the school garden, especially during the winter season and in dry periods during the summer.

## 7.6 SUMMARY

The *IRWH* technique was used by village members of two villages in the Eastern Cape, Guquka and Khayalethu, to greatly improve their household food security situation. The nutritional status in households also improved because of the availability of a variety of vegetables grown in the homestead gardens. The project also helped to reduce poverty. The majority of households (95%) were able to harvest enough maize for household food consumption and had sufficient surplus to feed animals, sell or give away to family and friends. Those who actually sold excess produce earned between R200 and R1500 per month. Previously, using the conventional or “old” way of cultivation, food had always been in short supply. Since the introduction of the *IRWH* technique village members have bought less food from the shops. The project has also enhanced the status of women in the villages. The majority of the people who participated in the project were women (60%) and their sudden ability to be self-sufficient, generating income and showing enthusiastic participation/leadership in the application of the technique, contributed to their better status in the villages.

Household members were all in agreement that their knowledge and skills levels had vastly improved since the first year of the project intervention. They were exposed to a new technique for the effective use of runoff rainwater and involved in its implementation and utilization. The introduction of the *IRWH* technique created more jobs at homesteads. Different cultivation practices were learned and more family members got involved in the production process. The project also brought about a general revival of committee structures and their activities, especially to coordinate joint actions. The project also brought about a more positive attitude amongst village members.

Tanks for roof water harvesting were installed at seven households in each village. Water collected in the tanks was used for household consumption and to provide supplementary irrigation for growing vegetables. This enabled village members to have access to a nutritionally balanced diet throughout the year.

Various aspects of rainwater harvesting and the *IRWH* technique were communicated to farmers and extension officers at a number of focus group discussions, information days and workshops. Both extension officers and farmers were assisted through formal and informal training. To ensure that they are well informed, focus group discussions were held at regular intervals. The knowledge and skills levels of the farmers and extension officers also showed a vast improvement after the project was launched in October 2004. The majority of participants in the project confirmed their intention to allocate more land, where available, for cultivation using the *IRWH* technique. Many of the village members have expanded the *IRWH* technique to more homestead gardens without much assistance from the project team and they have accepted full ownership of the project. They now have the skills and knowledge to implement and manage the *IRWH* crop production system and will be able to reduce food insecurity in their villages if they continue to use it. The *IRWH* committees in each village are functioning well and are able to support other village members, who want to implement the *IRWH* crop production system. Most of the village members are able to work independently and they buy most of their inputs themselves.

Village members who successfully applied and made use of the *IRWH* technique were awarded with certificates. Each year the village that made the best progress with the implementation of the *IRWH* technique, received prizes and a trophy to encourage them to keep up the good work. Extension officers were also rewarded for the support they provided to the village members.

The youth was also exposed to the *IRWH* technique and the technique was implemented at six schools in the Tyhume valley. Water tanks and gutter systems were installed and scholars and teachers were taught the principles of rainwater harvesting, how to take measurements from the water tanks as well as from the rain gauges. The scholars were also taught the importance of taking these measurements and were encouraged to do so. Festivals were held and scholars were invited to participate in the activities and to learn more about *IRWH*. A competition was held between the schools and the school that performed the best was awarded a prize. All the schools delivered outstanding performances in *IRWH* and they all stressed the importance of it in their communities through constant praise and letters to the research team. There was always an eager scholar attendance at the monthly contact sessions held at schools. The scholars responded well and took a great interest in the training material and three dimensional models. The main problem that occurred within the school setup was lack of maintenance, although this was improved with visits from the ARC technical assistants who constantly motivated the scholars and explained the importance of maintenance and especially weeding. The lack of fencing around the *IRWH* plots was a problem and stray animals destroyed a large percentage of harvests at a number of schools.

Farmers are willing to implement *IRWH* and roof water harvesting, but still lack sufficient technical skills and support to apply the technique effectively. Some farmers have abandoned the technique as it is too labour intensive to construct the rainwater harvesting structures and there is a lack of markets to sell their produce. However, those who have continued to use the *IRWH* technique have managed to produce enough for household food security.

## 7.7 CONCLUSIONS AND RECOMMENDATIONS

- Many rural households still depend heavily on hand-outs and government grants in the form of old age pensions and child support allowances. If these farmers could be made aware of the advantages of producing their own food, it would decrease the pressure on the government to support them financially and more money would be available for other essential services such as health and education. It is, therefore, recommended that more farmers be encouraged to implement the *IRWH* crop production system in order to improve the survival rate of their crops in an area where rainfall is the most limiting factor for crop production. Farmers should also be encouraged to plant a variety of crops in order to have access to a more nutritional diet and to ensure household food security.

- Farmers should be informed about the benefits of combining various rainwater harvesting techniques, such as *IRWH* and roof water harvesting, in order to have more water available for household consumption and food production. Although many households in Khayalethu and Guquka are already making use of roof water harvesting to give their crops some supplementary irrigation in periods of drought and during the winter, the potential of this technique has not yet been realized by all the village members.

- Many homestead gardeners in the selected villages who are using the *IRWH* technique are already making full use of their homestead gardens for food production. However, if village members want to completely eradicate poverty in their villages, they will have to expand to the croplands. A new project, also funded by the WRC, which focuses on rainwater harvesting and conservation (RWH&C) for rangeland and cropland productivity in communal areas in the semi-arid area of South Africa, has already been launched in a nearby village, Krwakrwa. Preliminary results from this project have indicated that it is possible to produce maize successfully on a large scale on clayey soils in a semi-arid environment by making use of RWH&C practices. The various RWH&C tillage implements (furrow and basin plough; combined chisel and basin plough; "Hap ploeg") have the potential to increase available water for crop production and, therefore, increase crop yields. Khayalethu does not have access to croplands, but in Guquka most of the croplands are not utilized at all. Those who are using the croplands are still making use of conventional tillage methods. However, a lot of runoff occurs from the conventional tilled plots on steep slopes, resulting in low or no yields. It is, therefore, recommended that the *IRWH* technique be implemented on the croplands in order to minimize these water losses, secure a more even distribution of water over the land and increase crop production. Although some village members have indicated that they would like to expand their production to the croplands, it has not been possible due to a lack of fencing and implements. Government departments, such as the Department of Agriculture, should take up their responsibility to provide the necessary infrastructure and inputs to cultivate the croplands. CASP funds can be used to put up fences and funds for inputs, such as seeds and fertilizer, can be provided through the Food Security Programme of the Provincial Department of Agriculture.

- The poor visibility of extension services in the selected communities should be improved so that village members can be provided with technical advice and support on all aspects of crop production. It is further advised that the extension officers be well educated in all aspects of agriculture, or that more specialized extension personnel be employed so that each extension officer can focus on their own area of expertise.

- Proper markets should be established for farmers to sell their produce.

- Youth involvement in agriculture should receive high priority. Schools that showed interest in the use of the *IRWH* technique should be supported with the necessary technical advice, inputs and fencing material.

- In order to eradicate poverty in the Eastern Cape, *IRWH* should be expanded to other districts in the province. Therefore, the villages of Khayalethu and Guquka could be used as a starting point towards poverty eradication in the Eastern Cape Province.

# 8 DEVELOPMENT OF INSTITUTIONAL ARRANGEMENTS

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## 8.1 INTRODUCTION

In South Africa, the *IRWH* technique has been applied successfully in the backyard gardens of several rural communities. Recently, there has been an attempt to up-scale the technique to communal croplands (Manona & Baiphethi, 2008). The technique is currently used in the backyard gardens of more than 1000 households in 42 villages in Thaba Nchu area of the Free State Province. Botha *et al.* (2003b) concluded that this technique has the potential to improve maize yields by up to 50%. As part of this research project this form of water harvesting technique was introduced in 2004 in backyard gardens in two villages of the Nkonkobe Municipality in the Eastern Cape Province, the study area for this research project. The project started off with two households (one in each village), which were used for demonstrations in April 2004. By the end of 2004, 22 households had adopted the technology in their gardens, a number which had increased to 38 by June 2006 (Monde *et al.*, 2006). The main aim of introducing *IRWH* technology in these villages was to reduce the challenges of poverty and food insecurity in these areas.

Botha *et al.* (2007) stated that *IRWH* technique cannot be practically applied unless it is preceded by additional institutional innovations, with more emphasis on the institutions governing rural development and technology application. These institutions have traditionally been ignored by national government and international development agencies as they perceived to be unable to play a leading role in reducing poverty. However, this perception was proved incorrect by high-performing local institutions in Burkina Faso that were extremely competent in reducing poverty and inequality (Agrawal *et al.*, 2008).

Botha *et al.* (2007) also indicated that for the successful adoption and implementation of *IRWH* technologies, institutions and organizations need to be in place. These institutions may not give attention to natural resources and water management institutions only, and so greater emphasis needs to be given to local institutions. Some of these may not be functioning up to the required standard for the sustainability of agricultural development, more specifically in the rural context. These local institutions may include land access and land management, market access and flow of marketing information, risks of possibility of failure (insurance), agricultural extension services and training for capacity building, credit facilities for resource users, associations, cooperatives and extensive participation and networking with other decision makers and institutions (Botha *et al.*, 2007).

Agrawal *et al.* (2008) emphasized that local institutions can shape livelihood impacts through a range of indispensable functions, which they perform in a rural context. These include information gathering and dissemination, resource mobilization and allocation of resources. Chikozho (2005) stated that a large number of smallholder farmers in South Africa do not even have access to information regarding new innovations. Land and markets are affected by several institutional constraints influencing the adoption of technology in rural areas of South Africa.

The main objectives of the institutional study were to:

- Investigate current institutions that influence the application of *IRWH*.
- Explore options to strengthen these institutions.

## 8.2 DEFINING INSTITUTIONS

In the context of this project institutions and organization are regarded as being different. Powelson (2003) explains the difference between the two by stating that an organization is a well-defined structure with its own limitations, while institutions are rules of the game. Organizations are seen as consisting of a group of people with one or more shared goals, while institutions are the procedures and norms of society. Institutions consist of both the formal and informal rules governing peoples' behaviour and this distinguishes them from organizations, which, along with individuals, are considered as players in the game. Institutions set targets for organizations and define the rules within which organizations should operate (Holden & Bazeley, 1999). Institutions include rules that structure human integration. Formal or informal institutions include among others, customs, laws, constitutions, norms and behaviour.

Commons (1931) further defined an institution as a collective action in control, liberation and extension of individual action. North (1990) defined institutions as the formal and informal rules of the game that have been formulated to rule people's behaviour and transactions. Uphoff (1986) added that institutions are complexes of norms and behaviour that persist over time by serving some socially valued purpose. It is through these formal and informal institutions that knowledge is then revealed and employed to assist coordination of economic activity and together with technology, determine the cost of production and exchange (Lal, 1999).

Kherallah & Kirsten (2001) emphasized that institutions are of extreme importance as they affect individual and society behaviour. They further stated that since institutions influence one's behaviour, they therefore influence performance of the economy, efficiency, economic growth and development. North (1990) added that institutions are the essential determinants of economic performance and they shape the organization of market transactions.

## 8.3 INSTITUTIONAL FRAMEWORK

Williamson (1998) identifies the forms of institutions based on four levels of social analysis. The first level consists of informal rules, which can be linked to the definition of North (1990). The second level can be seen as the Institutional Environment (IE) and the institutions at this level define the formal rules of the game. The third level defines the playing of the game and lastly institutions at the fourth level synchronize internal allocation or transactions within a firm.

### 8.3.1 Informal rules: Level 1 – Cognitive institutions

Level 1 is referred to as the social embededness level where customs, traditions, norms, value systems, sociological trends and religion are positioned. Institutions at this level change very slowly because of the spontaneous origin of the practices in which deliberative choice of a calculative kind is minimally implicated. Since these informal rules change slowly, economists see them as exogenous factors as they may retain agreements or habits for a long time, even if they have become less suitable.

### 8.3.2 Formal rules: Level 2 – Regulative

The formal rules involve the institutional environment (IE), whereby constitutions, laws, property rights, polity, judiciary and bureaucracy are discussed. The main challenge of formal rules is to get the rules of the game right and the definition and enforcement of property rights and contract laws are the critical features. Also of extreme important is the understanding of how things work.

### 8.3.3 Governance: Level 3 – Normative

It is one thing to get the rules of the game right, but quite another to get the play of the game (contract enforcement / property rights) right. At this level, Williamson (1998) mentions that institutions define the organizational structure of market transactions while the rules defined at level 1 and level 2 are considered. At this level, the rules agreed upon by actors in transaction, which are either formal or informal contracts, are discussed.

### 8.3.4 Resource allocation and employment: Level 4

Williamson (1998) stated that the institutions at the fourth level refer to the internal allocation of resources within a firm. They involve getting incentives right and change continuously, in response to changing markets and conditions of the economy.

The first two levels of institutions are vital as societies are generally governed by them and these levels do not only facilitate the growth of the economy, they can also delay it.

## 8.4 LOCAL INSTITUTIONS

Although local institutions have been undermined by higher institutions in the role they play in the development of agriculture in rural areas, Agrawal *et al.* (2008) emphasized that these institutions can shape livelihood impacts through a variety of essential functions, which they perform in rural context. These include information gathering and dissemination, resource mobilization and allocation of resources. In Burkina Faso, high performing local institutions were identified for their ability to fight against poverty and reduce inequality (Donnelly-Roark *et al.*, 2001).

Uphoff (undated) stated that appropriate technologies, supportive policies, ethics and changes in individual behaviour are all important in developing agriculture. Local institutions and their related local participation are also contributing factors, which require further attention (Uphoff, undated). These organizations can be identified as local government, user associations or service organizations, and government support services. Chikozho (2005) mentioned that throughout the history of agricultural development, local institutions have not been recognized. This is due to the fact that outside institutions tend to weaken and overpower local organizations. Chikozho (2005) further mentioned that without attention to local institutional arrangements, the successful adoption and spread of agricultural technologies remains doubtful.

Cases have been identified where the active participation of local institutions has resulted in the adoption of water conserving technologies in semi-arid areas resulting in increased yields, although they have remained localized success stories. If these success stories could be spread, this could lead to a significant improvement in agricultural production and technology adoption in other parts of the country and the rest of the world. Feder *et al.* (1985) (as cited by Zeller *et al.,* 1997) identified factors that have frequently influenced the adoption of agricultural technologies in Sub-Saharan Africa. These include farm size, risk exposure to the possibility of failure, human capital, and availability of capital, minimal access to credit, land tenure system, and minimal access to commodity markets. Local institutions may include those that deal with land access and land management, market access and flow of marketing information, agricultural extension services and training for capacity building, associations, and cooperatives.

## 8.5 METHODOLOGY

### 8.5.1 Methods used to collect data

The study employed mostly participatory techniques as tools for data collection. The investigation was carried out in two phases. Phase one involved the collection of data from project members. A semi-structured interview schedule was used to collect both qualitative and quantitative data on the demography of project members, institutional factors, and existing institutions pertaining to access and management of both arable and rangelands. In other words, the formal and informal rules and regulations put in place in order to access and manage resources, institutions and institutional arrangements. This made it possible to identify which institutions were in place, those that were missing, and those which needed strengthening.

The data collected during phase one was obtained by interviewing the water harvesting project members from Guquka and Khayalethu villages, who were selected for the introduction of the *IRWH* technology in 2004. The aim was to interview all project members in both villages. However, only 56 members (30 in Guquka and 26 in Khayalethu) were interviewed. The others (12 members) were not available at the time of the investigation. Data collection began in September 2009.

Phase two involved convening meetings with both project members and non-project members. The purpose of these meetings was to discuss the preliminary results of the initial investigation, and then to explore options for institutional arrangements with community members. All local structures were represented at these meetings, including the Residents Association (RA), Tribal Authority (TA), Water Harvesting Association (WHA), community members, who were not members of the water harvesting project, and land owners. Some members of the Sompondo community (a neighbouring village) also attended one of these meetings. They were invited to attend the meeting as they had a development plan that involved five villages in the Amakhuze Tribal Authority, including Guquka. Their plan involved starting a crop and vegetable project, which would utilize some fields closer to the Tyhume River. Some of the fields which had been identified for this project belonged to people in Guquka. In addition some project members had expressed the desire to up-scale the water harvesting project to arable land, the complication being that the land belonged to community members, who were not necessarily project members. So discussing these ideas as well as exploring institutional arrangements with project members, community members and land owners became vital.

## 8.6 INSTITUTIONS AND INSTITUTIONAL FACTORS IN THE STUDY AREA

According to Mjelde *et al.* (1990), institutional factors refer to policies of a local entity, region, state or federal government. The institutional arrangements for developing and managing any organization are the transmission gears between policy objectives and field activity (Guggenheim, 1992). Institutional arrangements are really an interrelated set of regulations and rules to enable coordinating activities to achieve social goals. Radosevich (1987) states that a good institutional arrangement recognizes that, to have a plan, there must be a policy and to have a policy, there must be a reason. In addition, he states that in many organizations, policies and laws either do not exist or are inadequate. The law should be an essential ingredient of effective management.

The institutional framework used in this study identifies three sets of institutions, namely, regulative (formal rules and regulations); cognitive, which are informal rules influenced mainly by customs, tradition and norms; as well as normative or governance (e.g. associations, organizational structures, co-operatives, etc.). The Institutional framework is established by legislation and provides the operative norm. Legislation is, however, often incomplete and formal institutions established by law are often supplemented by informal institutions that can either complement the function of the institution or compete with them (Guggenheim, 1992).

This section of the report is analysed against this institutional background. It begins by identifying the institutional factors and the types of institutions that existed in the study area, as revealed by survey respondents, and ends by suggesting institutional options that could be used to develop and strengthen these institutions (institutional arrangements). This was done together with project beneficiaries for the smooth application of the *IRWH* technology introduced.

### 8.6.1 Arable land ownership and tenure in the study area

The *IRWH* project members at Khayalethu had no access to arable land (there is no arable land in this community), while only a few project members had fields in Guquka. Land at Guquka is held by means of ‘Permission to Occupy’ (PTO). PTO is a form of communal land tenure that most people in rural areas have access to. The owners of land do not hold the title deeds nor do they have secured rights to the land they own. In 2009 Guquka had 132 residential sites and 41 individual fields, as was the case in 1997 (Monde *et al*, 2005). This meant that about 100 households did not own fields in this village.

Only eight of the project members in Guquka owned arable land during September 2009. Of these only one was is still cultivating her field. In fact, it is believed that the main reason she is still cropping the field is because she made it available for the demonstration of the *IRWH* technology. The sizes of arable holdings in Guquka are presented in Figure 8.1. Those who had access to more than 3 ha owned more than one field. The majority (87%) of them inherited the land from their forefathers while 13% indicated that the land they own was given to them by the Chief.

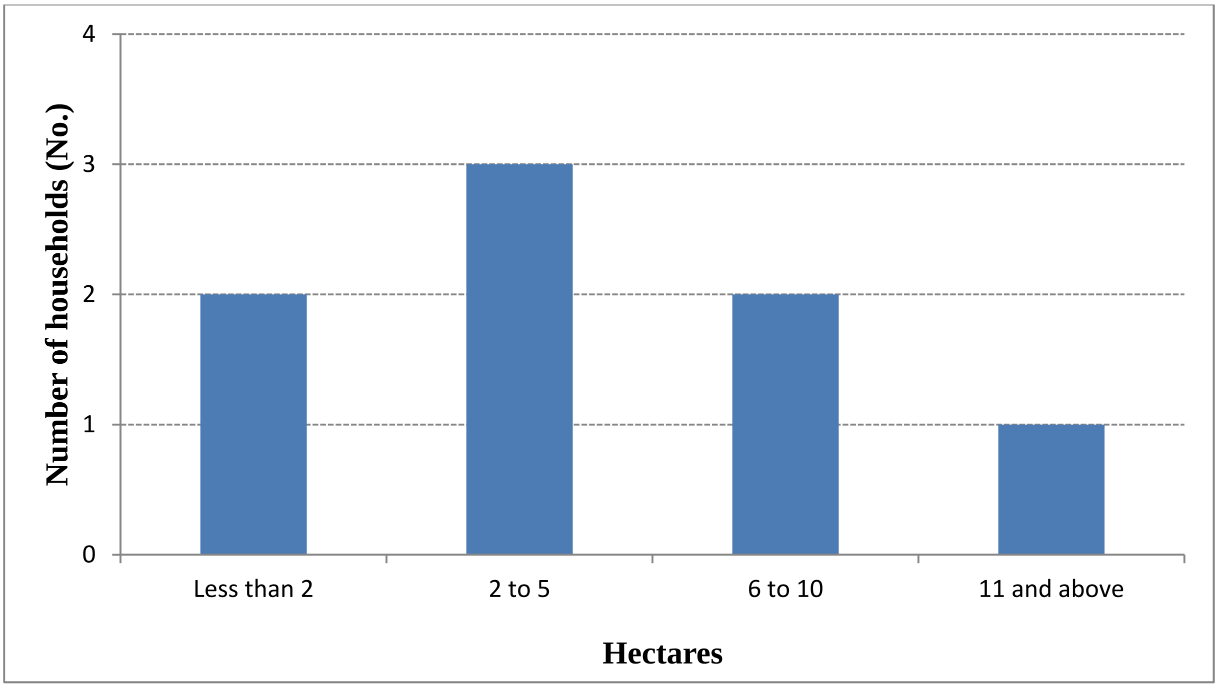


**Figure 8.1** Size of arable land as owned by project members in Guquka.

In most rural areas of South Africa, arable lands have been used to support rangelands during dry season when the land is left fallow. The people of Guquka have also adopted this practice. In Guquka, 82% of survey respondents indicated that the community uses arable lands together with their home gardens for grazing purposes. In Khayalethu where there is no arable land, 58% stated that their livestock use arable land in other villages as they do not own any of their own. None of their livestock had been preventing from entering the fields of other land owners. Villagers seemed to have a common understanding about these informal institutions and it is considered normal and common practice. Grazing of arable lands and gardens in both communities was mostly practised after the cropping season to allow livestock to remove stocks that had been left on the fields and in gardens after the harvesting season. This is done in order to make feed available for livestock during the winter season, which is usually characterized by a lack of forage in terms of quantity and quality.

#### 8.6.1.1 Institutions governing the use of arable land

About 80% of project members in Guquka were not aware of any formal rules for the use of arable lands. They indicated that they do whatever they want in the lands without consulting any member of the community, be it the chairperson or the Chief. When asked how people who did not own fields obtained access to land in Guquka, the survey respondents stated that the landless usually accessed land through share-cropping. Share-croppers usually receive little or no incentives. According to them, this is a long standing practice learnt from their fathers (cognitive institution). However, during the past 10 years or so, these arrangements have not been practised for following reasons: absence of institutions protecting both the land owner and the share-cropper, and lack of interest in crop production.

When asked about sources of conflict that usually arise with the share-cropping arrangement, about 76% of the survey respondents pointed out the unreasonable expectations of the land owners. In terms of the local arrangement land owners demand that share-croppers carry all production costs and hand over half of the yield to the land owner in payment for the use of his/her land. The share-cropping arrangement caused resentment on the part of past and potentially new share-croppers. The landless considered it unreasonable and would not enter or re-enter share-cropping unless the terms were substantially revised.

In terms of normative institutions, the local structure in both villages was a Residents Association (RA). The RA makes decisions on village matters in general. However, the responsibilities of the association did not seem to include ensuring access to arable land by those who did not own this resource. As already mentioned, that decision was made at household level without the involvement of any local structure. The RA is led by a five-member 'Residents Committee', which is elected annually.

The minimal rights with regard to land ownership may result in farmers being reluctant to invest in *IRWH* technology. Machete (2004) stated that access to land for production purposes is important if the poor are to enjoy the benefits of agricultural growth. In the study area, this is clearly not the case.

#### 8.6.1.2 Organizational structures and institutional arrangements pertaining to arable land

The first institutional arrangements were put in place in 2005 when the project team (UFH and ARC researchers) encouraged the participating villages to form a Water Harvesting Association (WHA). Both villages did so. The Guquka WHA was named *'Kuyasa'* (we can see the light), while the Khayalethu WHA was named *'Sibone Sakholwa'* (we saw and believed). Each association has a committee consisting of seven members: the chairman, vice chair, secretary, deputy secretary, treasurer and two additional members. The main responsibilities of the WHA committee are to coordinate water harvesting activities, ensure that members of the project plant vegetables in their gardens, resolve conflicts that arise amongst project members, involve the youth, and also ensure that none of the project members make use of hose pipes attached to water taps located in the streets. All villagers, whether project members or not, may only use containers to fetch water from the taps.

In September 2009 the WHAs in both communities were still in existence, but neither was registered and the constitutions were still in draft format. Meetings initiated by researchers were convened in both villages to get their associations registered. At the same time a young man from a neighbouring village (Sompondo) approached the researchers with a development plan that involved five villages, including Guquka and Khayalethu, and suggested that these villagers form an association with the purpose of starting a crop production project on arable land. He told the researchers that he was concerned that many of the young people in these villages were just sitting at home doing nothing and he wanted to engage them in something productive like farming. The targeted villages were those that were situated closer to the Tyhume River (Figure 8.2) so as the river water could be used for irrigation purposes.

**Figure 8.2** Tyhume River that could be used for irrigation purposes at Tyhume.

The majority of the project members in both communities indicated that they would be interested in applying the *IRWH* technique in the fields, especially after experiencing the benefits of the technique in their gardens. The majority of the project members (85%) indicated that they would prefer to rent land. These project members favoured a long term lease (a minimum of 5-10 years) against payment of a pre-determined fee. Since land for crop production is often a problem in rural areas, the researchers organized a meeting between project members and land owners in both villages. This was the beginning of a process of negotiation between the landless and land owners in Guquka. Land owners at the time of investigation had not cultivated their land for more than two decades. The owners agreed to release their land either by share-cropping or leasing it. In the former option (lending), no monetary payment is required, but compensation is payable in the form of produce when it is harvested. In the latter option (lease), the landless are expected to pay an annual rent.

The land holders were not entirely against renting out their land, but they favoured a shorter lease period (less than 5 years). They seemed to have fears of losing control over their land if they were to enter lease arrangements of longer duration. One of the important challenges to rural development in the region is to find out if enhancing security of tenure in the PTO system can remove such fears and lead to an increase in exchanges of arable land.

The other project members (15%) identified share cropping as a possible arrangement. They suggested that members should retain 65% of their produce with the remaining 35% going to the land owners after each harvest.

The researchers also encouraged the communities to form a legal co-operative or association that would include both water harvesting project members and non-members. This co-operative was formed and formally registered in March 2010. The name of the co-operative is called Nobantu Community-based Organization (NCBO). It is made up of 40 members from the different communities mentioned above, including some water harvesting project members from Guquka. For the first time, these communities have an organization that will look into the arable land issue. The responsibilities of the cooperative are to facilitate land access, formalize arrangements between the landless and land owners, and ensure that people use arable land for productive purposes. Of even more importance is the coordination of the three local structures (RA, WHA and NCBO) at village level. It was apparent in meetings that these structures needed to work together if initiatives were to be successful. Therefore, members of the NCBO were encouraged to attend RA meetings. There appears to be a positive relationship between the WHA and the RA. The water harvesting project members sometimes hold festivals and demonstrations. Invitations to attend these are usually extended to all community members, whether project members or not. According to the survey respondents, non-project members also attend these occasions.

Conflict resolution is important in the rural communities. The project members (85% in Guquka and 61% in Khayalethu) indicated that if conflicts should arise, they would like them to be resolved through dialogue in the presence of local authorities such as the RA chairperson or Chief of the Tribal Authority as interveners (Figure 8.3).

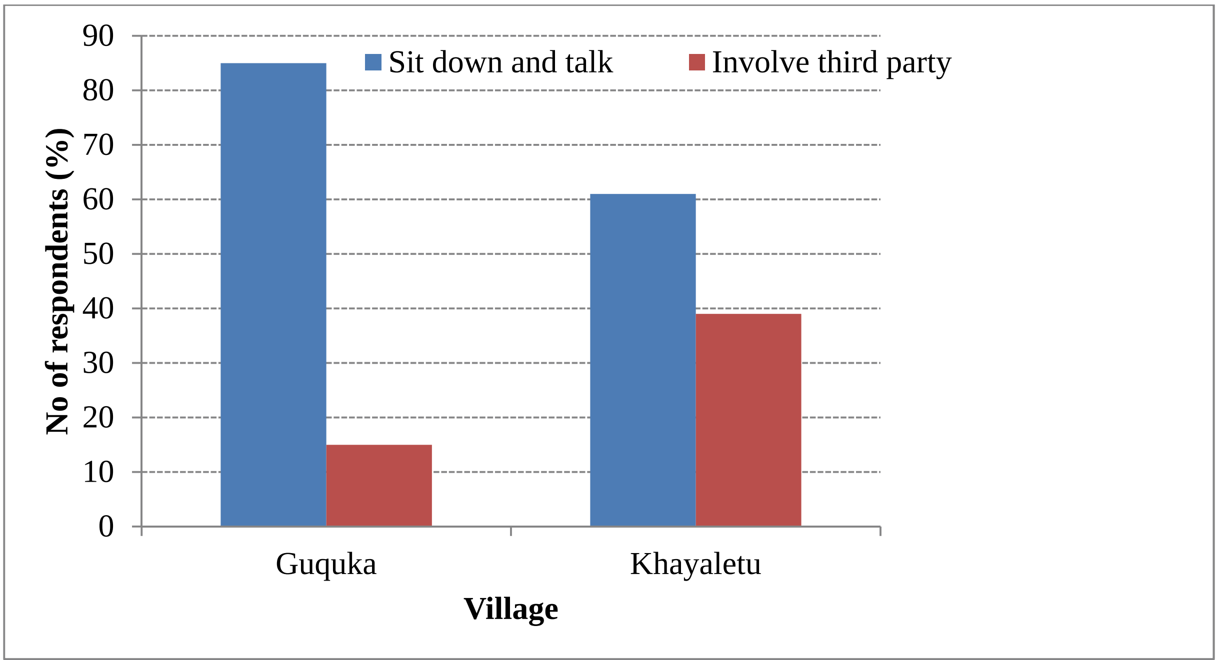


**Figure 8.3** Opinions on conflict resolution amongst the project members in Guquka and Khayalethu.

### 8.6.2 Access to and use of rangeland in Guquka and Khayalethu

Both communities have access to rangeland, which they use for grazing, firewood, grass (for building), dung (for cooking) and plants (for medicinal purposes). Access to this resource is obtained by virtue of being residents of these communities. Households in Guquka and Khayalethu share the rangeland with other surrounding communities in the Tyhume Valley, including Sompondo, Gilton, Msobomvu and Mpundu which fall within Amakhuze Tribal Authority. Conflict situations sometime arise because so many communities share the same rangeland. These can arise, for example, due to long queues on dipping days or loss and mixing of livestock because gates to camps have been left open. In addition, there is also a problem with theft.

8.6.2.1 Institutions governing the use of rangelands

The majority of survey respondents (80% in Guquka and 62% in Khayalethu) were aware of the rules governing the use of their rangeland (Figure 8.4). Some of the common rules mentioned by the members included conflict resolution management, sanction rights and monitoring. The households had different opinions on who enforced the rules pertaining to rangeland. In Guquka, project members said they were enforced by the community members (52%), RA chairperson (4%), Chief Mqalo (20%), or the community together with the Chief. At Khayalethu, most project members (42%) said it was the RA chairperson. The reason behind the establishment of rules was to ensure that the community worked together in a collective manner to ensure the orderly and sustainable use of rangeland.

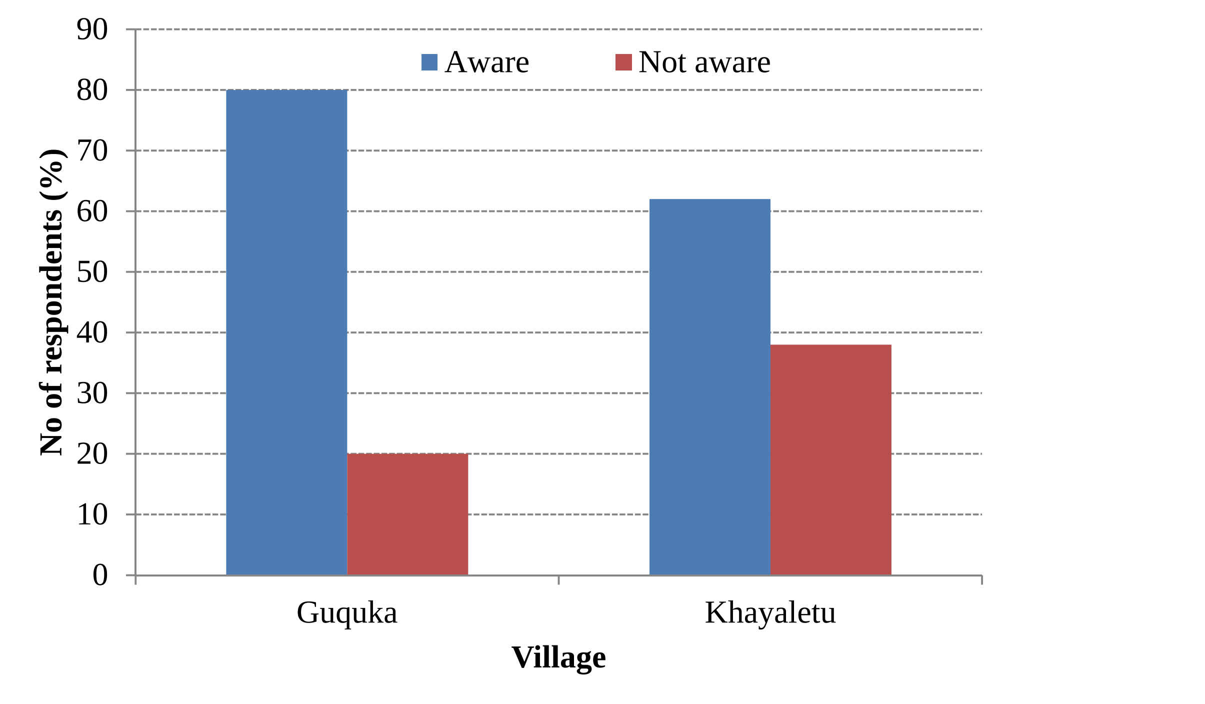


**Figure 8.4** Awareness of rules governing the use of rangelands in Guquka and Khayalethu.

The veld management practices adopted by survey respondents were limited to veld burning and removal of natural trees. They indicated that it was difficult for them to apply rotational grazing in a shared rangeland. In some parts of the rangeland there were no fences, making it even more difficult to practise rotational grazing. It became clear that the respondents were aware of the benefits of rotational grazing, but the conditions under which the rangeland was used did not allow them to use this management practice. This was identified as an area of intervention by the project team.

The availability of sufficient water is important in livestock farming. In Guquka, 58% of survey respondents indicated they used a combination of stock dams and the river as the main drinking points for their livestock. In Khayalethu, 54% also made use of this combination, while 30% made use of dams only. No major problems were mentioned with regard to distances from the drinking points. Those villagers living further from the river experienced a minor inconvenience when the dams were dry as the animals had to travel a longer distance to the river.

#### 8.6.2.2 Organizational and institutional arrangements in the rangeland

When survey participants were asked if they would be willing to apply water harvesting practices in the rangelands, 66% from Guquka and 74% from Khayalethu stated that they would be willing to do so, but did not know why they should. In response to this, livestock researchers made an effort to educate the villagers on the use of rainwater harvesting technologies in the rangeland.

A bigger challenge was to encourage the locals to introduce a formal institution to manage the rangelands. This was expected to be a daunting task for the following reasons: the rangelands are communal property; all the villagers were not members of the water harvesting project (it was anticipated that the project members would be more willing than the non-members); the rangeland is shared with communities other than the ones investigated; the rangeland has uses other than grazing (villagers, who do not have animals, may still wish to access the rangeland in order to collect firewood, medicinal plants, etc., and to exclude them simply because they did not own livestock would not work).

After a number of meetings were held with the communities to explore options, a decision was taken to adopt a collective action model. According to Meinze-Dick & Di Gregorio (2004), institutions of collective action and property rights shape how people use natural resources. They defined collective action as voluntary action taken by a group to achieve common interests, while property rights refer to the capacity to call upon the collective to stand behind one's claim to a benefit stream. Meinze-Dick & Di Gregorio (2004) also stated that property rights and collective action affect the application of agricultural technologies and natural resource management practices. Therefore, both property rights and collective action are crucial for the management of forests and rangelands. Property rights and collective action are interdependent. This is particularly clear in the case of common property where holding rights in common reinforces collective action among members, and collective action is needed to manage the resource. Property rights and collective action affect people's livelihoods. Poor people often lack resources and, therefore, have difficulty making their voices heard. Both property rights and collective action can be empowerment tools for poor people. Interventions to strengthen their property rights or help them participate in collective activities not only help them access resources, but also allow them to make decisions which take the future into consideration. However, evidence shows that collective action does not always work well. According to Ngaido & McCarthy (2004), when many people have access rights to the same resource, there is a potential for each individual to over-use and under-invest in the resource. So, the key is to build the capacity of participants, to put the right institutions in place, strengthening leadership (social capital) and assigning roles and responsibilities. At the time of this investigation, institutions prevailing in the rangelands in these areas included customary and tribal institutional arrangements. These generally allowed everyone access to rangelands, with little or no enforcement of user responsibilities.

Both communities agreed on two things: firstly, that existing institutions needed to be strengthened, and secondly, that a formal recognized structure was required in order to enforce rules among rangeland users. The rangeland users formed an association initially called the *Dalindyebo* Farmers Association. It was agreed that this should replace the Tribal Authority when it came to the management of the rangeland. But a decision was taken to always inform and update the TA. The responsibilities of the new structure would include setting boundaries in the rangeland; issuing grazing licences for camps to control rotational grazing; controlling access to the rangeland; monitoring rule violation; and enforcing sanctions.

Rule violations would be dealt with as follows. The first step would be to ask the violator to attend a community meeting at which he/she would be given a verbal warning. Should the person continue to violate the rules, the person would be sanctioned by the community. This took the form of traditional beer making (*umqombothi*) for the entire community. This appeared to be one of the preferred sanctions in both villages as it provided community members with an opportunity to socialize and share ideas with one another. In view of this social networking, a decision was taken not to scrap this sanction in order to strengthen social capital. However, the Farmers Association was allowed to introduce new sanctions, such as monetary payments in addition to the beer-making. The money paid as sanctions would be used to buy farming necessities (fencing, dip for animals, etc.), or alternatively, it would be invested.

Since the process of formalising institutional arrangements in the rangelands included designing and enforcing new rules, a decision was taken to build the capacity of communities through a series of workshops. These workshops will begin in March 2011. The intention of the workshops is to facilitate collective action and help communities learn about their rights and responsibilities and thus strengthen their ability to protect local rights and interests. A decision was also taken to approach a service provider that can use PRA techniques to plan, implement and monitor collective action in the study area. The PRA techniques will allow community participation and enable community members to make their own rules and to bear all costs of making and enforcing rules.

## 8.7 SUMMARY AND CONCLUSIONS

The results of this study show that the educational levels of households in the study area are generally low. The low levels of education are likely to be a challenge to the application and adoption of new farming practices as well as on institutional arrangements. This alone calls for continuous capacity building in these communities.

Land tenure and ownership are major challenges for both arable and rangeland, and affect the management of these resources. A number of options on how to access and manage these resources have been explored with the communities and institutional arrangements have been put in place. The study results show both regulative and normative institutions in the study area to be either weak or absent.

In the case of arable land, the main problem is access to land. Previous institutional arrangements did not work as these were either not formalized or the governance structures to enforce the institutions were absent. In this study, an attempt has been made to correct that. In the first place, options for access to arable land were explored with the landless and landlords. Two options have been identified, namely, renting and a formalized share-cropping arrangement. Secondly, the communities formed an association (NCBO), which by now is a legal community structure, whose main responsibility is to put regulative institutions governing arable land in place. So, both regulative and normative institutions have to a certain degree been strengthened during this investigation.

While access to arable land is a major problem in the study area, the results showed that almost everyone has access to rangeland. The free access as well as the absence of institutions that have made this resource so difficult to manage. In an attempt to alleviate the problem, the following institutions and organizational structures were put in place. Although not yet registered, the Dalindyebo Farmer’s Association was formed, based on the collective action model. The main responsibility of this association is to put rules and regulations governing the use and management of rangeland in place. Other responsibilities include issuing sanctions and grazing licences. Rules and regulations are important in any community to ensure that it looks after its natural resources. It is important that rules are clearly stated so that every community member is aware of what is expected from them.

# 9 IMPACT OF RAINWATER HARVESTING AND CONSERVATION TECHNIQUES ON SOCIAL AND ECONOMIC STATUS OF HOUSEHOLDS

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## 9.1 INTRODUCTION

The main aim of the *IRWH* project was to introduce sustainable techniques and practices for water harvesting and conservation in resource-poor agricultural production in the study area. The underlying objective was to improve access to water in order to improve agricultural production, and thus improve food security at household level. Water is one of the essential resources required for food production, making it a critical factor in food security. Achieving food security for a growing population with the same amount of water, therefore, becomes important (Wenhold, 2007). A growing population and an escalation in per capita consumption of water have implications for water supplies (Sekar & Randhir, 2007). Food production is the most water-intensive activity in society and water is the most limiting resource in South Africa and many other parts of Africa. Agriculture accounts for 70% of the worldwide human fresh water use (Hoddinot, 1999) and this figure can be higher in developing countries. FAO (1990) identifies agriculture as the largest single user of water, with about 75% of the world's freshwater being currently used for irrigation.

Food security is an essential, universal dimension of household and personal well-being. One of the continuing aims of the South African government is to ensure that all South Africans have enough to eat (NDA, 2007). Food insecurity and hunger are undesirable and are also possible precursors to nutritional, health and developmental problems. Therefore, monitoring food security can help to identify and understand the basic well-being of the population and to identify population subgroups or regions with unusually severe conditions. Accurate measurement and monitoring of food security can help policy makers, service providers and the public at large to evaluate the population's changing need for assistance.

The *IRWH* project consisted of three stages, namely, situation analysis, implementation (introduction and testing of technologies) and impact assessment. This chapter reports on the impact assessment phase of the project. An impact assessment was first conducted in 2007 with the focus on household food security. In 2008, another impact assessment was done to evaluate the project impact on the social and economic well-being of the communities involved in the project, as well as household food security. The 2007 and 2008 impact assessment reports only partially addressed the issue of nutrition, as they did not report on the nutritional status of the foods consumed or the contribution of home gardens to the nutritional status of household members. The 2009 impact assessment report made an attempt to address that aspect of food security. It compared the nutritional status of project members with that of non-project members. It reported on the energy, protein and micro-nutrient (Vitamins A and C and Iron) intakes. This comparison helped to establish whether the *IRWH* technique had had an impact on household food security.

## 9.2 MATERIALS AND METHODS

A number of methods were employed to measure the social and economic impact of the project from 2007 to 2009.

### 9.2.1 Socio-economic survey

In 2007, a socio-economic survey was undertaken and a semi-structured questionnaire was used as a data collection tool. Data were collected during November from 60 households (34 in Guquka and 26 in Khayalethu) that had implemented the *IRWH* technique in their home gardens. In order to get a clear picture of the impact of the technology on the social and economic status of households, a decision was taken to assess both the project members and non-project members. The non-project members (also 60 households) were selected randomly from those who were interviewed during the situational analysis in 2004.

The socio-economic impact assessment (SEIA) framework developed by the Commonwealth of Australia (2005) was employed. It provides a range of options for assessing social and economic impacts, and advice on appropriate methods for particular situations. It is also a useful tool for understanding a potential range of impacts of a proposed change, and the likely response of those impacted if the change occurs. The SEIA framework consists of three phases, namely, scoping, profiling and assessing the impacts.

### 9.2.2 Evaluating impact on household food security

Two methods of measuring food security were employed in this study. The first measured the quantities of food consumed by people at different times of the year, and then analysed them for nutrient adequacy. The second method used qualitative measures to capture people's own perceptions of the extent to which they suffer from hunger. Measuring food security in this investigation employed indicators of both diet quantity and quality. Diet quantity refers to the amount of food eaten by people. The indicator of diet quantity commonly used is the average household food energy available per person. It is measured as the amount of energy in the food acquired by the household over the survey reference period divided by the number of household members and days in the period (Smith *et al.*, 2006).

Indicators used to measure diet quality were household diet diversity and the percentage of households with low diet diversity. Diet quality refers to the variation of food consumed by households (Smith *et al.*, 2006). Based on the food quantity data, diet diversity was calculated by counting the number of food groups, out of seven, from which food was acquired over the survey reference period. A household was classified as having low diet diversity if it failed to acquire at least one food from four of the seven food groups over the survey reference period. The seven food groups considered were:

- Cereals
- Roots and tubers
- Pulses and legumes
- Dairy products
- Meats, fish and sea foods, and eggs
- Oils and fats
- Fruits and vegetables

Five indicators were used to assess household food security. These were household income, expenditure on food, diet diversity, energy-protein intakes, and micro-nutrient intakes (Vitamin A, C and Iron). The income and expenditure data were collected from 120 households, i.e. 60 project members and 60 non-members. However, the detailed food data were collected from selected cases at different times (seasons) of the year. These cases were selected mainly according to the degree of poverty. A total of 12 cases (six from each village) were selected and assessed. Two households (one project member and one non-member) were selected from each poverty class (non-poor, poor and ultra-poor) in each village. The main aim of selecting households in this way was to evaluate the impact of *IRWH* technology by comparing and contrasting food data of project members and non-members within each poverty class.

The food account method (FAM) was used to collect household food data. Each household was supplied with a diary to record the amounts and sources of all food products consumed on a daily basis during one month in each season. The gathering of food data began during spring in September 2008. Data was also gathered in summer (December), in autumn (March) and in winter (June). The data collected was on the type and quantity of products consumed, as well as the sources from where food was obtained.

A case study approach was employed to obtain detailed food data. A total of 12 cases were selected for investigation (six households per village). These were selected mainly according to the degree of poverty. The 2005 situation analysis report showed households belonged to three poverty classes, namely, the non-poor, poor and ultra-poor. Two households (one project member and one non-member) were selected from each poverty class (non-poor, poor and ultra-poor) in each village. The main aim of selecting households this way was to find out whether the livelihood strategy and level of income influenced diet of households, and to investigate the ways in which different categories of households were obtained food. The aim was also to evaluate the impact of *IRWH* technology by comparing and contrasting food data of project members and non-members.

### 9.2.3 Analysis and interpretation of data

The unit of analysis in this study was a household, but the unit of comparison was an adult equivalent (AE). The number of adult equivalents in a household was determined by means of the following equation:

No. of AE = $(\text{No. adults} + 0.5 \text{ children})^{0.9}$ (May, 1996), whereby No. of AE = number of adult equivalents in the household, No. of adults = number of household members aged 18 years or older, No. of children = number of households younger than 18 years old.

The data collected from households were quantities of food products consumed. These were reported in non-metric units of measure, e.g. bunches of carrots, cups of beans, spoons of maize meal, etc. The first step, therefore, was to convert the data into metric quantities (grams or kilograms).

A household’s total energy requirement was calculated as the sum of the requirements of all household members. The actual energy value of a food acquired was computed as metric value multiplied by the food’s caloric value.

The nutrient composition of the food was determined using the South African food composition tables. The recommended daily allowances (RDAs) of the nutrients evaluated were used as benchmarks. To calculate household energy availability, the total calories acquired by a household were divided by the number of household members (converted to AEs). The total energy in the food that the household acquired was then compared to the sum of the daily energy requirements for that particular household. The recommended daily caloric intakes used are presented in Table 9.1. The fact that people's energy needs vary substantially depending on their sex and age was taken into account. The household size comprised only those members, who were actually present in the household at the time of investigation and thus potentially eating the food acquired.

The second diet quantity indicator used was the percentage of households who did not consume sufficient dietary energy.

**Table 9.1** Recommended daily caloric intakes

| Age group | Kilocalories per day | | |
|---|---|---|---|
| **Young children** | | | |
| <1 | 820 | | |
| 1-2 | 1150 | | |
| 2-3 | 1350 | | |
| 3-5 | 1550 | | |
| **Older children** | **Boys** | **Girls** | |
| 5-7 | 1850 | 1750 | |
| 7-10 | 2100 | 1800 | |
| 10-12 | 2200 | 1950 | |
| 12-14 | 2400 | 2100 | |
| 14-16 | 2650 | 2150 | |
| 16-18 | 2850 | 2150 | |
| **Men** | **Light activity** | **Moderate activity** | **Heavy activity** |
| 18-30 | 2600 | 3000 | 3550 |
| 30-60 | 2500 | 2900 | 3400 |
| > 60 | 2100 | 2450 | 2850 |
| **Women** | **Light activity** | **Moderate activity** | **Heavy activity** |
| 18-30 | 2000 | 2100 | 2350 |
| 30-60 | 2050 | 2150 | 2400 |
| > 60 | 1850 | 1950 | 2150 |

Source: FAO/WHO/UNU (1985), as cited by Smith *et al.* (2006)

The RDAs of nutrients are usually given per gender and age group. The RDAs for each household are, therefore, likely to differ since households vary greatly in size and composition. One way to address this is to express households in terms of adult equivalents, where adult equivalence is determined by recommended daily allowances (Rose *et al.*, 2002). The RDAs of all individuals in each household were expressed in terms of adult female equivalents, with reference to their energy, protein, vitamins A and C as well as iron. Then the total nutrient intake for each household was divided by its number of household adult equivalents in order to obtain average figures.

## 9.3 HIGHLIGHTS OF RESULTS

### 9.3.1 Demographic characteristics of project members in Guquka and Khayalethu

#### 9.3.1.1 Age distribution of heads of households in both villages

The age distribution of project member household heads in Guquka and Khayalethu is shown in Figure 9.1. According to Randela (2005), the age of the household head is an important aspect in agriculture as it is an indication of experience. This experience influences household farming activities since household members usually get guidance from the head (Ngqangweni & Delgado, 2003). Also, to a certain extent, age indicates the position of the household in the life cycle (Randela, 2005).

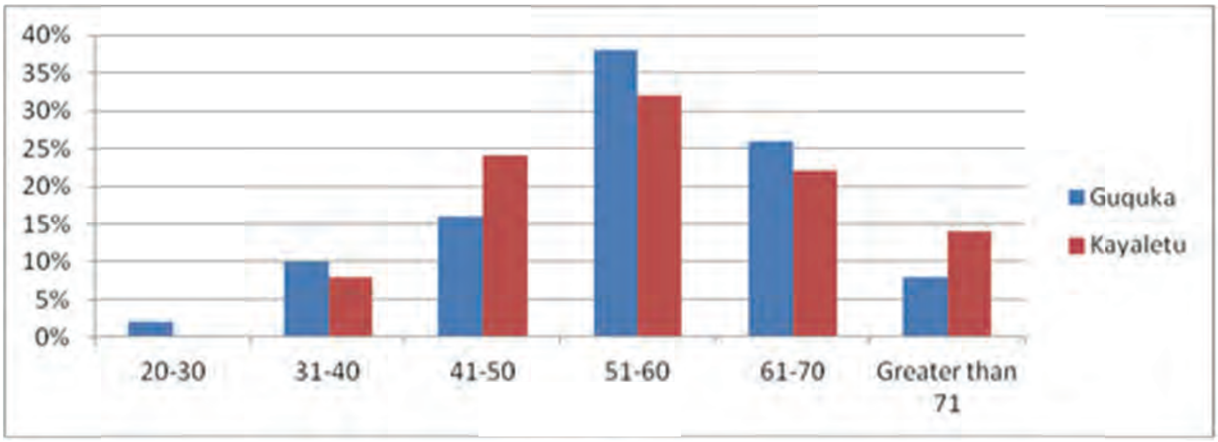


**Figure 9.1** Percentage age distribution of household heads at Guquka and Khayalethu during September 2009 (n = 56).

Approximately 80% of heads of households at Guquka and 78% at Khayalethu were 41-70 years old. Most (37% in Guquka and 32% in Khayalethu) fell in the 51-60 year age group. The percentage of heads of households under 40 years varied from 20% in Guquka to 30% in Khayalethu**.** Only 2% of household heads were younger than 31 in Guquka none in Khayalethu. Since project members were drawn from community members interested in agriculture, these statistics indicate that farming in these villages is practised mostly by the older generation, with young people showing little interest in agriculture.

#### 9.3.1.2 Gender distribution of members of the water harvesting project in Guquka and Khayalethu

The gender distribution of project members in the study areas is presented in Table 9.2 and shows the majority of members in both villages to be females (64% in Guquka and 62% in Khayalethu). Since project members were drawn from community members interested in agriculture these results indicate that agricultural initiatives and activities in these communities are mostly practised by women. Abula (1999) had similar findings and he acknowledged the importance of women in agricultural development in rural areas. While these women play a key role in agriculture, they are often not recognized or undervalued by development initiators. Bembridge (1982) stated that woman could considerably influence the development process if they could be organized and given the necessary support.

**Table 9.2** Gender distribution of project members in Guquka and Khayalethu (n = 56)

| | GUQUKA | | KHAYALETHU | |
|---|---|---|---|---|
| **Variable** | **No. of hh** | **%** | **No. of hh** | **%** |
| Males | 11 | 36 | 10 | 38 |
| Females | 19 | 64 | 16 | 62 |
| Total | **30** | 100 | **26** | 100 |

9.3.1.3 Education levels of project members in the study area

In this study, the highest educational level held by project members was recorded in order to determine the human capital level as well as their ability to interpret information. According to Montshwe (2006), people with higher educational levels are better able to interpret information than those who have less education or no education at all. Thus, education levels affect market information interpretation and hence, market participation level of farmers.

The educational levels of the water harvesting project members in both villages were found to be low. Figure 9.2 shows that about 6% of the project members in Guquka and 8% in Khayalethu had no schooling. Of those who had gone to school, 54% in Guquka and 40% in Khayalethu had attended primary school and 36% in Guquka and 44% in Khayalethu were in possession of secondary school education. Only 4% in Guquka and 8% in Khayalethu had a tertiary education (Diploma in teaching). Such farmers are considered to be educated enough as they can interpret information better than their counterparts (Makhura, 2001).

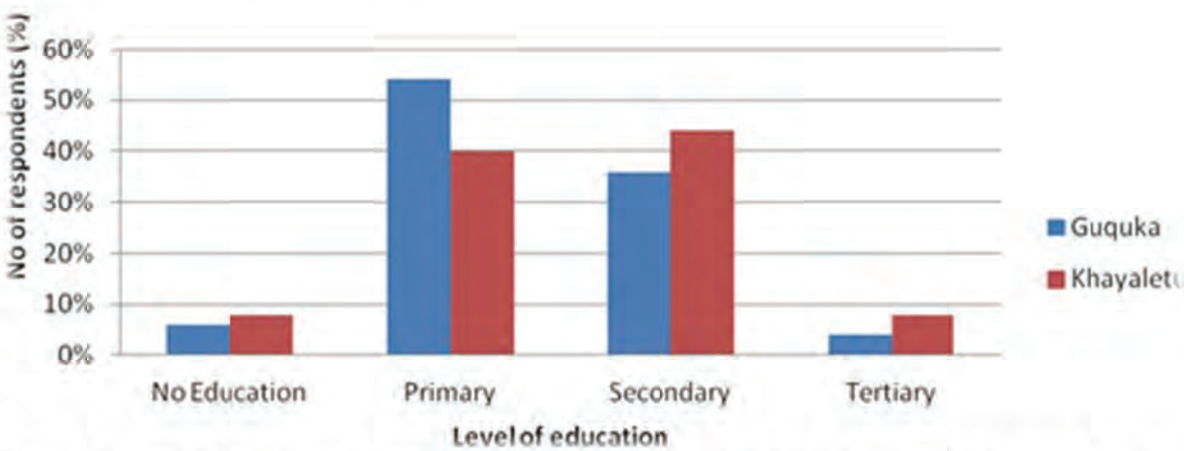


**Figure 9.2** Education level of project members in Guquka and Khayalethu during September 2009 (n = 56).

### 9.3.2 Social impacts

As already mentioned in section 9.2, socio-economic impact assessment is a useful tool to help understand the potential range of impacts of a proposed change, and the likely responses of those impacted if the change occurs. The focus of social impact assessment is usually on demographic changes, access to services and social relations, while economic impact assessment determines changes in levels of income, food security, employment and quality of life.

The results of the assessment revealed the water harvesting project had a great impact on gender. To begin with, the majority (65%) of the heads of households in both villages participating in the project were females. The assessment also revealed that after the introduction of the *IRWH* project, project members spent more time on vegetable gardening than was the case before the project. The responses ranged from 1-7 hours per day, with most members (27%) spending about 6-7 hours per day from Mondays to Fridays. This is a big change as only approximately three hours per day were spent in gardening before the introduction of the project.

According to respondents, all members of the two communities were aware of the *IRWH* project. Guquka and Khayalethu are home to 213 and 230 households, respectively. The rate of technology adoption was 14% at Guquka and 10% at Khayalethu at the time of this assessment, an average of 12% for the study area. According to experts on technology transfer, this is an acceptable rate for technology adoption in rural communities. According to respondents, more than half of the community members in both villages attend occasions such as farmer's days and festivals. These occasions were used as one of the means to promote rainwater harvesting technology (information transfer). However, the water harvesting technology has only been adopted by two non-members in Guquka and one in Khayalethu.

There seemed to be a good relationship between project members and initiators. Although the project members did not participate in project design, it appears that the intentions of the project were well communicated to the community members. When respondents were asked whether they understood the main objectives of the project, they highlighted three objectives which they perceived to be those of the *IRWH* project. These were poverty alleviation, food security and community development. Poverty alleviation followed by food security was perceived as the most important objectives, as shown in Figure 9.3.

The respondents also acknowledged the improvement in extension services. However, when asked about whether they get feedback from project initiators on various project activities, the response was not good. Only 29% indicated receipt of feedback. The rest (71%) did not seem to recall any feedback from project initiators.

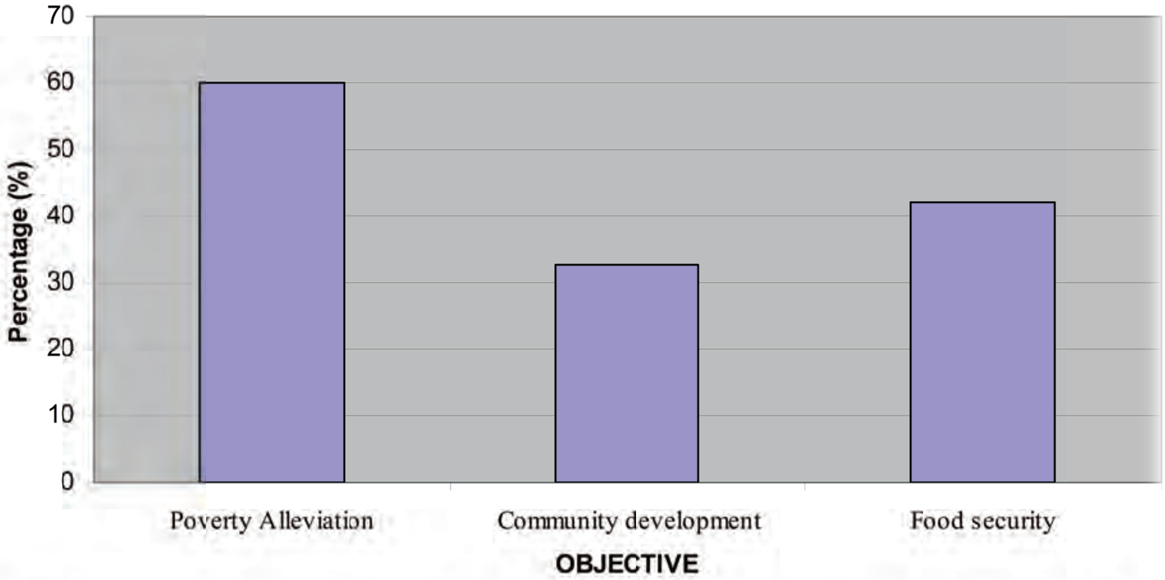


**Figure 9.3** The main objectives of the water harvesting project as perceived by respondents in Guquka and Khayalethu (n = 56).

### 9.3.3 Economic impact

9.3.3.1 Impact on food production and land use intensity

The water harvesting project has had a positive impact on agricultural production and land use intensity amongst the project members. Increase in yields was identified as the most important indicator of success (> 69% of respondents). Apparently, this success was not brought about by the adoption of the *IRWH* technology alone, it was also due to other knowledge and skills offered by the project implementers. These included mulching, correct time of planting, use of certified seeds, integrated pest management, use of fertilizers, use of new maize cultivars, and introduction of new vegetables.

The introduction of the *IRWH* technology in Guquka and Khayalethu has also resulted in the better utilization of gardens in these areas. Ninety-five percent of respondents revealed that they were cultivating their gardens throughout the year, although land use intensity varied between seasons. Only 23% of respondents cropped the whole garden area in winter. The majority (59%) cultivated half of the garden area as shown in Figure 9.4. Cultivating home gardens in winter is a big change in these communities. Previously, almost all gardens were fallow at that time. No changes were noticed in terms of yields and land use intensity amongst the non-project members.

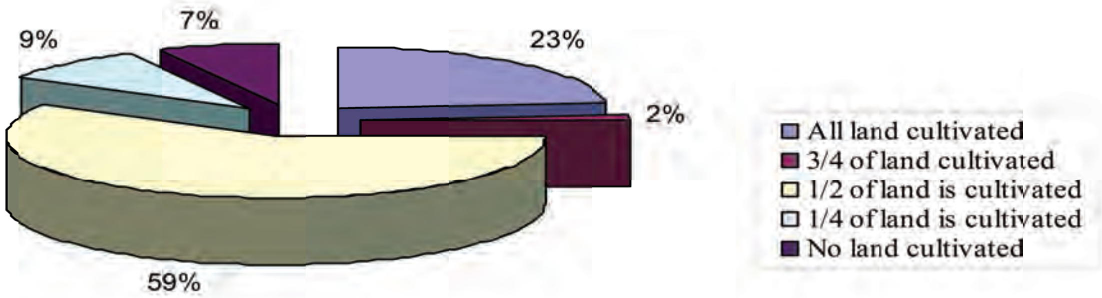


**Figure 9.4** Proportion of garden area cultivated during winter at Guquka and Khayalethu during November 2007 among project members (n = 56).

9.3.3.2 Impact on household income and poverty

The *IRWH* technology had little impact on household income (Table 9.3). The figures in Table 9.3 should be compared with those in Table 3.6. However, a slight improvement in come from agriculture was noticed amongst the project members, even though the contribution from this income source was still less than 15%. In 2005 (see situation analysis in Chapter 3), the contribution of farming was 10.7% in Guquka and 7.2% in Khayalethu. These figures were obtained before the introduction of the *IRWH* technology and, therefore, do not distinguish between project and non-project members. But when compared to the 2007 figures (i.e. after the introduction and adoption of the technology), farming contributions for project members had increased to 13.3%, although they were still below 10% for non-project members. This improvement is a result of better utilization of home gardens (land use intensity). Home gardening was the main agricultural activity and it made a significant contribution to agricultural income as revealed in Table 9.3. The 'other' category included the consumption and sale of chickens and pigs. There are still problems in the adoption of *IRWH* technology for the cultivation of arable land. Only one out of 120 households adopted the *IRWH* technique in the fields.

**Table 9.3** Sources of income and their contributions to household income among the project members and non-project members at Guquka and Khayalethu (n = 104; 2007)

| **Source** | **Project members (n = 56)** | | **Non-project members (n = 60)** | |
|---|---|---|---|---|
| | (R $month^{-1}$) | (%) | (R $month^{-1}$) | (%) |
| Remittances | 1298.79 | 5.1 | 1518.97 | 8.0 |
| Wages | 8887.78 | 34.9 | 4955.65 | 26.1 |
| Grants | 11459.88 | 45.0 | 10689.77 | 56.3 |
| Trade | 432.93 | 1.7 | 284.81 | 1.5 |
| Agriculture – gardening | 2062.78 | 8.1 | 949.36 | 5.0 |
| Agriculture – other | 1324.25 | 5.2 | 588.60 | 3.1 |
| **Total** | **25466.41** | **100.0** | **18987.16** | **100.0** |

Approximately 75% of respondents mentioned that they also earn money from selling vegetables. Before the project, no garden produce was sold as there was not even enough for home consumption.

Table 9.4 and Table 9.5 show sources of income and their contribution to household income for selected cases (project and non-project members) in Guquka and Khayalethu. These cases were selected according to poverty status (section 9.2.2). In each poverty class, a project member is compared to a non-project member.

**Table 9.4** Source of income and their contribution to household income amongst selected cases at Guquka

| Cases | Salaries (%) | Pensions (%) | C. grant (%) | Dis. Grant (%) | Agric. (%) | Remit (%) | Trade (%) | AE income (R $month^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| **GNPM**[a] | 60 | 20 | 10 | 0 | 5 | 3 | 2 | 918.94 |
| **GNPN**[b] | 55 | 30 | 12 | 0 | 3 | 0 | 100 | 618.86 |
| **GPM**[c] | 35 | 55 | 5 | 0 | 5 | 0 | 0 | 482.45 |
| **GPN**[d] | 28 | 60 | 5 | 0 | 2 | 5 | 0 | 289.66 |
| **GUPM**[e] | 20 | 70 | 5 | 0 | 3 | 2 | 0 | 185.59 |
| **GUPN**[f] | 25 | 65 | 5 | 0 | 2 | 3 | 0 | 161.92 |

Notes: a: Guquka non-poor member; b: Guquka non-poor non-project member; c: Guquka poor member; d: Guquka poor non-member; e: Guquka ultra-poor member; f: Guquka ultra-poor non-member.

**Table 9.5** Source of income and their contributions to household income amongst selected cases at Khayalethu

| Cases | Salaries (%) | Pensions (%) | C. grant (% | Dis. grant (%) | Agric (%) | Remit (%) | Trade (%) | AE income (R $month^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| **KNPM**[a] | 45 | 55 | 13 | 0 | 5 | 0 | 2 | 947.93 |
| **KNPN**[b] | 40 | 50 | 5 | 0 | 3 | 2 | 100 | 1260.41 |
| **KPM**[c] | 35 | 55 | 5 | 0 | 5 | 0 | 0 | 380.12 |
| **KPN**[d] | 30 | 58 | 5 | 0 | 2 | 5 | 0 | 675.11 |
| **KUPM**[e] | 25 | 65 | 5 | 0 | 3 | 2 | 0 | 203.32 |
| **KUPN**[f] | 25 | 65 | 5 | 0 | 2 | 3 | 0 | 278.51 |

Notes: a: Khayalethu non-poor member; b: Khayalethu non-poor non-project member; c: Khayalethu poor member; d: Khayalethu poor non-member; e: Khayalethu ultra-poor member; f: Khayalethu ultra-poor non-member.

The project appeared to have no positive impacts on poverty alleviation. Only 17% of households in the project member group were categorized as non-poor. The remaining households (83%) were categorised as poor, with 45% of these categorized as ultra-poor. Food remained the main expenditure category for both project member and non-project member households. However, the expenditure by non-project members was slightly higher as revealed in Figure 9.5 ($R^2$ = 0.8) and Figure 9.6 ($R^2$ = 0.94).

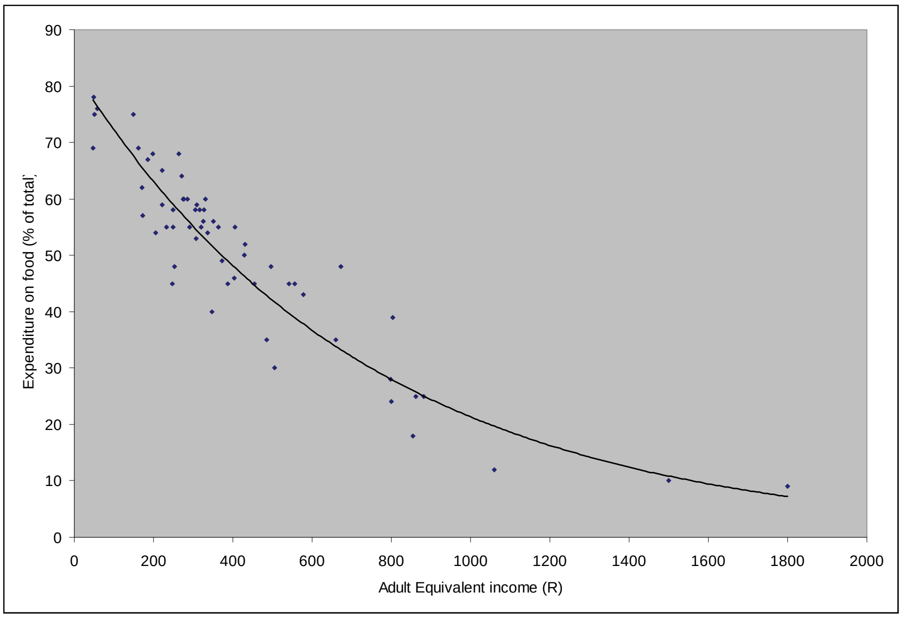


**Figure 9.5** Relationship between household income expressed in adult equivalent and the proportion of total expenditure spent on food among project members in 2007 (n = 60).

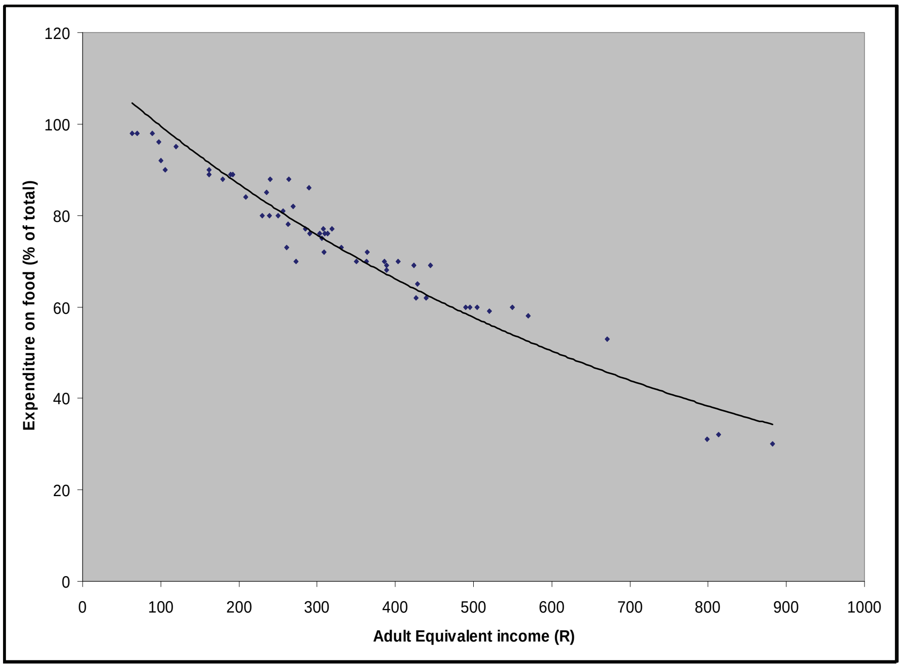


**Figure 9.6** Relationship between household income expressed in adult equivalent and the proportion of total expenditure spent on food among non-project members in 2007 (n = 60).

9.3.3.3 Impact on food security

The introduction of the water harvesting project has had a positive impact on household food security. About 96% of the project members felt that they were better off since the introduction of the *IRWH* technology in 2004 and the majority also indicated that their household members never went hungry. About 80% of respondents could afford three meals a day, whilst the remaining 20% ate two meals a day. None were living on one meal a day as was the case in the past (Monde, 2003). The respondents indicated that the quality of their diets had also improved since the introduction of the *IRWH* project as they had begun to produce more vegetables in their home gardens: cabbage, carrot, tomatoes, beetroot and spinach as well as new vegetables such as cauliflower, broccoli, turnips and green pepper. About 38% of the project members consumed vegetables on a daily basis.

The food security situation was a little bit different for the non-project members. Unlike the project members, they did not produce a variety of vegetables. The main vegetable produced in home gardens was still cabbage. Although the non-project members did not grow many vegetables in their gardens, they managed to consume a variety of vegetables obtained from friends and relatives, who were project members. The main source of vegetables for the non-project members was local producers during summer, while own production was the main source for project members during summer and autumn. This is a big change for these communities local sources were never the main sources of vegetables before 2004.

To assess food consumption and diversity, seven food groups were considered. These were: cereals, roots and tubers; pulses and legumes; dairy products; meats and meat products; oils and fats; fruits; and vegetables. Indicators of diet quality used were household diet diversity and the percentage of households with low diet diversity. Based on the food data collected from households, diet diversity was calculated by counting the number of food groups, out of seven, from which food was acquired over the survey reference period. The percentage of households with low diet diversity was measured by determining whether a household failed to acquire at least one food from four of the seven groups over the survey reference period. The seasonal food calendars for the different categories of households showing the amounts of food consumed by one person from each food group are presented in Figure 9.7 to Figure 9.12. The food calendars are for the non-poor, poor and ultra-poor project members and non-project members.

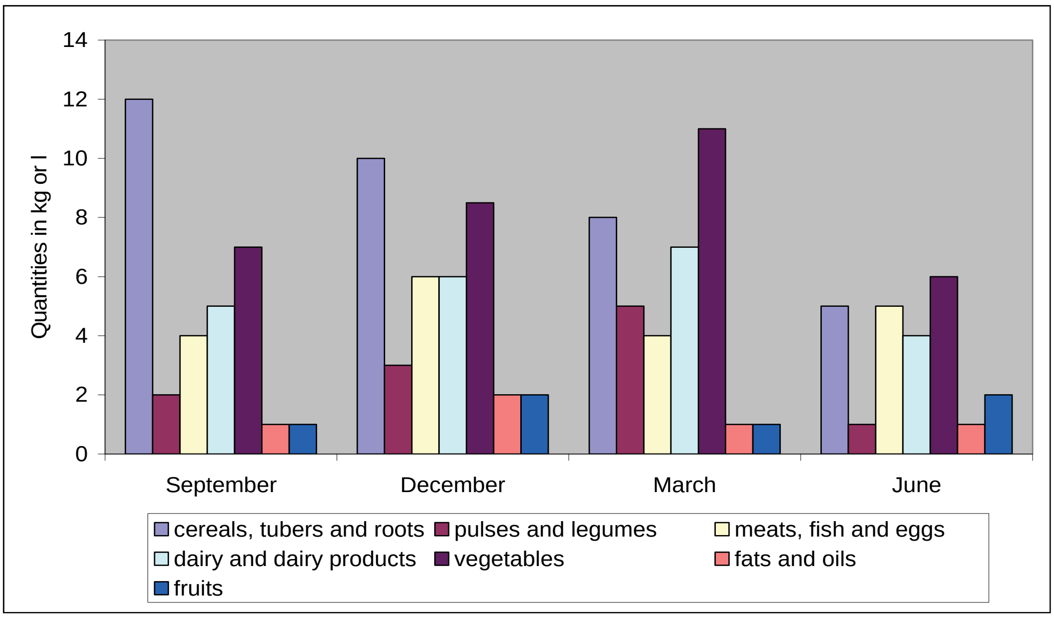


**Figure 9.7** Seasonal food calendar of non-poor households showing the amounts and kinds of food consumed by one adult equivalent in the project member category (September 2008 to March 2009).

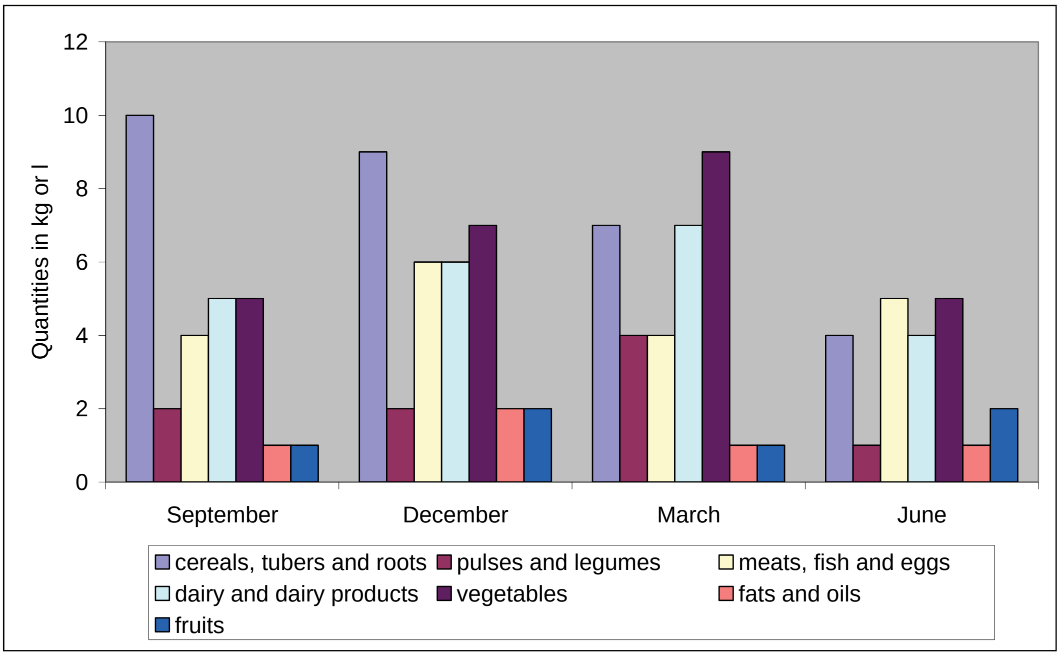


**Figure 9.8** Seasonal food calendar of non-poor households showing the amounts and kinds of food consumed by one adult equivalent in the non-member project category (September 2008 to March 2009).

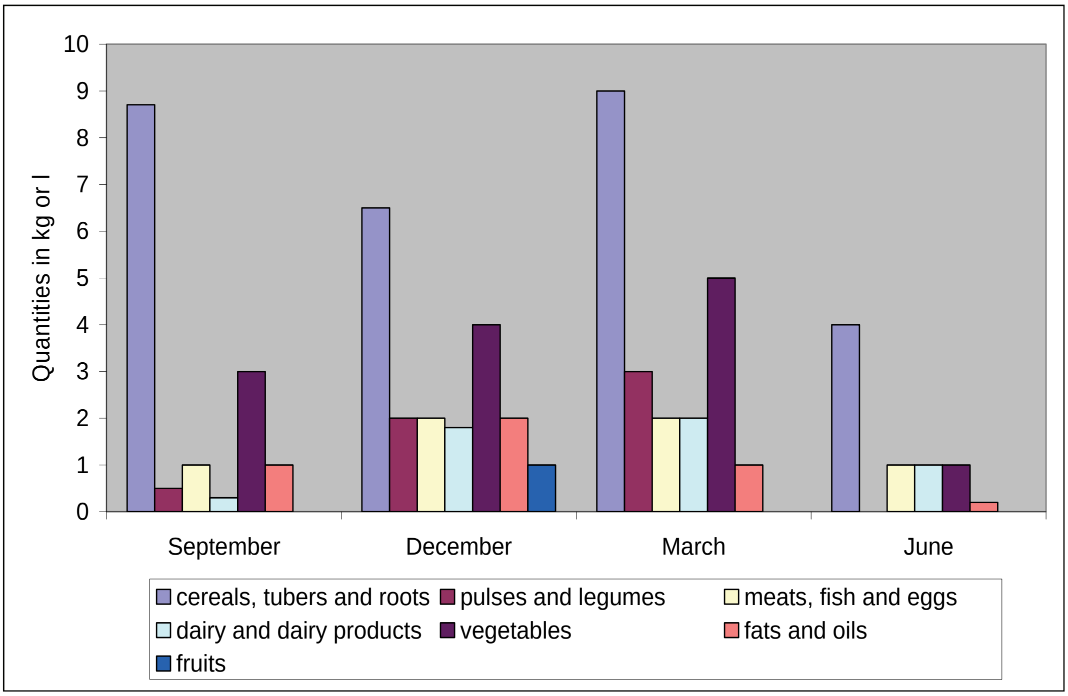


**Figure 9.9** Seasonal food calendar of poor households showing the amounts and kinds of food consumed by one adult equivalent in the project member category (September 2008 to March 2009).

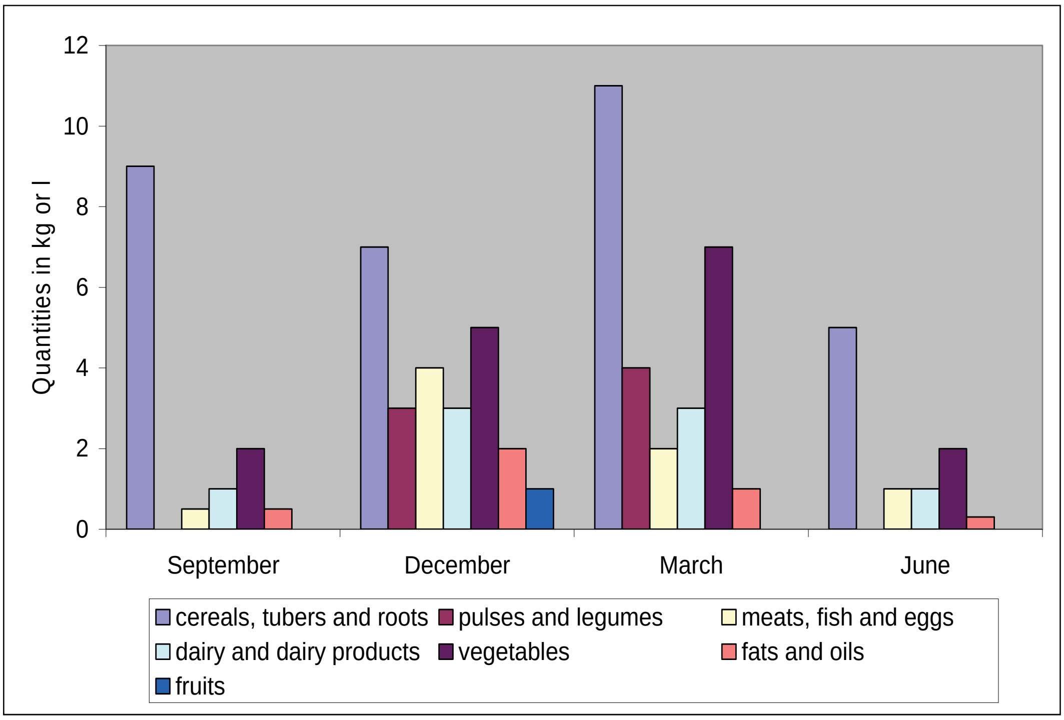


**Figure 9.10** Seasonal food calendar of households showing the amounts and kinds of food consumed by one adult equivalent in the non-member project category (September 2008 to March 2009).

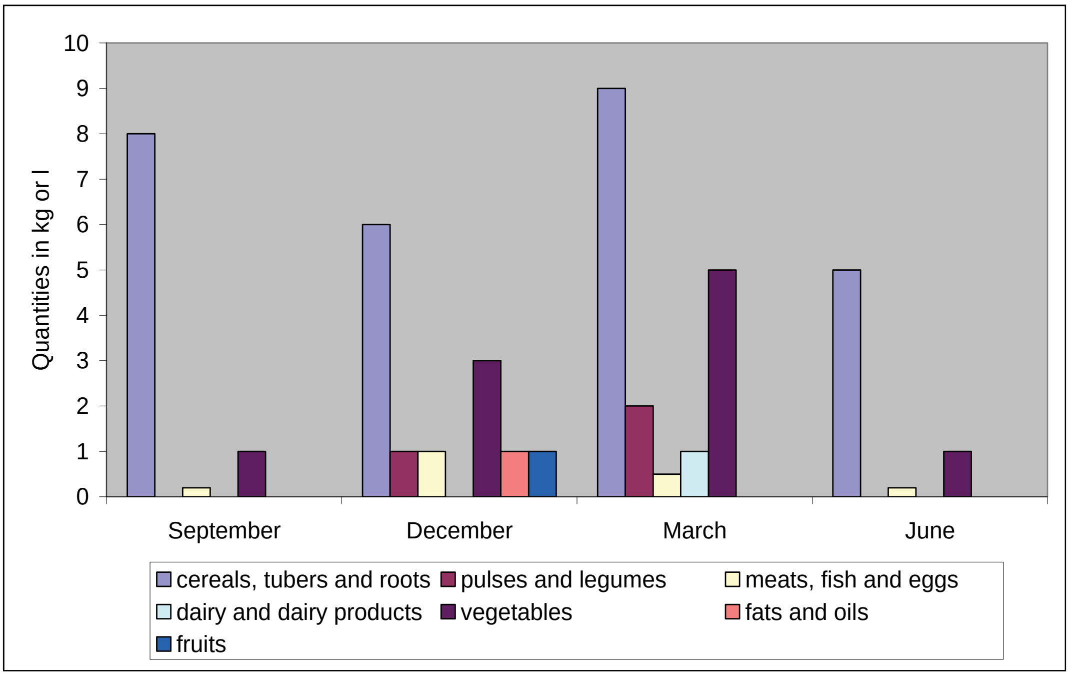


**Figure 9.11** Seasonal food calendar of ultra-poor households showing the amounts and kinds of food consumed by one adult equivalent in the project member category (September 2008 to March 2009).

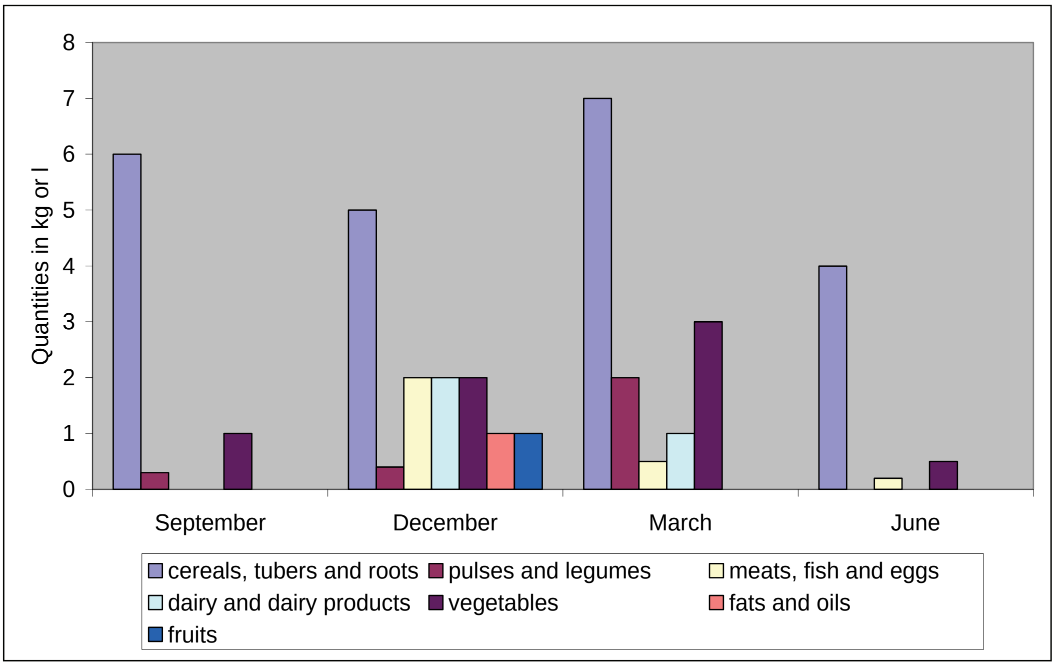


**Figure 9.12** Seasonal food calendar of ultra-poor households showing the amounts and kinds of food consumed by one adult equivalent in the non-member project category (September 2008 to March 2009).

In all non-poor households, both project members and non-members consumed foods from all seven food groups during all seasons. However, the consumption of cereals, legumes and vegetables was higher among project members than for non-members. The poor households also managed to consume foods from more than four food groups in all seasons, even though the portions consumed by one adult equivalent were small. Fruits and legumes were omitted from the diets of these households during September and June. The diet of the ultra-poor also showed variation during the summer (December) and autumn (March) seasons. However, their diet during the spring (September) and winter (June) was of poor quality. These households had low food diversity during these times as their diet was limited to three food groups only (cereals, vegetables and meats). The diet of these households during these critical times consisted mainly of cereals.

In all households in both villages the food category with the highest consumption of food was cereals, tubers and roots. Also, all households showed more consumption of cereals during the spring season (September). This appears to be the consumption pattern in this area. These results confirm findings by Monde (2003) in the same area. The majority of cereal products consumed are maize products, namely, maize meal and samp. Maize is harvested in June and hence more consumption of cereals occurs during spring. The consumption pattern of non-project members followed a similar pattern, but two important differences were noticed. Firstly, the portions of cereals, vegetables and legumes consumed by all poverty classes among the non-members were smaller. This difference was noted between households in the same village and between the two villages. The difference between villages was brought about by the differences in garden sizes. The Guquka households had slightly larger (300 $m^2$) home gardens than Khayalethu (211 $m^2$). Secondly, the ultra-poor households from the non-project member group consumed smaller portions of vegetables during the seasons of scarcity (winter and spring) than their counterparts in the member category group.

#### 9.3.3.3.1 *Food diversity at Guquka and Khayalethu*

Diet diversity is a good indicator of nutrient adequacy. From the information presented above, it is apparent that the non-poor households consumed a variety of foods during summer and winter seasons. The diet of the poor households also showed variation even though quantities from most food groups were very small. The consumption of fruit disappeared completely from the diet during September amongst the poor households in Guquka. On the other hand, the poor households at Khayalethu consumed fruit in both seasons. Most households in Khayalethu have a variety of fruit trees in their homesteads, hence greater consumption of fruit. In Guquka, very few households have fruit trees in their homesteads, and are usually are limited to peaches trees only.

The diet of the ultra-poor in both villages was limited to three food groups only in September, namely, cereals, pulses and vegetables. Pulses consumed at Guquka and Khayalethu were limited to dried peas and beans. Foods from the other four groups disappeared completely from the diet of these households in spring. Of those consumed, quantities were very small. The consumption of vegetables by project members amongst the ultra-poor was better though. Of the twelve cases investigated, four had low diet diversity, and these were ultra-poor households in both villages. However, this doesn't mean that the other eight households were food secure. It simply means that they were able to consume foods from at least four of the seven groups identified. One should note that some foods were consumed in very small quantities, presenting a likelihood of food insecurity amongst some households. The analysis of both macro- and micro-nutrients will reveal which households are foods secure or insecure, and whether the *IRWH* technology has the potential to improve food security in these areas.

When people omit certain foods from their diet, they are likely to show problems of food insecurity and poor nutrition. Cereals, roots and tubers contain starchy staples that are the main source of dietary energy. Pulses and legumes, dairy products, meats, fish and eggs contain foods that are high in protein. When pulses and legumes are combined in the same meal with cereals, they supply a favourable mixture of essential amino acids (Smith *et al.*, 2006). The protein of animal foods is of high biological value. In addition, animal foods are sources of micro-nutrients that are deficient in many people's diet. Examples are calcium (milk and dairy products), iron and zinc (meat, fish and eggs), vitamins A and D (fish, eggs, milk and dairy products). Fats and oils contain foods that may be good sources of fat-soluble vitamins, and they assist with their absorption. Fruits and vegetables contain foods that are good sources of micro-nutrients and fibre. Most vegetables are rich in carotene and vitamin C, and some contain significant amounts of iron and other micro-nutrients. The main nutritive value of fruit is their content of vitamin C (Smith *et al.*, 2006).

#### 9.3.3.3.2 *The main ingredients of diet at Guquka and Khayalethu*

The food groups used in the survey were used simply to indicate food type and quantity and no attempt was made to identify the exact products. In this section, these food groups are broken down into individual products to determine the main ingredients that make up the diet of rural households. Any product that was consumed at 1 kilogram or 1 litre per AE, or more, was regarded as a main ingredient. The mean monthly quantities consumed per person during the period of investigation are shown in Table 9.6. These findings showed cereals to consist of maize meal, samp, bread flour and rice for households in both villages. These products were consumed in larger quantities than any of the other food products.

Potatoes formed the next most important food product and were consumed in both spring and summer. *Amasi* was also one of the basic ingredients of the diet. However, the ultra-poor could not afford it in September. These results also show beef to be the main ingredient of diet in December only. These results, except for the consumption of vegetables, are somewhat similar to those of Monde (2003) in one of these villages. The consumption pattern of vegetables showed a big change in 2006. In 2003, the consumption of vegetables was limited to cabbages only, but the results of this investigation show an additional three vegetables, namely, onions, carrot and spinach. All these vegetables were the main ingredients of diet in both spring and summer.

**Table 9.6** Mean quantities (in kilograms or litres per month) of the main food products consumed during the months of September and December 2006 by one adult equivalent at Guquka and Khayalethu

| Product | **September** | | **December** | |
|---|---|---|---|---|
| | Guquka | Khayalethu | Guquka | Khayalethu |
| Maize meal | 3.4 | 3.2 | 3.2 | 3.0 |
| Samp | 2.8 | 2.5 | 2.5 | 2.6 |
| Flour | 3.2 | 3.6 | 2.7 | 3.0 |
| Rice | 2.5 | 2.3 | 2.1 | 2.7 |
| Potato | 2.3 | 2.1 | 2.2 | 2.1 |
| Cabbage | 1.0 | 0.8 | 1..0 | 0.9 |
| Onion | 1.1 | 1.0 | 1.5 | 1.3 |
| Spinach | 1.5 | 1.1 | 2.5 | 2.0 |
| Carrot | 1.8 | 1.1 | 2.3 | 2.0 |
| Dry beans | 1.1 | 0.8 | 2.2 | 1.8 |
| Amasi | 1.3 | 1.3 | 2.7 | 3.9 |
| Chicken | 1.3 | 1.2 | 2.2 | 2.5 |
| Beef | 0.1 | 0.2 | 2.1 | 2.2 |

9.3.3.3.3 *Sources of main products at Guquka and Khayalethu*

The sources from which Guquka and Khayalethu households obtained their main food products during September and December are presented in Table 9.7 to Table 9.10. The food sources included both urban and local markets. Urban markets were supermarkets and street markets (hawkers). Local markets included village shops, local producers, own production of food and donations. These were sources of main products in both seasons. But, in December, ceremonies were an additional source of food at both villages. Own production of food was important in terms of obtaining maize meal, samp and vegetables during September in both villages. During December, the main source of maize meal and samp was supermarkets. Own production remained the main source of vegetables in both seasons, whereas in 2003 the main source of vegetables was street market (hawkers) at both times of the year and the contribution of own production was significant during the autumn season only. There was also a change in the source of potatoes. During September, potatoes were mainly obtained from supermarkets, and in December, from own production.

These figures demonstrate a positive impact of the *IRWH* technology on home garden production and food security of households. With more production and consumption of vegetables, one could expect an improvement in nutritional status of household members in terms of more consumption or intake of micro-nutrients. But that judgment will only be made when all data has been gathered and the nutrient content analysis has been done.

**Table 9.7** Sources of main food products at Guquka in September 2008

| Product | Urban markets | | Local markets | | | |
|---|---|---|---|---|---|---|
| | Supermarkets (%) | Street market (%) | Village shops (%) | Local prod. (%) | Own prod. (%) | Donations (%) |
| Maize meal | 20 | 0 | 5 | 0 | 75 | 0 |
| Samp | 26 | 0 | 6 | 0 | 64 | 4 |
| Potato | 97 | 3 | 0 | 0 | 0 | 0 |
| Legumes | 85 | 0 | 2 | 0 | 13 | 0 |
| Vegetables | 0 | 9 | 0 | 6 | 81 | 4 |
| Amasi | 10 | 0 | 0 | 90 | 0 | 0 |
| Chicken | 82 | 0 | 0 | 8 | 10 | 0 |
| Beef | 100 | 0 | 0 | 0 | 0 | 0 |

**Table 9.8** Sources of main food products at Khayalethu in September 2008

| Product | Urban markets | | Local markets | | | |
|---|---|---|---|---|---|---|
| | Supermarkets (%) | Street market (%) | Village shops (%) | Local prod. (%) | Own prod. (%) | Donations (%) |
| Maize meal | 40 | 0 | 5 | 0 | 55 | 0 |
| Samp | 38 | 0 | 3 | 0 | 55 | 4 |
| Potato | 90 | 6 | 0 | 0 | 0 | 4 |
| Legumes | 80 | 0 | 7 | 0 | 10 | 3 |
| Vegetables | 15 | 0 | 0 | 4 | 75 | 6 |
| Amasi | 22 | 0 | 0 | 88 | 0 | 0 |
| Chicken | 90 | 0 | 0 | 0 | 10 | 0 |
| Beef | 100 | 0 | 0 | 0 | 0 | 0 |

**Table 9.9** Sources of main food products at Guquka in December 2008

| Product | Urban markets | | | Local markets | | | |
|---|---|---|---|---|---|---|---|
| | Super-markets (%) | Street market (%) | Village shops (%) | Local prod. (%) | Own prod. (%) | Cere-monies | Donations (%) |
| Maize meal | 65 | 0 | 5 | 0 | 20 | 10 | 0 |
| Samp | 65 | 0 | 5 | 0 | 25 | 5 | 0 |
| Potato | 20 | 0 | 0 | 0 | 65 | 5 | 10 |
| Legumes | 97 | 0 | 3 | 0 | 0 | 0 | 03 |
| Vegetables | 5 | 0 | 0 | 6 | 85 | 5 | 4 |
| Amasi | 70 | 0 | 0 | 30 | 0 | 0 | 0 |
| Chicken | 75 | 0 | 0 | 0 | 10 | 15 | 0 |
| Beef | 50 | 0 | 0 | 0 | 0 | 50 | 0 |

**Table 9.10** Sources of main food products at Khayalethu in December 2008

| Product | Urban markets | | Local markets | | | | |
|---|---|---|---|---|---|---|---|
| | Super-markets (%) | Street market (%) | Village shops (%) | Local prod. (%) | Own prod. (%) | Cere-monies | Donations (%) |
| Maize meal | 70 | 0 | 5 | 0 | 15 | 10 | 0 |
| Samp | 85 | 0 | 5 | 0 | 5 | 5 | 0 |
| Potato | 30 | 0 | 0 | 0 | 55 | 7 | 8 |
| Legumes | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| Vegetables | 5 | 0 | 0 | 6 | 80 | 5 | 4 |
| Amasi | 90 | 0 | 0 | 10 | 0 | 0 | 0 |
| Chicken | 81 | 0 | 0 | 0 | 10 | 9 | 0 |
| Beef | 55 | 0 | 0 | 0 | 0 | 45 | 0 |

9.3.3.4 Impact of *IRWH* technique on energy and protein intakes

The energy and protein intakes of households according to poverty class in both villages are shown in

The information presented Figure 9.11and Figure 9.12 show average figures in respect to recommended daily allowances of energy and protein as well as intakes of these nutrients at different times of the year by one AE in all households. It also shows the contribution of home garden produce throughout the year. As already mentioned, these are average figures recommended for and consumed by household members in each poverty class. With regard to the consumption of energy, Table 9.11 shows highest consumption of energy in summer followed by autumn. With the exception of ultra-poor households who were non-project members, all households met their energy requirements in summer. In autumn, none of the ultra-poor households, whether project members or not, achieved the required energy levels. During winter and spring food insecurity affected poor households as well. In winter none of the poor households, whether project members or not, achieved the required energy levels

The month of December is usually a period of plenty and households consume a variety of foods obtained from different sources. The popular food sources at this time are ceremonies and social functions. Even the poor households were able to achieve the required energy levels at this time (Table 9.11). The intake of energy by the ultra-poor households in summer also improved even though they still showed some energy deficiencies.

The contribution of home garden produce to energy intakes was highest during spring (September) due to high consumption of cereals. The main cereals consumed by all households were maize meal and samp. These are processed products derived from maize grown in gardens. Hence home gardens contribute more to energy intakes at this time of the year. Their contribution was also higher among the project members in all poverty categories.

**Table 9.11** Energy consumption (kcal) among the project members and non-members by poverty class and the contribution of home gardens at different seasons (Guquka and Khayalethu, 2008-2009)

| | **RDA[a] (kcal)** | **Sept (kcal)** | **HG[b] %** | **Dec (kcal)** | **HG %** | **Mar (kcal)** | **HG %** | **Jun (kcal)** | **HG %** |
|---|---|---|---|---|---|---|---|---|---|
| NPM[c] | **1923** | 2360 | 40.5 | 2450 | 28.5 | 2375 | 30.1 | 2290 | 35.3 |
| NPN[d] | **2336** | 2370 | 35.3 | 2495 | 25.3 | 2415 | 27.4 | 2355 | 33.6 |
| PM[e] | **2198** | 2315 | 38.1 | 2400 | 27.2 | 2385 | 28.5 | 2283 | 34.8 |
| PN[f] | **2760** | 2530 | 32.7 | 2775 | 23.4 | 2690 | 25.1 | 2512 | 30.2 |
| UPM[g] | **2655** | 2130 | 36.7 | 2345 | 25.8 | 2300 | 28.5 | 2105 | 30.5 |
| UPN[h] | **2241** | 1950 | 30.6 | 2100 | 22.1 | 2092 | 23.4 | 1937 | 28.7 |

Notes: a = recommended daily allowance; b = home garden; c = non-poor member; d = non-poor non-member; e = poor member; f = poor non-member; g = ultra-poor member; h = ultra-poor non-member.

Table 9.12 shows protein intake according to poverty class as well as the contribution of home garden produce at different times of the year. The figures presented show protein deficiencies amongst most households in the study area. Only the non-poor households were able to consume sufficient protein in all seasons. The poor and the ultra-poor households (irrespective of whether they were project members or not) did not have sufficient protein. However, the project members in all poverty classes managed to consume higher protein levels than their counterparts (non-members). The protein consumption was again highest in summer followed by autumn across all poverty classes.

As shown in Table 9.12, garden produce did not contribute much to protein intakes. The contributions ranged from 0.1 to 4.6 depending on the season. Highest contributions of garden produce to protein intakes were recorded during autumn season. Most of the protein consumed by households was animal protein. The protein composition of crops and vegetables produced in home gardens was too low to make a substantial contribution to protein intakes. Protein consumption was again higher among the project members.

**Table 9.12** Protein consumption (g) among the project members and non-members by poverty class and the contribution of home gardens at different seasons (Guquka and Khayalethu, 2008-2009)

| | **RDA[a] (g)** | **Sept (g)** | **HG[b] %** | **Dec (g)** | **HG %** | **Mar (g)** | **HG %** | **Jun (g)** | **HG %** |
|---|---|---|---|---|---|---|---|---|---|
| NPM[c] | **62** | 64 | 0.5 | 67 | 1.8 | 65 | 4.6 | 63 | 0.4 |
| NPN[d] | **57** | 59 | 0.3 | 65 | 0.7 | 61 | 2.4 | 59 | 0.2 |
| PM[e] | **61** | 56 | 0.4 | 59 | 1.2 | 57 | 3.3 | 54 | 0.3 |
| PN[f] | **62** | 53 | 0.2 | 59 | 0.5 | 55 | 2.1 | 51 | 0.1 |
| UPM[g] | **63** | 46 | 0.3 | 58 | 1.0 | 56 | 1.8 | 44 | 0.2 |
| UPN[h] | **57** | 43 | 0.1 | 53 | 0.3 | 51 | 1.2 | 41 | 0.1 |

Notes: a = recommended daily allowance; b = home garden; c = non-poor member; d = non-poor non-member; e = poor member; f = poor non-member; g = ultra-poor member; h = ultra-poor non-member.

#### 9.3.3.5 Impact on Vitamin A, C and iron

Table 9.13 and Table 9.14 show the intake of vitamins A and C according to poverty class as well as contribution of home garden produce to the intake of these essential minerals in all seasons. None of the households investigated met their requirements for Vitamins A and C and Iron, not even the non-poor households. However, the contribution of garden produce to the consumption of Vitamins A and C was significant especially during the wet seasons (summer and autumn). Similar findings were noted by Van Averbeke & Khosa (2007). The contribution of garden produce to the consumption of essential vitamins amongst the project members in all poverty classes was higher than that of non-members.

**Table 9.13** Vitamin A consumption (µg RE) among the project members and non-members by poverty class and the contribution of home gardens at different seasons (Guquka and Khayalethu, 2008-2009)

| | **RDA[a]** | **Sept** | **HG[b] %** | **Dec** | **HG %** | **Mar** | **HG %** | **Jun** | **HG %** |
|---|---|---|---|---|---|---|---|---|---|
| NPM[c] | **1181** | 1060 | 29.2 | 1155 | 45.1 | 1190 | 57.3 | 1053 | 27.5 |
| NPN[d] | **1197** | 1045 | 16.9 | 1142 | 30.8 | 1183 | 38.4 | 1036 | 15.1 |
| PM[e] | **1276** | 1005 | 27.3 | 1180 | 42.2 | 1198 | 51.5 | 1001 | 25.5 |
| PN[f] | **1160** | 990 | 15.1 | 1050 | 29.5 | 1075 | 35.6 | 996 | 14.3 |
| UPM[g] | **1248** | 1060 | 22.7 | 1148 | 38.6 | 1163 | 45.3 | 1045 | 20.4 |
| UPN[h] | **1323** | 998 | 14.8 | 1056 | 26.5 | 1089 | 32.7 | 987 | 13.9 |

c = non-poor member; d = non-poor non-member; e = poor member; f = poor non-member; g = ultra-poor member; h = ultra-poor non-member.

**Table 9.14** Vitamin C consumption (mg) among the project members and non-members by poverty class and the contribution of home gardens to nutrient intake at different seasons (Guquka and Khayalethu, 2008-2009)

| | **RDA[a]** | **Sept** | **HG[b] %** | **Dec** | **HG %** | **Mar** | **HG %** | **Jun** | **HG %** |
|---|---|---|---|---|---|---|---|---|---|
| NPM[c] | **74** | 68 | 22.8 | 70 | 43.2 | 75 | 54.2 | 65 | 20.1 |
| NPN[d] | **70** | 63 | 17.8 | 65 | 30.9 | 68 | 37.3 | 61 | 16.5 |
| PM[e] | **76** | 65 | 24.6 | 68 | 41.6 | 72 | 48.7 | 63 | 22.4 |
| PN[f] | **73** | 62 | 14.2 | 63 | 28.5 | 70 | 30.7 | 60 | 13.8 |
| UPM[g] | **74** | 66 | 20.1 | 69 | 38.9 | 71 | 45.3 | 63 | 19.5 |
| UPN[h] | **78** | 65 | 12.8 | 68 | 24.5 | 72 | 28.7 | 61 | 11.4 |

Notes: a = recommended daily allowance; b = home garden; c = non-poor member; d = non-poor non-member; e = poor member; f = poor non-member; g = ultra-poor member; h = ultra-poor non-member.

The food sources of Vitamin A include sweet potatoes, carrots, pumpkins, peppers, spinach, etc., but the amount of Vitamin A contained in these vegetables tends to differ. Some vegetables contain more Vitamin A than others. In fact, sweet potatoes contain higher amounts of Vitamin A than carrots. For example, one baked medium sweet potato contains 1096 mg of Vitamin A compared to only 671 mg in a half cup of cooked carrots. Also, the way people prepare or consume their vegetables is important. For example, a three-quarter cup of carrot juice seems to contain more Vitamin A (1692 mg) than cooked carrot or sweet potatoes for that matter. None of the households investigated produced sweet potatoes. The production of carrots was common, but none of the households consumed carrot juice. So, it is not only a question of what households produce and consume that has an effect on their nutritional status, but access to nutritional education as well.

As was the case with protein intakes, home gardens were not important in terms of supplying the households with iron. But the project members were still better off than the non-members during summer and autumn. Table 9.15 shows the intake of iron by poverty class as well as the contribution of garden produce to the intake of this mineral.

**Table 9.15** Iron consumption (mg) among the project members and non-members by poverty class and the contribution of home gardens at different seasons (Guquka and Khayalethu, 2008-2009)

| | RDA[a] | Sept | HG[b] % | Dec | HG % | Mar | HG % | Jun | HG % |
|---|---|---|---|---|---|---|---|---|---|
| NPM[c] | **15** | 9 | 2.2 | 11 | 2.7 | 10 | 2.9 | 9 | 1.8 |
| NPN[d] | **12** | 9 | 1.0 | 10 | 2.2 | 10 | 2.4 | 9 | 1.1 |
| PM[e] | **16** | 8 | 1.8 | 11 | 2.5 | 13 | 2.8 | 8 | 1.5 |
| PN[f] | **14** | 7 | 1.2 | 10 | 2.1 | 12 | 2.3 | 7 | 0.9 |
| UPM[g] | **17** | 9 | 1.5 | 12 | 2.4 | 11 | 2.6 | 9 | 1.1 |
| UPN[h] | **15** | 8 | 0.8 | 10 | 1.8 | 11 | 1.2 | 7 | 0.6 |

Notes: a = recommended daily allowance; b = home garden; c = non-poor member; d = non-poor non-member; e = poor member; f = poor non-member; g = ultra-poor member; h = ultra-poor non-member.

These results show that the *IRWH* has a positive impact on food security and nutrition of households. The technology made significant contributions to the amount of energy and vitamins A and C consumed by households, especially during wet seasons. Substantial contributions of garden produce were noted among the project members, but these were not enough to ensure household food security. The results indicate that there are nutritional problems in the study area. Firstly, there is protein-energy malnutrition mainly affecting poor and the ultra-poor households. Secondly, there is hidden hunger affecting all poverty categories, even the non-poor households. When people omit certain foods from their diet or consume relatively small quantities of these foods, they are likely to show problems of food insecurity and poor nutrition. Cereals, roots and tubers are the main source of dietary energy. In order to get sufficient nutrients, people need to consume enough quantities of meat and dairy products as well as fruit and vegetables on a daily basis (Smith *et al*., 2006). The 2007 United Nations report also revealed that while the poverty rate has declined by nearly 6% since 2000 in Sub-Saharan Africa, the region is not on track to reach the goal of reducing poverty and hunger by half by 2015 (UN, 2007).

#### 9.3.3.6 Categorization of households according to food security status

Bickel *et al.* (2000) noted the following four categories of household food security d to categorize households in United States of America:

- ***Food secure households:*** Those that show no or minimal evidence of food insecurity.
- ***Food insecure without hunger:*** Food insecurity is not evident amongst household members as the number of meals is not reduced, however, the quality of food consumed is poor and there is an increase in unusual coping patterns.
- ***Food insecure with hunger (moderate):*** Food intake for adults in the household is reduced to an extent that implies that adults have repeatedly experienced the physical sensation of hunger. In most (but not all) food-insecure households with children, such reductions are not observed at this stage for children.
- ***Food insecure with hunger (severe):*** All households with children have reduced the children's food intake to the extent that signs of malnutrition are visible, indicating that the children have experienced hunger. For some other households with children, this has already occurred at an earlier stage of severity. Adults in households with and without children have repeatedly experienced more extensive reductions in food intake.

## 9.4 SUMMARY AND CONCLUSIONS

The *IRWH* technology had a positive impact on home garden production even though it did not quite address seasonal production of food. Own production is the main source of vegetables consumed at Guquka and Khayalethu in spring and summer compared to only autumn in the past. The strength of the technique is in its potential to improve the intake of vitamins A and C, which are usually lacking in the diet of rural households. There appears to be a strong relationship between own production of food and household nutrition. When own production of food improves, the nutrition of household members improves as well.

The findings of this investigation also revealed income to be a key determinant of food security, having a large influence over both diet quantity and diet quality. The non-poor households had higher diet diversity and energy consumption in both seasons (spring and summer). The diet of the ultra-poor households showed deficiencies in both variables at all seasons. The poor households, whose diet showed better diversity, were obviously limited by their incomes in obtaining and consuming sufficient quantities.

# 10 GENERAL CONCLUSIONS AND RECOMMENDATIONS

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From this study it is clear that for effective moisture conservation the use of micro-catchments in combination with mulching in croplands, and brush in rangelands is vital. Micro-catchments ensure the collection of the water, while mulch or brush reduces evapotranspiration. In rangelands the brush also protects grass seedlings, thereby improving basal cover. It is also evident that the use of cover crops depresses maize yields, but the loss in yield can be compensated for by using the cover crops to feed livestock. In the rural areas of the Eastern Cape Province, including the study area, crop-livestock systems are intricately linked.

From surveys conducted in the target area it is apparent that poverty and unemployment are major problems. Social grants obtained from the state are now the most important source of income. Finding formal employment was shown to be the most effective way to escape poverty, but few households had members who were 'formally" employed. To augment their income, the large majority of households are engaged in agriculture. The contribution of agriculture to the livelihoods of rural homesteads was mainly in the form of food for own consumption. There is scope to further increase the contribution of farming in the food acquisition of households, especially among the ultra-poor.

The findings of this investigation revealed that income is a key determinant of food security, having a large influence over both diet quantity and diet quality. The non-poor households had a higher diet diversity and energy consumption in both growing seasons (spring and summer). The diet of the ultra-poor households showed deficiency in both variables during all seasons. The poor households, whose diet showed better diversity, were obviously limited by their incomes in obtaining and consuming sufficient food.

The results also showed that educational levels of households are generally low. The low levels of education affect the application and adoption of new farming practices as well as development of institutional arrangements. This alone calls for continual capacity building in these communities.

Land tenure and ownership are major challenges in both arable and rangeland, and thus affects the management of these resources. The study results show that both regulative and normative institutions are either weak or absent. Existing institutional arrangements did not work as they were either not formalized or the governance structures to enforce them were absent. In the case of arable land, the main problem is access to land. Options were explored with the landless and landlords on how best to access arable land. Two options were identified, namely, through rental and a formalized share-cropping arrangement. The communities have formed an association (NCBO), which is now a legal community structure, and its main responsibility is to put regulative institutions governing arable land in place. So, both regulative and normative institutions have, to a certain degree, been strengthened during this investigation.

While access to arable land is a major problem in the study area, the results show that almost everyone has access to the rangeland, which is communal property. But it is exactly that free access as well as the absence of institutions that makes this resource so difficult to manage. In an attempt to alleviate the problem the Dalindyebo Farmer's Association (still to be registered) was formed. Its main responsibility is to put in place rules and regulations governing the use and management of rangeland. Other responsibilities include issuing sanctions and grazing licences.

The rangeland condition assessment results showed that the lands at the selected study sites were considered in good condition in terms of protection against soil erosion and runoff. However, there were no veld management plans and, therefore, smallholder farmers in Guquka should be encouraged to apply a camp system (rotational grazing) to afford grazing areas rest periods to improve availability of forage during periods of feed shortages.

In terms of rainwater harvesting practices, the use of brush packs alone improved soil moisture retention. However, the combination of brush packs and minimal soil disturbance with *P. maximum* seeds had the highest moisture retention. Minimal soil disturbance with both *P. maximum* and *E. curvula* without brush packs was not effective in moisture storage. This implies that brush packs had a positive effect on soil water storage, which could be due to reduced evaporation.

Plant-available water at planting ($PAW_p$) indicated that both the $IRWH_{Mulch}$ and $IRWH_{Bare}$ treatments conserved more rainwater during the fallow period than *CON* and *STRIP*. This gave a significantly higher $PAW_p$ or pre-plant water advantage to $IRWH_{Mulch}$ and $IRWH_{Bare}$ compared to *CON* and *STRIP*. Ex-field runoff ($R_{Ex}$) was zero for all the *IRWH* treatments during all seasons while *CON* lost on average 10% of precipitation (P) to $R_{Ex}$. Evaporation from the soil surface (Es) results indicated that all the *IRWH* treatments lost more water to Es than *CON* and *STRIP*. Expressing Es in relation to evapotranspiration (ET) indicated that *IRWH* treatments showed either similar or slightly higher Es/ET values than *CON* and *STRIP*. $IRWH_{Mulch}$ and $IRWH_{Bare}$, through their ability to stop $R_{Ex}$ completely, increased maize grain and biomass yields significantly compared to *CON* and *STRIP*. $IRWH_{Mulch}$ and $IRWH_{Bare}$ produced on average a 20 to 37% higher grain yield than *CON* and *STRIP* and their rainwater productivity (RWP) values were on average between 20% and 33% higher. These results indicated clearly that $IRWH_{Mulch}$ and $IRWH_{Bare}$ are far more efficient than *CON* and *STRIP* at converting rainwater into grain yield.

A comparison of the *IRWH* techniques revealed that there was a consistent trend in grain yield during the experimental period, *viz*. $IRWH_{Mulch} > IRWH_{Bare} > IRWH_{Vet} > IRWH_{Lucerne} > IRWH_{GLDM}$. $IRWH_{Mulch}$ out-performed all the other *IRWH* treatments in all aspects. $IRWH_{Mulch}$ induced 3-16% and 9-14% higher grain yield and RWP, respectively, compared to $IRWH_{Bare}$. *IRWH* treatments without cover crops on the runoff areas produced higher grain yield and RWP increases of 59-86% and 60-100%, respectively, compared to *IRWH* treatments with cover crops. *IRWH* treatments with cover crops on the runoff areas ($IRWH_{GLDM}$; $IRWH_{Vet}$; $IRWH_{Lucerne}$) gave significant lower $PAW_p$, grain yield and RWP compared to *IRWH* treatments without cover crops on the runoff areas ($IRWH_{Mulch}$ and $IRWH_{Bare}$).

The crop model CYP-SA and long-term climate data were used to provide long-term yield simulations to quantify risk. Results obtained from simulations indicate that maize yields could be increased on average by 54% by changing from *CON* to $IRWH_{Bare}$, and by an additional 13% by changing to $IRWH_{Mulch}$. Results indicate that $IRWH_{Mulch}$ was the best treatment in terms of risk reduction, followed by $IRWH_{Bare}$, *CON*, $IRWH_{Vet}$, $IRWH_{Lucerne}$ and $IRWH_{GLDM}$.

The carbon cycle processes in the soil were drastically influenced by tillage (and the system responded accordingly), with the carbon content tending towards a lower equilibrium with long-term cultivation. Carbon trends predicted (based on short-term data) that carbon losses from the no-till *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) would be lower than from the *CON* treatment. It is also believed that the carbon content might stabilize at a relatively higher C content for the *IRWH* treatments ($IRWH_{Mulch}$, $IRWH_{Vet}$ and $IRWH_{GLDM}$) than the *CON* treatment. The highest carbon loss occurred on the *CON* treatment and the lowest on $IRWH_{GLDM}$.

Overall it was found that $IRWH_{Mulch}$ out-performed all the other treatments followed by $IRWH_{Bare}$ > *CON* > *STRIP* > $IRWH_{GLDM}$ > $IRWH_{Vet}$ > $IRWH_{Lucerne}$. It can be concluded that subsistence farmers in semi-arid areas could improve maize yields considerably by replacing *CON* practices with *IRWH* without cover crops and, if possible, apply mulch on the basin and runoff areas. *IRWH* without cover crops is agronomically more sustainable than *CON*.

Use of *IRWH* techniques contributed to a better nutritional status in households by as they planted a variety of vegetables in the homestead gardens. This helped to reduce food insecurity. The majority of households (95%) were able to harvest enough maize for household food consumption and also had surplus produce to feed livestock, sell or give away to family and friends. Those who actually sold surplus produce earned between R200 and R1500. Previously, using the conventional or “old” way of cultivation, food had always been in short supply. Since the implementation of the *IRWH* technique villagers have bought less food from shops.

The project has also enhanced the status of women in the villages. The majority of people who participated in the project were women (60%). Their new found ability to be self-sufficient, generating income and showing enthusiastic participation/leadership in the application of the *IRWH* technique, has contributed to their better status in the villages.

The knowledge and skills level of community members has vastly improved since the first year of the project intervention. The introduction of the *IRWH* technique has created more jobs at homesteads. Different cultivation practices have been learned and more family members have got involved in the production process. The project has also brought about a general revival of committee structures and their activities, especially to coordinate joint actions.

Tanks for roof water harvesting have been installed at seven households in each village. Water collected in the tanks is used for household consumption and to provide supplementary irrigation in homestead gardens to grow vegetables. Village members now have access to a nutritionally balanced diet throughout the year.

Various aspects of rainwater harvesting were communicated to farmers and extension officers at a number of focus group discussions, information days and workshops. Both extension officers and farmers have been assisted through formal and informal training on the various aspects of the *IRWH* technique. To ensure that they were well informed, focus group discussions were held at regular intervals. The implementation of the project resulted in an improvement of the knowledge and skills level of the village members and extension officers. The majority of participants in the project confirmed their intention to allocate more land, where available, for cultivation using the *IRWH* technique. Many of the village members have expanded the *IRWH* technique to more homestead gardens without much assistance from the project team and they have accepted full ownership of the project. They now have the skills and knowledge to implement and manage the *IRWH* crop production technique and will be able to reduce food insecurity in their villages if they continue to use it. The *IRWH* committees in each village are functioning well and are able the support other village members who want to implement the *IRWH* crop production system. Most of the village members are able to work independently and they buy most of their inputs themselves.

The youth were also exposed to the *IRWH* techniques which were implemented at six schools in the Tyhume Valley where water tanks and gutter systems were installed. Scholars and teachers were taught the principles of rainwater harvesting, and how to take measurements from the water tanks as well as from the rain gauges. The scholars were also taught the importance of taking these measurements and were encouraged to do so. Festivals were held where the scholars were invited to participate in the activities and to learn more about *IRWH*.

Farmers are willing to implement *IRWH* and roof water harvesting to collect and save enough water to produce food for household consumption, but still lack sufficient technical skills and support on how to apply the techniques effectively. Some farmers have abandoned them as it is too labour intensive to construct the rainwater harvesting structures and there is a lack of markets to sell their produce. However, those who have continued to use the *IRWH* technique have managed to produce enough for household food security.

The *IRWH* technology has had a positive impact on home garden production even though it did not address seasonal variation in food production. Own production is now the main source of vegetables consumed at Guquka and Khayalethu in spring and summer compared to only autumn in the past. There is a strong relationship between own production of food and household nutrition. When own production of food improves, the nutrition of household members improves as well, especially in the intake of vitamins A and C, which are usually lacking in the diet of rural households.

## 10.1 RECOMMENDATIONS

Implementation of the water harvesting project needs to pay attention to the diversity of livelihoods encountered in the two villages, and focus its attention on households that are most vulnerable to food insecurity, i.e. those falling in the category of the ultra-poor.

It is further, recommended that more farmers be encouraged to implement the *IRWH* crop production system in order to improve the chances of survival of their crops in an area where rainfall is the most limiting factor to crop production. Farmers should also be encouraged to plant a variety of crops in order to have access to a more nutritional diet and to ensure household food security.

Farmers should be informed of the benefits of combining various rainwater harvesting techniques, such as *IRWH* and roof water harvesting, in order to have more water available for household consumption and food production. Although many households in Khayalethu and Guquka are already making use of roof water harvesting to give their crops some supplementary irrigation during drought spells in summer and winter months, the potential of this technique has not yet been realized by all the village members.

Government departments should assist communities by providing the necessary infrastructure and inputs to cultivate the croplands. Fences can be put up using CASP funds and inputs, such as seeds and fertilizer, can be provided by the Food Security Programme of the Provincial Department of Agriculture.

Extension services to support communities should be improved. Continued training of extension personnel to improve service delivery is strongly encouraged as is the establishment of proper markets for farmers to sell their produce.

Youth involvement in agriculture should receive high priority. Schools that showed an interest in the use of the *IRWH* technique should be supported with the necessary technical advice, inputs and fencing material.

In order to eradicate poverty in the Eastern Cape, *IRWH* should be expanded to other districts in the province using Khayalethu and Guquka as a starting point.

Rainwater harvesting practices in rangelands could provide and store water that is useful for vegetation restoration. This study recommends rangeland restoration through various tested rainwater harvesting and restoration techniques, with a strong emphasis on the need to idenify barriers to natural recovery. It is also recommended that a post-restoration management plan be developed that will allow for identification of major factors that influence degradation and will help in circumventing consequences of secondary degradation.

Rangeland water storage is influenced by landform, species composition, basal cover, water use efficiency of grass species, and soil properties. More research in these areas could contribute to incorporating rangeland hydrology into rangeland management practices.

Based on the results from this study and the intricate linkage between the crop and livestock systems in the Eastern Cape it is recommended that the use of micro-catchments in combination with mulch and brush be encouraged. Furthermore, an investigation into the use cover crops that can also be used for livestock feed should be conducted.

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# APPENDICES

**Appendix 1** Description of soils observed at various sites in Khayalethu

| Site No. | Soil form | Horizons | Depth | Clay | Texture | Colour (moist) | Structure | Other features present | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|---|
| K1 | Cartref (Cf) | A-orthic | 300 | 18 | loam to silty loam | very dark greyish-brown | structureless | | 32.6359 | 26.92857 |
| | | E | 1000 | 18 | loam to silty loam | brown to dark brown | structureless | concretions | | |
| | | B-lithocutanic | 1100+ | | | | structureless | | | |
| | | | | | | | | | | |
| K2 | Oakleaf (Oa) | A-orthic | 250 | 20 | loam to silty loam | dark brown | structureless | | 32.63376 | 26.92539 |
| | | B1-neocutanic | 900 | 25 | clay loam to silty clay loam | dark brown | structureless | | | |
| | | C-ud* | 900+ | 35 | clay loam to silty clay loam | | weakly structured | | | |
| | | | | | | | | | | |
| C13 | Oakleaf (Oa) | A-orthic | 250 | 22 | silty loam | brown to dark brown | weakly structured | | 32.63939 | 26.92956 |
| | | B1-neocutanic | 350 | 22 | silty loam | brown to dark brown | weakly structured | | | |
| | | B2-neocutanic | 500 | 25 | loam to silty loam | brown to dark brown | weakly structured | concretions | | |
| | | C1-ud* | 700 | 25 | loam to silty loam | brown to dark brown | weakly structured | concretions | | |
| | | | | | | | | | | |
| C14 | Oakleaf (Oa) | A-orthic | 300 | 24 | loam | brown to dark brown | structureless | | 32.63633 | 26.92372 |
| | | B1-neocutanic | 600 | 26 | loam | light reddish brown | structureless | | | |
| | | B2-neocutanic | 1200+ | 42 | clay | dark reddish brown | structureless | | | |
| | | | | | | | | | | |
| C15 | Vilafontes (Vf) | A-orthic | 150 | 14 | loam | dark greyish brown | weakly structured | | 32.63956 | 26.92806 |
| | | E | 400 | 12 | loam | dark greyish brown | weakly structured | | | |
| | | B-neocutanic | 1000 | 20 | loam to silty loam | | weakly structured | concretions | | |

*ud = unconsolidated material without signs of wetness

**Appendix 2** Analytical results of soil samples taken at various sites in Khayalethu

| Site No. | Horizon | Particle Size (in %) | | | Extractable Cations (Cmol(+)/kg) | | | | | | pH | | Phosphorus (Bray) | Organic C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Na | K | Ca | Mg | S-Value | T-Value | $H_2O$ | KCl | ppm | % |
| C13 | A | 24.6 | 53.4 | 22.0 | 0.18 | 0.13 | 4.89 | 1.33 | 6.53 | 8.73 | 6.70 | 5.08 | 4.90 | 1.28 |
| | B | 25.9 | 52.1 | 22.0 | 0.17 | 0.10 | 8.92 | 1.19 | 10.37 | 9.89 | 6.64 | 5.03 | 1.54 | 1.24 |
| C14 | A | 29.6 | 46.4 | 24.0 | 0.08 | 0.10 | 1.86 | 0.74 | 2.78 | 6.37 | 5.40 | 3.97 | 1.81 | 0.91 |
| | B1 | 28.5 | 45.5 | 26.0 | 0.10 | 0.08 | 2.28 | 1.01 | 3.46 | 8.41 | 5.94 | 4.52 | 1.17 | 1.10 |
| | B2 | 22.2 | 35.8 | 42.0 | 0.16 | 0.11 | 2.32 | 2.51 | 5.10 | 10.00 | 5.96 | 4.80 | 1.07 | 0.35 |
| C15 | A | 40.0 | 46.0 | 14.0 | 0.20 | 0.11 | 1.55 | 0.76 | 2.62 | 4.19 | 6.14 | 4.75 | 0.96 | 0.72 |
| | E | 40.2 | 47.8 | 12.0 | 0.37 | 0.09 | 1.39 | 1.02 | 2.87 | 6.02 | 6.74 | 5.21 | 0.21 | 0.31 |

**Appendix 3** Description of soils observed at various sites in Guquka

| Site No. | Soil form | Horizons | Depth | Clay | Texture | Colour (moist) | Structure | Other features present | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|---|
| GG28 | Wasbank (Wa) | A-orthic | 300 | 20 | loam to silty loam | dark greyish-brown | structureless | | 32.64953 | 26.9422 |
| | | E | 650 | 15-20 | loam to silty loam | dark greyish-brown | structureless | | | |
| | | B-hard plinthite | 750+ | | | | | concretions | | |
| | | | | | | | | | | |
| GG29 | Longlands (Lo) | A-orthic | 200 | 25 | loam to silty loam | dark greyish-brown | structureless | | 32.64491 | 26.9401 |
| | | E | 500 | 20 | loam to silty loam | dark greyish-brown | structureless | | | |
| | | B-soft plinthite | 600+ | 30 | clay loam to silty clay loam | greyish-brown | weakly structured | yellow mottles & concretions | | |
| | | | | | | | | | | |
| GG42 | Cartref (Cf) | A-orthic | 200 | 20 | loam to silty loam | very dark greyish-brown | structureless | | 32.64722 | 26.9422 |
| | | E | 400 | 20 | loam to silty loam | very dark greyish-brown | structureless | | | |
| | | B-lithocutanic | 600+ | 25 | loam to silty loam | | | concretions | | |
| | | | | | | | | | | |
| C11 | Tukulu (Tu) | A-orthic | 300 | 20 | loam | dark yellowish-brown | structureless | | 32.64953 | 26.9417 |
| | | B1-neocutanic | 600 | 22 | loam | dark yellowish-brown | weakly structured | concretions | | |
| | | B2-neocutanic | 900 | 25 | loam | dark yellowish-brown | weakly structured | orange mottles | | |
| | | C-uw* | 1150 | 25 | loam to silty loam | dark yellowish-brown | weakly structured | | | |
| | | | | | | | | | | |
| C12 | Oakleaf (Oa) | A-orthic | 200 | 18 | loam | dark yellowish-brown | weakly structured | | 32.64736 | 26.94283 |
| | | B1-neocutanic | 450 | 20 | loam | dark yellowish-brown | weakly structured | | | |
| | | C1-ud* | 700 | 25 | loam to silty loam | dark yellowish-brown | weakly structured | concretions | | |
| | | C2-saprolite | 700+ | | | | structureless | gravel | | |
| | | | | | | | | | | |
| GG16 | Cartref (Cf) | A-orthic | 300 | 15-20 | loam to silty loam | | structureless | | 32.65033 | 26.93786 |
| | | E | 500 | 15-20 | loam to silty loam | | structureless | concretions | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | B-lithocutanic | 1000+ | 25 | loam to silty loam | | structureless | concretions | | |
| | | | | | | | | | | |
| GG17 | Tukulu (Tu) | A-orthic | 400 | 15-20 | loam to silty loam | | structureless | | 32.65029 | 26.93632 |
| | | B-neocutanic | 900 | 25 | loam to clay loam | | weakly structured | | | |
| | | C-uw* | 1200+ | 25 | loam to silty loam | | structured | yellow mottles | | |
| | | | | | | | | | | |
| GG19 | Oakleaf (Oa)/ Vilafontes (Vf) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.65028 | 26.93356 |
| | | B1-neocutanic/E | 500 | 20 | loam to silty loam | | structureless | | | |
| | | B/C-neocutanic/ud* | 700+ | 25 | loam to silty loam | | weakly structured | | | |
| | | | | | | | | | | |
| GG23 | Sepane (Se) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.64744 | 26.93564 |
| | | B-pedocutanic | 700 | 30 | clay loam to silty clay loam | | structured | | | |
| | | C-uw* | 800+ | 30-35 | clay loam to silty clay loam | | structured | greyish mottles & concretions | | |
| | | | | | | | | | | |
| GG25 | Swartland (Sw) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.64833 | 26.93774 |
| | | B-pedocutanic | 500 | 30-35 | clay loam to silty clay loam | | structured | gravel | | |
| | | C-saprolite | 700+ | 35+ | Clay-loam to clay | | structured | | | |
| | | | | | | | | | | |
| GG26 | Oakleaf (Oa) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.64831 | 26.93881 |
| | | B1-neocutanic | 600 | 25 | loam to silty loam | | weakly structured | | | |
| | | C-ud* | 700+ | 30 | loam to clay loam | | weakly structured | | | |
| | | | | | | | | | | |
| GG27 | Wasbank (Wa) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.64671 | 26.93919 |
| | | E | 600 | 20 | loam to silty loam | | structureless | yellow mottles | | |
| | | B-hard plinthite | 600+ | | | | | | | |
| | | | | | | | | | | |

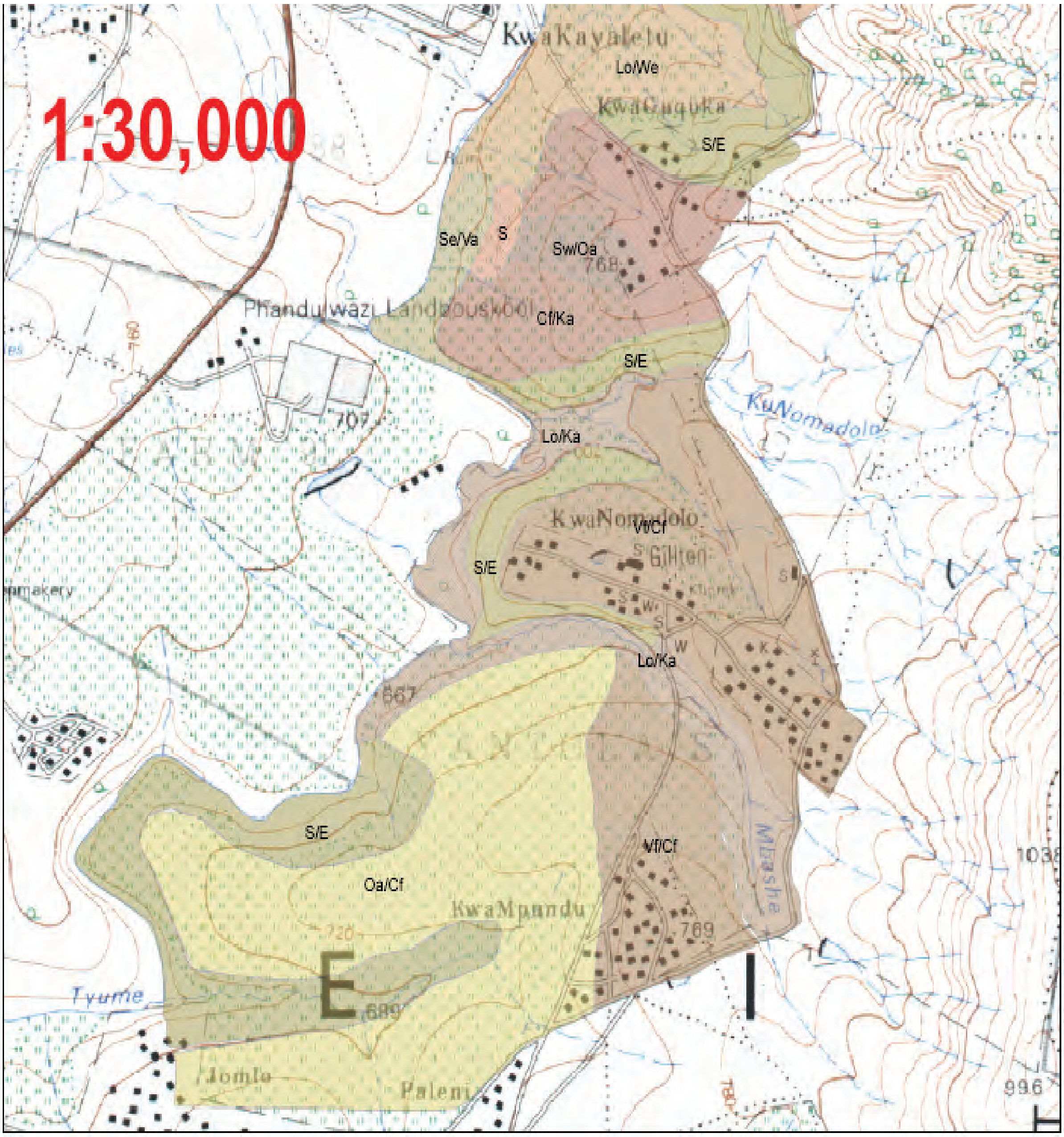
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| GG32 | Longlands (Lo) | A-orthic | 200 | 15 | loam to silty loam | | structureless | | 32.64158 | 26.93578 |
| | | E | 450 | 15 | loam to silty loam | | structureless | | | |
| | | B-soft plinthite | 900+ | 20 | loam to silty loam | | structureless | yellow mottles & concretions | | |
| | | | | | | | | | | |
| GG33 | Longlands (Lo) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.643 | 26.93453 |
| | | E | 600 | 20 | loam to silty loam | | structureless | yellow mottles | | |
| | | B-soft plinthite | 900+ | 25 | loam to silty loam | | structureless | yellow mottles & concretions | | |
| | | | | | | | | | | |
| GG34 | Longlands (Lo) | A-orthic | 200 | 15-20 | loam to silty loam | | structureless | | 32.63965 | 26.93862 |
| | | E | 500 | 15-20 | loam to silty loam | | structureless | concretions | | |
| | | B-soft plinthite | 600+ | 30 | clay loam | | weakly structured | yellow mottles & concretions | | |
| | | | | | | | | | | |
| GG35 | Longlands (Lo) | A-orthic | 200 | 15-20 | loam to silty loam | | structureless | | 32.64119 | 26.93951 |
| | | E | 500 | 15-20 | loam to silty loam | | structureless | concretions | | |
| | | B-soft plinthite | 600+ | 30 | clay loam | | weakly structured | yellow mottles & concretions | | |
| | | | | | | | | | | |
| GG38 | Longlands (Lo) | A-orthic | 200 | 20 | loam to silty loam | | structureless | | 32.64051 | 26.93713 |
| | | E | 400 | 20 | loam to silty loam | | structureless | | | |
| | | B1-soft plinthite | 700 | 30 | clay loam | | weakly structured | yellow mottles & concretions | | |
| | | B2-hard plinthite | 700+ | | | | | | | |
| | | | | | | | | | | |
| GGP1 Profile | Cartref (Cf) / Wasbank (Wa) | A-orthic | 330 | 18-22 | loam to silty loam | | structureless | | 32.65153 | 26.93714 |
| | | E | 600 | 18-22 | loam to silty loam | | structureless | | | |
| | | B-hard plinthite/sl* | 720 | 25-30 | loam to clay loam | | weakly structured | concretions | | |
| | | B-lithocutanic | 800+ | 40+ | clay loam to clay | | weakly structured | concretions | | |

*ud = unconsolidated material without signs of wetness *uw = unconsolidated material with signs of wetness *sl = stone line

**Appendix 4** Analytical results of soil samples taken at various sites in Guquka

| Site No. | Horizon | Particle Size (in %) | | | Extractable Cations (Cmol(+)/kg) | | | | | | pH | | Phosphorus (Bray) | Organic C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Na | K | Ca | Mg | S-Value | T-Value | $H_2O$ | KCl | ppm | % |
| C11 | A | 44.0 | 35.7 | 20.7 | 0.10 | 0.31 | 2.46 | 1.11 | 3.98 | 9.04 | 6.12 | 5.16 | 18.24 | 1.35 |
| | B | 41.2 | 36.8 | 22.0 | 0.13 | 0.22 | 2.59 | 1.34 | 4.28 | 6.37 | 6.48 | 5.23 | 6.39 | 1.03 |
| C12 | A | 44.8 | 37.2 | 18.0 | 0.12 | 0.31 | 2.01 | 0.94 | 3.38 | 5.32 | 6.24 | 4.87 | 8.09 | 0.70 |
| | B | 44.5 | 33.5 | 22.0 | 0.18 | 0.23 | 2.39 | 1.36 | 4.16 | 7.22 | 6.90 | 5.64 | 1.28 | 0.55 |

**Appendix 5** Soil map indicating the distribution of soils in the study area. (Potgieter, 2005)




| Map Unit | Dominant soil forms and families | Map Unit | Dominant soil forms and families |
|---|---|---|---|
| Cf | Cartref<br>1110 | Vf | Vilafontes<br>1120 |
| Ka | Katspruit<br>1000 | Wa | Cartref<br>1110 |
| Lo | Longlands<br>1000 | Wa | Wasbank<br>1000 |
| Oa | Oakleaf<br>2220 | We | Westleigh<br>1000 |
| Swa | Swartland<br>1112 | | |

## **Appendix 6** Soil profile description of the University of Fort Hare/Oakleaf-Ritchie ecotope

**NATIONAL SOIL PROFILE NO**:
**Map / photo:**
**Latitude & Longitude:**
**Land type No**:
**Climate zone:**
**Altitude:**
**Terrain unit**: Foot slope
**Slope:** 1%
**Slope shape:** Straight
**Aspect**: West
**Micro relief:** None
**Parent material solum**
**Underlying material:**

**Soil Form:** Oakleaf
**Soil Family:** Ritchie
**Surface rockiness:** None
**Surface stoniness:** None
**Occurrence of flooding:** None
**Wind erosion:** None
**Water erosion:** None
**Vegetation / Land use:** Agronomic Cash Crops
**Water table:**
**Described by:** L.F. Joseph
**Date described:** 05 November 2005
**Weathering of underlying material:** Strong physical and weak chemical
**Alteration of underlying material:** Generalised

| Horizon | Depth (mm) | Description | Diagnostic horizons |
|---|---|---|---|
| A | 0-300 | Dry colour: dark brown 10YR3/3; moist colour: very dark brown 10YR 2/2; structure: sub-angular; consistence (dry): soft; consistence (moist): friable; wet-stickness: non-sticky common fine pores; water absorption: 3 second(s); many roots; abrupt transition | Orthic |
| B1 | 300-600 | Dry colour: very dark greyish brown 10 YR 3/2; moist colour: very dark grey 10YR3/1 consistence (dry): slightly hard; consistence (moist): slightly firm; wet-stickness: slightly-sticky coarse fragments: none; water absorption: 3 second(s); many roots; many fine pores; abrupt transition | Neocutanic |
| B2 | 600+ | Dry colour: dark yellowish brown 10YR 4/6; moist colour: dark yellowish brown 10 YR 4/4; consistence (dry): soft; consistence (moist): friable, many fine pores; clear transition | Neocutanic |

## **Appendix 7** Soil profile description of the Phandulwazi/Westleigh ecotope

**NATIONAL SOIL PROFILE NO**:
**Map / photo:**
**Terrain unit**: Upper foot slope
**Slope:** 3%
**Slope shape:** Straight
**Aspect:** East
**Micro relief:** None
**Parent material solum:** Solid rock
**Underlying material:** Mudstone

**Soil Form:** Westleigh
**Soil Family:** Helena
**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:** L.F. Joseph
**Date described:** November 2006
**Weathering of underlying material**: Strong physical and weak chemical
**Alteration of underlying material**:

| Horizon | Depth (mm) | Description | Diagnostic horizons |
|---|---|---|---|
| A | 0-400 | Dry colour: dark greyish brown 10YR4/2; moist colour: very dark greyish brown 10YR3/2; loam; structure: apedal, consistence (dry): very hard; consistence (moist): friable; wet-stickiness: non-sticky; few very fine pores; water absorption: 3 second (s); many roots; abrupt transition | Orthic |
| B1 | 400-700 | Dry colour: grey 5 YR 5/1; moist colour: very dark grey 5YR3/1; loam, structure: angular blocky; consistence (dry) hard; consistence (moist): slightly firm; non-sticky, few fine pores; water absorption: 2 second (s); common roots; abrupt transition. | Soft plinthic |
| B2 | 700-1100 | Dry colour: red 2.5YR 4/8; moist colour: dark red 2.5YR 3/6; loam; structure: angular blocky, consistence (dry): loose; consistence (moist): friable, few fine pores; water absorption: 2 second (s), gradual transition | Soft plinthic |

**Appendix 8** Soil profile description of the Guquka/Cartref-Frosterley ecotope

**NATIONAL SOIL PROFILE NO:**
**Map / photo:**
**Latitude & Longitude:** 32 39 05 & 26 56 13
**Land type No:**
**Climate zone:**
**Altitude:**
**Terrain unit:** Upper midslope
**Slope:** 4%
**Slope shape:** Concave
**Aspect:** North
**Micro relief:** None
**Parent material solum:**
**Underlying material:** Grey mudstone

**Soil Form:** Cartref 1100
**Soil Family:**
**Surface rockiness:** None
**Surface stoniness:** None
**Occurrence of flooding:** None
**Wind erosion:** None
**Water erosion:** None
**Vegetation / Land use:** Agronomic Cash Crops
**Water table:**
**Described by:** L.F. Joseph
**Date described:** 19 May 2005
**Weathering of underlying material:** Strong physical and weak chemical
**Alteration of underlying material:** Generalised

| Horizon | Depth (mm) | Description | Diagnostic horizons |
|---|---|---|---|
| A | 0-330 | Dry colour: yellowish brown 10YR5/6; moist colour: dark greyish brown 10YR4/2; loam to silty loam; structure: apedal massive; consistence (dry): loose; consistence (moist): friable; wet-stickness: non-sticky; few fine pores; water absorption: 2 second(s); many roots; abrupt transition. | Orthic |
| E | 330-600 | Dry colour: dark grey 10 YR 4/1; moist colour: very dark grey 10YR3/1; loam to silty loam consistence (dry): loose; consistence (moist): friable; wet-stickness: slightly-sticky; few fine pores; coarse fragments: very few sesquioxide concretions; water absorption: 4 second(s); few roots; clear transition | E |
| B | 600+ | Dry colour: yellowish brown 10YR 5/4; moist colour: red 2.5 YR 4/6; loam to silty loam; consistence (dry): hard; consistence (moist): very firm, common fine pores; few medium pores; gradual transition | Lithocutanic |

**Appendix 9** Soil analytical data for the University of Fort hare/Oakleaf-Ritchie ecotope

| Depth | pH ($H_2O$) | C | P (Bray 1) | Na | K | Ca | Mg | S-value | CEC | C-sand | M-sand | F-sand | VF-sand | C-Silt | F-silt | Clay | Texture | Sand grade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | | % | mg $kg^{-1}$ | | | | | cmol(+)$kg^{-1}$g | | % | | | | | | | | |
| 0-300 | 6.41 | 1.05 | - | 0.23 | 0.42 | 6.38 | 2.64 | 9.68 | 16.02 | 0.21 | 1.91 | 12.00 | 15.50 | 31.95 | 15.82 | 20.86 | Loam | Fine |
| 300-600 | 7.16 | 0.65 | - | 0.41 | 0.17 | 7.51 | 2.59 | 10.68 | 15.17 | 0.21 | 0.63 | 11.45 | 18.38 | 30.30 | 15.44 | 22.01 | Loam | Fine |
| 600-900 | 7.74 | 0.47 | - | 0.56 | 0.18 | 7.49 | 2.81 | 11.04 | 13.92 | 0.00 | 0.62 | 10.37 | 17.97 | 30.08 | 15.30 | 23.67 | Loam | Fine |
| 900-1200 | 7.52 | 0.33 | - | 0.51 | 0.18 | 7.19 | 2.79 | 10.66 | 13.25 | 0.20 | 0.60 | 9.93 | 16.54 | 14.09 | 16.41 | 21.00 | Loam | Fine |

**Appendix 10** Soil analytical data for the Phandulwazi/Westleigh ecotope

| Depth | pH ($H_2O$) | C | P (Bray 1) | Na | K | Ca | Mg | S-value | CEC | C-sand | M-sand | F-sand | VF-sand | C-Silt | F-silt | Silt | Clay | Texture | Sand grade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | | % | mg $kg^{-1}$ | | | | | cmol(+) $kg^{-1}$ | | % | | | | | | | | | |
| 0-300 | 5.89 | 0.86 | 2.62 | 0.10 | 0.38 | 3.28 | 0.95 | 4.69 | 8.26 | 1.5 | 1.1 | 13.6 | 16.4 | 33.7 | 13.4 | 47.1 | 17.6 | Lm | Fine |
| 300-600 | 5.91 | 0.63 | 2.13 | 0.15 | 0.16 | 2.55 | 1.07 | 3.93 | 6.10 | 3.5 | 1.2 | 13.9 | 16.2 | 31.4 | 13.3 | 44.7 | 18.8 | Lm | Fine |
| 600-900 | 6.26 | 0.35 | 2.18 | 0.28 | 0.13 | 2.20 | 1.52 | 4.13 | 7.20 | 14.1 | 3.2 | 8.8 | 13.8 | 24.6 | 13.1 | 37.7 | 20.7 | Lm | Coarse |
| 900- 1200 | 6.70 | 0.13 | 2.58 | 0.45 | 0.15 | 3.60 | 3.14 | 7.33 | 9.05 | 8.5 | 1.5 | 5.3 | 12.2 | 29.2 | 18.4 | 47.6 | 22.7 | Lm | Fine |

**Appendix 11** Soil analytical soil data for the Guquka/Cartref-Fosterley ecotope

| Depth | pH ($H_2O$) | C | Phosphorus (Bray 1) | Na | K | Ca | Mg | S-value | CEC | C-sand | M-sand | F-sand | VF-sand | C-Silt | F-silt | Silt | Clay | Texture | Sand grade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | | % | mg kg$^{-1}$ | | | | | cmol(+) kg$^{-1}$ | | % | | | | | | | | | |
| 0-330 | 6.04 | 0.56 | 3.06 | 50 | 53 | 442 | 118 | | | 2.9 | 2.0 | 27.3 | 19.96 | 21.1 | 12.1 | 12.7 | SaLm | FINE | Fine |
| 330-600 | 6.70 | 0.56 | 1.18 | 54 | 32 | 520 | 157 | | | 5.2 | 1.5 | 24.3 | 18.63 | 22.4 | 11.1 | 15.1 | Lm | FINE | Fine |
| 600-1200 | 7.19 | 0.28 | 1.16 | 125 | 52 | 555 | 315 | | | 14.0 | 2.0 | 23.13 | 2.9 | 15.3 | 12.3 | 28.6 | ClLm | FINE | Fine |

**Appendix 12** Examples of records of vegetables produced in the homestead gardens kept by individual community members

MAUD PETENI'S HARVEST OF SIBONE-SAKHOLWA
KHAYALETHU LOCATION

Carrots planted on 8 May 2005
1 bunch as from 22 Aug. eaten at home.
3 bunches sold
7 bunches eaten
7 bunches sold → These are from carrots planted 4 July sold from 7 Nov.
18 bunches total
I am still having carrot.

SPINACH transplanted 13 June sold from October
15 bunches sold
10 bunches eaten
10 bunches to friends
45 Still having more

ONION transplanted 13 JUNE sold towards end Oct.
20 bunches sold
8 bunches eaten
Still having more

CABBAGES transplanted 7 July sold towards end Oct.
TOTAL eaten, sold and given to friends = 35
Still having cabbage

NAME: MAUD PETENI
VILLAGE: KHAYALETHU
SIZE OF BACKYARD LENGTH X BREATH
UBUDE NOBUBANZI BEGADI

| ENTERPRISE (UDIDI LWESITYALO) | ENTERPRISE SIZE UTYALE KWI ENGAKANANI) (L x B) | PLANTING DATE (UTYALE NINI) | HARVESTING DATE (UVUNE NINI) | AMOUNT HARVESTED (UVUNE KANGAKA | PRICE/BUNCH (IXABISO) |
|---|---|---|---|---|---|
| ONION | 4x 3m | 8 May 2007 | Nov. 2007 | 45 bunches | R5.00 |
| SPINACH | 3X 3 m | 7 June | October 07 | 10 bunches | R3.50 |
| CARROTS | 4X 3 m | 6 July | Nov/Dec 07 | 21 bunches | R4.00 |
| BROCHOLLI | 3 x 3m | ✓ | DEC. 07 | 50 heads | R5.00 |
| ONION | 4 X3 | ✓ | JAN. 2008 | 25 bunches | R5.00 |
| CABBAGE | 3X3 | ✓ | DEC. 07 | 24 heads | R5.00 |
| BEETROOT | 3X3 | ✓ | DEC. 07 | 15 bunches | R5 |
| SPINACH | 3X3 | ✓ | Nov/DEC 07 | 11 bunches | R3.50 |
| CAULIFLOWER | 3X3m | 13 AUG. | JAN. 08 | 30 heads | R5.00 |
| SQUASH | 3 X 3m | ✓ | Nov. 07 | 45 | R3.00 |
| BEANS | 6x3 m | 17 Aug. | DEC. 07 | 2x5 l. | |
| BRUSSEL SPROUTS | 3x3m | 17 Aug. | ? | ? | |
| GREEN PEPPER | 2X3 m | 17 Aug. | | 2 pockets | |
| LETTUCE | 1 X3m | ✓ | NOV. 07 | 10 heads | R3.00 |
| TOMATOES | 2 x 3m | ✓ | JAN. 08 | 16 bunches | R4.00 |
| PARSLEY | 2 x 3m | 11 SEPT. | | 30 [illegible] | |
| CARROTS | 4x 3m | 25 SEPT. | | 20 bunches | |

NAME: S.M. Sonjani
VILLAGE: KhayaleThu
SIZE OF BACKYARD LENGTH X BREATH
UBUDE NOBUBANZI BEGADI

| ENTERPRISE (UDIDI LWESITYALO) | ENTERPRISE SIZE UTYALE KWI ENGAKANANI) (L x B) | PLANTING DATE (UTYALE NINI) | HARVESTING DATE (UVUNE NINI) | AMOUNT HARVESTED (UVUNE KANGAKA | PRICE/BUNCH (IXABISO) |
|---|---|---|---|---|---|
| Onions | 3X3 mitres | 6-7-2007 | used | | R4. bunch |
| spinach | 3X3 mitres | 6-7-2007 | sold | 2 bunches | R4. each |
| Beetroots | 3X3 mitres | 9-7-2007 | used | 14 bunches | R4. |
| Carrots | 3X3 mitres | 9-7-2007 | | | |
| Cabbage | 4X3 mitres | 9-7-2007 | to be used | not D/K | in house |
| Cabbage Trans. | 6X3 [illegible] | 23-8-2007 | all sold | [illegible] 48 | @R5.00 each |
| onions Trans. | 1x3 mitres | 22-8-2007 | sold | 2 bunches | R4.00 each |
| Butternuts | 3X3 mitre plots | 24-8-2007 | [illegible] | 2 bunches | R4.00 each |
| water melon | 3X3 " " | 24-8-2007 | | | |
| Green pepper | 2X3 " " | 13-08-2007 | coming up bit by bit | | |
| Garden Beans | 3X3 " " | 18-09-2007 | | | |
| Sprayed vegetables | | 19-09-2007 | | | |
| Tomatoes | 2X3 " | 1st 10 2007 | | | |
| Cabbage | 3X3 " | 05-10-2007 | | | |
| Green pepper | Trans(10) plants | 24-10-2007 | in Front of Butternuts | | |
| Sprayed | cabbage onion | 26-10-2007 | | | |

**Appendix 13** Socio-economic survey on RWH&C conducted in Khayalethu and Guquka during 2004

## Questionnaire identification

| | |
|---|---|
| **Enumerator's name** | |
| **Date** | |
| **Village** | |
| **Name of respondent** | |
| **Questionnaire reference number** | |

### A. DEMOGRAPHIC INFORMATION

A1. Household characteristics

| Relation to head of hh | Age | Gender | Marital status | Education | Employment status | Occupation | Field of employment | Time home |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

Household size =
Active pp =
Gender head =
Age head =

### B. LAND AND AGRICULTURE

B1 Does this household own a residential site?
Yes = 1 No = 2

B2 What is the size of your residential site?

................................m x....................................m

B3 Do you have a garden on your residential site?
Yes = 1 No = 2

B4 What is its size?
...........................m x .....................m

B5 Do you grow crops or vegetables in your garden?
Yes =1 No = 2

B6 Please indicate the kinds of crops or vegetables you grow, the area allocated to these as well as the reasons for growing them

| Crop | Area | Yield in kg (2003/2004) | Reason for growing |
|---|---|---|---|
| Maize | | | |
| Dry beans | | | |
| Dry peas | | | |
| Pumpkins | | | |
| Butternut | | | |
| Potatoes | | | |
| Cabbages | | | |
| Carrots | | | |
| Beet | | | |
| Spinach | | | |
| Onions | | | |
| Other (specify) | | | |

B7 Which factors influence your choice of crops in any growing season? Name them in order of importance.

a)…………………………………………………………………………………………………
b)………………………………………………………………………………………………...
c)…………………………………………………………………………………………………
d)………………………………………………………………………………………………...
e)…………………………………………………………………………………………………

B8 What method of cultivation do you normally use in your garden?

a. A Tractor-equipment set
b. Animal Draught traction
c. Hand ploughing

B9 Who is responsible for the following garden activities in your household?

a) Ploughing
b) Planting
c) Weeding
d) Irrigating
e) Harvesting

B10 Do you sometimes irrigate crops/vegetables grown in your garden?

Yes =1 No = 2

B11 If yes to B9, what is the source of this water?

…………………………………………………………………………………………

B12 How is water brought to the garden area?

…………………………………………………………………………………………………..

B13 Do you make use of chemical fertilizers in your garden?

Yes =1 No = 2

B14 Do you apply kraal manure in your garden?
Yes =1 No = 2

B15 If yes to B14, where do you obtain manure?

a) Own kraal
b) Neighbours and relatives

B16 If manure is obtained outside, do you pay for it?
Yes = 1 No = 2

B17 If yes to B16, how much do you pay?
………………………………………………………………………………………………….

B18 How often do you apply manure?

a) Once a year
b) Once in two years
c) Once in five years
d) Other (specify)

B19 Do you have a preference for a particular type of manure in terms of animals?
Yes = 1 No = 2

B20 If yes to B19, which animal manure do you prefer?
…………………………………………………………………………………………………

B21 What are your reasons for preferring this manure?
………………………………………………………………………………………………….
…………………………………………………………………………………………………..

B22 Do you have access to one or more arable fields?

Yes = 1 No = 2

B23 If yes, how many fields do you have access to? (indicate number)
……………………………………………………………..……..……………………………………….

B24 What is the size of each of the fields?

| | | Area (indicate units) |
|---|---|---|
| 8.1 | Field 1 | |
| 8.2 | Field 2 | |
| 8.3 | Field 3 | |

B25 How did you obtain access to each of the fields?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

B26 Did you grow any crops on your arable land during the past three seasons?
Yes = 1 No = 2

B27 If no, why not?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

B28 If yes, which crops did you grow? Please indicate acreage, yield and reasons for growing them

| **Crop** | **Area** | **Yield in kg (2003/2004)** | **Reason for growing** |
|---|---|---|---|
| Maize | | | |
| Sorghum | | | |
| Dry beans | | | |
| Dry peas | | | |
| Pumpkins | | | |
| Potatoes | | | |
| Other (specify) | | | |

B29 What method of cultivation do you normally use in your field?

a) A Tractor-equipment set

b) Animal Draught traction

c) Other (specify)

B30 Who is responsible for the following field activities in your household?

a) Ploughing
b) Planting
c) Weeding
d) Harvesting

B31 Do you make use of chemical fertilizers in your field?

Yes = 1 No = 2

B32 Do you apply kraal manure in your field?

Yes = 1 No = 2

B33 How often do you apply manure in your field?

a) Once a year
b) Once in two years
c) Once in five years
d) Other (specify)

B34 Which of the following equipments do you use in your field? Please indicate whether it's your own, borrowed or hired.

| **Equipment** | **Own** | **Borrowed** | **Hired** |
|---|---|---|---|
| Plough | | | |
| Planter | | | |
| Cultivator | | | |
| Spade | | | |
| Rake | | | |
| Fork spade | | | |
| Hoe | | | |
| Other (specify) | | | |

B35 Which of the following animals do you keep? Indicate numbers owned and reasons for keeping them.

| TYPE | Number owned | Reason for keeping |
|---|---|---|
| Broilers | | |
| Layers | | |
| Dual-purpose chickens | | |
| Pigs | | |
| sheep | | |
| Goats | | |
| Cattle | | |
| Donkeys | | |
| Horses | | |

## C INCOME

What are the sources of income available to your household and what amounts are received per month or per year?

C1 EXTERNAL SOURCES

| | Source | C | Exp/C (R) | Tot. inc/C (R) | No. C/a | Net inc/a (R) |
|---|---|---|---|---|---|---|
| C1.1 | Remittances (Cash) | | | | | |
| C1.2 | Remittances (Kind) | | | | | |
| C1.3 | Child support from parent outside household | | | | | |
| C1.4 | Salaries & Wages | | | | | |
| C1.5 | Overtime | | | | | |
| C1.6 | Bonuses | | | | | |
| C1.7 | Pensions | | | | | |
| C1.8 | Disability grant | | | | | |
| C1.9 | Child support grant | | | | | |
| C1.10 | Other government grants | | | | | |

C2 LOCAL SOURCES: TRADE

| | | | | | | |
|---|---|---|---|---|---|---|
| C2.1 | Hawking (Food) | | | | | |
| C2.2 | Hawking (Other) | | | | | |
| C2.3 | Spaza shop | | | | | |
| C2.4 | Shop | | | | | |
| C2.5 | Selling liquor/shebeen | | | | | |
| C2.6 | Lending money | | | | | |
| C2.7 | Other trade | | | | | |

C3 LOCAL SOURCES: AGRICULTURE

| C3.1 | Source | C | Exp/C | GI/C | C/a | NI/a |
|---|---|---|---|---|---|---|
| C3.2 | Agriculture (Kind) : Crops | | | | | |
| C3.3 | Agriculture (Kind) : Animals | | | | | |
| C3.4 | Agriculture (Cash) : Crops | | | | | |
| C3.5 | Agriculture (Cash) : Animals | | | | | |

C4 LOCAL SOURCES: HOUSING INDUSTRY

| | | | | | | |
|---|---|---|---|---|---|---|
| C4.1 | Building of houses/thatching | | | | | |
| C4.2 | Carpentry | | | | | |
| C4.3 | Electrical installations | | | | | |
| C4.4 | Plumbing | | | | | |
| C4.5 | Making toilets | | | | | |
| C4.6 | Sewing and selling clothing | | | | | |
| C4.7 | Brick making | | | | | |
| C4.8 | Brooms, baskets and other weaving | | | | | |
| C4.9 | Making and selling foods or meals | | | | | |
| C4.10 | Preparing and selling traditional medicines | | | | | |
| C4.11 | Arts and craft | | | | | |
| C4.12 | Chopping and selling wood | | | | | |

C5 LOCAL SOURCES: TRANSPORT

| | | | | | | |
|---|---|---|---|---|---|---|
| C5.1 | Transport of goods and people | | | | | |

C6 LOCAL SOURCES: MAINTENANCE

| | | | | | | |
|---|---|---|---|---|---|---|
| C6.1 | Repairs (electric) | | | | | |
| C6.2 | Repairs (mechanical) | | | | | |
| C6.3 | Repairs (other) | | | | | |

C7 LOCAL SOURCES: AGRICULTURAL SERVICES

| | | | | | | |
|---|---|---|---|---|---|---|
| C7.1 | Land preparation for farmers | | | | | |
| C7.2 | Fencing and kraal making | | | | | |

C8 LOCAL SOURCES: OTHER

| | | | | | | |
|---|---|---|---|---|---|---|
| C8.1 | Provide casual labour to other community members (All tasks) | | | | | |
| C8.2 | Other self-employment activities | | | | | |

**D. EXPENDITURE**

D1 How much money does your household spend on the following items per month or per year?

| | Item | | C | Exp/C (R) | C/a | Exp/a (R) |
|---|---|---|---|---|---|---|
| D1.1 | Groceries | Food | | | | |
| D1.2 | | Cleaning materials | | | | |
| D1.3 | | Cosmetics | | | | |
| D1.4 | Fuel | | | | | |
| D1.5 | Clothing | | | | | |
| D1.6 | Furniture | | | | | |
| D1.7 | Medical expenses | | | | | |
| D1.8 | Educational expenses | | | | | |
| D1.9 | Transport (work) | | | | | |
| D1.10 | Transport (other) | | | | | |
| D1.11 | Housing rates and rentals | | | | | |
| D1.12 | Maintenance/building of residence | | | | | |
| D1.13 | Maintenance (Other) | | | | | |
| D1.14 | Hiring of labour | | | | | |

| | Item | C | Exp/C (R) | C/a | Exp/a (R) |
|---|---|---|---|---|---|
| D1.15 | Telephone and postage | | | | |
| D1.16 | Subscription and membership fees | | | | |
| D1.17 | Church contributions | | | | |
| D1.18 | Entertainment, tobacco and liquor | | | | |
| D1.19 | Interest on loans | | | | |
| D1.20 | Other (Specify) | | | | |

D2 Do you save any money in any of the following? (Tick where applicable)

| | | Total amount<br>a | Amount per month (R)<br>b | Total amount per annum (R)<br>c |
|---|---|---|---|---|
| D2.1 | Formal institutions (bank, building societies, trusts) | | | |
| D2.2 | Saving policy/insurance | | | |
| D2.3 | Burial clubs | | | |
| D2.4 | Mgalelo | | | |

D3 Do you have any credit outstanding?
Yes = 1 No = 2

D4 If Yes, please provide the following information

| | Institution or person<br>a | Amount (R)<br>b | Interest rate<br>c | Guarantee<br>d | Duration<br>e |
|---|---|---|---|---|---|
| D4.1 | | | | | |
| D4.2 | | | | | |
| D4.3 | | | | | |
| D4.4 | | | | | |

## E MARKETING AND AGRICULTURAL SUPPORT SERVICES

E1 Where do you purchase your inputs (seed, seedlings, fertilizer and chemicals)?

a) local shops
b) Alice
c) KWT
d) EL

E2 Do you sell some of the products you produce?

…………………………………………………………………………………………
…………………………………………………………………………………………

E3 If yes, which products do you normally sell?

a) ………………………………………………………………………………………
b) ………………………………………………………………………………………
c)……………………………………………………………….……………………….
d) ………………………………………………………………………………………
e) ………………………………………………………………………………………

E4 Who are the buyers of your products?

a) ………………………………………………………………………………………
b)……………………………………………………………………………………….
c)……………………………………………………………………………………….
d) ………………………………………………………………………………………
e) ………………………………………………………………………………………

E5 How do buyers get the products?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………...

E6 What marketing problem do you encounter?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………….

E7 What can be done to solve the problem?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

E8 Do you have storage facilities for your products?

Yes No

E9 If Yes, how is the condition of the storages?

…………………………………………………………………………………………
……………………………………………………………………………………....

E10 If No, how do you store your products?
…………………………………………………………………………………………………
……………………………………………………………………………………………....

E11 Do you have access to agricultural extension services?

Yes No

E12 If Yes to E10, what kind of extension advice do you receive?

a) Technical advice
b) Marketing and business skills
c) Management
d) other (specify)

E13 Who provides the agricultural extension advice?

a) extension officers of the DOA
b) NGO (specify)
c) Other (specify)

E14 How often are the visits?

| **Service** | **Frequency** |
|---|---|
| EO of the DOA | |
| NGO | |
| Other | |

E15 Do you have access to credit facilities?

Yes No

E16 If yes, where do you obtain credit? Mention both formal and informal institutions
…………………………………………………………………………………………………
…………………………………………………………………………………………………

**F SOCIAL SUPPORT SERVICES**

F1 Do you have access to water and sanitation?

Yes No

F2 What is the source of water for domestic purposes?

a) river
b) dam
c) underground water
d) tap water
e) other, specify

F3 Do you have access to electricity?

Yes No

F4 If Yes, for what purpose is electricity used for?
a) lighting
b) cooking
c) operating machines (e.g. TV. Radio, fridge, etc.)
d) other, specify

F5 Which of the following educational institutions available in your village?
a) crèche
b) primary school
c) high school

F6 Do you have access to medical services in this village?

Yes No

F7 If Yes, which medical services available within your community?
a) Clinic
b) Mobile clinic
c) Hospital
d) Traditional healer
e) Other, specify

F8 Does your household have access to rangeland?
Yes No

F9 What does your household use the range land for?
a) Graze livestock
b) Collect fruit and vegetables
c) Collect firewood
c) Other, specify

**G NUTRITION**

G1 Does your household always have enough food to eat?
Yes No

G2 If No, what are the reasons?
………………………………………………………………………………………………
…………………………………………………………………………………………….

G3 Are there particular times of the year during which food is in short supply?
Yes No

G4 If Yes, indicate the period or season
………………………………………………………………………………………………

G5 Are there particular times of the year during which food is abundant?
Yes No

G6 If yes, indicate the period or season
……………………………………………………………………………………………………

G7 How many meals does your household usually have a day?
a) one
b) two
c) three

G8 What are the main ingredients of diet in this household? List them
………………………………………………………………………………………………………
………………………………………………………………………………………………………

G9 How much of these ingredients are consumed per month? List them and indicate quantities

| **Ingredient** | **Quantities** |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |
| | |

G10 Indicate the main source (purchased or grown) of these ingredients in every season, e.g. summer, autumn, winter, and spring

| **Ingredient** | **Summer** | **Autumn** | **Winter** | **Spring** |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

G11 How often does your household consume vegetables?
a) Everyday
b) Five times a week
c) Twice a week
d) Once a week
e) Once a month
f) Other, specify

G12 How much of these vegetables do you consume per month?

| Vegetable | Quantity |
|---|---|
| Cabbage | |
| Carrot | |
| Spinach | |
| Beetroot | |
| Onions | |
| Butternut | |
| Pumpkin | |

G13 Indicate the main source (purchased or grown) of these vegetables in every season, e.g. summer, autumn, winter, and spring

| Vegetable | Summer | Autumn | Winter | Spring |
|---|---|---|---|---|
| Cabbage | | | | |
| Carrot | | | | |
| Spinach | | | | |
| Beetroot | | | | |
| Onions | | | | |
| Butternut | | | | |
| Pumpkin | | | | |

**H GENERAL**

H1 What are the three major community needs?

………………………………………………………………………………………………………
………………………………………………………………………………………………………
……………………………………………………………………………………………………...

H2 What are you three major household needs?

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

H3 What are your three major agricultural needs?

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H4 Compared to five years ago, has the quality of life of your household

a) improved
b) deteriorated
c) remained the same

H5 State your reasons

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………………………………………………………………………………………………....

H6 Compared to five years ago, has you agricultural production

a) improved
b) deteriorated
c) remained the same

H7 State your reasons

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