UPTAKE OF KNOWLEDGE, TECHNOLOGY AND PRACTICES FOR IMPROVING WATER PRODUCTIVITY IN RAINFED CROPPING SYSTEMS IN THE EASTERN FREE STATE PROVINCE

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Concurrent factors like erratic rainfall events and a low awareness of alternative management practices cause variation in productivity levels that can severely affect food and nutritional security of rural communities. Smallholder farmers in semi-arid areas of South Africa are faced with challenges of small farm sizes, poor soil fertility and low adoption of improved management practices, thus low productivity is a common phenomenon. This project was designed to support the rural communities in the Thaba Nchu area by promoting knowledge uptake to increase productivity through engagement of smallholder farmers, extension officers and researchers to enhance the adoption of alternative farming techniques.

Therefore there was a critical need to devise alternative techniques to increase smallholders' productivity that is based on improved ability to capture and use natural resources more efficiently. Among many alternative techniques available to smallholders in the semi-arid areas near Thaba Nchu are the integration of in-field rainwater harvesting (IRWH) and inter-cropping practices, seen as complementary with inherent sustainability to increase household food security. Hence, based on previous knowledge of IRWH techniques, this study's attempts were made to motivate a bottom-up approach that considers farmers' knowledge and their participation in the planning and implementation processes.

Project Objectives

The overall goal of this project is to increase agricultural productivity through increasing the knowledge uptake of smallholder farmers about practicing integrated *viz.,* IRWH- and intercropping techniques to promote food security and improve natural resource management.

The two specific objectives are:

i. Evaluation of IRWH and intercropping techniques by smallholder farmers through conducting on-farm field demonstrations; and
ii. Engage smallholder farmers, extension officers, researchers and policy advisors to enhance knowledge uptake and exchange on the proposed techniques.

Project site and farmers engagement

The Thaba Nchu rural community in the Free State was chosen for this case study. Through continuous engagement with representative farmers and extension officers of the Department of Rural and Agrarian Reform (DRAR), two villages (Paradys and Morago) on the northern side of Thaba Nchu were nominated for the study and seven homestead gardens (as demonstration plots) were selected to conduct field trials. The first approach of the study was to engage smallholder farmers and extension officers in the project implementation processes by identifying relevant procedures. Based on the manual guidelines published in WRC reports TT 492/11, TT 542/12 and TT 590/14, demonstration plots were designed to compare IRWH vs CON tillage (conventional) for the two cropping systems during the 2018/19 growing season.

Field measurements

All six treatments (2 tillage x 3 cropping systems) were used to measure growth parameters, soil water use, canopy radiation interception, water productivity, and radiation use efficiency. Hence, using the field data, two-hypothesis were tested: i) Maize-beans intercropping under the IRWH tillage system increases productivity compared to a sole grown crop because of improved efficiency in the capture and use of resources (water and radiation), and ii) There are positive relationships between the water productivity (WP) and radiation use efficiency (RUE) in both tillage systems (IRWH and CON), with higher water deficit and lesser available radiation use in CON compared to IRWH.

Qualitative data collection

A systematic engagement strategy was used to identify contextual factors preventing farmers from accepting the IRWH tillage system. This exploratory, qualitative research activity was attended by a total of 48 farmers. Participants were drawn randomly from nine villages in Thaba Nchu, based on recommendations from extension officers. Twelve farmers invited by the extension officers piloted the questionnaire. Mini-pilot interviews were also conducted by research assistants in their mother tongue (Sesotho) with a small group of farmers to determine the validity and reliability of the questionnaire's transparency. The study established two differing attitudes based on age and the farmers' experience of the IRWH tillage system. Further discussions were conducted to investigate the reasons why the IRWH tillage was accepted or rejected. Descriptive statistics were created to reflect the opinions of farmers on informed choice for different aspects of socio-economic demographics.

Key Findings

The villages around Thaba Nchu are known as semi-arid areas that are frequently exposed to extreme drought conditions. The growing season during the project period (2018/19) is a typical example of drought conditions associated with long dry spells in December and January. Many farmers did not sow their seed after cultivating the land, and consequently, much of the arable land remained fallow. However, it was evident that farmers saw the advantage of IRWH when the basins collected ample rainwater after the first rainstorm (31 mm) on 31st December 2018. The soil at the two study areas is generally characterized by high clay content and shallow soil depth as the two villages fall under Dc17 and Db37 land types, respectively. During the early growth stage of the crops, the long dry spell in January coupled with compacted clay soils adversely affected the germination and emergence of both maize and beans resulting in the final plant population far below the optimum.

From SWC monitored by a Neutron probe at Morago village, the IRWH maintained a higher SWC than that of CON in sole maize plots throughout the season. Due to the early season rains, IRWH had higher soil water content than CON at planting time across all treatments. The cumulative amount of ex-field runoff during the growing season was estimated to be 83.6 mm (27%). The rainfall distribution through the growing season was poor so IRWH plots had the advantage of using stored water during those dry spells. During the fallow season (June-

December), the recorded precipitation was 115.9 mm, which is 27.2% of the total precipitation (426.5 mm). During the growing season, P_g (January-May), the amount of rainfall received was 310.6 mm, of which 32.6% was received during growth stage 3 (GS-3) between 63-70 days after emergence (DAE). During this growing stage (GS-3), the highest run-on (R_{on}) water (27.2 mm) was collected in the basin area of the IRWH tillage treatment.

For the sole maize, sole beans and intercropping under IRWH, the ET was estimated as 340.4 mm, 301.8 mm and 359.8 mm, respectively during the growing season at Morago trial site. The CON with intercropping gave higher ET values (262.2 mm) than their respected solely grown beans and maize treatments. Thus, all intercropped beans benefitted from the canopy shade on both ridge and basin sides, and the mean ET across the CON tillage was significantly lower than the IRWH tillage system. The CON tillage had an advantage in reducing soil evaporation by shading effect (due to evenly spaced rows) compared to IRWH because the runoff strips between the tramlines were exposed to soil evaporation while the basin area of the IRWH promoted infiltration to the crop root zone.

At both project sites (Morago and Paradys), the total above ground dry matter biomass (AGDM) and grain yield (GY) were affected (at value $P \leq 0.05$) by both the tillage and cropping systems. Moreover, the IRWH tillage had a significantly higher AGDM for both sole maize (29%) and intercropped maize (27%) compared to CON treatments. At both sites, the beans' AGDM was increased (at value $P \leq 0.05$) by the tillage systems, which meant there were highly significant differences between the IRWH and CON practices for the total AGDM. At Morago, an average bean GY under both tillage systems showed that IRWH-Sole > IRWH-Ic > CON-Sole > CON-Ic, with values ranging from 878.2 kg ha^{-1} to 618 kg ha^{-1} ($P \leq 0.05$). At Paradys, the GY was also affected by tillage with sole beans under IRWH producing a mean GY of 761.4 kg ha^{-1} compared to 573.2 kg ha^{-1} of the intercrop beans. The harvest index (HI) varied between 0.21-0.38 across different treatments at the two sites. In general, the HI values were relatively low compared to literature that could have been due to the effect of drought, as the harvest yield was below expectations.

The precipitation use efficiency (PUE) results indicate that the IRWH tillage was better at converting rainwater into maize biomass and grain yield compared to CON but the cropping system treatments did not show a consistent trend. The results show that the PUE for AGDM varied between 10.01-6.07 and 9.93-7.67 kg ha^{-1} mm^{-1} for maize and 7.36-3.95 and 7.07-3.89 kg ha^{-1} mm^{-1} for beans during the growing season for different tillage and cropping system treatments for Morago and Paradys, respectively. The PUE for GY showed similar trends with significant highest values of PUE under IRWH tillage systems for Morago sites, but there were no significant differences for PUE (GY) at Paradys site in both tillage and cropping systems. The WP as a function of AGDM, the results varied between 15.12-8.34 and 10.10-5.34 kg ha^{-1} mm^{-1} for maize and beans, respectively. A different WP trend for GY was observed *viz.* the maize sole (IRWH-S-M) was significantly higher than both sole and intercropped maize (CON-S-M & CON-Ic-M) and the opposite WP was shown in beans with highest values in sole beans under IRWH (IRWH-S-B) compared to intercropped beans with no significant differences. Nevertheless, there was a significant difference between the tillage systems in Paradys site.

The results indicate that the WUE_{ET} for AGDM varied between 13.06-9.87 and 10.14-6.44 kg ha^{-1} mm^{-1} during the growing season for different tillage and cropping system treatments. Statistical analysis revealed that, the IRWH tillage system on (AGDM) had a significant effect on the efficiency of water use as a function of evapotranspiration with higher values in IRWH-S-M (10.40) and no significant differences observed in both cropping systems under CON and in the intercropped beans under the IRWH. On the contrary, the function of evapotranspiration for WUE significantly showed the lowest values in the CON-intercrop (9.87 and 6.44 kg ha^{-1} mm^{-1} for maize and beans, respectively). With regard to GY as a function of WUE_{ET}, the results showed irregular trends, with higher values in sole-cropping compared to intercropping for both under IRWH and CON tillages. Nevertheless, neither the tillage nor the cropping systems show significant differences for both crops.

The production of dry matter and grain depends on the ability of crops to capture resources, such as the intercepted canopy photosynthetic active radiation (PAR). At the Morago site for both crops, there was a high variation of the fractional intercepted photosynthetic active radiation (fIPAR). In all treatments, the fIPAR was higher in beans compared to maize under both tillage systems with higher value in CON intercropped beans (CON-Ic-B) and peaked (0.93) at 85 DAE. Similarly, in IRWH intercropped beans (IRWH-Ic-B), sole beans (IRWH-S-B) and CON sole beans (CON-S-B) the fIPAR reached a peak between 70-85 DAE with fIPAR values of 0.70, 0.62 and 0.66. This variation indicates the difference of canopy configuration and plant raw arrangement between the CON and IRWH tillage systems that influence the radiation interception the cropping systems.

At Paradys demonstration plots, the fIPAR of sole beans under IRWH (IRWH-S-B) increased slowly to the maximum interception (0.70 at 85 DAE) and the value of fIPAR was greater by 14%, 20% and 9% compared to CON-Ic-B, CON-S-B, and IRWH-Ic-B, respectively. In general, the architecture of the canopy, which was affected by plant population, crop height, and row arrangement could be the most influential factor for crop intercepted PAR. The relationship between LAI and fIPAR was logarithmic with R^2 values of 0.68, 0.54 and 0.69 for CON tillage and 0.51, 0.94 and 0.73 for IRWH in sole maize, sole beans and intercropping, respectively. In all cropping systems, fIPAR increased with an increase in LAI, initially at a high rate and then at a slower rate and finally flattening as the canopy closed.

The RUE under IRWH estimated 0.65 and 0.39 g DM MJ^{-1}, in sole maize and intercropping respectively at Morago site. However, in beans sole and intercropped the RUE showed higher with values of 1.02 g DM MJ^{-1} and 0.73 g DM MJ^{-1}, respectively. A similar trend was observed at Paradys with higher RUE in intercropping with 1.35 and 1.12 g DM MJ^{-1} for IRWH and CON tillage. In general, higher RUE were found in the intercropping compared to sole cropping systems. The results indicate the contribution of maize-bean intercropping under IRWH tillage showing improvements in maize canopy size, radiation interception and RUE compared to CON tillage. Thus, increased water availability through IRWH enhances the water productivity of maize-bean intercropping and closely associated with radiation use efficiency. Furthermore, in the analysis attempts were also made to show the radiation saturation level with an increase of seasonal rainwater use for biomass production by the crops.

Prevailing weather conditions, available water in the soil, crop species, and cropping systems (inter- vs sole-cropping) influence crop water use. The actual soil water content during the growing and fallow season in the different tillage systems (IRWH vs CON) also influences crop water use. This study indicates different cropping systems have different water requirements and respond differently to the IRWH and CON tillages. The water use in IRWH showed higher by 15.1%, 8.3% and 10.1% over the CON for sole maize and beans and intercropping. Similarly, the intercropping system showed water use advantages over the solely growing crops by 5% and 8% for maize and by 16% and 12% for beans under IRWH and CON tillages respectively. In relating the WP and RUE, the high water requirement as a water deficit and proportional to lower RUE: the result from this study showed in sole cropping for maize and beans and intercropped beans, the CON showed the higher water deficit and lesser efficient in using the radiation available during the season compared to IRWH. However, despite the advantages of IRWH over the CON, the intercropped maize showed more water deficit compared to CON tillage, this could be due to higher competition of resources from the partner shallow-rooted crop (beans) with shallow clay soils in the study area.

Knowledge uptake

The demographic and socio-economic dimensions showed that 58.8% of those who completed the survey are men, and only 45.8% of household heads are married. The household head age distribution shows that only 47.9% of household heads are older than or exactly 41 years, and 52.1 percent are less than 40 years old. The highest number of farmers (80%) work in their own household gardens and are active full-time with mixed crop-livestock farming. All part-time farmers irrespective of owning a household garden, outfield, or both were predominantly livestock only farmers. Crop production of farmers working in household gardens is significantly higher than that of the farmers working in the outfield.

Farmers were divided into two classes by age (i.e. above 41 and below 40 years) to determine the percentage rating of questions that they viewed as essential and relevant. Knowledge about IRWH was the most popular rating among farmers over the age of 41 (60%), showing the relevance of practical previous experience in using IRWH tillage system. The age group above 41 years ranked the use of tillage systems as important information. The younger farmers are highly aware of the drought and this is reflected in their rating of critical information questions, as important. Ten farmers (83%) considered having excellent knowledge to be vital, while eight farmers (67%) thought a positive attitude was most important.

Twenty-seven percent of farmers were assessed to have made an informed choice according to the survey instrument. Of the total sample, it was calculated that 58.3% had excellent knowledge and that 89.6% had a positive attitude (10.4% had a negative attitude). Of the 73% that were perceived to have made an informed decision, 65.4% had excellent knowledge, and 88.5% had a positive attitude. There were no significant differences with demographic and socio-economic variables in the bivariate study of informed choice. It seems both groups have a "positive attitude" so maybe it was due to the selection of farmers by extension workers. A high percentage of household heads willing to adopt the IRWH tillage system were under the age of 40 years (25%). In the current use of the IRWH tillage method, farmers aged 41 and above had the highest frequency of 75%. Females had higher frequency for adoption of the IRWH tillage system, indicated by the increase from 45% (once adopted) to 56.2% (currently adopting). Similarly, high school educated household heads have also continued to adopt the IRWH tillage system.

A Kruskal-Wallis test showed age group significantly affected knowledge scores ($H(7)=18.4$, $P<0.01$). One-way variance analysis (ANOVA) revealed that in comparison to the 41 and above age group, the 40 and below age group had significantly lower knowledge scores ($U= 79.3$, $P<0.0001$, $r= 0.25$). On the scale for attitude, there were no significant differences and the farmers' perception scale can be summarized as follows:

- Perceptions of farmers about the uptake of the IRWH tillage system collected from the questionnaire survey showed that the majority (63.3%) strongly agree that the perception of drought hinders the knowledge uptake.
- The majority (56.3%) disagreed with the perception that there was a lack of training, showing that the issue of knowledge about IRWH tillage is not a factor limiting its adoption unless other training needs are required.
- The condensed narratives of farmers' perceptions obtained from interviews show that farmers raised concerns about being trained on other kinds of crops that could be intercropped on IRWH and requested an introduction to alternative conservation practices.
- In addition, their perceptions from the interviews included that the older farmers are more concerned with their age and health when it comes to the intensive labour needed to establish IRWH systems. Lack of commitment was also another concern to the majority of the farmers as raised during the interviews.

Conclusion and Recommendations

There is a critical need to devise alternative techniques to promote an increase in smallholders' productivity, based on improved ability to capture and use resources more efficiently. In this study, the efficient resource use or capture considered were water and radiation, although the soil nutrients were not included, the soils can benefit from the ability of legumes to fix N in the intercrop. The relationships between WP and RUE indicate the links between the efficiencies in the use of radiation and water remain when upgrading the CON to IRWH tillage and from sole grown crops to intercropping in a semi-arid environment. The efficient use of resources to improve WP under IRWH has been selected as an alternative technique with practicing appropriate cropping systems (such as intercropping, cereal-legume/vegetable/forage crops).

In relating the WP and RUE, the high water requirement as a water deficit and proportional to lower RUE: under semi-arid conditions, where vapour pressure deficit (VPD) is high, those partner crops under IRWH having limited transpiration rate, produce higher yield due to water-saving by minimizing ex-field runoff. Therefore, the higher water deficit and lesser efficiency in using the radiation available during the season can be improved through practicing IRWH techniques. Furthermore, it is important to increase transpired water for yield by minimizing unproductive water losses through soil evaporation by applying dry and green mulches on the wide runoff area of the IRWH system. Besides, by practicing continuous IRWH techniques, the fallow period and early season conservation of water would give the crop water reserve to complete development and growth during seed-filling stages of both partner crops, in particular during dry seasons. However, it is also crucial to consider critical crop growth stages of cereal and legume to water use (e.g. maize at tassel – grain filling and for legume at bloom – fruit-set). As shortage in moisture supply during the growth stages can cause yield reduction, choosing appropriate sowing dates of each partner crop would be an advantage to minimize production risk in semi-arid areas.

The research team notes that there is an immense knowledge among the elders about IRWH tillage; however, it seems to play no role in whether farmers have sustained continued use or whether they are behaving in line with their attitudes. Considering the role knowledge uptake plays in the informed choice process, the results show that awareness was linked neither to continued adoption nor to views. This finding suggests the value of initiatives aimed at improving continued adoption by addressing the idea of informed choice. Besides, the study highlights several practical areas of concern regarding the adoption of technology such as availability of basic implements, labour for basin/runoff area construction and maintenance, attitude change, and the lack of continued formal extension provision. Although the complexity of technology uptake is portrayed, a need for future research in knowledge-improvement approaches is noted.

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AGDM	above ground dry matter (kg ha^{-1})
AI	aridity index (unit less)
Alt	Altitude (m)
ARC-SCW	Agricultural Research Council – Soil, Climate and Water
BD	bulk density (Mg m^3)
D	deep drainage (mm)
DAE	days after emergence
DM	dry matter production (kg ha^{-1})
DOY	day of the year
DUL	drained upper limit of plant available water (mm)
E_{pot}	potential evapotranspiration (mm d^{-1})
Es	soil water evaporation (mm)
ET	evapotranspiration (mm)
ETo	reference crop evaporation (mm)
Ev	transpiration (mm)
F	Fraction of radiation interception
F_B	Fraction of radiation interception by beans
F_M	Fraction of radiation interception maize
$F_{M/B}$	Fraction of radiation interception by maize and beans
FAO	Food and Agricultural Organization of the United Nations
F_{MU}	Maize upper canopy layer
GY	grain yield (kg ha^{-1})
h_M	height of maize (cm)
h_B	height of beans (cm)
HI	harvest index
IFPRI	International Food Policy Research Institute
I_{RA}	infiltration in the runoff area
Io	incident radiation (MJ s^{-1} m^{-2})
IRWH	in-field rainwater harvesting
K_B	canopy extinction coefficient beans (0.64)
K_M	canopy extinction coefficient maize (0.43)
LAI	leaf area index upper canopy
L_B	bean canopy layer
L_{ML}	maize canopy layer
L_{MU}	Leaf area index
NWM	neutron water meter
P	precipitation (mm)
PAR	photo synthetically active radiation (MJ s^{-1} m^{-2})
PAWC	plant available water capacity (mm)

P_f	rainfall during the fallow period (mm)
P_g	rainfall during the growing period (mm)
PUE	precipitation use efficiency
PUE*fg*	precipitation use efficiency fallow and growing season (kg ha^{-1} mm^{-1})
R^2	coefficient of determination
RA	runoff area of runoff strip
RF	amount rainfall (mm)
RH	relative humidity (%)
RMSE	root mean squared error
Rn	net radiation (W m^{-2})
Ro	in-field runoff (mm)
R_{off}	runoff (mm)
R_{on}	run-on (mm)
Rs	solar radiation (MJ m^{-2} day^{-1})
RUE	radiation use efficiency (kg m^{-2} MJ m^{-2} g^{-1})
RUE_b	radiation use efficiency beans (kg m^{-2} MJ m^{-2} g^{-1})
RUE_m	radiation use efficiency maize (kg m^{-2} MJ m^{-2} g^{-1})
RWP	rainwater productivity (kg ha^{-1} mm^{-1})
SAST	South African standard time
SPAC	soil-plant-atmosphere continuum
SWC	soil water content (mm)
t	time after drainage started (h)
t	time of day (h)
TDM	total above ground biomass (kg ha^{-1})
T_{max}	daily maximum temperature (ºC)
T_{mean}	mean daily temperature (ºC)
T_{min}	daily minimum temperature (ºC)
u	wind speed (m s^{-1})
UNEP	United Nations Environmental Programme
UP	"*upper portion*" of canopy
USDA	United States Department of Agriculture
VPD	vapour pressure deficit (KPa)
W_B	dry matter (kg)
W_M	dry matter (kg)
WP	water productivity calculated with transpiration
WRC	Water Research Commission
WUE	water use efficiency (kg ha^{-1} mm^{-1})
$\sum$RF	total precipitation over n consecutive years (mm)
$\sum$Ro	total runoff during the growing season (mm)
ΔS	change in soil water storage (mm)
θr	root zone water content (mm)

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CHAPTER 1: INTRODUCTION

1.1 Overview and Background

Global food insecurity remains a serious problem in water-scarce areas of arid and semi-arid climates, particularly for smallholder farmers in sub-Saharan Africa (SSA). Achieving food security of smallholder farmers involves increasing access to food and agricultural production. Food production in semi-arid areas depends on the availability of water. Consequently, improving rainwater productivity and modifying the available energy for unproductive water loss is an important and necessary step towards promoting rainfed agriculture in dryland farming. It has been argued that water management strategies on rainfed semi-arid areas, including in-field rainwater harvesting (IRWH), deserves considerable attention. Therefore, over the last few decades, attention has been paid to traditional techniques of water harvesting, especially in dryland crop production (Boers and Ben-Asher, 1982; Hensley et al., 2000; Van Rensburg et al., 2005; Botha, 2006).

In South Africa, many smallholder farmers lack access to adequate water for agricultural production, mainly use traditional management practices and do not readily adopt improved water harvesting techniques. Besides, with a changing climate in South Africa, rainfall distribution patterns have become more irregular with temporal and spatial variations. Prolonged droughts and long dry spells during the crop-growing period have become a common phenomenon, while on the other hand excess water during a heavy rainy season or La Niña episode causes runoff, soil erosion, nutrient depletion and crop damage, which reduces the productive capacity of the land. The IRWH technique is specifically suited to many ecotopes around South Africa and in other countries with arid and semi-arid areas. According to Kahinda et al. (2008), based on soil and topographic physical layers, about 25% of South Africa was suitable IRWH (categorized as very high). This includes large areas of the Free State, North West and Limpopo as well as parts of Eastern Cape, KwaZulu-Natal and Mpumalanga (Kahinda et al., 2008).

Over the years, various rainwater harvesting (RWH) techniques have been developed in the central part of South Africa (Free State province) and some traditional and indigenous techniques were modified and improved. In the last two decades, several rural communities around Thaba Nchu in the eastern part of the Free State have practiced various techniques of RWH. Many biophysical and socio-economic studies addressed water scarcity to improve the livelihoods of smallholder communities in semi-arid areas of the Free State. In contrast, various farming communities have practiced disorganized intercropping systems. For many years, many organizations and researchers have advocated the advantages and use of various RWH and intercropping techniques for improved productivity. The uptake of knowledge dissemination and systematically integrated management practices have, however, been slow or insufficient to improve smallholder farmers' livelihoods. There could be various reasons for the slow technology uptake of RWH by smallholder farmers in semi-arid areas. Various stakeholders involved in promoting IRWH techniques (farmers, extension officers, researchers, policymakers and funding organizations) have different views and explanations on why the knowledge uptake of IRWH technology has declined irrespective of a positive prospect on increasing yield. Therefore, the main challenge is how to transform smallholder agriculture in semi-areas to become a productive sector, which can drive rural economic development. This requires the efficient use of resources (water, radiation and land), the introduction of integrated practices and engaging smallholders through motivating 'learn by doing' principles.

1.2 Motivation

Smallholder farmers' crop production under rainfed conditions contributes between 10 to 70% to the gross domestic product (GDP) across Africa (Dessy et al., 2006: World Bank, 2008). However, in general, agriculture remains the mainstay of most economies in Africa, accounting for 37% of GDP, nearly 60% of export earnings, and over 76% of employment (World Bank, 2013). In South Africa agricultural production only accounts for 2.7% of the country's GDP mainly from commercial farms, but it increases to 12% with food processing share (BFAP 2013). However, the contribution of smallholders' production is insignificant but creates income streams for their livelihood; (BFAP 2013; Baiphethi and Jacobs, 2009). These systems have a low productivity rate, because of the high inter-annual rainfall variability and poor agronomic practices. Therefore, there is the potential to increase production. Sub-Saharan Africa (SSA) is one of the world's regions where food and nutrition have declined per capita (Sachs et al., 2004). In SSA, 95% of cultivated land is under rainfed agriculture and an estimated 41% of the region's population (~260 million) lives in drought-prone dryland areas (UNCCD, 2009). In addition, irrigation is not an affordable option for smallholder farmers, because the direct investments are very expensive. It has been estimated that it can be about USD 18,000 ha^{-1} when indirect infrastructure costs are included (Birhanu et al., 2012). Consequently, a different solution is needed to improve levels of productivity without incurring high initial capital costs.

High variability of rainfall events, poor farm management practices, and low intensification rates are chronic problems in SSA. Concurrent factors like low awareness and slow technology uptake of alternative management practices cause variation in productivity levels, which can severely affect the food and nutrition security of rural populations. Among many water harvesting techniques and mixed agricultural practices, the IRWH system (Botha et al., 2003; Van Rensburg et al., 2012; Tesfuhuney et al., 2015), and intercropping (Ic) of cereals with legumes (Tsubo et al., 2003) can address water scarcity in semi-arid areas, allowing increased crop production and productivity.

Many of the rainfed cropping systems are dominated by mono-cropping or disorganized intercropping systems and lack water and soil conservation management techniques. These on-farm management practices, given the unpredictable rainfall and negative impact on yield, will lead to a series of critical issues and associated risks, including the following:

i. Food production: Low crop productivity; Low water use and land use efficiency.
ii. Agronomic and environmental: Poor crop performance and low resource use by crops; Soil fertility decline and depletion; Reduction in soil microbiota; Increase in unproductive water losses like runoff and soil evaporation from farmland.
iii. Nutrition: Overdependence on a single crop; unbalanced dietary nutrition available to smallholder farmers.
iv. Sustainability: Mono-cropping could lead to decline in soil fertility; social and cultural acceptability by local communities.

The project addresses the priority sector of Sustainable Agricultural Intensification (SAI), specifically, the action of Ecological Intensification (EI) approaches under dryland systems by answering different aspects of the Ecosystem Services (ES) as defined by UNEP (Alcamo et al., 2003). A broader gap is identified by the project, which investigates the adoption rate of water harvesting techniques aimed at water saving for improved productivity in a semi-arid area (for example, Free State Province). This is simply the management of a cultural issue, which answers one of the aspects of ES of a poor resource farming community.

In addition, the multidimensional nature of food security and nutrition, as set out in the Sustainable Developmental Goals (SDGs) of food security in Goal-1 (UN, SDGs, 2013), poses many challenges for measurements and data collection techniques. Extreme poverty and hunger are predominant in rural areas where smallholder farmers and their families make up a significant portion of the population. Thus, eradicating poverty and hunger is linked to boosting food production, agricultural productivity, and rural income. Land use efficiency, healthy and fertile soils, water use and conservation are key inputs into food production and must be used and managed sustainably (FAO, 2005). Wise management of scarce water through improved water harvesting and mixed cropping (intercropping) can contribute to sustainable dryland productivity. This will be crucial if future food needs are to be met and will include climate risk-based research with farming community participation. There are many elements of traditional smallholder farmers' knowledge that enriched by the latest scientific knowledge, can support productive food systems through sound and sustainable soil, land, and nutrient management.

The multidisciplinary nature of the project, therefore, assesses integrated indigenous knowledge of various water harvesting and intercropping agricultural techniques being used in both formal and informal ways. Consideration of indigenous knowledge is a priority in the project, which focuses on community engagement and capacity building. All genders and young adults are part of the implementation process through workshops, operational training and other relevant academic spheres on various levels. After completion of the project, it is expected that sustainability will be achieved through project outcomes and include:

i. Financial sustainability: Farmers adapt and practice alternative techniques.
ii. Institutional level: Through the involvement of extension officers from the beginning of the project.
iii. Policy level: Recommendations from the project outcomes can be documented in reports, articles and academic studies, possibly contributing to policy documents.
iv. Environmental sustainability: As a cross-cutting issue, the wider environmental benefits by soil water conservation (including less soil erosion, less runoff and soil evaporation and enhanced productivity of water).

1.3 Problem Statement

In the implementation of any water conservation practices, the potential for improving productivity in resource-constrained rainfed subsistence systems is in the continuous uptake of technology. The Water Research Commission of South Africa (WRC) places particular emphasis on helping resource-constrained rainfed subsistence farmers to develop their adaptive ability (Kahinda and Taigbenu, 2011). Many projects were funded by the WRC, including the development of tillage techniques for IRWH in the rural community areas of Thaba Nchu, with the primary objective of transferring knowledge of this technology to local and surrounding communities (Botha et al., 2003). The deployment of IRWH technology expanded after the initial intervention, which included just six households in four farming communities (2001/02 growing season) (Backeberg et al., 2010). Nevertheless, due to the desirability of yields associated with IRWH tillage and dissemination of information, the number of households adopting the technology increased. The increased take-up resulted in 108 farmers ' in 6 villages (growing season 2002/03), 400 households in 37 communities (growing season 2003/04), 1033 homes in 42 communities (growing season 2004/05) and 1033 homes in 42 communities (2004/05 growing season) (Botha et al., 2003). Knowledge and promotion of the technique was disseminated using several methods and included mass approaches using local television and radio stations, brochures, and training manuals (Backeberg et al., 2010). Demonstration plots on-station and capacity building actions with farm extension officers and the youth were applied to some of the group approach methods. However, after a decade or so of efforts to implement and facilitate knowledge transfer of IRWH to smallholder farmers in Thaba Nchu, there has been minimal effort to justify the role of extension officers and farmers in ensuring the continuity or uptake of practices.

Many innovations from different organizations (including NGOs, South African government organizations and universities) have been introduced to help resource-constrained rainfed subsistence farmers (Kahinda and Taigbenu, 2011). Products, especially enhanced plant varieties (drought-tolerant, high-yielding and disease-resistant) and mineral fertilizers are provided to increase productivity while addressing the risks of climate change (Baiphethi and Jacobs, 2009). Could the dissemination of such packages, however, have little impact on complementing IRWH tillage techniques? When adopted jointly, these technologies can provide better productivity and improve social and economic status than when used independently. Feder et al. (1985) support the receptiveness of subsistence farmers to new technological innovations. For Thaba Nchu, even in cases where it was participatory to implement the IRWH tillage, most farmers abandoned the technology on their land. There is little knowledge about the underlying structural and community-level factors that influence the choices and attitudes of farmers towards the uptake. Participatory approaches using empirical inquiry techniques can, therefore, allow investigators to elucidate underlying issues.

As a case study in two villages of Thaba Nchu, beneficiaries were chosen using two criteria. Firstly, these groups are located in a semi-arid area and generally need water-saving techniques. Secondly, extension officers have a prior knowledge of the farmers and subsequently, a working relationship with trust between researchers and farmers. The target groups are smallholder farmers, including female-headed households and young farmers, who are already active in dryland farming, predominantly cereals. These poor-resource farmers use low inputs for their agronomic management; and often produce very low yields due to the erratic rainfall patterns. Female-headed households have even less access to resources, because of their status in society. Young farmers are disillusioned about farming due to their inability to cope with climate variability. The target groups in our study areas need a combination of climate information, efficient resource use (water, radiation and land) and support systems, used together with their indigenous knowledge to improve their productivity.

1.4 Project Objectives

The overall goal of this project is to increase agricultural productivity through increasing the knowledge uptake of smallholder farmers about practicing integrated IRWH and intercropping techniques to promote food security and improve natural resource management. Thus, poverty and hunger are reduced in the semi-arid Thaba Nchu area in South Africa.

The specific objectives are:

i. Evaluation of IRWH and intercropping techniques of smallholder farmers by conducting on-farm field demonstrations;
ii. Engage smallholder farmers, extension officers, researchers and policy advisors to enhance knowledge uptake and exchange on the proposed techniques.

1.5 Scope and Limitation of the Study

This project focuses on developing on-farm demonstration trials through engaging smallholder farmers and extension officers, and by conducting qualitative studies to support the knowledge uptake of alternative management practices. The first approach of the study was to engage smallholder farmers and extension officers in the project implementation processes to identify relevant procedures. Formal and informal meetings, training, farmers' information day, and monitoring and evaluation processes were carried out to assess the understanding the knowledge of the alternative techniques that can improve smallholders' productivity. The experimental layout, land preparation, cultivar choice and routing management were performed in collaboration with farming communities and extension officers. Through the experimental field measurements, two-hypothesis were tested to compare the three cropping systems (sole maize, sole beans and intercropping) under the two tillage systems (IRWH and Conventional, CON). The second approach that could generate the proposed objective was to understand the knowledge uptake of the alternative techniques through farmers' informed choices. The purpose of the qualitative study was to assess farmers' knowledge uptake and attitudes and perceptions of the tillage system. To test the construct validity farmers' were engaged in interviews with questions drawn from the questionnaire. In this project, therefore, the above two approaches allow in covering the evaluation of practical field measurements and smallholders' knowledge uptake assessments through wide participation of the rural communities in Thaba Nchu.

On-farm demonstrations are a valuable tool in the teaching of alternative management practices or improved technologies, though the size of the homestead gardens was limited to employ replications of the treatments. Hence, in the study replications were considered by using several households in both representative villages. The difficulties of taking regular field measurements at the same time on both villages for all demonstration plots were achieved by involving students and continuous farmers' participation. The drought in the 2018/19 growing season and the late onset of rainfall had severe consequences on seedling emergence and to obtain optimum plant population as planned. However, this was an opportunity to demonstrate the advantages of IRWH over CON tillage in semi-arid environments. Continuous monitoring and evaluation operations were taken as a device to motivate the active farmers' participation in all farming activities and measurements. In general, as on-farm participatory trials in rural communities, every challenge and limitation faced during the study were solved in different ways and used as a lesson and experience and to share the information with the farmers during the qualitative study.

1.6 Structure of the Report

The first approach of the study was to engage smallholder farmers and extension officers in the project implementation processes. The study comprises and discusses the conceptual and theoretical framework for addressing the research questions to be evaluated and then the study has organized into three main research areas (Chapter 3). The details of the methodologies applied for the study were presented in Chapter 4. In Chapter 5 using field measurements from the demonstration trials, the water use and radiation use were assessed and quantified for three cropping systems under two tillage systems (IRWH and CON). In Chapter 6 a qualitative study was employed to assess farmers' knowledge and attitudes, uptake and perceptions of the tillage system. As part of engagement processes and technology transfer to smallholder, farmers' information day was conducted along with demonstration plots visit by participants. The discussions and views of the farming community, extension officers and researchers were documented in Chapter 7. Finally, Chapter 8 gives a general conclusion, prospects for further research and lessons have learnt from the Thaba Nchu community project.

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CHAPTER 2: LITERATURE REVIEW

2.1 Global Water and Food Security

With the changing climate, several questions emerge. Will smallholder farmers in semi-arid areas be able to produce enough food to eradicate hunger and malnutrition? What constraints are there in terms of access to knowledge and knowledge transfer? Is there sufficient water to secure enough for yield? What socioeconomic and environmental considerations have to be taken into account and adapted to improve management practices by smallholder farmers?

The world population is likely to increase to 7.5 and 9.0 billion in 2025 and 2050 (FAO, 2007), respectively. Based on projections of population growth and the increase in the standard of living, there are various views on the rate of increase in food production required to cope with rapidly increasing populations (Schultz et al., 2005). The vision of 'Water for Food and Rural Development' indicates the need for doubling the food production over the coming 25 years, whereas the International Food Policy Research Institute (IFPRI) suggests that a doubling in food production would only be required in the forthcoming 50 years (Schultz et al., 2005). Whichever is true, food production must increase. However, it is important to focus on the grassroots level where smallholder farmers contribute to global food security by increasing water productivity to optimize the yield.

Globally, concerns on water shortage whose profile is rapidly transitioning from being 'water-scarce' to 'water-stressed' situations are increasing (Rosegrant et al., 2002) particularly in arid and semi-arid areas. Currently, it is estimated that 41% of the earth's population (translating to about 2.3 billion people) live in 'water-stressed' environments (Fitzmaurice, 2007). In these environments (arid and semi-arid areas), rainfall is unreliable because of its amount, distribution, or unpredictability (Hudson, 1987). Erratic and low rainfall (350-700 mm yr^{-1}) associated with periodic droughts characterizes these regions (Oweis et al., 1996).

Achieving food security for smallholder farmers involves increasing access to food and increasing agricultural production. The majority of the world's population lives in emerging and least developed countries where roughly 80% of poor people depend on agriculture for their livelihood (Hatibu, 2003; FAO, 2007). Dryland crop production contributes 95% of the food production in SSA. There may be 130 million poor subsistence farmers in SSA, and a substantial proportion depend on maize as their staple food (Schultz et al., 2005). According to FAO Report on the State of Food Insecurity in the World (FAO, 2010), about 800 million people in developing countries do not have sufficient food. Thus, optimal utilization of the natural resources, water, energy and soil is critical in order to be able to maintain more sustainable food production practices.

Future needs of water for food are extremely high and up-to-date water management systems will be required at various scales. In different regions of the world, depending on local climatic and other factors, different types of water management with different levels of services will be appropriate (Schultz, 2001; 2003). For instance, IRWH, based on the collection and concentration of surface runoff in the field for cultivation, has been practiced in different parts of the world for thousands of years (Reij et al., 1988). Rainwater harvesting, which collects runoff from short slopes, is especially useful in arid and semi-arid regions, where irrigation water is not available or too costly to use (Boers et al., 1986). Therefore, the promotion of improved rainwater management, which includes rainwater capture and conservation, use of dry and living mulch cover, mixed / inter-cropping and soil improvement will be important in order to reduce rural poverty and to ensure food security. The incorporation of grain legume into cereal-based cropping systems can contribute to the replenishment of soil fertility and land and water use efficiency.

2.2 South African Agriculture

In South Africa, as in developing countries, the incidence of poverty tends to be disproportionately high amongst the rural population. The Development Bank of South Africa (DBSA, 1993) estimated that more than 50% of the population of South Africa live below the poverty line. The poorest rural households mostly live in semi-arid and arid areas and rely heavily on dryland crop production for their livelihoods, often farming on marginal and fragile soils. In dry areas, the lack of adequate water poses a major constraint to increasing agricultural production and attempts to develop other economic activities (Twomlow et al., 2006). However, many agricultural scientists agree that with the use of appropriate production techniques, especially those that encourage conservation of water and soil resources, it is possible to increase and sustain agricultural output in semi-arid areas (Hatibu et al., 2003). Therefore, the adoption by farmers of management practices that ensure efficient rainfall utilization for dryland production of a wide variety of crops is essential for agronomic, economic and social sustainability. To improve precipitation, use efficiency (PUE), it is, therefore, necessary to adopt water harvesting and soil conservation techniques to enhance production (Hensley and Snyman, 1991).

In most arid and semi-arid climates, the common phenomenon of low precipitation is aggravated by the high evaporative demand of the atmosphere. Schulze (2006) showed an increase in annual rainfall from less than 125 mm along the arid west coast to more than 800 mm on the eastern seaboard of South Africa (Schulze and Lynch, 2006). The low mean annual rainfall (P, mm year^{-1}) is associated with a high mean annual potential evapotranspiration (ET_{pot}, mm) resulting in more than 80% of the country having semi-arid and arid climates (Bennie and Hensley, 2001; Schulze and Maharaj, 2006). These zones can be further divided into winter and summer rainfall regions. At least one-third of the country, particularly the central and north-western portion, has less than 400 mm of rain (P) annually. Most of the dryland crop production occurs in the semi-arid zones where the aridity indices (P/ET_{pot}) vary between 0.20 and 0.50. This inadequate rainfall is the main reason that a relatively small portion of South Africa is considered suitable for rainfed crop production (Bennie and Hensley, 2001).

In order to sustain crop production in arid and semi-arid areas, one needs to rely on alternative and manageable conservation techniques that emphasize the optimum utilization of resources. Amongst various water conservation techniques, the IRWH has the potential to increase available resources (in particular water) for successful crop production. The IRWH technique as proposed by Hensley et al. (2000), improves maize yield on some benchmark ecotopes in South Africa. On the basis of water and energy balance studies about the effective use of resources in a sustainable manner, the IRWH technique can increase crop yield and decrease production risk under semi-arid conditions.

The demand for water exceeds natural water availability in several river basins, making the regions water scarce (Welderufael et al., 2013). A typical example is South Africa, which has different climates with variable rainfall patterns and high evaporation demands (Kahinda et al., 2009; Everson et al., 2011). Most of the South African population residing in communal settlements depend on agriculture and pastoralism for subsistence. Suboptimal crop (predominantly staple maize) cultivation practices under subsistence farming rely on rainfed irrigation, which causes serious soil degradation (Tully et al., 2015) and a rapid decline of soil fertility (Vanlauwe et al., 2015).

In South Africa, socio-economic and demographic factors contribute to water scarcity. Some of the factors are financial, age and educational status of subsistence farmers, which influences participation. Unfortunately, communal settlement distribution is determined by mineral deposits rather than water resources. Hence, poor farmers occupy marginal croplands for production and where groundwater is available, which is then frequently over-exploited (Van der Merwe-Botha, 2009). However, the current population and economic growth has resulted in an increased demand for grain, requiring ensured supply to meet needs for food, feed and fuel (Godfray et al., 2010). In light of the foregoing, it is most likely that the available water resources will not be sufficient for future needs (Van der Merwe-Botha, 2009). Hence, agronomic options for optimization and management of soil water are critical, as it is the most significant resource influencing crop production (Hensley et al., 2000).

2.3 Crop Production and Climate of the Free State

Out of the total land surface area of South Africa (122.8 million ha), the Free State occupies 12.9 million ha. However, the potential arable area of the Free State covers only approximately 3.82 million ha, while natural veld and grazing cover approximately 8.7 million ha (South

Africa Yearbook, 2002/03). It is estimated that, of the arable land, 8% is of very low, 49% of low and 43% of medium agricultural potential (Hensley et al., 2006). Field crops contributed an average of 54.3% to gross agricultural income for years 1983, 1988, 1991 and 1993 (Department of Agriculture – Free State Province, 1996). Small-scale farmers occupy large areas of the Free State (Department of Agriculture – Free State, 1996), but they do not all experience food security, because most of the area is marginal for crop production. According to Hensley et al. (2000), there are three reasons for poor production levels:

- low and erratic rainfall amounting to mean of 543 mm per annum;
- a correspondingly high evaporative demand of 2198 mm per annum; and
- dominantly duplex and clay soils on which the precipitation use efficiency (PUE) is low due to high runoff and evaporation losses.

As a result, in the Free State, the most important factor limiting agricultural production is the availability of water (Eloff, 1984).

Crop production in the Free State generally contributes approximately 34% to South Africa's maize production. It is a common practice integrating legumes into cereal cropping systems, small-scale farmers in low-resource settings can invest in the long-term health and resilience of their soils. Statistics obtained from the Department of Agriculture – Free State (2006) revealed that Free State agriculture contributes on average 4.6% and 9.2% of the gross geographical product and agricultural production in South Africa. Proper knowledge of agricultural potential and a good understanding of characteristics of specific ecotopes is therefore of utmost importance for optimum and sustainable resource utilization in practicing IRWH.

The rainfall in Free State varies considerably from west to east and has an approximate annual rainfall of 200-800 mm from dry semi-arid to dry sub-humid zones (Figure 2.1). Thus, the climate of the Free State has a wide precipitation range, characterized with water deficit areas and the daily mean potential evaporation levels are very high ranging from 6-8 mm d^{-1} (Schulze and Lynch, 2006), which is much higher during summer. In the western and central parts of the Free State, rainfall is highly erratic, and some rain falls as intensive convective storms with extreme spatial and temporal rainfall variability. As a result, the semi-arid part of the Free State has a risk for annual drought and inter-annual dry spells. This has a serious effect on crop yield, particularly during water-sensitive stages such as flowering or tasselling. According to the aridity index (AI), as defined by United Nations Environmental Programme (Middleton and Thomas, 1992), criteria for bioclimatic zoning, the climate of the Free State is semi-arid (Hensley et al., 2006). Despite this, the province is one of the major contributors to agricultural production in South Africa.

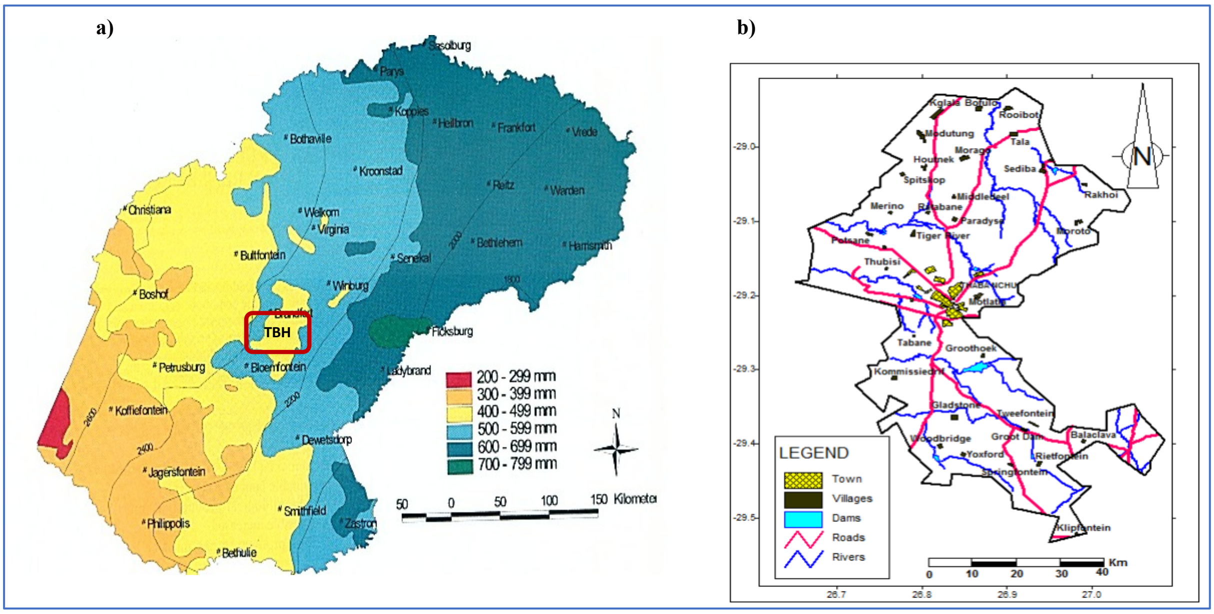

Figure 2.1 Map showing a) generalized mean annual rainfall and evaporation isolines a A-pan equivalent (Schulze, 1997) in the Free State, and b) Thaba Nchu (TBH) distribution of villages (Akwensioge, 2012)

The study was carried out in the Thaba Nchu area of the Free State province (Figure 2.1). Thaba Nchu is located about 60 km east of Bloemfontein and consists of 42 communities spread to the northern and southern sides of the town. The rural community is mainly small-scale livestock farmers and many grow vegetables in their homesteads' backyards.

2.4 Rainwater Harvesting and Conservation Techniques

Rainwater harvesting techniques and conservation agriculture (CA) are promoted by the South African government as one strategy to improve water resource availability in rainfed cropping systems of the country. Conservation agriculture helps to address soil degradation by protecting soil resources from erosion, increasing infiltration, reducing evaporation and improving soil quality through the additions of organic matter from cover cropping and crop residues (Thierfelder and Wall, 2009). The problem of inadequate resources (residues and irrigation) and limited land, encourage the development of simplified CA approaches to rainwater conservation in subsistence systems, keeping in mind the technical and financial limitations (Bulcock and Schulze, 2011).

On the other hand, rainwater harvesting can aid smallholder crop farmers to effectively use low and erratic rainfall in order to grow sufficient crops to sustain their livelihoods. A simple classification of RWH based on the work of Oweis et al. (2001) is referred as micro-catchment, macro-catchment and floodwater harvesting systems. Oweis et al. (2001) divided micro-catchments into two groups, on-farm and rooftop. On-farm catchment surfaces may be natural with no vegetation modification. The soil surface can be cleared of vegetation or be treated with a substance to induce runoff. Micro-catchment rainwater harvesting is a domestic system, which describes the small-scale concentration, collection, storage, and use of rainwater runoff for production purposes (Oweis et al., 1999). In South Africa, Van Rensburg et al. (2005) proposed an alternative system for rainwater harvesting classification, where methods are simply categorized as ex-field (outside the farm), in-field (within the farm) and non-field (rooftops).

In-field rainwater harvesting (IRWH) describes a system where water is collected from the untilled-overland flow on short catchment lengths within the farm/ or field (Hensley et al., 2000). The runoff water is stored in basins to facilitate enhanced infiltration directly in the soil profile and there is no provision for the overflow of excess water (Bothma et al., 2012). This practice is most suited for domestic purposes such as crop production in small land sizes, such as home gardens. In-field rainwater harvesting is one of the most appropriate and simplified water conservation management practices and has been successfully implemented in most communal systems in the Free State, such as in Thaba Nchu rural communities. The IRWH techniques increased yields by 40%, 30% and 90% in maize, sunflower and dry beans respectively under conventional tillage. (Botha et al., 2003). Thus, among various techniques of rainwater harvesting, this project identified IRWH as an appropriate practice for homestead garden demonstration trials for the Thaba Nchu rural communities.

2.4.1 Water conservation in the context of rainwater harvesting

Rainwater harvesting (RWH) is an age-old practice used in water-scarce rainfed crop production areas. The primary objective of RWH systems in terms of water conservation is to facilitate "runoff farming" (Van Rensburg et al., 2005). Hence, water conservation practices reduce erosion, improves soil quality and increases PUE. Stroosnijder (2003) claims that in semi-arid Africa, water conservation can easily double PUE thus contributing to food security. In the semi-arid climate zone, the most limiting resource is water. Rainwater harvesting was practiced to provide additional water for crops with insufficient rainfall amounts for optimum yield. It involves collecting rainwater from an area, which is not in use and directing water to an area used for production (i.e. to an area where a crop is grown). Oweis et al. (2001) defined RWH simply as "the process of concentrating precipitation through runoff and storing it for beneficial use". One way of increasing rainwater productivity (RWP) and decreasing production risk in dry areas, is through water harvesting. The IRWH technique as described by Hensley et al. (2000) showed potential in a semi-arid area of South Africa (Figure 2.2). The main objective of this technique is to maximize RWP. The technique is also referred to as "mini-catchment runoff farming" by other authors (Owies et al., 1999; Mo et al., 2018).

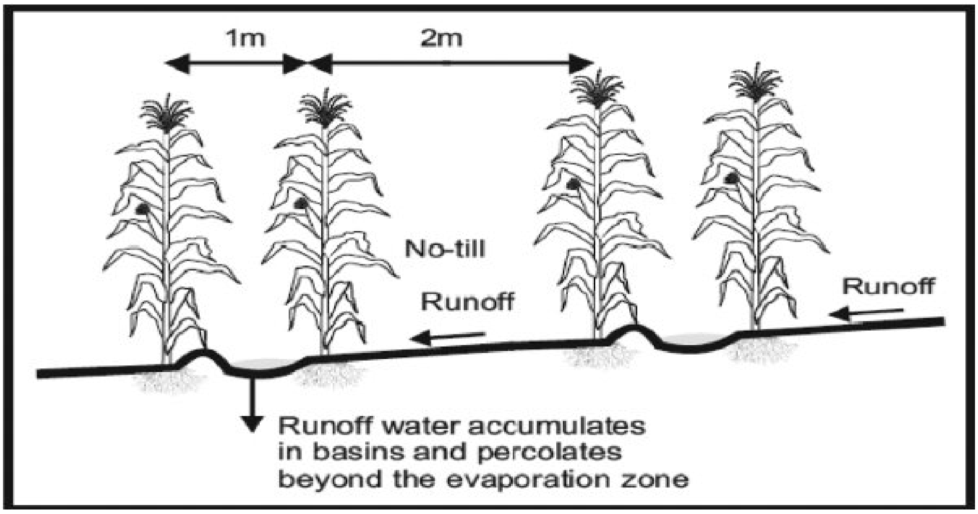

Figure 2.2 diagrammatic layout of the IRWH technique, showing the 2 m width runoff strips and 1 m width basin strip (collection area) modified as micro basins (Hensley et al., 2000)

This innovative water conservation technique has the potential to eliminate runoff from the field and reduce soil evaporation considerably, potentially resulting in increased yields due to increased plant available water. Several studies were conducted on the biophysical sustainability of the IRWH technique on different soils and under different climatic conditions. For example, Botha (2006) evaluated the performance of IRWH on four ecotopes with clay, fine sandy clay, clay loam and fine sandy loam soils (45, 38, 37 and 17% clay content, respectively) in the central Free State. Botha concluded that the IRWH technique is sustainable and superior to mouldboard ploughing conventional tillage. Yields of maize and sunflower were between 30 and 50% higher than those under conventional practices. Botha (2006) explained that yield advantages could be attributed to total stoppage of ex-field runoff and reduction of evaporation from the soil surface, supplying more water for transpiration. The enhancement of in-field runoff towards the basins induces or increases water availability to crops, thereby increasing RWP significantly (Botha, 2006). However, the IRWH technique was mainly field tested on clay soils, with a fixed runoff strip length (2 m) to basin area (1 m) arrangement, and this may not be a sufficiently rigorous evaluation compared to existing production systems.

2.4.2 Research studies on in-field rainwater harvesting (IRWH)

In-field rainwater harvesting incorporates the advantages of '*no-till'*, '*basin tillage*', and '*mulching*' on high drought-risk clay soils for water harvesting (Hensley et al., 2000). Basin tillage is also known as tied ridging, furrow disking, furrow blocking, micro-basin or reservoir tillage (Temesgen et al., 2009; Araya et al., 2012). Basin tillage practice was verified by earlier researchers as suitable for small-scale adoption (Rockstrom, 2000). The reduction of runoff to zero through IRWH represents an opportunity for sustainable alternative tillage system, as traditional tillage (conventional tillage, CON) increases the risk of drought effects (Hensley et al., 2000). Long-term research studies demonstrated that IRWH produced significantly higher grain yield and rainwater productivity than CON (Botha et al., 2003). Yield improvements under IRWH are affected through higher infiltration rates, increased soil moisture and reduction in runoff (Hensley et al., 2001; Botha et al., 2003a; Anderson, 2007; Mzezewa and Van Rensburg, 2011; Bothma et al., 2012).

Many follow-up studies on IRWH (summarized in Tables 2.1 and 2.2) clarified the soil water processes (rainfall intensity, rainfall-runoff relationships) and optimized the process (different mulching materials and rates, runoff strip lengths) in order to maximize efficiency (Walker and Tsubo, 2003; Zere et al., 2005; Botha 2006; Anderson, 2007; Mzezewa and Van Rensburg, 2011, Mzezewa et al., 2011; Bothma et al., 2012; Zerizghy, 2012; Tesfuhuney et al., 2013). A study conducted by Botha et al. (2003) emphasized mulch application on basin areas with sufficient material on the runoff area to minimize evaporation loss. The application of organic mulch in the basins resulted in the highest maize yield compared to stone mulching in the runoff area, which reduced soil erosion (Botha et al., 2003). Mulching with stones on the runoff strip generated more runoff to the basin resulting in higher maize yields (Botha et al., 2012). However, mulching treatments showed no significant differences in rainfall productivity. Soil moisture evaporation control under IRWH also influenced runoff, which was influenced by rainfall patterns (Botha et al., 2012; Tesfuhuney et al., 2013). Walker and Tsubo, 2003a and b utilized the rainfall data of Hensley et al. (2000) in developing a simulation model for the support results. Tesfuhuney et al. (2013) quantified the influence of runoff strip lengths and mulching rates on in-field runoff.

Rainwater harvesting tillage practices offer benefits such as promoting self-sufficiency for cash-constrained farmers through increased rainfall water productivity and yields (Hensley et al., 2000). In Zimbabwe, basin tillage systems reduce the incidence and amount of both runoff and soil loss, whilst increasing infiltration by 13-22% compared to conventional tillage (Munodawafa and Zhou, 2008). A recent case study in South Africa showed that application of IRWH to improve water productivity of an intercropping system resulted in increased water use compared to sole cropping for cowpea and sunflower in the first and second seasons, respectively (Mzezewa et al., 2011). This practice is an ecologically friendly alternative approach to addressing the country’s critical water shortage needs in crop production. Although water stored in the profile through IRWH supplies crop demand, there is a need to increase soil water conservation by exploring various cropping systems such as integration with intercropping practices.

Table 2.1 Rainfall-runoff relationship contributions under the IRWH system with an emphasis on experimental treatments and research findings

Experimental treatments	Research findings		Reference
	Soil properties	**% Runoff-rainfall**	
No-till runoff catchment area and bare flat crusted surface	The soil was melanic, dark brown and had a 45% clay content	29.2% with an average rainfall of 500 mm yr^{-1}	Hensley et al. (2000)
No-till runoff catchment area with bare, organic or stone mulches in the basin and runoff areas	The soil was melanic, dark brown and had a 45% clay content. Organic mulch in the basin with bare runoff area resulted in higher Es loses	25% stone mulch and 6% organic mulch with an average rainfall of 538 mm yr^{-1}	Botha et al. (2003); Botha et al. (2012)
No-till runoff catchment area with bare, varying lengths (1, 1.5, 2 and 3 m) with mulch application for surface coverage (0%-bare, 39% and 96%)	The soil was orthic, red brown and had an 8.5% clay content. Runoff strip length of 3 m with 96% mulch cover was shown to reduce runoff	Highest of 43% was recorded under bare and 1 m runoff strip length with an average rainfall of 350.2 mm yr^{-1}	Tesfuhuney et al. (2013)
Rainfall simulation under IRWH, CON and cowpea living mulch in a sunflower cropping system	Runoff time was significantly reduced in IRWH compared to CON	IRWH resulted in more water compared to CON (45.54 $m^{-3}ha^{-1}$)	Mzezewa and Van Rensburg, (2011)
Clay plus silt content (physical properties) and rainfall intensity simulation at 33, 59, and 122 mm yr^{-1}	RI correlated with roughness index, clay plus silt content, PR and SOM	-	Bothma et al. (2012)

Table 2.2 Soil evaporation contributions under the IRWH system with emphasis to experimental treatments and research findings

Experimental treatments	Research findings			Reference
	Soil properties	Water productivity	Crop productivity	
No-till, bare, organic or stone mulches in the basin and runoff areas	The soil was melanic, dark brown and had a 45% clay content. Organic mulch in the basin with bare runoff area resulted in higher Es loss	RUE was higher on stone mulches in the runoff area. No significant treatment differences were obtained with mulch treatments on rainfall productivity	Increased crop yields	Botha et al. (2003); Botha (2012)
No-till, bare, runoff area lengths (1, 1.5, 2 and 3m) and mulch surface cover (0, 39 and 96%)	Higher Es values were observed in bare soil and no significant difference with mulch levels	Soil evaporation (ES) reduction as influenced by the degree of both "*dry-mulch*" beneath the maize canopy and "*green mulch*"	Improve maize water productivity	Tesfuhuney et al. (2015)
Cowpea living mulch	-	WU and PU were increased with intercropping cowpea living mulch	Sole sunflower had higher crop yields than intercropped with living mulch	Mzezewa et al. (2011)

Despite the considerable efforts that have been undertaken to expand the knowledge of IRWH techniques in Thaba Nchu rural communities, the adoption of the IRWH measures is still minimal and causing yield reduction and food shortage, in particular in dry seasons with long dry spells. Through personal communication with the icon of IRWH research in particular in semi-arid areas of Thaba Nchu rural community, Prof Molcam Hensley state that:

> "*Although the value of IRWH for increasing the crop yields of subsistence farmers in a semi-arid area was demonstrated clearly in a WRC report published in 2000 and followed by many similar WRC reports and postgraduate studies, it is disappointing that no consistent, concerted, diligent effort has been made during the last 19 years, to implement this practice over a wide area".* (Personal communication on 22 November 2019).

2.5 Cropping System under Rainwater Harvesting

Diversifying the cropping systems through intercropping, cover cropping, mulching and utilization of livestock manure can present an opportunity for maintaining soil cover, fertility, reduce evaporation and conserve the harvested soil moisture (Botha et al., 2003; Mzezewa et al., 2011; Tesfuhuney, 2012). For example, rainfed systems under subsistence management are constrained with limited biomass production. For example, maize harvest crop residues are used as livestock feed, which decreases residue cover and retention in the soil. One important opportunity in using dry or green mulch is to increase water productivity and reduce water deficit in continuous cropping system. For example, maize-fallow-maize cropping systems is the traditional cropping method in rainfed systems to minimize production risk in dry seasons. By comparing the conventional tillage practices to other systems such as no-tillage and minimum tillage (including the IRWH), promotes the application of herbicides to alleviate weed pressure, particularly in the early stages of implementation (Muoni et al., 2014). Utilizing the fallow period for the growth of cover crops and mechanically terminating them for mulch towards the summer season can provide important information for the IRWH system.

Subsistence cash-constrained smallholder farmers have realized the economic benefits of IRWH in their home gardens, but rising costs of herbicides may be unrealistic, and the development of glyphosate-resistant weeds has sparked renewed interest in cropping systems diversification. A major challenge to farmers and researchers in South Africa is in the identification of cover crops that are adapted to rainfed environments. Introducing the growing of cover crops under IRWH for cover has the potential to diversify and increase profitability. Cover crops are crops grown primarily for the purpose of protecting and improving soil between periods of regular crop production (Kasper and Singer, 2011). Replacing fallow with cover cropping has long been valued for providing soil conservation benefits including increased soil organic matter, reducing erosion, increasing infiltration, weed suppression, and improving soil quality (Kasper and Singer, 2011; Cercioglu et al., 2018). The ability to reduce erosion particularly in rainfed crop production systems with low soil organic carbon levels is important. Incorporating winter cover crops in a maize-fallow system in the Eastern Cape Province reduced soil strength, increased soil organic carbon levels, cumulative infiltration and water retention (Mupambwa and Wakindiki, 2012). However, soil responses to agronomic practices like cover cropping take a long time to occur and depend on factors like soil type and climate (Bescansa et al., 2006).

Despite the potential of soil fertility, the uncertainty of water availability during the fallow period makes cover cropping adoption unpopular in rainfed systems. The ability of intercropping and/or cover crops to utilize water that otherwise would be available for the subsequent main crop is equally important. Opportunity does exist to grow intercrop or cover crops in rainfed cropping under IRWH harvesting system and return them as cover residue or harvest for livestock feed for subsistence farmers. This cropping system can take advantage of any additional rainfall received during the winter season in the IRWH system.

Improved on-farm management through the integration of RWH and other cultural practices, such intercropping can prove to be an opportunity to upgrade current farming practices in the arid and semi-arid regions. The success of RWH systems in dryland agriculture has already been documented by several researchers (Araya et al., 2012; Makurira et al., 2011; Mo et al., 2018), but they identified large gaps in knowledge on the influence of cropping system in facilitating efficient utilization of resources. Crop intensification and diversification through intercropping and crop rotation systems are high yielding with efficient use of water resources, and thus reduces water stress risk in arid and semi-arid climates (Guilpart et al., 2017). Thus, less risk of crop failure due to crop water deficits may improve farmers' willingness and ability to adopt IRWH, residue management and cropping systems. However, there is a need to find optimal ways to ensure sustainable crop production through soil and water conservation practices with efficient use of limited water.

2.6 Engagement and Knowledge Transfer

2.6.1 Community engagement

Ensuring food security for households in arid and semi-arid areas remains a significant challenge. Subsistence farmers in SSA face challenges with restricted access to financial and agricultural extension and advisory support (Bedeke et al., 2019). Climate variability and change exacerbate these problems not only by reducing soil water storage but also by changing the frequency and duration of rainfall (Touhami et al., 2015). Frequent fluctuations in seasonal rainfall affect the engagement of farmers and can increase variability in crop yields due to water stress during crop growth. Unpredictable precipitation and dry spells exacerbate the vulnerability of farmers to climate change by limiting access to and availability of agricultural water, resulting in drought pressure (Speranza et al., 2008; Gandure et al., 2013). The occurrences of drought conditions in semi-arid areas and its intensity triggers an increase in the level of distress farmers experience, affecting their informed choices. This affects adoption of improved alternative techniques such as the abandonment of rainwater harvesting. The result is a shift in the ability of farmers to engage in sustainable systems, hampering potential capacity for investment (Gandure et al., 2013). The adverse effects of climate change will exacerbate poverty and malnutrition by increasing subsistence farmers' inputs and expenditure. Therefore, adaptation by subsistence farmers to climate change impacts is of significant concern to various stakeholders worldwide and in South Africa.

2.6.2 Farmers informed agricultural conservation decision-making

Based on previous efforts to transmit information, one can infer that the Thaba Nchu society is knowledgeable "on" or "about" the IRWH tillage technology. An inquiry approach is a more convenient approach, rather than opinions of extension officers who are the farmers ' sole provider of technical services (Mafongoya et al., 2016). Furthermore, comparing responses among farmers categorized by age groups to determine the transfer of knowledge is another approach in determining the information required for informed choice (Tittonell et al., 2012). Knowledge of the IRWH tillage is believed to be strongly correlated with older age groups. Consequently, incentives can involve the transfer of knowledge regarding technology use from farmer to farmer, which is considered an effective method of agricultural extension (Franzel et al., 2001). Hence, knowledge correlated with the best results can be described as excellent knowledge. The first step in developing a knowledge measure is to agree on the appropriate content. Supported by beginning with enough questions for comprehensive coverage of the focus research and by asking experts and other related groups to rate them in importance.

RWH techniques has great potential to achieve sustainable agriculture in semi-arid arid regions. Knowledge in developing countries is a weak determinant of technological adoption. Thus, the RWH system consists synergetic combinations of technological innovations such as to integrate to conservation agriculture (CA) for sustainability. For example, Mafongoya et al. (2016), in a systematic review, found that farmers are aware of the associated outcomes of (CA) in increasing their crop yields and conserving resources. However, labour demands and additional expenditure (such as herbicides) contribute to factors that hamper uptake. More studies on farmers' awareness, behaviour, and attitudes could improve their acceptability and help to develop policies to increase acceptance by addressing particular concerns (Mafongoya et al., 2016). Having sufficient knowledge of a method of water conservation in subsistence farming is therefore not considered a prerequisite to making an informed choice. Farmers with low resources make a choice representing their socio-economic and financial values. It is crucial to understand farmers' views when encouraging technology take-up. Little was evaluated on the IRWH tillage awareness and the related attitudes and perceptions that affect farmers ' adoption of the technology. Therefore, it is beneficial to develop a tool for measuring informed choice about the IRWH tillage technique in the Thaba Nchu rural communities, where the technology had been showing (for example as indicated on the WRC reports, such as WRC reports TT 492/11, TT 542/12; and TT 590/14) a positive impact in promoting productivity.

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CHAPTER 3: CONCEPTUAL AND THEORETICAL FRAMEWORK

3.1 Conceptual Framework

Firstly, the project formulated an appropriate conceptual framework for addressing the research questions to be evaluated while characterizing and diagnosing project components. Based on this concept, the research has organized into three main research areas spanning a sequence of stages of activities involved in moving system research outputs to development impacts (Figure 3.1).

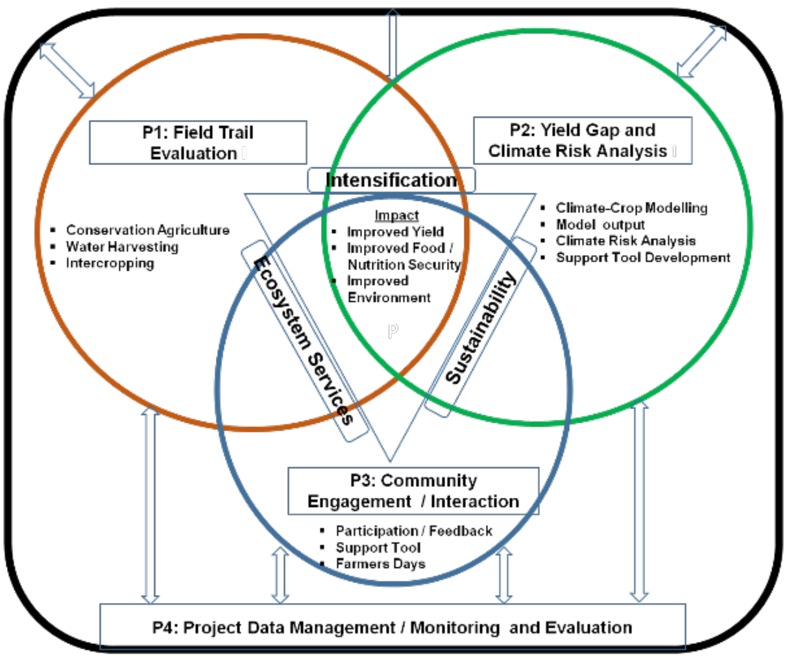

Figure 3.1 Schematic representation of the interaction between three programme activities (field evaluation, engagement and climate risk analysis)

Programme 1 – Objective – Evaluation of intercropping and IRWH techniques by smallholder farmers:

This part of the study includes setting up demonstration trials in the Thaba Nchu area in selected villages. The aim is to compare commonly or conventional used current management practices, the proposed alternative management strategy of IRWH, and cropping systems (sole- and inter-cropping) for each area. According to the project plan, the focus was on farmers' homestead gardens that were representative of their selected villages in terms of soil type and climatic factors. For each selected demonstration plot, soil and crop data collected at regular intervals was one priority during the growing season. It was planned to collect all climatic parameters from assembled weather stations or from a nearby weather station. Water balance components and canopy radiation-interception measurements were also part of the field data collection. During crop growth and harvest, detailed growth parameters and yield analyses were performed for each location and management strategy. Students, technicians and farmers participated during field data collection, instrument installation and data analysis. It was vital to obtain trial results because without directly comparing conventional and alternative management strategies, farmers will not be able to visually quantify the benefits of the techniques and cropping systems. This procedure enhanced the 'learning by doing' principles as opposed to a 'top-down' research-oriented programme where trials are conducted at research stations. The methodology of using farmers' fields as demonstration examples has been successfully applied in previous projects in South Africa, including many WRC projects.

Programme 2 – Objective – Engage smallholder farmers and enhance knowledge exchange on the proposed techniques:

The engagement activity involved participatory action research and 'learning by doing' principles. The first activity was the introduction of the project to extension officers and local leaders (village headmen and representative farmers) to receive their feedback and advice, followed by the launch of the project in the respective communities to identify the demonstration plots where the trials were carried out. The engagement with leaders followed local cultural norms and protocols. Since the target groups needed the knowledge and understating of the techniques, the project team providing practical training, which related the effects of soil, climate and improved management practices on crop growth and production. Thus, dedicated meetings and informal discussions were performed continuously during the project implementation period. Farmers' information-days and demonstration trial visits during the growing seasons were organized for each location.

At the end of the growing season, the project team formulated a participatory evaluation through engaging local extension officers and representative farmers from the villages. Questionnaires and templates for data collection were developed to evaluate systematically the knowledge uptake of the farming community to alternative techniques. Farmers and extension officers had the chance to comment and steer the visual presentation of the information provided. These activities of engagement had a vital contribution to the success of the project. If the project team did not garner local support from the target groups and local leaders, then the project would not succeed. By including the target group feedback and interactions from the beginning, the team developed a sense of 'project ownership' among them, which could greatly improve the chance of technology adoption and have a multiplicative effect.

Programme 3 – Overarching all the objectives: data management plan, evaluation, monitoring and project management):

The activities conducted in this programme helped to deliver the project in a timely manner. The data management plan was vital for field trial measurements and quantitative and qualitative data because the aim was to develop standardized protocols, data format and sampling strategies for smallholder farmers to adopt. The regular monitoring activities included regular meetings and phone/SMS communications, which helped to keep the project on track, followed by bimonthly to quarterly based internal reports that summed up the activities and result in a certain timeframe. Finally, the project management activities produced the reports as well as controlled and managed the finances of the project. The justification of keeping these activities outside the other programmes was to enable an over-arching function across all the objectives of the project.

The conceptual framework for the study partially followed the application of smallholder farmers' responses to the technology by using the theories of diffusion and adoption of innovations. According to Rogers (2003) and Adolwa et al. (2012), the diffusion of innovation occurs through five steps processes: awareness (Knowledge), interest/willingness (persuasion), evaluation (decision), trial (implementation and adoption confirmation)

3.2 Sustainable Livelihood Framework

The sustainable livelihood framework explains how smallholder farmers’ livelihoods benefit from the available resources by engaging them in certain farming activities. The research focuses by including smallholder farmers in the project to undertake livelihood strategies using the assets that they own to transform their lives. In this study, assets owned by smallholder farmers were key in implementing livelihood strategies such as crop farming (including homestead gardens), livestock rearing, and implements for cultivation. These were necessary to realize the desired livelihood outcomes and to minimize climate risk and vulnerability impacts. The sustainable livelihood framework illustrated in Figure 3.2 shows the relationships within the context of smallholder farmers’ assets (different forms of capital), technology transfer, livelihood strategies and livelihood outcomes.

Given the assets, households make decisions regarding improved technology uptake and intensification to generate positive social and economic outcomes. As illustrated in Figure 3.2, the system is characterized by forward and backward linkages in response to changes in farm and farmer specific variables. This becomes evident if farmers adopt alternative technologies or improved practices such as IRWH techniques and effective mixed cropping to enhance land productivity and ultimately improve their livelihoods. Therefore, the expected positive benefits from these practices influence farmers' choice about technology uptake. The alternative techniques of IRWH or cereal-legume / cereal-vegetable intercropping are intervention mechanisms through which rural communities in Thaba Nchu, given their farming potential and socio-economic characteristics, can transform poor resource farming.

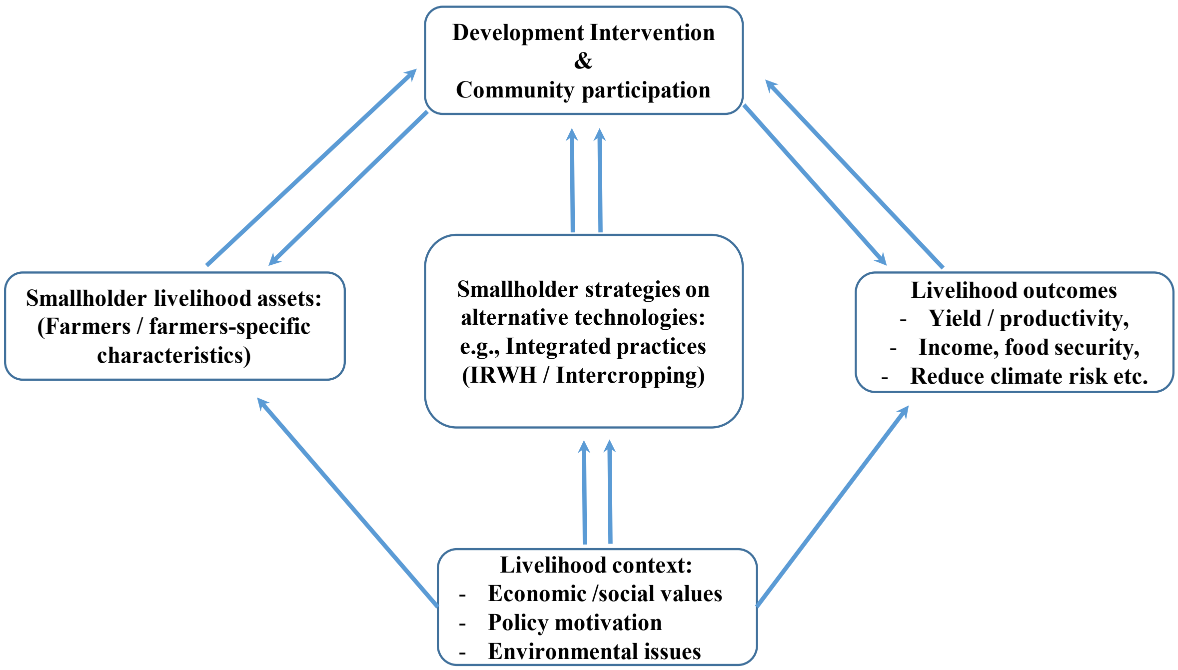

Figure 3.2 Linkage between alternative techniques and livelihood outcomes as a sustainable livelihood framework for smallholder farmers in rural communities.

3.3 Community-Based Natural Resources Management

Community-based natural resource management (CBNRM) is a major global strategy for enhancing conservation outcomes while also improving rural livelihoods; however, little evidence of socioeconomic outcomes exists (Brain, 2004; Anderson and Mehta, 2013). CBNRM has been widely promoted as a strategy to conserve biodiversity, while simultaneously enhancing rural livelihoods (Lund, 2007). The underlying theory indicates devolving control of natural resources to local communities, in particular the smallholder farmers.

Improvements are needed in natural resources management in order to take advantage of adopting improved and alternative techniques among smallholder farmers. Efforts are required to achieve efficient use of available resources such as water for agriculture. This pooling of research and extension resources aid in developing strategies to increase the productivity of poor resource farming communities in rural areas (such as Thaba Nchu; Figure 3.3). In other words, a coordinated approach is required to raise the productivity of smallholder farmers in arid and semi-areas, where water for agriculture is a scarce and fertile land for agricultural use has deteriorated. To combat rural poverty and to conserve the deteriorated natural resources requires community-based research and to integrate resource management strategies (Anderson and Mehta, 2013). Focused attention to the linkages between agriculture and natural resource management will help greatly to solve the challenges of poverty, food insecurity, and environmental degradation in the rural communities around Thaba Nchu (Figure 3.3a-e). To benefit the rural poor, research should operate on a "bottom-up" approach, using and building upon the resources already available. This includes local people (smallholder farmers), their indigenous knowledge and the natural resources around their homeland (Figure 3.3c). It must also be implemented through participatory approaches. Nevertheless, achieving demonstrable benefits to rural communities will be crucial for CBNRM; future success in Thaba Nchu rural areas (Figure 3.3a).

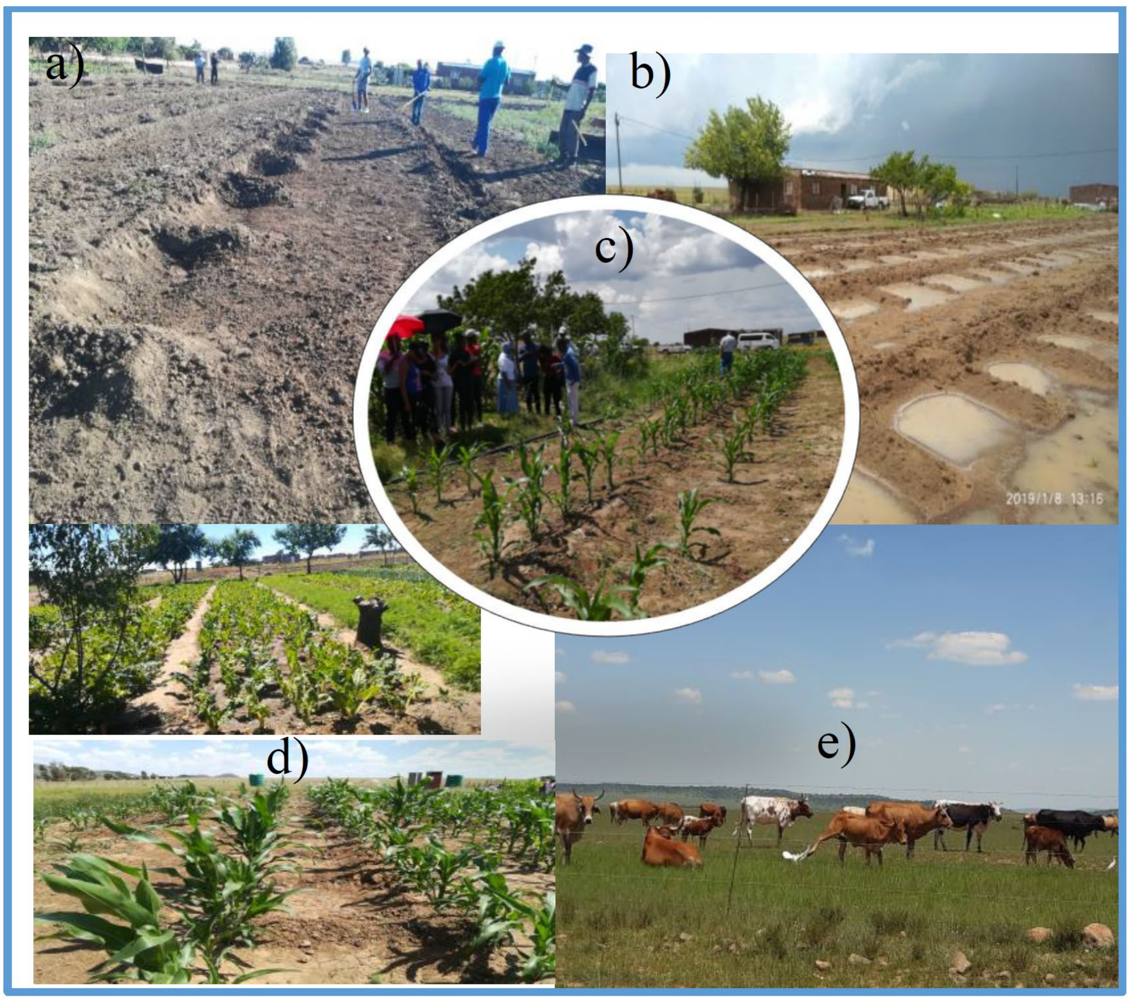

Figure 3.3 Representation for community-based natural resources management at Thaba Nchu including introduction of alternative techniques, demonstration of natural resources use and mixed crop and livestock production

Many governmental programmes seek to improve agricultural productivity including the use of effective soil and water conservation techniques. Promising research areas for evaluation and promotion of alternative technologies (Figure 3.3a & b include rainwater harvesting, intercropping suitability, green and dry mulch application, use of manure, cover crops, crop-livestock mixed systems (Figure 3.3d & e), and integrated pest management (IPM) interventions. The expected results of the project could initiate more research and contribute to achieving food or nutrition security in rural communities, but the potential and further adoption depend on the knowledge uptake of the technology. The majority of the rural poor live in areas that are resource-poor, highly heterogeneous and risk-prone environment. Their agricultural systems are small-scale, complex and diverse. The worst poverty is often located in arid or semi-arid zones, and in mountains and hills that are ecologically vulnerable (Conway, 1997). Such resource-poor farmers and their complex systems pose special research challenges and demand appropriate technologies that are:

- Based on indigenous knowledge or rationale
- Economically viable, accessible and based on local resources
- Environmentally sound, socially and culturally sensitive
- Risk-averse adapted to farmer circumstances
- Enhance productivity and stability

3.4 References

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CHAPTER 4: METHODOLOGY

4.1 Site Description and Target Group Selection

4.1.1 Site selection

The Thaba Nchu rural community from the Free State was chosen for the case study (Figure 4.1). The area has many communities/villages actively engaged in various rainwater harvesting and conservation practices for agricultural and domestic purposes. Besides, the Thaba Nchu area was the site of experimentation and dissemination of IRWH techniques by the Agricultural Research Council – Soil, Climate and Water (ARC-SCW) over the past two decades. Two villages (Paradys and Morago) in Thaba Nchu were selected for the study. The choice of these two villages was made considering the continuous engagement with representative farmers and extension officers of the Department of Rural and Agrarian Reform (DRAR) in Thaba Nchu. From these two villages, seven homestead gardens (as demonstration plots) were selected to conduct field trials. In addition, nine representative villages was used for qualitative and social aspects study.

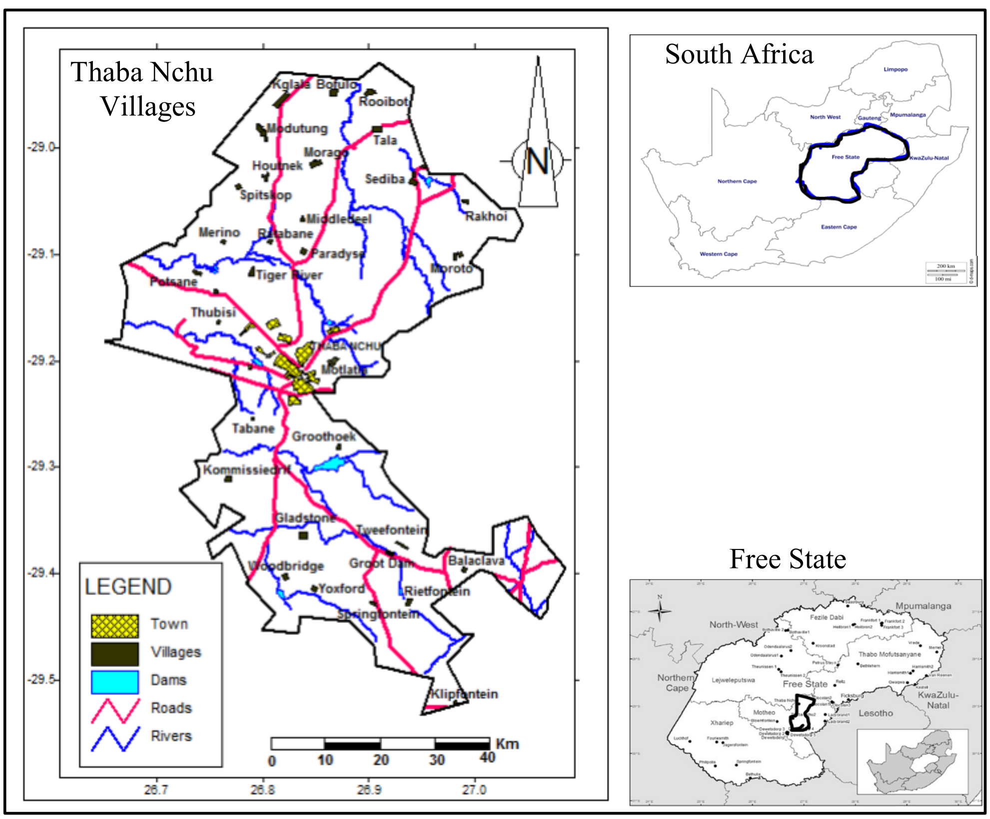

Figure 4.1 Project area of Thaba Nchu villages (left) located in Easter Free State, South Africa (right)

4.1.2 Target group selection processes

Thaba Nchu is home to several thousand small-scale resources poor homestead gardeners. The area has a large population living in approximately 42 villages scattered around the two towns of Thaba Nchu and Botshabelo (Botha, 2006). Many households in the villages has access to an average of 2-4 ha of arable land, but Botha et al. (2003) reported that these households do not use the available cropland to their economic benefit. The semi-arid nature of Thaba Nchu villages and other environmental factors makes the arable land marginal for crop production under rainfed agriculture. Therefore, integrating IRWH techniques and efficient land use through intercropping systems has the potential to increase yield, reduce risk losses, thus improving food security and sustainability.

The study followed a participatory approach. The selection processes of the villages and the demonstration plots for the field trials were started by conducting continual meetings with extension officers and representative farmers from the rural communities/villages. During the first meeting on the 30th of May 2018, the extension officers identified 7 villages for the demonstration sites across Thaba Nchu (Figure 4.1). These villages are situated in the southern part (Springfontein, Yoxfort and Tweefontein), central (Felloane) and the northern part (Talla, Morago, Sediba and Paradys) of Thaba Nchu. A field visit and informal meetings with the farming communities and extension officers were conducted to finalize the selection processes. During the meeting with farmers and extension officers, a thorough discussion was held to identify the demonstration plots. There were two options to carry out the trials, either in homestead gardens or on arable crop fields (out of the farmers' backyards). The security and theft issues were one of the main concerns raised by farmers with regard to the arable farmers' crop fields for demonstration plots. Some farmers suggested fencing around the plots; other farmers mentioned that this would not deter theft. Additionally, the affordability of the infrastructure and timing was also a constraint for such a small and short-term project.

After several meetings and visits, the research team with extension officers and representative farmers agreed to select only two nearby villages from the northern part (Morago and Paradys) and nominate homestead gardens as demonstration trials (Figure 4.2). After the meeting with selected farmers (from Morago and Paradys villages) on 10 July 2018, another field visit was performed on both the selected homestead gardens and arable farm/fields. This followed by an extensive discussion with farmers to evaluate plot size, soil type and land preparation/cultivation, fencing and accessibility.

Figure 4.2 Research team, extension officers' discussion with the farming community in the selection processes

Following the selection of the demonstration plots (in both villages), soil characterization was performed using field evaluation techniques and as a preliminary survey, soil samples were collected from different horizons for chemical and physical properties analysis. The research team checked each selected backyard plot for fencing and a rough plan-sketch was designed to continue with land preparation. The farmers who participated in demonstration trials for the growing season 2018/19 completed a consent form (see Appendix V).

4.2 Experimental Layout / Plot Arrangement

The project team conducted a second meeting (05 November 2018) in Thaba Nchu at the DRAR office with extension officers and visited all the selected plots at Paradys and Morago villages. During the field visit the research team discussed the following points:

- Experimental layout and treatments to be included for demonstration trials;
- Crops to be planted and choice of cultivars for both sole- and intercropping;
- Cropping pattern and expected time of planting;
- Land preparation and other farming activities, such as basin and runoff construction;
- Row orientation according to slope and size (in particular for IRWH plots).

The plan was to use different plot sizes according to the total size of the backyard plots in order to fit in each backyard's width and length. The demonstration plots included both sole- and intercropping treatments under the two tillage systems *viz.,* in-field rainwater harvesting (IRWH) and conventional tillage (CON). The research team with beneficiary farmers agreed to use a simple experimental layout as the main plot for tillage (IRWH and CON) and as a sub-treatment, the cropping systems (sole- and inter-cropping). The team also agreed at least to have one complete treatment with full instrument installation in each village for measurement and follow up. Replication was implemented by considering different homestead gardens within each village and for each measurement. Replication was employed accordingly when crop growth measurement was implemented during the growing season.

4.3 Land Preparation

A mouldboard plough was used for cultivation, followed by disking to loosen the soil and for easy construction of the basin, ridge and runoff structures. The first step in the construction of the IRWH structure was to determine the basin to runoff strip width (Van Rensburg et al., 2012). In this study, a 2:1 basin to runoff strip width was used as recommended by Botha et al. (2006) and Tesfuhuney et al. (2015). Construction of ridges was initiated by using ridge plough, to establish a ridge on the contour (Figure 4.3a), and continued to form the foundation of the basin that stops runoff and directs the flow of runoff water to be collected in the basin area (Figure 4.3b). A puddle plough (basin maker) was employed to create cross ridges in the contours to prevent the collected water from moving laterally along the contour. Soon after creating the basins, a rotavator cultivated the 2 m runoff to loosen and smooth the soil for easy levelling towards the slope. A scraper was used to pull away from the soil from the basin area towards the slope to establish a gradient for runoff water to accumulate in the basins (Figure 4.3c). In each demonstration plot, up to 5-6 IRWH strips were constructed according to the slope of the field. This was followed by hand levelling of the runoff area (~<1-3% slope toward to basin area) using hand rakes. Farmers participated in modifying the basin and runoff area, in particular those portions disturbed by tractor wheels (Figure 4.3d). This work was relatively tedious and time-consuming but was managed with extra family labour involvement. However, once it is constructed, it can be used for several years with only minimum maintenance in the basin area. After completion of the structure, the basin area harvested rainwater and infiltrate into the profile as illustrated in Figure 4.4.

Figure 4.3 Operations in constructing the IRWH structures and levelling the runoff area through farmers' engagement. a) ridge maker, b) basin area, c) scraper to create slope and d) hand levelling

Figure 4.4 Water storing and infiltration into the soil profile in the basins after a rainstorm

4.4 Crop Management Practices

As recommended by the extension officers and farmers, a sugar bean (common beans) local landrace and maize cultivars commonly used by the local people were selected for the trial. These cultivars have as high yield ability and very good yield stability in the Thaba Nchu area. The maize cultivar is a medium maturing yellow maize hybrid (cultivar: P2434R) performing excellently in the warmer dryland areas of South Africa. The anticipated sowing date was from mid-November to mid-December as it depended on the onset or start of rain during the growing season. However, the rain was delayed that season with extended dry spells to January 2019. Thus, the planting date was started on 07 January and continued until 12 January 2019 in the homestead garden demonstration plots in both villages.

The cropping system treatments were maize (sole), beans (sole), and maize-beans (intercrop). For maize and beans mixtures, the plant equivalence was calculated according to the ratio of the estimated optimum plant population of the component crops in pure stands (Karel et al., 1982). On this basis, plant equivalence was calculated to be one maize plant to 3-4 bean plants. According to Austin and Marais (1987), replacement intercropping could lead to a cropping strategy that would reduce the risk of rainfed crop production in semi-arid areas. In semi-arid conditions, Du Plessis (2003) recommended a plant population of 28 000 plants ha^{-1} for maize to attain a yield of 4-4.5 ton ha^{-1}. This ensures low competition for resources such as solar radiation and water. Under IRWH individual plot sizes for each treatment measured ∼180 m^2 and all rows were ∼10 m long.

To attain the targeted plant population, an in-row spacing of 0.23 m was used for sole and intercrop maize and 0.05-0.08 m for sole and intercrop beans. For the CON plots, treatments measured an area of 80 m^2 and rows were arranged 1 m apart and 10 m long. The inter-row spacing for the sole crop (maize and bean) and intercropping (maize + beans) were 0.35 m and 0.18 m, respectively. The beans intercrop rows were made about 0.10 m from the maize rows. This gave a population of 28000 plants ha^{-1} (sole and intercrop maize) and for bean sole and intercrop about 110 000 plants ha^{-1}. Thus, the target plant population was estimated to 3 and 11 plants m^{-2} for maize and beans, respectively. However, due to long dry spells at the seedling emergence stage and the effect of tractor wheel traction or compaction, there was poor emergence even after some farmers applied water using water cans for poorly emerged seedlings to promote survival. At the early stage, (10-15 days after planting (DAP)), plant count was performed from 10 m length alongside rows to estimate the emergence rate. Outside the demonstration plots in Paradys, simple maize germination and emergence test in a 4 m^{-2} quadrant were carried out. The aim of this trial was to illustrate to the farming community, the effect of adding crop residue and manure (abundantly available materials in the farmers' backyard) to enhance germination and emergence on clay soils during dry conditions (Details of the methodology and results are presented in (Appendix IV). The final plant population at harvest was also counted using a 2 m^2 area quadrant from each treatment to avoid errors in calculating final yields from the target plant population.

Planting and fertilization were done by hand by participating farmers. Fertilizers, at rates of 90 kg N ha^{-1}, 45 kg P ha^{-1} and 60 kg K ha^{-1} were applied in all plots for a target yield of 4-5 tons ha^{-1}. All the P, K and a third of the N fertilizer were applied at planting as a compound (6.7% N; 10% P; 13.3% K + 0.5% Zn) and the rest (60 kg) was applied as LAN at 6 weeks after planting (WAP) by banding.

4.5 Field Data Measurements

4.5.1 Weather variables

An automatic weather station (AWS) was assembled and erected at a standard height of 1.5 m in one of the demonstration plots in Paradys (-29º 09'S, 26.84'E). The AWS consists of a tipping bucket rain gauge, cup anemometer and wind vane, a pyrometer and combined temperature and humidity sensor. All meteorological data (rainfall, minimum and maximum temperatures, minimum and maximum relative humidity, wind speed and direction, and solar radiation) were recorded on a CR10X data logger (Campbell Scientific, USA) every 5 minutes and averaged over one hour for storage. In the processes of installing the AWS and data downloading, farmers, extension officers and students were participated along with the technicians (Figure 4.5). The long-term climatic data (2007 to date) were collected from ARC-SCW (Agricultural Research Council of South Africa – Soil, Climate and Water). The rainfall that was recorded from the AWS during the season was collected on a 5-minute rainfall amount basis. Thereby each rain event could constitute several rainstorms and various rainfall durations, which were considered for runoff estimation. As part of farmers' engagement, manual rain gauges were also installed on each demonstration plot and farmers monitored and recorded rainfall amount after the rain events.

Figure 4.5 The assembled AWS erected in the demonstration plot of Paradys village. Showing regular weather data downloading by students and technicians.

4.5.2 Soil characteristics

Soils of the study areas are generally characterized by high clay content and shallow soil depth (Botha et al., 2003). From the preliminary description of the soils in Thaba Nchu (Land Type Survey Staff, 1972-2011), the Thaba Nchu soils can be represented in three main land types, namely Dc17 (52.8%), Db37 (29.3%), and Ca33 (13.3%). Thus, the Paradys and Morago villages fall under Dc17 and Db37 land types, respectively (Figure 4.6). The land type Dc17 in Paradys has a high dolerite intrusion and with higher clayey but minor issues of waterlogging during the wet season while the Db37 land type in Morago has lower levels of dolerite intrusion, compared to Dc17 and it has relatively lower clay content (Botha et al., 2007). To identify the row orientation and treatment arrangements for each demonstration trial, a rough sketch of the selected homestead backyard gardens was prepared. This indicates the position of the homestead gardens with residential areas such as houses, stores, animal shades, roadside and neighbourhood houses as a reference point (Figure 4.6). The size area of the selected homestead gardens ranged from 50 x 30 m to 30 x 25 m as illustrated in Figure 4.6.

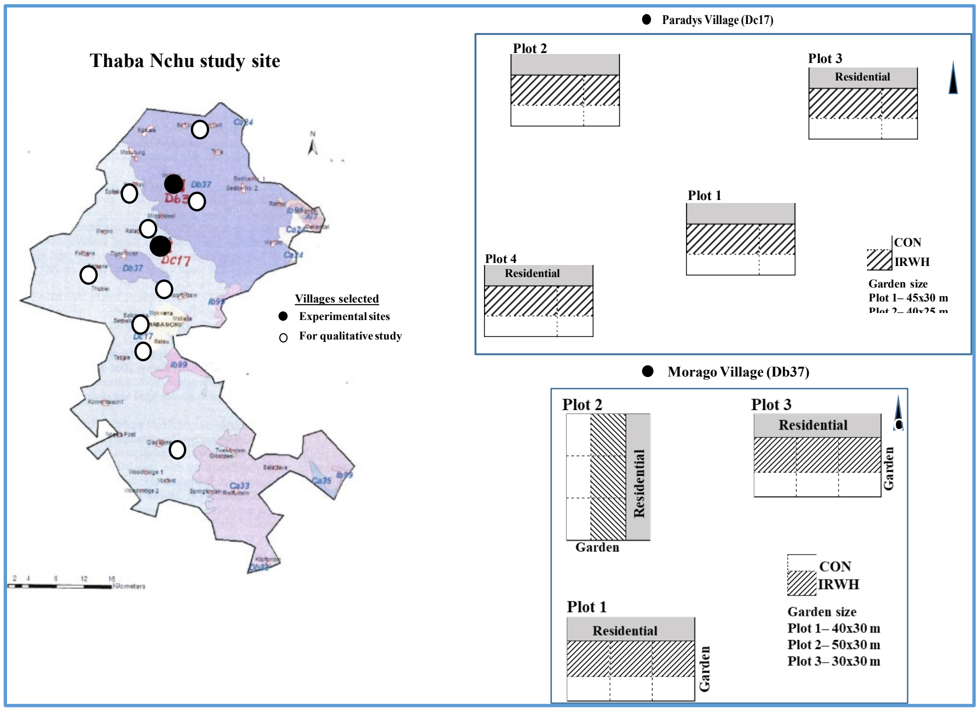

Figure 4.6 Location map of the Thaba Nchu area with dominant land type demarcation and the two study areas of Morago and Paradys villages (•), which fall under Db37 and Dc17 land type soils, respectively (left); selected villages for qualitative study (o); and the sketch of the selected homestead backyard gardens for demonstration plots (right)

As shown in Figure 4.6, the Paradys site with Dc17 land type soils can represent more than half of the Thaba Nchu area, which is characterized by high dolerite intrusions. According to Hensley et al. (2006), the Dc17 land type soils with high vertic and melanic in A horizon, have high water holding capacity. This soil (Dc17) is highly recommended for IRWH practices if the profile is deep enough. However, soil studies from Thaba Nchu (Hensley et al., 2000) indicated that this type of soil consists of high clay content with shallow profile (400-700 mm deep). The other site (Morago) with Db37 land type soil has lower in clay content and mainly Duplex soils (dominated by Valsriver and Swartland). From previous studies, a waterlogging problem on this soil was reported during wet season. This may have a negative effect on practicing IRWH tillage during heavy rain occurrences or La Niña episodes.

Detailed characteristics of the pedological layers were identified in soils at selected demonstration plots through both field and laboratory evaluations. First, as a preliminary survey, soil samples were collected by auguring up to 120 cm deep and characterization was performed during the field selection processes. Farmers participated in soil sample collection and identifying the characteristic of the soil from the tacit knowledge obtained over the years (Figure 4.7).

Figure 4.7 Soil field evaluation and data collection by auguring to a depth of 120 cm with the participation of farmers and students after site selection

4.5.3 Measurements of water balance components

A simple form of water balance quantification appropriate for IRWH and CON in arid and semi-arid areas was adopted from Hillel (l982). Evapotranspiration (ET) can be estimated with the water balance equation for dryland crop production in soils without a water table and without significant internal lateral water movement and can be written as follows (Bennie et al., 1994):

$$Water\ for\ yield = water\ gains - water\ losses$$

$$ET = (P \pm \Delta S) - (R_{off} + D) \tag{4.1}$$

The equation states the general concept that water for yield is equal to the water gains minus water losses. In this model, a portion of rainfall (P) infiltrates into the soil and becomes available for root extraction, together with the change in soil water content (ΔS) between the beginning and end period of the growing season. The losses include the amount of water evaporated from the soil surface and plant transpiration (ET), the surface runoff (R_{off}) and the drainage amount (D). The IRWH technique has two different sections in each field, the basin and runoff area, that are practically linked as the runoff strip feed water into the basins as run-on (R_{on}) while the CON tillage exposed to ex-field runoff losses. Therefore, the water balance components needed are as follows:

$$ET = P - R_{off} - D \pm \Delta S \quad (4.2)$$

Where R_{off} represents the ex-field losses from CON plots while no runoff losses occur under IRWH tillage. The units for all the water balance parameters were in mm of water for a selected time. For the CON treatments, the amount of runoff water component was inaccessible to the plants or as the ex-infield runoff losses. The most crucial parameter to determine was how much water for productivity was harvested/conserved to the profile into the basin and stopped ex-field runoff losses under IRWH techniques.

The water balance model described in this study analysed the relationship between rainwater harvested in the basin as part of the amount of rainfall (P), where the crop roots easily accessed under IRWH and as ex-field losses in the CON tillage. However, on both tillage systems, the water lost through evapotranspiration and deep percolation depend on the amount of soil water, soil physical properties and crop characteristics.

4.5.3.1 Soil water content

To monitor the soil water content of the root zone (θ_r), a DFM (CLP180 Moisture probe) was used and inserted to a depth of 1500 mm, in one demonstration plot in Paradys village. This depth was greater than the expected root depth of both maize and beans. The DFM probes were placed in between the rows in CON and at the centre of the basin area in the IRWH treatments. The DFM moisture probes installed only one for each treatment, as it was not affordable to use more probes for replication. Measurement of soil water content was also made in one of the demonstration plots at Morago village (Figure 4.8). To monitor θ_r, neutron water meter steel access tubes were inserted to a depth of 1500 mm, that is, to a depth greater than the expected roots. Soil water content was measured at an interval of 1-2 weeks to a depth of 1500 m using a neutron water meter (NWM, Campbell Pacific Nuclear model 503, CA USA, 1994) to take neutron counts down the access tubes. Measurements of θ_r were carried out during the growing season at 300 mm depth intervals starting at 150 mm (being 150, 450, 750, 1050 and 1350). This procedure ensures that the different pedological layers in the soil have been adequately represented.

Figure 4.8 Monitoring soil water content using a) neutron water meter or neutron probe (NWM) during the growing season at Morago site demonstration plot, and b) DFM (CLP180 Moisture probe) installed between plant rows (at Paradys site)

4.5.3.2 In-field runoff

The runoff measurement plots were prepared with enclosure frames. The galvanized iron sheeting (2 m wide) was installed (restrained by pegs to stand upright) on three sides, across the runoff strip and near the next row of plants. The iron sheets were inserted into the soil surface to 5 cm depth to ensure that runoff would collect only from within the enclosure metallic frame area. A gutter ran along the outside edge of the basin area to transfer the runoff water into the tipping bucket. However, continuous measurement of runoff after every rainstorm is difficult, as it requires maintenance and continuous checking and cleaning the tipper. Due to that fact, the runoff data downloaded from the automated runoff tipper was incomplete and unreliable to include in the water balance estimations. Thus, an empirical model developed by Anderson (2007) for clay soils Glen Bonheim ecotopes was used to estimate the R_{on} amount during the growing season, and equated as follows (eq. 4.3):

$$R_{off} = 0.2678P - 2.5298 \qquad (4.3)$$

Where P = amount of rain and R_{off} = run-off, this indicates part of the amount of rainwater that could be a loss as ex-field run-off from the CON plots.

4.5.3.3 Drained upper and lower limit of available water

Deep drainage is one of the water losses in the process of water balance calculations. The magnitude of water holding capacity of the root zone is determined by the drained upper limit of plant-available water (DUL). The DUL of the soil is the highest field measured water content of each soil layer after it has been thoroughly wetted and allowed to drain until drainage becomes practically negligible. Ratliff et al. (1983) stated that a DUL of a particular soil can exist when the water content in profile decreased by less than 0.1-0.2% per day.

The lower limit of the plant available water (LL) is the lowest field measured water content of the soil after plants have stopped extracting water at or near premature death or when dormant as a result of water stress (Ratliff et al., 1983). The LL was determined during the course of a growing season by taking the lowest water content measured for each soil layer. The value of LL could vary according to different seasons and is highly related to soil water-crop relationships for a particular ecotope (Hensley et al., 1997; Hensley et al., 2000; Ratliff et al., 1983). Plant available water capacity (PAWC) in the root zone can be estimated by simply subtracting the LL values from the DUL values (Hensley et al., 2000) (eq. 4.4):

$$PAWC = DUL - LL \tag{4.4}$$

Where, DUL and LL are upper and lower limits of the plant available water, all in mm.

4.5.4 Crop growth parameters and grain yield

Out of the six-row planting strips allocated to each treatment, the four middle rows were selected for sampling crop growth (plant height, leaf number and leaf area), biomass and final grain yield measurements. Samples were collected for each plot from both rows from the ridge and basin sides for IRWH. Plant densities were also assessed after emergence and again during final harvesting for each plot as there were variations in emergence due to long dry spell at the beginning of the growing season and some incidences of theft were noticed when the crops are ready for green consumption.

The above ground dry matter (AGDM) was measured periodically from 20 days after planting (DAE) until the plants attained maximum size (85 DAE). During sampling, the height of each plant was recorded, cut at the soil surface and then separate into green and dead leaves, stems, and reproductive organs. Three plants were harvested (above ground section only) from each plot. To determine the harvested biomass, samples were dried in an oven regulated at 70°C for 72 hrs. Thus, the AGDM, partitioned into leaf, stem and reproductive organs, was calculated as oven-dry material in kg ha^{-1}.

To determine the final grain yield of both crops, a sample quadrant of 2 m^2 from each treatment was delineated which meant to harvest 2 m along the rows at the end of the season. Before the final harvest started, sampling quadrants were marked, and the sampling area was enclosed using barrier tape. Farmers were informed to be cautious around the sampling areas until the crops were fully mature. However, unfortunately, some maize copes and bean pods are removed from the marked sampling quadrants and irregular plant population was observed. Subsequently, the action was taken to use five plants per sample with 3 replications from each treatment. The grain was shelled and weighed, oven-dried and adjusted to 12.5% seed moisture content expressed as kg ha^{-1}. Harvest index (HI) was calculated as the ratio of grain seed yield to above-ground dry matter production (Bennie et al., 1998) (eq. 4.5):

$$HI_{AGDM} = Y_g / Y_{AGDM} \quad (4.5)$$

Where HI_{AGDM} is the harvest index for above-ground dry matter, Y_g is the grain seed yield (kg ha^{-1}), and Y_{AGDM} is the total above-ground biomass (kg ha^{-1}).

4.5.5 Water use / productivity

Precipitation use efficiency **(*PUE_{fg}*):** For the growing and previous fallow periods together, PUE_{fg} was determined as an acceptable and simple way to describe the efficient use of rainwater available for dryland crop production as given by Hensley et al. (2000):

$$PUE_{fg} = Y_g / (P_g + P_f) \text{ or } PUE_{fg} = AGDM / (P_g + P_f) \quad (\text{kg ha}^{-1}\ \text{mm}^{-1}) \quad (4.6)$$

Where P_f and P_g are the precipitation during the fallow period and growing season.

***Water productivity (WP_g)*:** Water productivity was determined with an approach used by Passioura (2006) as productivity is a function of amount of rainwater during the growing season. WP_g, therefore, measures the efficiency with which a particular crop can convert the water used by the plant into grain yield or biomass during a particular growing season:

$$WP_g = Y_g / P_g \text{ or } WP_g = AGDM / P_g \quad (\text{kg ha}^{-1}\ \text{mm}^{-1}) \quad (4.7)$$

Where WP_g is water productivity and Pg is the amount of rain during the growing season in mm.

***Water use efficiency (WUE_{ET})*:** Water use efficiency was used to measure the efficiency with which a particular crop can convert the water available during the growing season (Hillel, 1972; Tanner and Sinclair, 1983; Botha et al., 2001; Botha et al., 2003). Thus, WUE_{ET} was determined with a slightly modified version of Hillel (1972); Passioura (1983) and Tanner and Sinclair (1983) as follows:

WUE_{ET}= Y_g/ET or WUE_{ET}= $AGDM/ET$ (kg ha^{-1} mm^{-1}) (4.8)

Where WUE_{ET} is water use efficiency in terms of total evapotranspiration (ET) in mm.

4.5.6 Radiation canopy interception and radiation use efficiency (RUE)

The sub-treatment included two cropping systems that affected the microclimate, namely sole cropping with no shading and intercropping with shading effect and resources use competition. Moreover, the different tillage systems also differ in canopy configuration, which may affect the radiation interception of the crop canopies. The photosynthetic active radiation (PAR 0.4-0.7 μmol) in the wavelength was measured above and beneath the plant canopy with a single line quantum sensor that was set at perpendicular in between the cropping rows. The line quantum sensor was placed in between the maize, beans and maize-beans intercrop rows at the soil surface and above the canopy. The PAR measurement was taken at an interval of 7-15 days throughout the growing season. The PAR was measured around midday between 12:00-14:00 South African Standard time (SAST).

To measure radiation intercepted by each component crops in intercropping, a partitioning equation adopted from Tsubo and Walker (2002; 2004) was used. The fraction of radiation intercepted by crop canopy (F) was estimated on the bases of Beer's laws (Monsi and Saeki, 1953):

i) In maize/beans intercropping, the lower canopy layer consists of both maize and beans layers while the upper layer only includes maize. Incident solar radiation at the top of the intercropping bean canopy is equivalent to F by the maize in the upper (F_{MU}) this will be estimated by using a simple equation (Adopted from Tsubo and walker, 2002) (eq. 4.9):

$$F_{MU} = 1 - \exp(-K_m L_{MU}) \tag{4.9}$$

Where K_m is canopy extinction coefficient for maize and L_{MU} is a LAI with uniform leaf density in the upper canopy (eq. 4.10):

$$L_{MU} = \frac{h_M\, h_B}{h_m} T_{LM} \tag{4.10}$$

Where T_{LM} is a total maize leaf area h_M and h_B are the height of maize and beans canopy.

ii) To measure radiation intercepted by each component of the crops in intercropping, a partitioning equation adopted from Tsubo and Walker (2002) was used. Therefore, the fraction of radiation intercepted by beans (F_B) and fraction maize at the lower layer (F_{ML}) was estimated as follows (eqs. 4.11 and 4.12):

$$F_B = \frac{K_B L_B}{K_B L_B + K_M L_{LM}} F_{M/B} \tag{4.11}$$

$$F_{ML} = \frac{K_M L_{ML}}{K_B L_B + K_M L_{LM}} F_{M/B} \tag{4.12}$$

Where:

- K_B and K_M is the canopy extinction coefficient for beans and maize (according to Tsubo and Walker (2002), it was estimated at 0.64 and 0.43 respectively).
- L_{ML} and L_B are maize and beans LAI in the lower canopy layer.
- $F_{M/B}$ is a fraction of radiation interception by the crops of maize and beans in the lower canopy layer. This is equivalent to the difference between overall F by the intercrop and F by maize in the upper layer.

iii) The LAI in the lower maize layer in the intercropping and the total intercepted was radiation estimated as (eq. 4.13):

$$L_{ML} = \frac{h_B}{h_M} T_{LM} \tag{4.13}$$

Therefore, the fraction intercepted by maize crop includes both upper and lower (eq. 4.14):

$$F_M = F_{MU} + F_{ML} \tag{4.14}$$

iv) Radiation use efficiency (RUE) for beans and maize can be calculated as (Monteith 1974) (eqs. 4.15 and 4.16):

$$RUE_B = \frac{W_B}{I_o F_B} \text{ and } RUE_M = \frac{W_M}{I_o F_M} \tag{4.15}$$

$$RUE_{BM} = \frac{W_{BM}}{I_o F_M} \tag{4.16}$$

Where W_B and W_M are dry matter (in kg) for beans and maize, respectively and I_o is the incident radiation in (MJ m^{-2} d^{-1}).

In the study, a relationship between RUE and WP was analysed for different cropping systems under different tillage to understand the effect of available soil water for productivity and the atmospheric demand in the semi-arid crop production system.

4.6 Farmers' Information Day

Interactions were performed regularly in various forms of engagements with farmers and extension officers. On top of that, researchers and experts were consulted at various stages of the project to get advice from their experiences. The beneficiary farmers (demonstration plot owners) were continually involved in all of the project implementation processes and practiced a 'learning by doing', which included site selection and land preparation until final harvesting. A farmers' information-day was organized when the crops reached near the flowering stage and was followed by field visits and discussions. Farmers and extension officers participated regularly through monitoring and final evaluation processes.

4.7 Qualitative Data Collection for Technology Transfer

To address the technology uptake, a systematic engagement strategy was used to identify contextual factors preventing farmers in the Thaba Nchu area from accepting the IRWH tillage system. The focus of this qualitative study was to assess farmers' knowledge, attitudes, uptake and perceptions of the tillage system. The questionnaire was tested to construct validity by using simultaneous qualitative approaches (Appendix VI). In the study, two distinct age groups were established based on the farmers' narratives of the knowledge and experience of the IRWH tillage system. The design of the survey method to test informed choices and sampling/data collection methods in detail are in Chapter 6. Data analyses were carried out using IBM Social Sciences Statistical Suite, SPSS version 24 (SPSS, Inc., Chicago, IL, USA) (SPSS Inc., 2015). The questions of knowledge and attitude were marked, and the scores were dichotomized as 'excellent' or 'insufficient' and 'positive' or 'negative' respectively. If farmers had excellent knowledge and the attitude was positive regarding the adoption of IRWH tillage, an informed choice was considered to have been made. An evaluation of informed choice (n=12) omitted farmers with responses for the potential use of IRWH tillage. The accuracy of the questions of knowledge and attitude was tested using the alpha of Cronbach. Alpha values ranging from 0.7-0.9 suggested a good internal accuracy measure. Descriptive statistics were created to reflect the opinions of farmers on informed choice with different aspects of socio-economic demographics. The data from interviews on farmers' perceptions are reported as narratives, which were transcribed verbatim.

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CHAPTER 5: WATER AND RADIATION USE OF MAIZE-BEAN INTERCROPPING IN HOMESTEAD GARDENS

Abstract

The purpose of this study was to evaluate alternative management practices such as in-field rainwater harvesting (IRWH) and intercropping (Ic) techniques through conducting on-farm field demonstrations. During the growing season 2018/19, seven homestead gardens (four in Paradys and three in Morago villages) in Thaba Nchu rural communities were selected for demonstration trials. The soil at the study areas of Paradys and Morago villages fall under Dc17 and Db37 land types, respectively. Two tillage systems [conventional (CON) and IRWH] as the main plot and three cropping systems as sub-treatment, (sole-maize and beans and intercropping) were used to measure crop growth, water use and radiation use parameters. The results show the IRWH tillage had a significantly higher above ground dry matter (AGDM) for both sole maize (29%) and intercropped maize (27%) compared to CON treatments. The grain yield (GY) under both tillage systems showed that IRWH-Sole >> IRWH-Ic >> CON-Sole >> CON-Ic, with values ranging from 878.2 kg ha^{-1} to 618 kg ha^{-1} ($P \leq 0.05$). The low harvest index (HI) values (0.21-0.38) could have been due to the effect of drought during the growing season. The water use in IRWH showed higher by 15.1%, 8.3% and 10.1% over the CON for sole maize and beans and intercropping, respectively. Similarly, the intercropping system showed the water use advantages over the solely growing crops by 5% and 8% for maize and by 16% and 12% for beans under IRWH and CON tillages, respectively. The WP of various treatments was positively related to the radiation use and the degree of associations varied for different tillage systems. Maximum RUE was found for solely grown maize and beans under IRWH and higher by 13% and 55% than the CON tillage, respectively. This relationship indicates the intercepted radiation by plants for photosynthesis is directly related to the transpiration rate until radiation saturation occurs. Therefore, the higher water deficit and lesser efficiency in using the radiation available during the season can be improved through practicing IRWH techniques. To further improve water and radiation use efficiency in maze-bean intercrop under IRWH, there is a need to optimize plant population and sowing dates relative to water availability and on-set of rainfall.

Keywords: Smallholder farmers; In-field rainwater harvesting (IRWH); Water use; Radiation use

5.1 Introduction

In arid and semi-arid areas, water is the most limiting resource for improving rainfed agricultural production. Improving rainwater productivity is one of the outstanding strategies for use in rainfed agriculture or dryland farming. However, in dryland farming, much of the productive rainwater is lost through runoff and soil evaporation (Es), resulting in extremely low rainwater productivity (Somme et al., 2004). Oweis et al. (2001) suggested that in dryland agriculture over 50% of lost water could be recovered through improved water harvesting techniques. Farmers in the semi-arid areas have therefore developed strategies, including in-field rainwater harvesting (IRWH), to cope with these uncertain and erratic rainfall patterns.

In the semi-arid crop production areas in the central part of South Africa, the problem of low and erratic rainfall is exacerbated by two major factors, *viz*. high runoff and high atmospheric evaporative demand (Hensley et al., 2000) which lead to high evaporation of water from the soil surface. These losses hamper the efficient use of available water for crop production and water losses need to be minimized to optimize rainwater productivity. Therefore, the approach of IRWH with appropriate cultural management practices such as intercropping (Hatibu et al., 1995; Hensley et al., 2000; Botha et al., 2003; Van Rensburg et al., 2005) is an important consideration for rainfed agriculture and can be an adaptation strategy against climate change (Rockstrom et al., 2007).

Intercropping, which is one type of multiple cropping systems, has been practiced traditionally by smallholder farmers in the tropics. In particular, cereal and legume intercropping are recognized as a common cropping system throughout tropical developing countries (Ofori and Stern, 1987). Maize and beans are staple and supplementary crops respectively, in many African countries and contribute to food and nutrition security in the livelihood of smallholders. Canopy structures and root systems of cereal crops are generally different from those of legume crops. In cereal-legume intercropping, cereal crops form relatively higher canopy structures than legume crops and the roots of cereal crops grow to a greater depth than those of legume crops (Tsubo et al., 2003). This indicates that the component crops probably have different spatial and temporal use of environmental resources such as radiation, water and nutrients (Willey, 1990). Therefore, by integrating the techniques of rainwater harvesting (such as IRWH) and cereal-legume intercropping on smallholders' arable field or homestead gardens, it may improve productivity through efficient use of resources (water and radiation and nitrogen for soil fertility). There are many such studies conducted on water use and radiation use on experimental stations but very scarce to get comparable results from on-farm trials with farmers commonly used cultural practices.

In sole crops, water use efficiency (WUE) is directly related to radiation use efficiency (RUE), for example (Sadras et al., 2006; Caviglia and Sadras, 2001). Key physiological and agronomic aspects of intercropping were also widely investigated (Calvino et al., 2002; Calvino et al., 2003a; Calvino et al., 2003b; Tsubo et al., 2003). There are limited reports, however, comparing capture and efficiency in the use of resources (water and radiation) and their relationship of maize-bean sole and inter-cropping under the IRWH technique as compared to CON tillage. Therefore, in this study hypothesized that: firstly, maize-bean intercropping under IRWH tillage system increases the productivity of resources and use efficiently in relation to solely grown crop because of improved efficiency in the capture and use of resources (water and radiation). Secondly, there are positive relationships between the water productivity (WP_g) and radiation use efficiency (RUE) in both tillage systems (IRWH and CON), with higher water deficit and lesser available radiation use in CON compared to IRWH.

5.2 Materials and Methods

5.2.1 Study area and experimental design

The project area (Thaba Nchu) is situated at a latitude 25°12'S, Longitude 30°39'E, and Altitude of 1516 m, about 65 km from Bloemfontein in the Free State Province of South Africa (Figure 4.1). The two selected target study areas (Paradys and Morago villages) are located on the northern side, approximately 8 km from Thaba Nchu town (as shown in Figure 4.6). Arable land and communal grazing areas surround both these villages. Growing vegetables and rearing livestock in backyards is a common practice of smallholder households. Paradys and Morago villages have 271 and 300 ha of arable land as well as 1795 and 1650 ha of communal grazing area, respectively. Each household has access to about 2 to 4 ha of arable land. Besides, households have 0.25-0.50 ha residential land, a portion of which can be used as homestead garden on which a household can produce crops such as maize, legumes, vegetables and to some extent forage to their livestock. The demonstration trials were conducted on seven household homestead gardens (as described in Chapter 4; section 4.5 and illustrated in Figure 4.6). Accordingly, there were two tillage systems as main treatment (IRWH and CON) and three cropping systems sub-treatments (Sole-maize, sole-beans and maize-beans inter-cropping) each combination treatment replicated in four and three demonstration plots in Paradys and Morago villages, respectively.

5.2.2 Treatments

For this experiment (2018/19 growing season), all the six treatments (2 tillages x 3 cropping systems), were used to measure for the soil water, radiation canopy interception, water productivity, and relationships of water use with radiation use efficiency studies. Furthermore, crop growth parameters, the grain seed yield and biological yield (above ground dry matter, AGDM) values were used to compare the two tillage systems for sole maize and beans and intercropping systems. Detailed description of the site, land preparation, runoff and basin area construction, farmers' cultivar choice, cropping season and crop management aspects were described in Chapter 4; Sections 4.1-4.4.

5.2.3 Field measurements

Detailed field measurements and instrumentation and data analysis are presented in details in Chapter 4; section 4.5. An automatic weather station (AWS) was assembled and erected at a standard height of 1.5 m in one of the demonstration plots in Paradys (-29º 09'S, 26º 84'E). As part of farmers' engagement, manual rain gauges were also installed on each demonstration plot and farmers monitored and recorded rainfall amount after the rain events. Characteristics of the pedological layers were identified in soils at selected demonstration plots through both field and laboratory evaluations. Farmers participated in soil sample collection and identifying the characteristic of the soil from the tacit knowledge obtained over the years. All the six treatments (2 tillages x 3 cropping systems), were used to measure for the water use, radiation canopy interception, water productivity, and relationships with radiation use efficiency studies. Furthermore, crop growth parameters, the grain seed yield (GY) and biological yield (above ground dry matter, AGDM) values were used to compare among the treatments.

5.2.4 Statistical analysis

Analysis of variance was done for comparison of different treatments using SAS 9.1.3 for windows (SAS Inst Inc., 2006). Means were compared using LSD test. Significance levels of $P \leq 0.05$ and $P \leq 0.001$ were used based on the variability associated with the type of measurements. Empirical relationships of the parameters were derived using regression procedures. Different statistical designs were adopted, and detailed statistical analyses are presented, accordingly.

5.3 Results

5.3.1 Climate and weather

The climate of the study area is classified as semi-arid with high evaporative demand and low rainfall by the Köppen climate classification of South Africa (Conradie, 2012; Kruger, 2004). Kruger (2004) described the climate of Thaba Nchu as very hot summers and cold winters. The long-term climate data recorded at Thaba Nchu was used to describe the general climatic characteristics. Rainfall, temperature and reference evapotranspiration (ET_O Penman-Monteith) data for Thaba Nchu (ARC-ISCW Climate Data Bank) for 9 years (2008-2017) is shown in Figure. 5.1. Monthly mean values for rainfall and ET_O are presented in Figure 5.1a. The study area has an annual mean of the minimum and maximum temperature of 9.2ºC and 23.9ºC with a mean annual rainfall (MAR) of 569 mm, making this a semi-arid climate. The rainy season stretches from October to April, although some rain also occurs during September and May. December and January have the highest aridity index (AI) of 1.2 and 1.3, respectively.

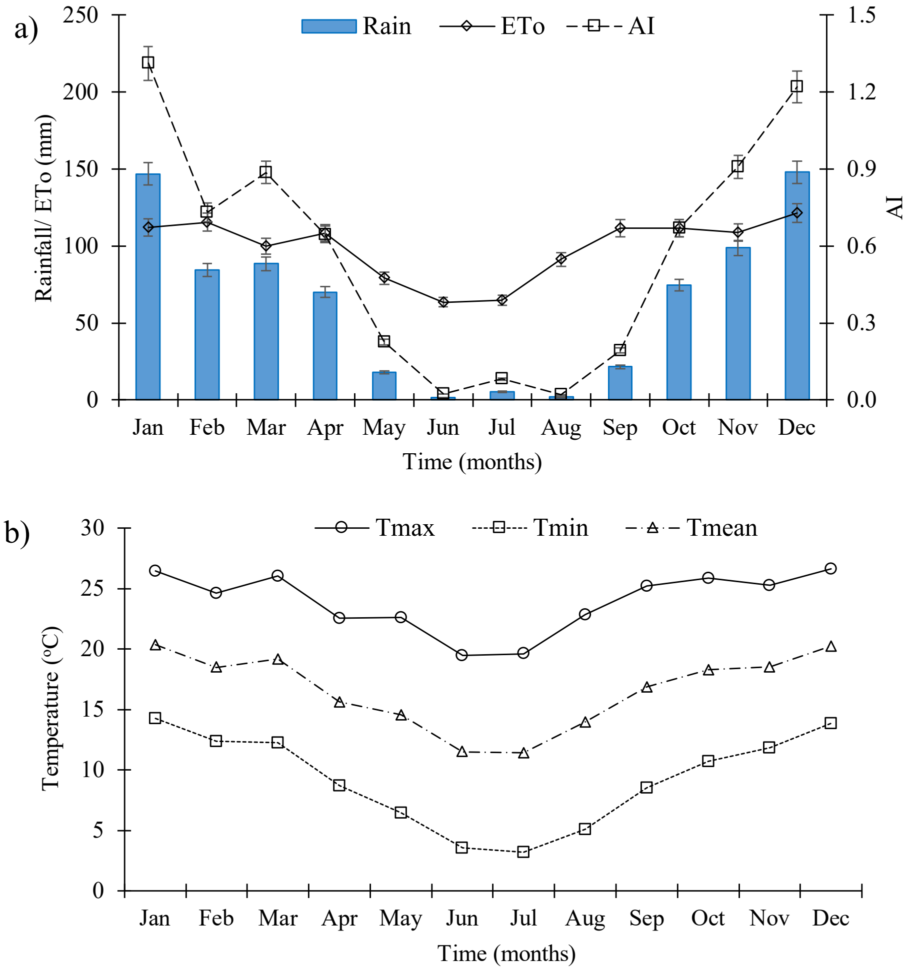

Figure 5.1 (a) Long-term mean monthly rainfall data (RF), reference evapotranspiration (ETo Penman-Monteith), and aridity index (AI); (b) minimum and maximum temperatures from the Enkeldoorn Thaba Nchu meteorological station. Data set from 2008-2017. (Source ARC-SCW)

The villages around Thaba Nchu known, which are semi-arid with low and erratic rainfall not exceeding 550 mm per annum, are frequently exposed to extreme drought conditions. The growing season 2018/19 is one of the typical examples of a drought condition that was associated with long dry spells in December and January. During this growing season, there was insignificant rain in the early growing season (October-December) but more rain fell, with a few strong rainstorms, during the late growing season (February and March). As a result, many farmers did not sow their seed after cultivating the land, and consequently, much of the arable land obliged to leave them fallow.

The prevailing weather conditions during the growing season (January-May) were captured by the hourly changes in the air temperature (Tmax & Tmin in Fig. 5.2a), solar radiation and wind (Rs & u in Figure. 5.2b), and rainfall (RF in Figure 5.2.c). During late summer, as expected for that time of the year the solar radiation increased over the months of January and February and decreased latter in March-May, resulting in a higher mean daily air temperature over the early growth (17.4ºC) compared to the later growth stages (13.5ºC).

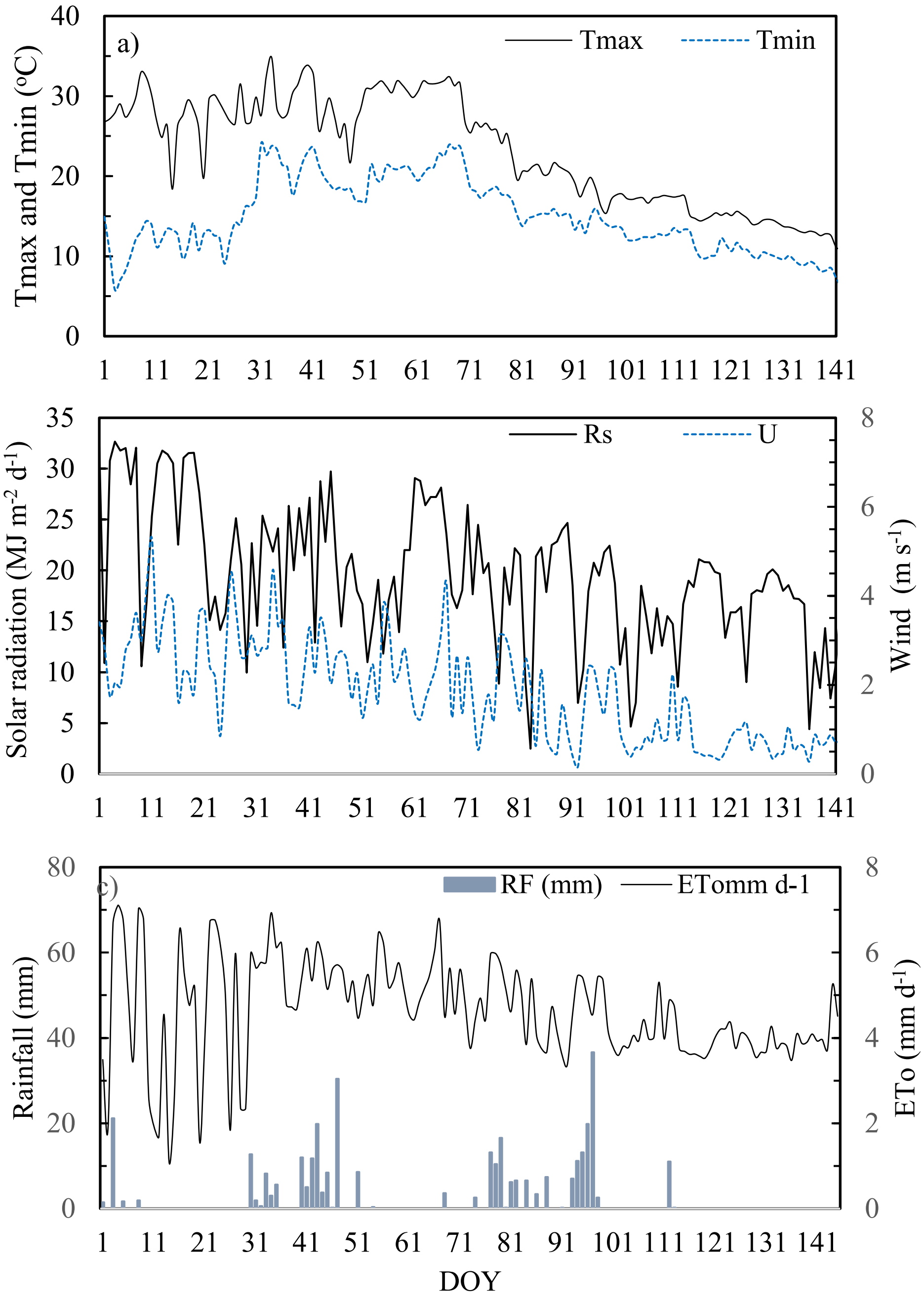

Figure 5.2 Daily weather variables from automatic weather station measurement during the growing season (01 Jan-15 May 2019): a) air temperature (Tmax and Tmin); b) solar radiation (Rn) and wind (u); c) rainfall (RF) and Reference evapotranspiration (ETo). DOY refers days of the year.

The wind speed was generally weaker after mid-February (1.5 m s^{-1}) compared to the January (~2.0 m s^{-1}), but there were days with peak wind speeds of > 4.0 m s^{-1}. During the summer season, the rain started late (end of December = 31 mm) and there was also rain on the first week of January but followed a long dry spell that affects the emergence of the seedlings. However, a large amount of rain recorded on February and March and this makes to increase the soil available water during the anthesis/flowering and grain filling stages.

5.3.2 Soil and topography

Topographically the demonstration plots are located in an area with the range of less than 2% slope some of them falling Northward and some with less steep or gentle to Southward. Field soil profiles can be assessed by digging into the ground and looking at the different layers of soil, also known as on-field evaluation of a soil profile. During field selection processes as a preliminary survey, field soil characterization was performed. The soil of the two villages showed some variations, as presented in Table 5.1.

Table 5.1 Profile description of the clay/sapane soil form in Paradys (a) and Morago (b) villages from the preliminary field surveys carried out by students and local farmers.

a)

Horizon	Depth (cm)	Description / characteristics	Diagnostic horizon
A	0-30	Moist state: Dry colour – strong brown (7.5YR4/3) and moist colour – brown (7.5YR2/2); Texture – clay; Structure – Granola: Consistence – weak, few fine pores; Abrupt transition.	Orthic A
B	30-55	Moist state: Moist colour – brown (7.5YR4/4); Texture – clay; Structure – Sud angular blocky; Consistence – friable, few fine pores; Abrupt transition.	Pedo cutanic
C	55+	Moist state: Moist colour – brown (10YR5/4); Texture – clay; Structure – angular blocky; Consistence – hard; few fine pores, Abrupt transition.	Unspecified

b)

Horizon	Depth (cm)	Description / characteristics	Diagnostic horizon
A	0-30	Moist state: Dry colour – yellow grey (10YR5/4), moist colour – yellow grey (10YR3/4); Texture – clay; Structure – Granola, Consistence – strong, few fine pores; Gradual transition.	Orthic A
B	30-60	Moist state: Dry colour – yellow grey (10YR5/3), moist colour – yellow grey (10YR4/3); Texture – clay; Structure – Angular blocky; Consistence – strong, few fine pores; Mottles – yellow and orange; Gradual transition.	Pedo cutanic
C	60+	Moist state: Dry colour – yellow grey (5y8/3), moist colour – yellow grey (5y7/4); Texture – clay; Structure – Crump; Consistence – medium, few fine pores; Abrupt transition.	Unspecified

The farmers and extension officers assisted the students during field evaluations and soil characterization by doing the auguring and soil identification for each horizon. This process ensured community engagement and in this way, farmers came to understand the characteristics of the soil in Thaba Nchu. As shown in Table 5.1, the clay/sapane soil at the project sites revealed differences in form and color, which could influence the deep-rooted crops' ability to extract soil water and nutrients from the subsurface horizons. For different tillage systems such as the IRWH tillage system, crop productivity depends on the effective depth of the A-horizon. The accumulation of water in the basin area where the plant rows are lined-up on the tramline has the advantage to increase yield. Farmers suggested that shallow-rooted crops (legume or vegetables) were suitable for shallow profiles of clayey soils with Lithic properties. Soil samples for laboratory analysis were also taken with an augur from the top 30 cm to a depth of > 55 cm at the end of February 2019 for each site. Samples were transported and analyzed to determine physical-chemical and morphological properties (Table 5.2).

Table 5.2 Important characteristics of the sapane soil form of Paradys and Morago villages

Descriptions	Diagnostic horizons (Paradys)			Diagnostic horizons (Morago)		
	Orthic A	Pedocutanic	Unspecified	Orthic A	Pedocutanic	Unspecified
Depth (m)	0-30	30-60	60+	0-30	30-60	60+
Texture class	Clay Loam	Clay	Clay	Clay Loam	Clay	Clay
Structure	Granola	Sud angular blocky	Angular blocky	Granola	Angular blocky	Crump
Mottling	Absent	Red, yellow	Magnesium nodules	Absent	Yellow, orange	Absent
BD (g. cm^{-3})	1.67	1.66	1.66	1.66	1.66	1.66
Colour (Wet)	7.5YR2/2	7.5YR4/4	10YR5/4	10YR5/4	7.5YR4/4	10YR5/4
Clay %	34	55	54	29	50	53
pH (KCL)	7.3	7.4	7.8	7.0	7.4	7.6
P (mg kg^{-1})	17.1	7.4	7.5	30.5	8.1	9.1
Ca (mg kg^{-1})	2720	3090	3100	1990	3100	3720
Mg (mg kg^{-1})	796	1586	1664.	710	1 436	1630
K (NH_4Oac)	280	333	346	416	433	414
Zn (mg/kg)	1.7	0.7	0.9	4.4	1.1	0.7
OC %	0.49	0.50	0.52	0.47	0.52	0.54
NH_4 (mg/kg)	20.6	11.2	10.1	9.9	10.3	5.1

The clay loam soils of the demonstration plots belong to Sapane ecotope. The basic soil morphological properties are deep dark brown and brown grey-black, for Paradys and Morago with A horizon of clay loam having a particle size of clay 34.0% and 29.4%, respectively. The basic concentration of certain plant nutrients is shown in Table 5.2, for both Paradys and Morago, respectively. The soils of the demonstration plots are slightly alkaline with pH range 7.30 and 7.77 and 7.04-7.56 for Paradys and Morago, respectively. The organic carbon (OC) content varies from

0.49-0.52 and 0.47-0.54 for Paradys and Morago, respectively. Details soil profile description for both sites are presented in Appendix – VII.

5.3.3 Effect of hard compacted clay soils on germination

In both study locations (villages), sowing was carried out by hand in early January (7-12 January 2019) after receiving about 30 mm of rain on 31 December 2018. However, this rainstorm in December and early January was followed by a long dry spell that affected the germination and emergence of both maize and beans. The emergence rate of both crops were extremely variable with final plant populations in some demonstration plots far below the optimum. This was due to dry conditions coupled with compacted clay soils in the planting rows (on both basin and ridge side of the IRWH tillage). As the early growing season was very dry, there was an inadequate amount of rain to restore moisture to the surface layer. Tillage tractions left during the construction of structures on the clay soil contributed to a lack of moisture restoration to the surface layers. The high soil evaporation caused by high temperatures at the early stage (in January) of the crops was seen when seedlings wilted and died, particularly the shallow-rooted beans. Due to the challenges of drought during the early stage of germination and seedling emergence, the research team decided to make adjustments for poor seedling survival on the clay soils of the experimental sites (through transplanting and applied micro-irrigation in some of the plots which are highly stressed). The percentage emergence rate was calculated by counting the seedlings that emerged after 7-12 days on both sole- and inter-cropping systems (Figure 5.3). Counting of emerged seedling was done for both crops under sole- and inter-cropping systems on three selected demonstration plots under IRWH (for both basin side and ridge side) and for the CON plot.

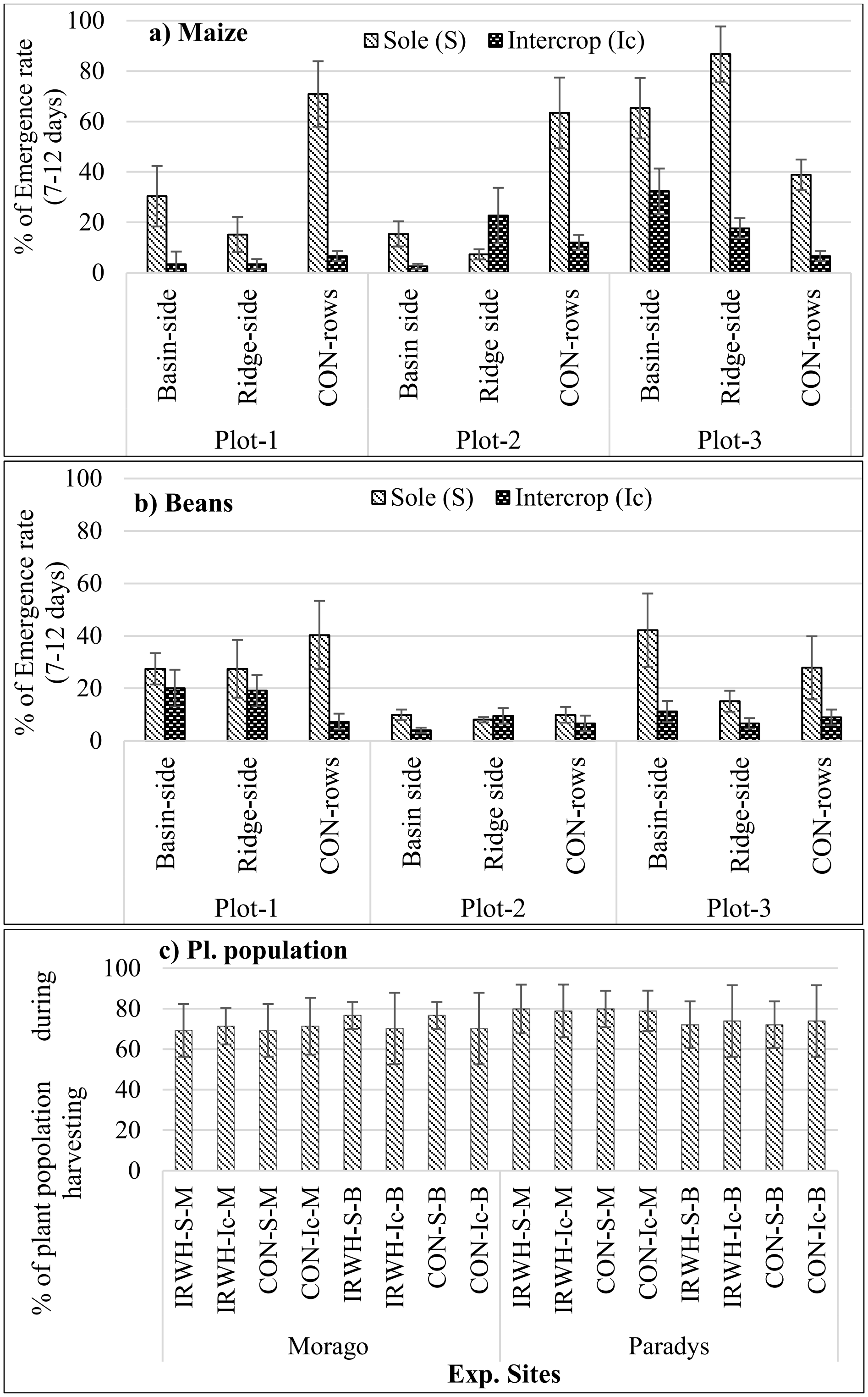

Figure 5.3 Emergence rate assessments by counting on three selected demonstration plots for maize-bean sole- and inter-cropping systems (a & b), to justify the poor seedling emergence due to dry conditions. Percentage of final plant population covered during harvesting on both sites (c).

In all three selected demonstration plots, the maize sole-cropping systems showed the highest emergence percentage rates. However, in plot-1 and 2, the CON tillage exceeded 60% of the emergence rate while in plot-3, the basin (65%) and ridge (85%) sides showed higher emergence rates compared to CON tillage (Figure 5.3a). A lower percentage of germination/emergence was noted in beans under IRWH tillage. The emergence rate of beans was much lower compared to maize; however, the variation between sole- and inter-cropping beans was relatively less compared to maize (Figure 5.3b). In most demonstration plots, seedling growth halted, and some seedlings wilted about a week after the onset of rain and the soil surface started drying out. Seedling growth only resumed after the receiving rainwater. As a consequence, deterioration of seed germination/emergence initially took place but recovered the plant population for the final harvest (70-80%) with the late rains after mid-February (Figure 5.3c). Two farmers (one from Paradys and another from Morago) tried to apply micro-irrigation using watering cans on the wilted seedlings. Crop residues such as mulch or manure application can improve soil structure, impede poor germination or enhance seedling emergence on compacted clay soils during dry conditions. The assessment of seed emergence rate can indicate the potential use of available manure and/or crop residue application prior to planting to address the problem of compaction in IRWH tillage in dry soils.

Moreover, there is a need for a successful establishment of a uniform stand of the desired planting density in rainfed crop production. Therefore, in considering the drought incidences during the growing season (2018/19), a pilot experiment was conducted in 2 m x 2 m quadrant at farmers' backyard near the demonstration plots of Paradys village. This pilot experiment hypothesized that germination and seedling survival would be greater in soil treated with organic amendments. The details of the methodology and results is presented in Appendix IV as a pilot experiment. This pilot experiment intended to demonstrate farming community the effect of moisture, temperature and soil surface treatments (addition of manure or residues) on emergence and seedling survival rate. When the climate is unfavourable without soil surface treatments, emergence is delayed or expose to poor seedling survival. This leads to low and non-uniform plant populations, which resulted in low yield and productivity.

5.3.4 Crop growth parameters

In this study, a comparison was made between the CON and IRWH tillage systems for maize and bean growth parameters grown as sole- and inter-cropped for two project sites. Plant height, leaf number and leaf area index data are summarized in Tables 5.3-5.5, respectively.

5.3.4.1 Plant height and leaf number

The highest plant height (~200 cm) was recorded when maize was grown solely at Parady's plots (Table 5.3) under IRWH tillage. However, at Morago, significantly higher plant height was observed under the IRWH tillage system in both sole- and inter-cropped CON tillage. The tallest plant height was recorded when maize was cultivated as sole, but at the late growing season, the highest plant height was found under IRWH. The CON maize intercropped showed a significantly higher plant height for all growth stages than the sole-maize. In Paradys village, both sole and intercropping maize showed similar height throughout the growth stages (193 and 197 cm), however, there were significant differences between the sole and intercropping systems with slightly higher plant height in intercropping. There was higher plant height observed in sole beans under IRWH, in particular after 50 days after emergence (DAE). The CON intercropped beans showed lower plant height compared to CON for sole beans under CON tillage. Intercropping beans at Paradys village under IRWH resulted in a plant height 90 cm, which was significantly higher ($P \leq 0.05$) compared to CON. In general, the CON beans were higher but had no significant differences between sole and intercropped beans with final heights of up to 45 cm.

The leaf number of bean and maize was measured by counting the number of visible fully expanded leaves at every 7-15-days intervals up to 85 DAE. In maize, a leaf was fully expanded when the ligule at the base of the lamina was visible above the enclosing sheath of the preceding leaf (Muchow and Carberry, 1989). In beans, the leaf number was counted when it had expanded to at least 2-3 cm of length from the petiole. The successive leaf number per plant during the measurement period is presented in Table 5.4 for maize and beans, respectively under both CON and IRWH tillage systems. In the IRWH plots of Morago village (Table 5.4), the leaf number of solely grown maize was initially similar to the intercropped maize, but after leaf 11 the sole maize had a higher leaf number compared to intercropped. However, there was a significantly ($P \leq 0.05$) higher leaf number for IRWH compared to CON tillage until the beginning of the late-season growth stage (Table 5.4). The final leaf number (12) at 85 DAE was similar in both cropping systems under both tillage systems, which may have been after the old leaves died and detached from the stems. At Paradys village, the sole maize under IRWH initially had the lowest leaf number and intercrop maize had the highest leaf number during the early growth stages (Table 5.4). The leaf number of maize did not show variations at the initial stage between sole and intercropping in CON tillage.

In the intercropping CON tillage, the maize leaf number increased more slowly at the initial growth stage and suddenly increased rapidly after 38 DAE while the sole cropping increased slowly to reach maximum leaf number of 12 at 70 DAE. In general, there was no significant difference between the treatments, however, at both sites (Morago and Paradys), the sole maize in CON tillage showed a slower increase in leaf number compared to intercropped maize during the development or mid-season crop growth stage. Higher leaf number (14) was observed in sole maize at Paradys village and a very slow increase of leaf number was observed in intercropped maize at Morago village throughout the growing stages. With increasing, leaf number, it is expected to increase the leaf growth rate. This was probably due to compacted nodes' nature to form internodes. The effect of intercrop over solely cultivated maize or beans on growth and development might have been due to intra- or inter-specific competition (Silwana and Lucas, 2002).

The leaf number and plant height increased linearly with time after emergence, but in both cropping systems, the magnitude (rate) of increment was different. Under the IRWH plots in Morago village, the leaf number of beans increased at a faster rate in both sole and inter-cropping compared to CON tillage and reached a higher leaf number of 33 after 70 DAE (Table 5.4). In the IRWH tillage systems, there were no significant differences found ($P \leq 0.05$) between the sole and intercropping. However, the CON tillage showed a lower and slow increment of leaf number and consistent leaf number variation throughout the growth stages between the two cropping systems. The sole beans had relatively higher leaf number, though not statistically significant higher leaf number was noticed during the growing season. In general at Morago village, during the early growing season (28-38 DAE), there was no significant difference in leaf number between the treatments while in Paradys the CON intercropped beans showed significantly lower leaf numbers compared to sole beans. At a later stage, the intercrop under both tillages showed significantly lower leaf numbers compared to sole-cropped beans.

In Paradys village very fast leaf number increase of sole was observed under IRWH tillage from 28-50 days after planting and reached maximum leaf number of 48 at 85 DAE (Table 5.4). For the intercropping, the final leaf number was recorded up to 50 at 70 DAE but had a slower increment rate compared to sole cropping and a sharp increase was noticed at 85 DAP. The lowest leaf number and plant height with slow increment were observed in the intercropping system under the CON tillage. In general, there was a difference in leaf number and plant height recorded between the two experimental sites (villages) with very low leaf numbers per plant from Morago, where the leaf number dropped drastically after 38 DAE. At the beginning of pod filling, near 50 DAE, leaf numbers decreased rapidly, and leaf decay increased regardless of the tillage and cropping systems. This indicated the early developing seeds induced the promotion of leaf senescence.

Table 5.3 Means of plant height measurements (cm) for maize and beans during the growing season for both Morago and Paradys villages

Plant Height (cm)	Morago village (DAE)						Paradys village (DAE)					
	28	**38**	**50**	**63**	**70**	**85**	**28**	**38**	**50**	**63**	**70**	**85**
a) Maize												
IRWH-Sole-M	18.7a	70.3a	107.5a	162.5a	182.0a	195.0a	70.0a	100.0a	140.0a	177.5a	190.0a	193.0a
CON-Sole-M	18.4a	28.2b	32.3a	66.5b	95.0a	142.5b	29.6b	34.0c	70.0c	100.0bc	150.0a	170.0a
IRWH-Ic-M	25.7a	34.0b	97.5.a	120.0ab	165.0a	200.0a	63.0a	74.0b	130.0ab	184.5a	190.0a	197.5a
CON-Ic-M	19.0a	38.0b	57.0a	95.0b	123.5a	157.7ab	40.0b	60.0b	100.0bc	130.0b	166.0a	168.5a
LSD	37.1	25.3	127.1	63.5	279.5	54.1	11.3	13.9	39.0	45.2	45.7	53.0
b) Beans												
IRWH-Sole-B	19.0a	22.0a	30.0a	53.0a	57.5a	68.0a	20.0a	13.0c	33.5a	60.5ab	65.5a	67.5a
CON-Sole-B	11.1a	20.3a	16.8a	30.9a	47.5a	59.4a	29.3a	25.7ab	39.5a	72.5a	75.5a	89.0a
IRWH-Ic-B	5.0a	17.0a	33.5a	35.0a	44.5a	57.5a	21.3a	17.7bc	32.5a	52.5ab	62.5a	66.5a
CON-Ic-B	18.1a	18.9a	24.4a	35.6a	35.4a	47.5a	22.0a	29.0a	35.0a	30.0b	45.0a	56.5b
LSD	63.8	8.6	19.1	101.6	165.2	133.4	11.5	10.3	13.6	34.9	51.9	27.7

Table 5.4 Means of leaf number measurements for maize and beans during the growing season for both Morago and Paradys villages

Leaf Number	Morago village (DAE)						Paradys village (DAE)					
	28	**38**	**50**	**63**	**70**	**85**	**28**	**38**	**50**	**63**	**70**	**85**
a) Maize												
IRWH-Sole-M	5b	6a	9a	11a	13a	12a	6a	7a	8a	11a	13a	12a
CON-Sole-M	6a	5a	7a	9a	10a	12a	7a	8a	9a	11a	13a	13a
IRWH-Ic-M	4b	6a	8a	10a	12a	12a	8a	9a	10a	11a	12a	13a
CON-Ic-M	6ab	6a	7a	10a	11a	12a	7a	7a	10a	12a	13a	12a
LSD	1.4	2	6.3	6.3	6.3	5.8	3.6	1.7	5.2	3.9	3.0	4.3
b) Beans												
IRWH-Sole-B	15a	18a	30.a	32a	33a	35a	20a	34a	42a	43a	45a	48a
CON-Sole-B	10a	16a	23ab	25ab	32a	35a	18a	23b	35a	39a	42a	43a
IRWH-Ic-B	15a	20a	30a	31a	32a	33a	19a	25b	35a	40a	49a	50a
CON-Ic-B	11a	15a	21b	23b	29a	32a	7b	7c	11b	12b	13b	13b
LSD	9.8	8.0	7.7	7.2	9.9	9.7	11.0	3.6	9	23.7	29.7	30.3

5.3.4.2 Leaf area

With increase leaf number, it is expected to increase the leaf growth rate. This is probably due to compacted nodes nature to form internodes. Leaf area (LA) or leaf area index (LAI) was lower in the sole cropping under both IRWH and CON tillage (Table 5.5). The vigorous growth of leaves noticed in maize plants could because a result of high rainwater stored during the early season compared to CON tillage, which had shorter and fewer leaves. This could have resulted in high evaporation and more competition of water between the crops under CON systems. Generally, maize sole had higher LAI for both tillage systems. Results in Table 5.5 at Morago show that the lowest and highest LAI were 3.3 and 4.5, whereas in Paradys village 4.8 and 5.3 for monocrop and inter-cropping, under IRWH, respectively. In IRWH plots, maize planted sole produced the largest leaves with LAI of 5.3. Intercropping maize with beans in CON led to the production of leaves with slightly small LAI 50 DAE at the early growing stage (1.4). In Paradys, the sole cropping maize led to the production of plants with a maximum LAI of 5.2 and 5.1 at 70 DAE. The minimum LAI at 70 DAE (3.3) was observed when maize was grown in intercrop with beans under CON tillage.

Table 5.5 Means of leaf area index measurements (m2 m-2) for maize and beans during the growing season for both Morago and Paradys villages

Leaf Area Index	**Morago village (DAE)**						**Paradys village (DAE)**					
(m^2 m^{-2})	**28**	**38**	**50**	**63**	**70**	**85**	**28**	**38**	**50**	**63**	**70**	**85**
a) Maize												
IRWH-Sole-M	0.11c	1.18a	2.12b	3.38a	3.89a	3.74b	1.69a	3.09a	4.15a	5.08a	5.19a	5.33a
CON-Sole-M	0.18b	1.34a	3.08a	3.61a	4.03a	4.38a	1.41a	3.24a	3.80a	4.25b	4.61ab	4.80b
IRWH-Ic-M	0.04d	0.30c	1.39c	2.76b	3.30b	3.30b	1.35a	2.98a	3.599a	4.96ab	5.08a	5.12ab
CON-Ic-M	0.23a	0.75b	2.29b	2.57b	3.33b	3.44b	0.79b	2.41b	2.71b	3.51c	3.62b	4.52b
LSD	0.04	0.35	0.58	0.6	0.45	0.56	0.43	0.75	0.87	0.69	0.95	0.29
b) Beans												
IRWH-Sole-B	0.16a	0.18b	0.65a	1.64a	1.80a	2.02a	0.44a	0.73a	1.33a	2.58a	3.33a	3.66a
CON-Sole-B	0.06b	0.12bc	0.23b	0.83b	1.40b	2.04a	0.07b	0.07b	0.40b	1.48b	1.81b	2.00b
IRWH-Ic-B	0.01c	0.39a	0.79a	1.80a	1.87a	1.88a	0.18b	0.47a	1.20a	2.43a	3.00a	3.38a
CON-Ic-B	0.06b	0.07c	0.20b	0.53b	0.75c	1.49b	0.08b	0.06b	0.32b	0.79c	1.57b	2.08b
LSD	0.04	0.06	0.42	1.02	0.35	0.31	0.25	0.15	0.72	0.65	0.54	1.01

5.3.5 Soil water balance components

5.3.5.1 Soil water content (SWC)

Stored soil water is one of the most important drivers of crop production in rainfed agriculture. In this study, two different measurement techniques were used for the two project sites, due to limited soil moisture monitoring equipment. In Paradys, the SWC was monitored continuously by using DFM probes while in Morago pipes were installed (neutron probe) to measure soil water content (0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm) on the interval of 7-14 days across the growing season. By their very nature, the field SWC measurements either by DFM probes or through access tubes (WMM) can be with high accuracy to adequately represent the moisture content of the plots, if only applied replications. However, this brings with adequate logistics and maintenance to provide more measurements that are accurate. Thus, with insufficient replications during the measurement period, one can notice unexpected trends and variations or less water extraction of roots with the amount of rain and growth stages, though both SWC measurement equipment used in this study, indicated SWC changes between the tillage and cropping systems.

The soil water content was monitored with the aid of a Neutron probe in Morago, the accuracy and precision of measurement was not affected (Figure 5.4). The soil water content of IRWH was higher than that of CON in sole maize plots throughout the season. The differences in soil water content between the two tillages ranged from 18.2 mm to 58.3 mm for the whole season. However, in sole-beans and intercropping plots, IRWH was not higher than CON throughout the season. In the sole-beans plot, 57 days after planting (29 March), both tillage systems recorded the same amount of soil water content. Meanwhile, by the end of the season, IRWH had recorded higher soil water content (365 mm) than CON (346 mm). The SWC was the same for both IRWH and CON for intercropping plots on 52 days after planting (24 March). Soil water content was also higher in IRWH than CON by the end of the season. These patterns suggest more investigation into soil water extraction patterns of crops in intercropping treatment plots. Nevertheless, IRWH had higher soil water content than CON at the beginning of the season in all the treatments. This showed a means of good water storage before the growing season.

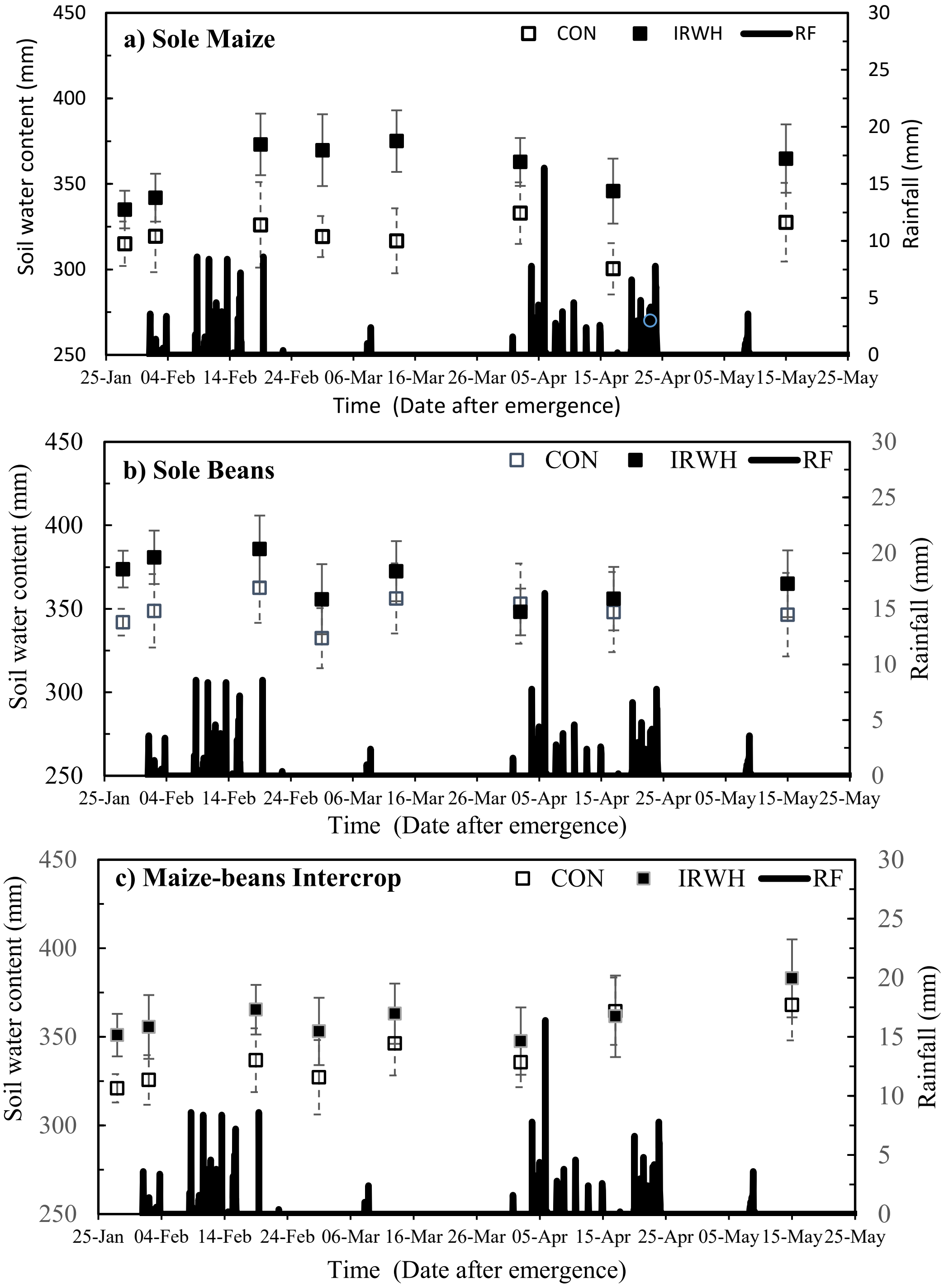

Figure 5.4 Measured changes in soil water contents of the root zone (0-1500) in the basin area of the IRWH and between plant rows in the CON tillage through the 2018/19 cropping season, and daily rainfall (RF) for the growing season.

5.3.5.2 In-field runoff

In the tillage technique of IRWH, rainfall-runoff processes are modified in a major way by the cultural management practices. Relating runoff to rainfall amount is an approach widely used in many semi-arid climates, where water resources are usually the most limiting factor. Under practical crop production conditions, the theoretical relationship of rainfall amount, intensity and duration to runoff has great importance and is fundamental to the success of the IRWH technique. Estimating in-field runoff is also particularly difficult, due to many options for management practices such as different tillage techniques and various types of surface treatments. Measuring in-field runoff is also particularly difficult due to many factors, including employ reliable instruments after rainstorms and calibration processes. Hensley et al. (2000) mentioned that the adoption of linear regression analysis, using rainfall as independent and runoff as a dependent variable yields a reasonable relationship. In this study, to estimate the in-filed runoff (R_{off}) an equation developed for clay soils was used (Anderson, 2007).

Runoff is classified into two different water collecting aspects, these are: i) water running out of the planted field and water harvested on the basin area under IRWH structures, *viz*., ex-field runoff (R_{off}) and Run on (R_{on}), respectively. The (R_{off}) occurs under the conventional tillage system and the R_{off} referred, water harvested to the basin area from the 2 m runoff strip area, which means no ex-field runoff occurs for the IRWH tillage. Hensley et al. (2000) and Botha (2006) indicated that no such water loss by ex-field runoff in the IRWH plots. Therefore, in computing the water balance in the cropped field; in CON tillage the (R_{off}) water is the amount of water loss from the planted field, which negatively affects the water productivity of the crops. Whereas in the IRWH tillage the R_{on} of water to the basin area positively contributes to the available water in the root zone of the crops and the R-off, in this case, becomes zero.

Therefore, it was assumed that R_{off} amount is zero on the IRWH tillage system and R_{off} occurs only on CON tillage but the rate of R_{off} amount varies over the growing season. The result in Figure 5.5 indicates the cumulative amount of ex-field runoff during the growing season, which is estimated to the total amount of runoff of 83.6 mm. After the planting date, a substantial rain was received at the end of January, which created 8 mm of runoff, this 9.5% of the total runoff harvested during the growing season. However, there was a long dry spell period after that rainstorm. At the later stage of the crops, i.e. 55 DOY, 75 DOY and after 86 DOY the runoff was estimated 27 mm (32%), 23 mm (27.5%), and 25 mm (29.0%, respectively. The rainfall distribution was very poor and the IRWH plot had the advantage to use the stored water during those dry spell events. These results accentuated that; firstly, under the technique of IRWH from 2 m runoff strip, it is possible to harvest about one quarter (27%) of the amount rainfall, which could be a loss as ex-field runoff from the cropped field. This amount of water contributes to the productivity of water-scarce dryland farming in semi-arid areas.

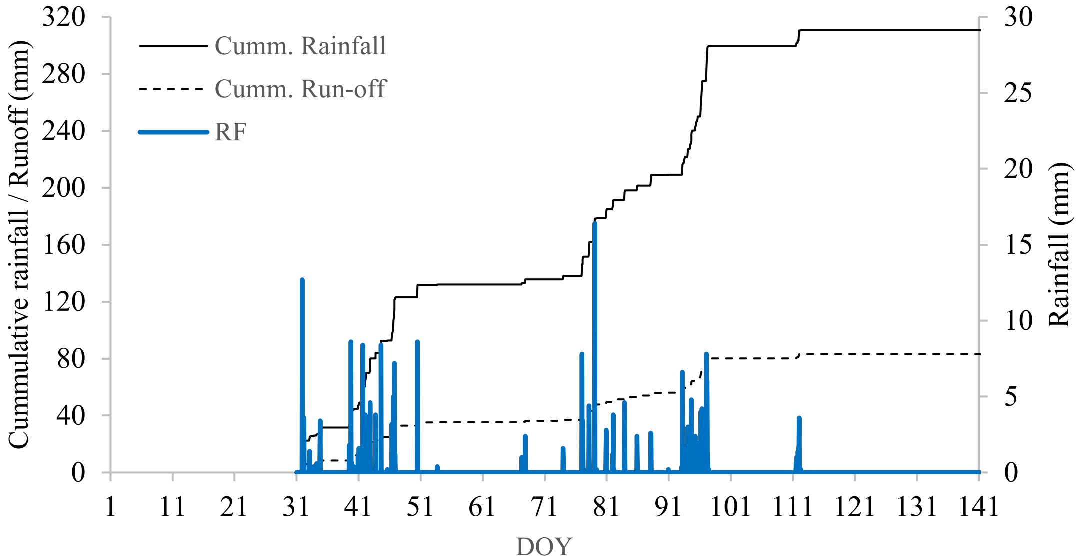

Figure 5.5 Estimation of in-field runoff from the rainfall during the growing season using an empirical model developed by Anderson 2007

Secondly, from the graph, it can be seen that the increase of R_{on} water on crucial growth stages, when the crops reached flowering and grain filling to influence the yield and productivity of the crops. The continuous small rain events also contribute to keeping the soil surface structure of the runoff strip stable and compacted to yield enough runoff. This shows the importance of small rain events in producing in-field runoff under varying surface treatments (Tesfuhuney, 2012). Many long-term statistical models (Hensley et al., 2000; Walker and Tsubo 2003a; Zere et al., 2005; Welderufael et al., 2008) excluded small rain events to obtain a realistic R_{on} amount. However, Anderson et al. (2007) concluded that statistical models provide a better estimation of runoff at low rainfall amounts, as their R^2 using all data points were generally considered better than those with only rain amounts greater than 8 mm. Thus, it is considered that for long-term prediction the inclusion of all sorts of rain events (small rains – higher events) is a valuable asset for the IRWH system. However, in estimating the in-field runoff for IRWH tillage, on top of the rainfall amount, it is important to consider the rainfall intensity, duration as well as the surface treatments.

In this study, the total precipitation use (p_{fg}) was divided into two parts, *viz.,* the fallow season (June-December) and the growing season (January-May). During the fallow season, the recorded precipitation was 115.9 mm, which is 27.2% of the total precipitation (426.5mm). During the growing season (P_g), the rainfall received was 310.6 mm, out of which 32.6% rained during the

GS-3 between 63-70 DAE. During this growing stage (GS-3), the highest R_{on} water (27.2 mm) was collected in the basin area of the IRWH tillage. This indicates that there was more water storage in the IRWH tillage compared to CON. In this study, to compute the Precipitation Use Efficiency (PUE_{fg}) and water productivity (WP_g) the total amount of rainwater used for production estimated to 426.5 and 310.6 mm, respectively for both CON and IRWH tillage systems (Table 5.6).

Table 5.6 Estimating in-field runoff and run-on at different growth stages (GS-I – GS-IV) and the total precipitation during the fallow (Pf) and growing season (Pg) in 2018/2019

Growth Stage (GS)	**GS-I**	**GS-II**		**GS-III**		**GS-IV**		**Total**	
DAE (mm)	**1-28**	**29-38**	**39-50**	**51-63**	**64-70**	**71-85**	**85-121**	$\mathbf{P_g}$	$\mathbf{P_f}$
P (mm)	14.2	46.2	71.2	19.8	46.6	101.4	11.2	310.6	115.9
R-off (mm)*	-3.8	-12.4	-19.1	-5.3	-12.5	-27.2	-3	-83.2	-
R-on (mm)*	+3.8	+12.4	+19.1	+5.3	+12.5	+27.2	+3	+83.2	-
P_{fg} (mm)**								426.5	

** R_{off} and R_{on} represent the ex-field runoff losses from CON plots and the amount of rainwater harvested in the basins under the IRWH tillage, respectively.*
*** refer the precipitation amount during both fallow and growing season*

5.3.5.3 Drainage and soil water extraction management levels

The drainage curve for the whole root zone (1500 mm) provides the information for determining the DUL value for the experimental sites (Figure 5.6). The drainage curve for the experimental site of (Sapane/ecotope) for the root zone represented from a previous study of Hensley et al. (2000) and Botha et al. (2003) as shown in Table 5.7. The plant-available water capacity of the root zone is calculated from the difference between the drained upper limit of plant-available water (DUL) value of 385 mm and the maize and beans lower limit (LL). Due to the clay loam soil texture on the top surface and increasing clay content with depth down the profile on both sites, the soil is expected to reach a maximum water holding value within the 600-900 mm layer. The high clay content below 900 mm reduces deep percolation, so drainage losses are considered to be negligible throughout this study.

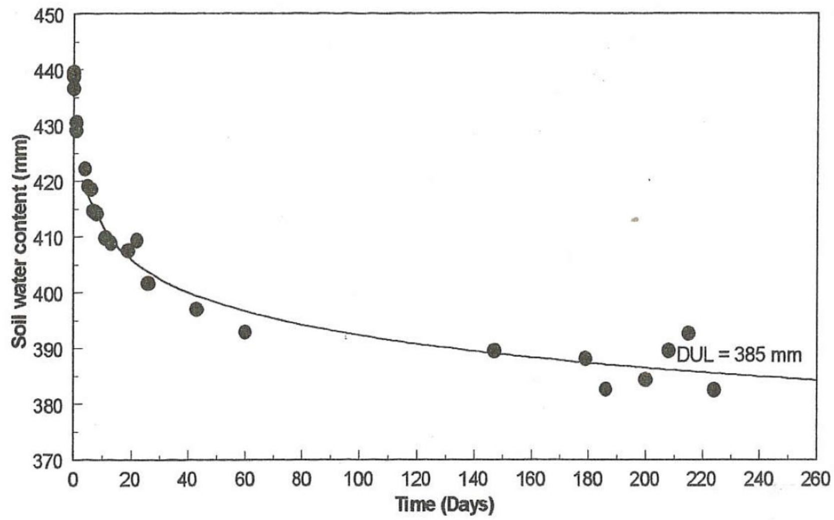

Figure 5.6 Drainage curve for the project site Sapane/ecotope for the root zone 0-1200 mm determined from field data of Hensley et al. (2000).

The polynomial fitted line for determining DUL is as follows (Hensley et al. (2000):

$$SWC = 446.64 - 6.84(ln\ (t)) \qquad R^2 = 0.95 \tag{5.1}$$

Where SWC is the soil water content of the root zone of 0-1200 mm soil profile and t is time (in hours) after drainage starts from the root zone water content of field saturation.

Equation 5.1 would be used to calculate drainage (D) of the root zone if heavy rainstorms occur for the IRWH experimental site on that specific ecotope. The total extractable soil water (PAWC) was 222.0 mm and 248.5 mm for the maize and beans, respectively (based on measured data from [Hensley et al., 2000]). This is 10.7% higher for maize compared to the beans. This was probably possible as a result of the potentially higher root ramification and root length. However, the amount of extractable water actually available may vary with intercropping (not included in this study).

Table 5.7 Soil profile components of the clay soils (Sapane ecotope) at the experimental plot. The effective root zone is considered 1200 mm (Hensley et al., 2000).

Horizon[1]	Clay* %	BD[2] ($Mg\ m^{-3}$)	Depth (mm)	DUL (mm)	LL Maize (mm)	LL Beans (mm)	PAWC[3] (mm)	
							Maize	Beans
A	29 & 34	1.68	300	69	12.1	10.4	56.3	57.5
B1-B2	55 & 50	1.66	600	103	47.4	34.1	25.4	38.7
B2-B3	54 & 53	1.66	900	110	51.2	45.7	29.1	34.6
B3	54 & 54	1.67	1200	103	49.5	46.6	35.1	38.0
Total				385	253.3	226.8	222.0	248.5

[1] Horizon soil depth classification A (0-300 mm), B1 (300-600), B2 (600-9000), and B3 (900-1200, [2]BD=Bulk density and [3]PAWC= plant available water capacity. Clay indicate the clay content of both sites*

5.3.5.4 Estimation of evapotranspiration

Crop water use, also known as evapotranspiration (ET), is the water used by a crop for growth and development. ET is influenced by prevailing weather conditions, available water in the soil, crop species and growth stage.

The growth stages of these two partner crops (maize and beans) can be dived into different developmental stages. The growth stages of the maize and beans described in this study are almost identical to other previous studies (for example that reported by FAO: Doorenbos and Kassam, 1986; FAO, 2000). For both crops, the growth stages can be divided into four phases:

- For maize – GS-1 = initial vegetative phase, GS-2 = active vegetative phase, GS=3 initial grain-filling phase, and GS-4 = active grain-filling phase.
- For beans – GS-1 = emergence and early vegetative growth, GS-2 branching and rapid vegetative growth, GS-3 = flowering & pod formation and GS-4 = pod fill and maturation

According to the measurement dates, the four growth stages of the crops correspond to 0-40, 41-65, 66-85, and 86-125 days after planting, respectively.

The water balance processes identified in eqs. 4.1 is relevant in the functioning, productivity and in explaining the soil-plant-atmosphere continuum (SPAC) under the CON and IRWH techniques. Thus, it is important to monitor these processes through field measurements and estimations of water balance components in order to obtain a good understanding of improved crop productivity for different cropping systems under different tillages. Evapotranspiration (ET) was estimated as residual using the water balance equation as determined by eq. 4.2. In this study, ET was not separated into its components, *viz.* soil evaporation from the soil surface (Es) and crop transpiration (Ev), due to the lack of Es measurements and failed to use Es model estimations from previous studies for clay soils. In addition, in this analysis of water balance components, the Morago site SWC measurements are only considered to compute ET values during the growing season, since the DFM probes in Paradys showed less soil water extraction and with consistent change throughout the growing season. Therefore, Table 5.8 shows the summary of the whole water balance components for the growing season (January-May 2019).

In the Sole maize and beans and intercropping under IRWH, the ET was estimated 340.4 mm, 301.8 mm and 359.8 mm, respectively during the growing season. Overall, the intercropping under CON tillage used the absolute highest ET. However, the IRWH with intercropping gave lower ET values than their respected solely grown beans and maize treatments. Moreover, ET from the CON tillage (262.4 mm) was obtained at the relatively lower with intercropping, but the sole beans under CON tillage produced lower ET compared to Sole maize. The reason could lie in the effectiveness of additional water stored in the basin area and allowing water to penetrate and infiltrate as well. Thus, all intercropped beans benefitted from the canopy shade on both sides, and the mean ET across the CON tillage was significantly larger than the other tillage system (IRWH). The CON tillage had an advantage in reducing soil evaporation through shading effect compared to IRWH because the runoff strips between the tramlines are exposed to soil evaporation while the basin area of the IRWH promoting infiltration to the crops root zone.

Table 5.8 Seasonal evapotranspiration (ET) as calculated from the change of soil water content (ΔSW) and in-field runoff (Roff) and for different cropping systems (Sole- and intercropping under a) CON and b) IRWH tillage systems for the growing season 2018/19

a)

Growth Stage (GS)	**GS-I**	**GS-II**		**GS-III**		**GS-IV**		**Total**
DAE	**1-28**	**29-38**	**39-50**	**51-63**	**64-70**	**71-85**	**85-121**	
P (mm)	14.2	46.2	71.2	19.8	46.6	101.4	11.2	310.6
Run-off (R_{off})*	3.8	12.4	19.1	5.3	12.5	27.2	3	-83.2
Sole-Maize								
ΔSW (mm)	4.4	6.7	-6.8	-2.5	16.2	-32.6	27.3	12.7
ET (mm)	14.8	40.5	45.3	12.0	50.3	41.6	35.5	240
Sole-Beans								
ΔSW (mm)	6.8	13.8	-30.2	23.8	-3.1	-5.1	-1.6	4.4
ET (mm)	17.2	47.6	21.9	38.3	31.0	69.1	6.6	231.7
Ic-Maize/beans								
ΔSW (mm)	4.7	11.1	-9.6	19.1	-10.6	16.9	3.5	35.1
ET (mm)	15.1	44.9	42.5	33.6	23.5	91.1	11.7	262.4

b)

Growth Stage (GS)	**GS-I**	**GS-II**		**GS-III**		**GS-IV**		**Total**
DAE	**1-28**	**29-38**	**39-50**	**51-63**	**64-70**	**71-85**	**85-121**	
RF (mm)	14.2	46.2	71.2	19.8	46.6	101.4	11.2	310.6
Run-off (R_{off})*	0	0	0	0	0	0	0	0
Sole-Maize								
ΔSW (mm)	6.9	31.1	-3.4	5.3	-12.2	-17.1	19.0	29.8
ET (mm)	21.1	77.3	67.8	25.1	34.4	84.3	30.2	340.4
Sole-Beans								
ΔSW (mm)	7.1	5.0	-30.1	16.8	-24.4	8.0	8.9	-8.8
ET (mm)	21.3	51.2	41.1	36.6	22.2	109.4	20.1	301.8
Ic-Maize/beans								
ΔSW (mm)	4.6	9.7	-12.3	10.0	-15.5	31.0	21.4	49.0
ET (mm)	18.8	55.9	58.9	29.8	31.1	132.4	32.6	359.6

5.3.6 Yield and yield components

In both project sites (Morago and Paradys), the maize total AGDM and grain yield (GY) were affected (at value $P \leq 0.05$) by the tillage and cropping systems (Table 5.9a). In Morago, both the CON sole- and inter-cropping maize had a significantly lower total AGDM than the IRWH treatments, however, there were no significant differences of total AGDM observed among the

CON treatments (both sole- and inter-cropping). In additions, there was unexpected significantly higher AGDM in the intercropped maize than the sole cropping was observed in the IRWH system. Similarly, in Paradys, the total AGDM showed no significant differences between the sole- and inter-cropping maize under both CON and IRWH tillage systems. Moreover, the IRWH tillage had a significantly greater AGDM for both sole maize (29%) and intercropped maize (27%) compared to CON treatments (Table 5.9a).

In both sites, the beans' AGDM was affected (at value $P \leq 0.05$) by the tillage systems, which meant there were highly significant differences between the IRWH and CON practices for the total AGDM (Table 5.9b). However, the cropping systems (sole- and inter-cropping) in both tillage practices showed no significant variations in total AGDM and the sole beans under the IRWH practice gave the highest AGDM (3138.1 kg ha^{-1}). Under CON tillage, the beans' AGDM was reduced by 45% and 30% compared to sole- and inter-cropping under IRWH, respectively. The same statistical results of AGDM were obtained in the other demonstrations plots of Paradys village, with a significantly higher AGDM for IRWH than CON tillage. In comparing the two sites, the sole beans under IRWH showed higher AGDM in Morago and the intercrop beans (under IRWH) were higher in Paradys. The lowest AGDM was observed in sole beans under CON tillage at both villages.

The patterns of GY showed the same trend as the AGDM, however, there were relatively lower variations for both tillage and cropping systems. The final GY of beans showed significant differences between the treatments in both project sites (Table 5.9b). There was significantly higher GY under IRWH tillage systems compared to CON practices. In Morago, an average bean GY by two tillage systems showed that the IRWH-Sole > IRWH-Ic > CON-Sole > CON-Ic, with values ranging from 878.2 kg ha^{-1} to 618 kg ha^{-1} ($P \leq 0.05$) with LSD value of 250.9 kg ha^{-1}. In Paradys, the GY was also affected by tillage with sole beans under IRWH producing a mean GY of 761.4 kg ha^{-1} compared to 573.2 kg ha^{-1} of the intercrop beans.

The main reason for the results of AGDM and GY having higher values in IRWH tillage could be due to the fact that more water for biomass or yield was harvested during the growing season. This meant more soil water was available in the root zone and by minimizing the ex-field water loss due to runoff. On the other hand, the wide runoff area of 2 m in the IRWH structure may have caused the soil evaporation to increase as the plant rows were partially shaded on both ridge and basin sides while the CON plots were relatively less dense, but evenly distributed in 1 m rows. In semi-arid areas, soil evaporation losses are the main factors that determine yield and biomass accumulation. Thus, the comparison of water or precipitation use efficiency or rainwater use productivity is crucial for evaluating the variation in the IRWH and corresponding CON tillages in semi-arid areas. The harvest index (HI) varied between 0.21-0.38 for AGDM of maize across different treatments of the two sites (Table 5.9a). In general, the HI values were relatively low compared to literature and could have been due to the effect of drought, as the harvest yield was below expectations. The highest HI was observed in sole maize under IRWH, but there were no significant differences among the treatments in both villages. Therefore, HI appeared not to be sensitive to tillage and cropping system treatments.

Table 5.9 Grain seed yield, biomass and Harvest Index (HI) for sole- and intercrop maize bean under CON and IRWH tillage a during growing season 2018/19 at Morago and Paradys villages

a) Maize

Treatment	Morago village			Paradys village		
	AGDM (kg ha^{-1})	GY (kg ha^{-1})	HI	AGDM (kg ha^{-1})	GY (kg ha^{-1})	HI
IRWH-Sole-M	3944.8b	1159.9a	0.28a	4210.2a	1099.9a	0.27a
IRWH-Ic-M	4695.5a	1096.4a	0.21a	4234.9a	997.6a	0.24a
CON-Sole-M	2976.0c	829.5b	0.25a	3271.2b	750.8b	0.24a
CON-Ic-M	2590.8c	818.2b	0.29a	3331.2b	696.3b	0.22a
LSD	518.3	250.9	0.094	127.5	103.2	0.068

b) Bean

Treatment	Morago village			Paradys village		
	AGDM (kg ha^{-1})	GY (kg ha^{-1})	HI	AGDM (kg ha^{-1})	GY (kg ha^{-1})	HI
IRWH-Sole-B	3138.1a	878.2a	0.26a	3016.1a	761.4a	0.22a
IRWH-Ic-B	2442.8a	779.4ab	0.31a	2846.1a	717.7ab	0.23a
CON-Sole-B	1685.8b	687.6b	0.38a	1660.4b	573.2c	0.31a
CON-Ic-B	1689.6b	618.0b	0.33a	1870.6b	577.8bc	0.27a
LSD	747.7	158.1	0.128	525.2	142.9	0.119

5.3.7 Use of efficient rainwater for yield

Comparison of results of rainwater use efficiencies, such as Precipitation Use Efficiency, Water Productivity, and Water Use Efficiency (PUE_{fg}, WP_g and WUE_{ET}, respectively) for different cropping systems under CON and IRWH tillage are presented in Table 5.10.

Table 5.10 Different water use indicators for maize-beans sole- and inter-cropping under CON and IRWH at two sites (Morago and Paradys villages)

Indicators	Treatments for each parameter	Sites (villages)			
		Morago		Paradys	
		AGDM	GY	AGDM	GY
$PUE_{(gf)}$ ($kg\ ha^{-1}\ mm^{-1}$)	IRWH-Sole-M	9.25b	2.72a	9.87a	2.58a
	IRWH-Ic-M	11.01a	2.57a	9.93a	2.34a
	CON-Sole-M	6.98c	1.94b	7.67b	1.76b
	CON-Ic-M	6.07c	1.92b	7.81b	1.63b
	LSD	*1.58*	*0.53*	*2.01*	*0.48*
	IRWH-Sole-B	7.36a	2.83a	7.07a	1.79a
	IRWH-Ic-B	5.73a	2.51a	6.67a	1.68a
	CON-Sole-B	3.95b	1.61b	3.89b	1.34a
	CON-Ic-B	3.96b	1.45b	4.39b	1.35a
	LSD	*1.69*	*0.86*	*1.83*	*0.85*
$WP_{(g)}$ ($kg\ ha^{-1}\ mm^{-1}$)	IRWH-Sole-M	12.70b	3.73a	13.56a	3.54a
	IRWH-Ic-M	15.12a	3.53b	13.63a	3.21ab
	CON-Sole-M	9.58c	2.67b	10.53b	2.42bc
	CON-Ic-M	8.34c	2.63b	10.73b	2.24b
	LSD	*2.21*	*1.01*	*2.48*	*1.08*
	IRWH-Sole-B	10.10a	2.83a	9.71a	2.45a
	IRWH-Ic-B	7.86b	2.51a	9.16a	2.31a
	CON-Sole-B	5.43c	2.21a	5.35b	1.85b
	CON-Ic-B	5.44c	1.99a	6.02b	1.86b
$WUE_{(ET)}$ ($kg\ ha^{-1}\ mm^{-1}$)	*LSD*	*1.95*	*0.91*	*2.12*	*0.42*
	IRWH-Sole-M	11.59a	3.41a	-	-
	IRWH-Ic-M	13.06a	3.05a	-	-
	CON-Sole-M	12.40a	3.46a	-	-
	CON-Ic-M	9.87b	3.12a	-	-
	LSD	*1.68*	*1.22*		
	IRWH-Sole-B	10.40a	2.91a	-	-
	IRWH-Ic-B	6.79b	2.17a	-	-
	CON-Sole-B	7.28b	2.97a	-	-
	CON-Ic-B	6.44b	2.36a	-	-
	LSD	*2.13*	*1.08*	-	-

**Means followed by the same letter are not significantly different ($P \leq 0.05$).*

5.3.7.1 Precipitation use efficiency (PUE_{fg})

Precipitation use efficiency (PUE_{fg}) was calculated in terms of the use of rainwater through the fallow and growing period together. In both sites for both crops, there were significant differences between IRWH and CON tillage on PUE_{fg} for both the AGDM and the GY, with LSD values of 1.58 & 2.01 and 0.53 & 0.48 for maize and 1.69 & 1.83 and 0.86 & 0.85 for beans, respectively, however, no significant differences observed among the cropping systems except between IRWH-Sole-M and IRWH-Ic-M. With the highest PUE_{fg} (AGDM) of 11.01 and 9.93 for intercropped maize under IRWH, the lowest PUE_{fg} was found in the intercropped (6.07) and sole maize (7.67) under CON tillages for Morago and Paradys, respectively. Using the GY to compute the PUE_{fg} of different tillage also varied between 2.72-1.92 and 1.58-1.63 kg ha^{-1} mm^{-1}, for Morago and Paradys sites. However, the statistically highest PUE_{fg} value was found in IRWH sole maize treatment. The trend showed variations for different tillage with slightly better in Morago compared to Paradys and significantly different according to the statistics.

The PUE_{fg} results indicate that the IRWH tillage was better at converting rainwater into maize biomass and grain yield compared to CON but the cropping system did not show a consistent trend, though there was a significant difference among the cropping systems for Morago site. The possible reason for low and irregular variations in PUE_{fg} within cropping systems is due primarily to the variation in the pre-seasonal advantage of stored water from the fallow period. Moreover, there were advantages of in-field runoff versus CON tillages to increase the efficiency of the rainwater for semi-arid environments. For sole and intercropped beans, the PUE_{fg} showed similar trends with significant highest values of PUE_{fg} under IRWH tillage systems for Morago sites, but there were no significant differences for PUE_{fg} (GY) at Paradys site in both tillage and cropping systems.

5.3.7.2 Water productivity (WPg = WP)

The overall results indicate that the WP varied between 15.12-8.34 and 10.10-5.34 kg ha^{-1} mm^{-1} for maize and beans AGDM, respectively (Table 5.10). The statistical results show that there were significant differences due to the effect of rainwater harvesting in basin areas on WP_g, but in Paradys, among the cropping system treatments for both crops were not significant (Table 5.10). However, in Morago there were a significant variation between the cropping systems in both crops. A different WP trend for GY was observed *viz.* the maize sole (IRWH-S-M) was significantly higher than both sole and intercropped maize (CON-S-M & CON-Ic-M) and the opposite water productivity was shown in beans with highest WP values in sole beans under IRWH (IRWH-S-B) compared to intercropped beans with no significant differences. Nevertheless, there was a significant difference between the tillage systems in Paradys site and no significant variation observed between the treatments of beans in Morago.

The results of WP, in general, showed similarities with those in a previous study on maize under IRWH, where the range of value was 10.7-11.7 kg ha^{-1} mm^{-1} (Botha, 2006). Passioura (2006) and Gregory (1989) found a range between 8 to 15 kg ha^{-1} mm^{-1} for semi-arid ecotope, and these are equivalent or within the range with the IRWH results of this study but higher compared CON tillages water productivity results. Further explanations for these efficiencies need to be investigated. This result has important implications for the management practices of IRWH; as it confirms the need to optimize water use in terms of yield per unit water for transpiration to achieve higher WP in water-scarce semi-arid conditions. Besides, it is important to describe the effectiveness with which rainwater was converted into grain yield.

It was suggested by Passioura (2006); Botha (2007) and Hensley et al. (2000)) that the advantage of using of rainwater productivity is that one considers long-term values of rainfall, which give a truer reflection of the ability of the management practices to convert rainwater to grain yield. One would have wanted more than 2 years of data to be able to consider rainwater productivity (RWP) over many more cropping seasons. Therefore, for reliable recommendations concerning the best and alternative strategies of surface treatments and to compare the management options, it is desirable to have long-term yield predictions of the IRWH system. Thus, many researchers suggested the use of a simple empirical model with only long-term rainfall data as input to achieve this objective of evaluating management practices of the IRWH techniques in a semi-arid area. Alternatively, long-term crop yields can be obtained with a crop growth simulation model such as DSSAT or APSIM or AquaCrop and compared to the transpiration, rainfall, or water use and can be integrated to decision support tools. In addition, in considering reliable ET measurements or estimations, one can consider the WUE as a preferable indicator to evaluate management practices in dryland agriculture.

5.3.7.3 Water use efficiency (WUE)

The consideration of evapotranspiration in evaluating rainwater efficiencies may be able to show an advantage in practicing IRWH techniques for semi-arid climatic conditions. WUE_{ET} was calculated using the residual ET from the water balance calculations from planting (January 2019) until harvest (May 2019). However, to compute a reliable water use based on ET, require sufficient soil water content measurement that shows the changes based on the continuous plant roots water consumption and losses due to environmental factors. In this study, measuring the SWC by using DFM at Paradys site showed insignificant extractions of water by plants throughout the growing season. Due to that fact, the WUE_{ET} is only analysed for the Morago site, where the SWC was measured by NMM at an interval of 7-15 days on different growth stages. The results indicate that the WUE_{ET} for AGDM varied between 13.06-9.87 and 10.140-6.44 kg ha^{-1} mm^{-1} during the 2019 growing season for different tillage and cropping system treatments for maize and beans, respectively (Table 5.10). The highest WUE_{ET} of maize (AGDM) was found in the intercropped maize under IRWH system with no significant differences in both tillage systems (IRWH & CON) of the solely growing maize. Statistical analysis revealed that the IRWH tillage system on beans (AGDM) had a significant effect on the efficiency of water use as a function of evapotranspiration with higher values in IRWH-S-M (10.40) and no significant differences observed in both cropping systems under CON and in the intercropped beans under the IRWH. On the contrary, the function of evapotranspiration for WUE showed significantly the lowest values in the CON-intercrop (9.87 and 6.44 kg ha^{-1} mm^{-1} for maize and beans, respectively).

With regard to GY as a function of WUE_{ET}, the results showed irregular trends, with higher values in sole cropping compared to intercropping for both under IRWH and CON tillages. Nevertheless, neither the tillage nor the cropping systems show significant differences for both crops. However, one can consider, maximize crop WUE, by either using improved management, it is necessary both to conserve water and to promote maximal growth or minimizing losses through runoff, evaporation, and transpiration. It also includes optimizing growing conditions by proper timing and performance of planting and harvesting, tillage systems, fertilization, and pest control. In short, raising water-use efficiency requires good farming practices from start to finish by collecting additional water to the root zone. Generally, but not always, the yield of cropping systems is proportional to total growth, hence also to transpiration rather than applying an un-partitioned ET component in computing the water balance components in considering crop water use. Some inconsistent was found in the degree of yield and total above-ground efficiency in terms of ET. From the results in Table 5.10 therefore, it can be seen that the WUE variations could be due to the dual effect of additional soil water and canopy shading. Moreover, the fluctuation of water use, therefore, must be a reflection of SWC measurement. However, these variations in the efficiency should be examined further by applying the water productivity as a function of growing seasonal effective rainwater of the crop (WP) or as a function of transpiration.

5.3.8 Radiation canopy interception

Above ground production of biomass can be closely related to light use efficiency, but only marginally to intercepted radiation during the season and mainly caused by management practices and canopy structures. The crop intercepted photosynthetically active radiation (PAR) and radiation use efficiency (RUE) vary markedly in cropping systems and/or tillage systems and related with LAI, plant height. The RUE is another important factor for dry matter accumulation in addition to intercepted PAR. Differed from the previous studies in RWH techniques, in this study, some relationships were established among different cropping systems (sole and intercropping) with different canopy configurations in both CON and IRWH.

5.3.8.1 Dry matter accumulation (DM)

In Morago village, during the early growing stage (38 DAE), there was significantly lower above-ground dry matter (DM) accumulation in sole cropping among the tillage systems compared to IRWH (Table 5.11). Only sole beans had a significantly higher (7.5 and 7.2 g m^{-2}) DM accumulation compared to maize. Later growth stages, before the crops reached flowering, the maize crops showed no significant difference among the treatments, but higher DM values were observed for IRWH sole maize (31.8 g m^{-2} at 50 DAE). During tasselling, the DM accumulation of maize significantly increased in all treatments except for CON sole maize, however, at 85 DAE, when the crops started grain filling, the DM showed significant differences among all the treatments. In Paradys village, the DM was higher compared to Morago village demonstration plots. In Paradys, the sole cropping under IRWH tillage showed significantly higher DM accumulation throughout the growing season among the treatments (except at 50 DAE). From flower initiation to grain filling (63-85 DAE), there were no significant differences in DM accumulation between both sole cropping (under IRWH and CON) systems and CON intercropped maize but inconsistent measurements were noticed due to variation in growth after the long dry spells. However, in both villages the CON intercrop maize showed higher DM accumulation during the growing season compared to IRWH.

Similarly, with beans under IRWH, the Paradys demonstration plots showed higher DM accumulation compared to Morago village demonstration plots while the CON beans showed higher DM in Morago compared to Paradys (Table 5.11). During the later stage, the DM accumulation revealed high variations in all treatments. Even though the IRWH sole beans showed significantly higher DM accumulation in Morago village, there were no significant differences in DM among the treatments during grain filling while the IRWH showed significantly greater DM accumulation compared to CON. In Paradys, significantly higher DM (812.3 g m^{-2}) of maize and beans intercrop was found under IRWH tillage compared to CON but in Morago, there was no significant difference of DM observed between the two tillages systems.

The sole crop produced significantly more DM accumulation than maize intercropped with beans. The maize DM accumulation was not affected by the tillage used in the two cropping systems. Competition among mixtures is thought to be a major factor affecting DM accumulation as compared with sole cropping of cereals (Ndakidemi, 2006). The high maize DM accumulation observed in the sole maize crop could be attributed to lack of competition for resources such as light, nutrients and water. However, differences in the depth of roots, lateral root spread and root densities are some of the factors that affect competition between the component crops in an intercropping system for nutrients (Eskandari and Ghanbari, 2009). Maize is usually taller with a faster-growing or more extensive root system; particularly a larger mass of fine roots and is competitive for water and soil nitrogen (Eskandari and Ghanbari, 2009). The maize plants in the intercrops in the present study could have shadowed beans, thus reducing the amount of light required to stimulate growth. However, it is important to consider the number of maize copes and pods for beans in comparing sole- and inter-cropping under various tillage systems, as the plant spacing varied accordingly.

Table 5.11 Total above ground dry matter (DM) accumulation for sole and intercropping systems under CON and IRWH tillage

DAE	Total DM, [g m^{-2}], (Morago village)					Total DM, [g m^{-2}], (Paradys village)				
	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Total M+B	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Total M+B
IRWH										
28	1.2	0.5	3.8	1.8	2.3	1.8	4.5	2.9	2.2	6.7
38	1.6	0.8	7.5	2.4	3.2	14.1	9.5	12.5	9.1	18.6
50	31.8	4.2	23.4	19.0	23.3	42.1	69.5	48.3	29.9	99.4
63	34.6	21.1	89.2	70.6	91.7	128.4	90.6	109.9	106.4	197.0
70	196.8	88.1	544.6	311.1	399.2	216.2	107.6	534.0	241.0	348.6
85	243.1	220.2	549.2	476.0	696.1	272.8	126.2	642.8	261.2	367.4
96	231.1	205.3	530.6	440.7	646.0	312.1	146.9	738.6	665.4	812.3
CON										
28	1.0	2.2	2.1	0.8	3.0	1.4	3.2	1.5	2.8	6.o
38	1.5	3.1	7.2	1.0	4.1	1.6	2.4	1.6	4.5	6.9
50	2.4	20.3	12.8	1.9	4.2	10.4	24.2	10.4	16.3	40.5
63	9.9	23.0	47.4	10.4	33.4	28.8	80.5	28.8	75.8	156.3
70	27.4	76.5	78.7	91.1	167.6	241.1	163.2	241.1	149.5	312.3
85	229.1	155.1	166.5	326.6	481.7	265.7	252.8	265.7	248.9	501.7
96	252.4	240.2	428.3	449.6	689.7	287.9	270.2	288.0	292.1	562.3

5.3.8.2 Fraction of intercepted photosynthetic active radiation (fIPAR)

In the Morago site in both crops (Figure 5.7a and b), there was a high variation of the fraction intercepted photosynthetic active radiation (fIPAR). In demonstration plots, the fIPAR for intercropped maize under CON (CON-Ic-M) peaked at 63 DAE (0.88) while the intercropped maize under IRWH (IRWH-Ic-M) peaked at 85 DAE (0.64). However, in sole maize under CON and IRWH (CON-S-M and IRWH-S-M) peaked at 70 DAE and the fIPAR was 0.60 and 0.52, respectively (Figure 5.7a). The fIPAR of CON-S-M and IRWH-Ic-M showed no significant differences throughout the measurement period during the growing season. Nevertheless, the CON-Ic-M and IRWH-S-M showed the highest and the lowest fIPAR across the growing season (Figure 5.7a). This indicates the difference of canopy configuration and plant raw arrangement between the CON and IRWH tillage systems that influence the radiation interception by maize crops.

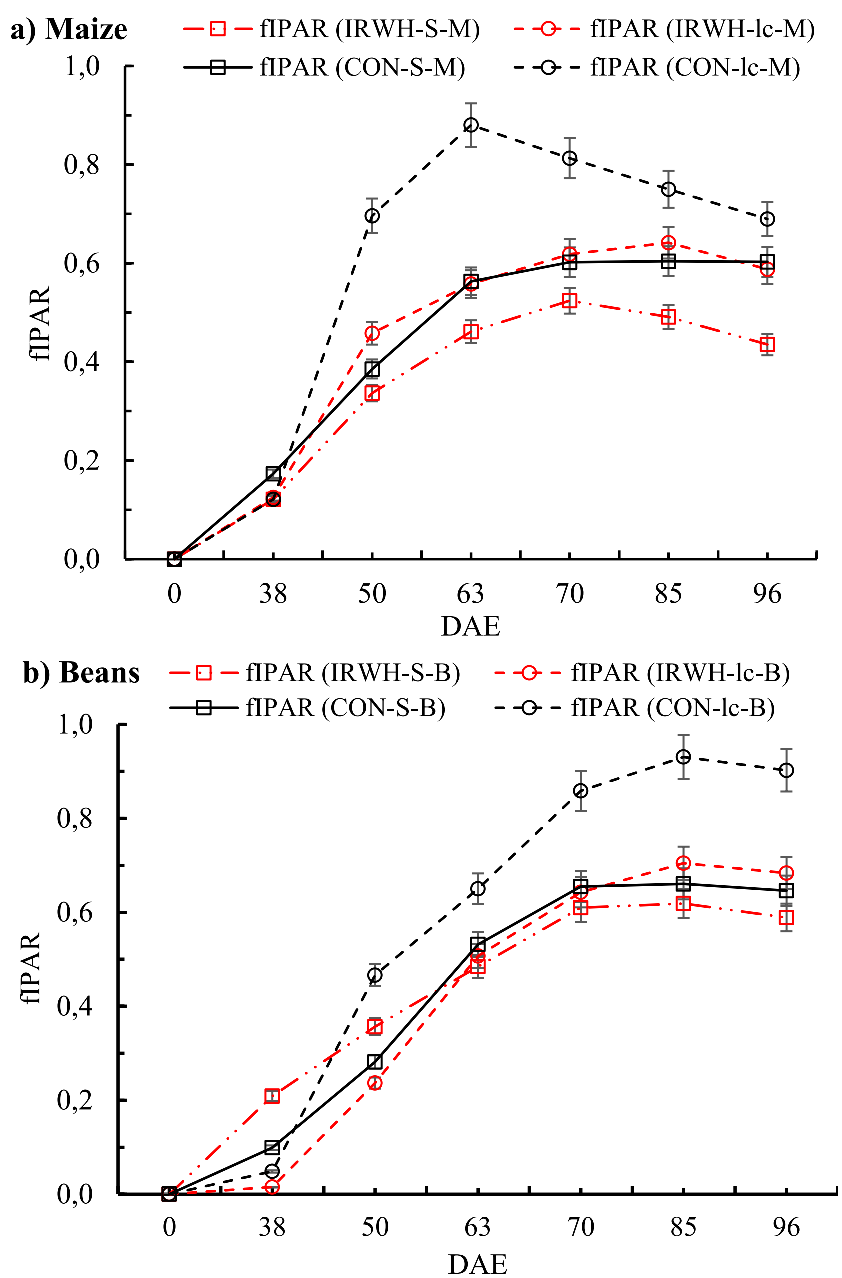

Figure 5.7 Fraction of intercepted photosynthetic active radiation (fIPAR) of two cropping systems (sole and intercropping) under two tillage systems (CON and IRWH) from the Morago demonstration plots measurement: a) maize and b) beans

In sole and intercropped beans, a different radiation interception amount was observed compared to maize treatments (Figure 5.7b). In all treatments, the fIPAR was higher in beans compared to maize under both tillage systems with higher value in CON intercropped beans (CON-Ic-B) and peaked (0.93) at 85 DAE. Similarly, in IRWH sole and intercropped beans and CON sole beans (IRWH-Ic-B, IRWH-S-B, and CON-S-B, respectively) the fIPAR reached a peak between 70-85

DAE with fIPAR values of 0.70, 0.66 and 0.62. Similar to maize the CON-S-B showed the highest fIPAR values compared to the other three treatments (IRWH-Ic-M, IRWH-S-B, and CON-S-B), but the CON-Ic-B was shown higher values at the early stage until 50 DAE.

In Paradys demonstration plots (Figure 5.8a and b), the fIPAR for sole maize under IRWH (IRWH-S-M) increased sharply from DAE 38-63 DAE with the highest peak value of 0.77, but the sole maize under CON (CON-S-M) showed lower intercepted fraction and peaked at 50-63 DAE compared to IRWH (Figure 5.8a). However, both intercropped maize under CON and IRWH (CON-Ic-M and IRWH-Ic-M) peaked at 63 and 70 DAE with fIPAR value of 0.49 and 0.64. There were large variations of fIPAR between sole and intercropped maize for both CON and IRWH tillages. In Paradys demonstration plots (Figure 5.8b), the intercepted fraction (fIPAR) of sole beans under IRWH (IRWH-S-B) increased slowly to the maximum interception (70% at 85 DAE) and the value of fIPAR was greater by 14%, 20%, and 9% compared to CON-Ic-B, CON-S-B, and IRWH-Ic-B, respectively. In general, the architecture of the canopy, which was affected by crop densities, crop height, and row arrangement could be the deciding factor for crop intercepted PAR. The separation of the maize upper canopy in the intercropping led to more intercepted PAR of beans compared to the sole cropping. Moreover, the distance between maize tramlines under IRWH was also another issue for radiation interception advantageous to the increase of intercepted PAR for the short crop canopy.

The increase in LAI may be attributed to foliage expansion because of the development of new leaves and enlargement of existing leaves (Ogindo and walker, 2005). The graphical relationship between LAI and fIPAR is presented in Figures 5.9a-c. The LAI and fIPAR showed a logarithmic relationship with R^2 values of 0.68, 0.54 and 0.69 for CON tillage and 0.51, 0.94 and 0.73 for IRWH in sole maize, sole beans and intercropping, respectively. In all cropping systems, fIPAR increased with an increase in LAI, initially at a higher rate and then at a lower rate and finally flattening. This could be ascribed to the lower rate of change of fIPAR to the higher rate of change of LAI after achieving the peaks of fIPAR and LAI, respectively (Thomas 2013). Overall the trends, the sole cropping in both crops showed significant differences between the IRWH and CON tillages with higher values in fIPAR in CON compared to the IRWH with wide runoff strips between the tramlines. Notwithstanding, the different canopy architecture in the intercropping with maize and beans, there were no significant differences between IRWH and CON in the relationship of LAI and fIPAR. Moreover, there was a high variation of fIPAR in CON plots compared to IRWH. In general, due to selected date of measurement, the logarithmic relationships can be applied to eliminate some outliers due to changing light interception and/or un-foreseen atmospheric conditions.

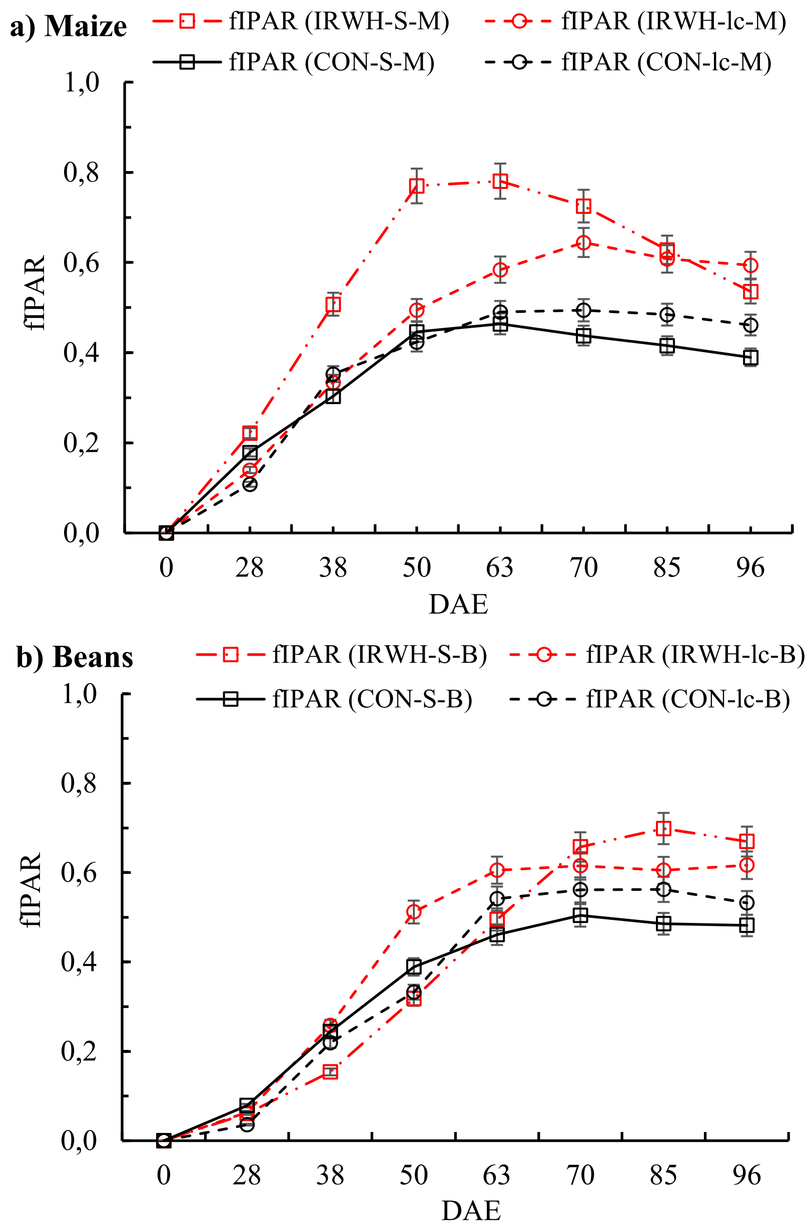

Figure 5.8 Fraction of intercepted photosynthetic active radiation (fIPAR) of two cropping systems (sole and intercropping) under two tillage systems (CON and IRWH) from the Paradys demonstration plots measurement: a) maize and b) beans

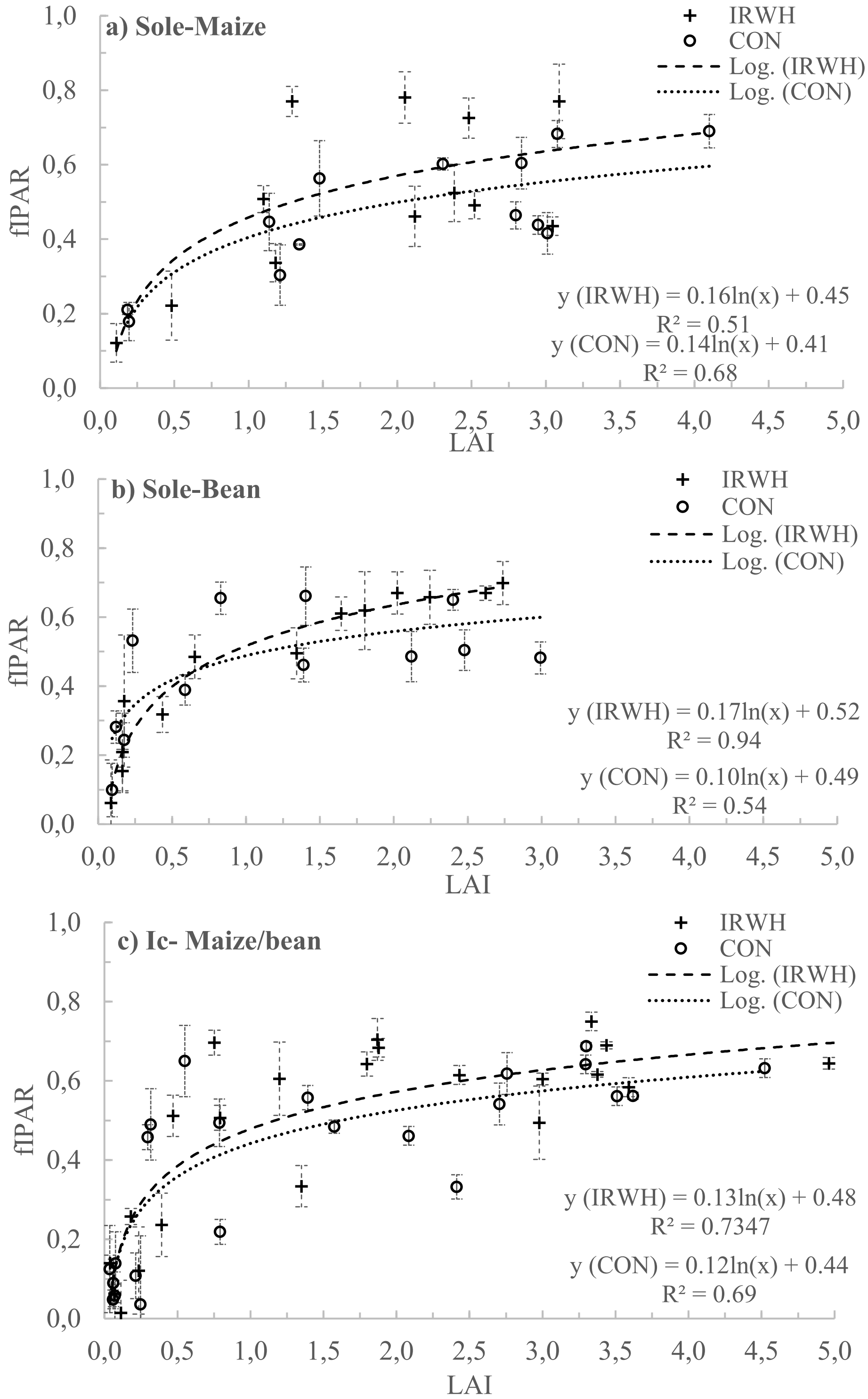

Figure 5.9 The logarithmic relationship between LAI and fraction intercepted photosynthetic active radiation (fIPAR) for different cropping systems; a) sole maize, b) sole beans and c) intercropping under CON and IRWH tillage systems.

5.3.8.3 Total intercepted radiation (TPAR) and radiation use efficiency (RUE)

As part of the study, measurements of growth parameters were performed such as leaf area index, above ground biomass accumulation (Table 5.3, 5.4, and 5.11) and partitioning intercepted photosynthetic active radiation (IPAR) and calculated RUE as a function of DM accumulation (Table 5.12). In all treatments, the TPAR increased linearly with days after planting during the growing season in both experimental sites. The results in Table 5.12a show the highest TPAR in Morago demonstration plots found for CON tillage with intercropped maize and beans treatments with total values of 611.8 MJ and 800.4 MJ, respectively. Lowest TPAR was measured in IRWH tillage with 385.9 MJ and 522.5 MJ for sole maize and some beans, respectively. At Paradys, the measurements from the IRWH showed a higher TPAR value, intercropped 582.0 MJ for intercropped maize and 655.9 MJ for sole beans and the lowest TPAR found in the CON tillage for maize sole treatment (Table 5.12b).

Results of RUE for all treatments and sites are also shown in Table 5.12a and b. In comparing the results during the growing season, the RUE values varied and observed inconsistencies due to differences in growth stages and climatic conditions like the cloud cover and timing of the measurements. For example, the IRWH in sole maize and intercropping, the RUE ranges from 0.04-0.65 and 0.0-0.39 g DM MJ^{-1}, respectively. However, in beans sole and intercropped the RUE range show much wider with value 0.11-1.31 g DM MJ^{-1} and 0.19-0.89 g DM MJ^{-1}, respectively. In combining RUE of maize and beans intercropping treatments, the highest RUE value was found at 85 DAE (1.34 g DM MJ^{-1}) for IRWH (0.95 g DM MJ^{-1}) and at 96 DAE for CON tillage. In general, the greater RUE was found in the intercropping compared to sole cropping. A similar trend was observed in Paradys with higher RUE in intercropping which is 1.35 and 1.12 g DM MJ^{-1} for IRWH and CON tillages. The results indicate the contribution of maize-bean intercropping under IRWH tillage showing improvements in maize canopy size, radiation interception, and RUE. Thus, increased water availability through IRWH enhances the productivity of maize-bean intercropping and closely associated with radiation use efficiency. The total TPAR of both maize and beans under IRWH showed the trend of sole- > Inter-cropping, but under CON tillage the intercropped beans gave higher DM production compared to IRWH. The highest TDM under IRWH was observed in sole beans (738.6 g m^{-2}) at Paradys site. The CON sole beans in Morago site gave lower TDM compared to intercropped. The dry matter of intercropping systems higher than the solely grown crops. The results indicate the contribution of maize-bean intercropping under IRWH tillage showing improvements in maize canopy size, radiation interception, and RUE. Thus, increased water availability through IRWH enhances the productivity of maize-bean intercropping and closely associated with radiation use efficiency.

Table 5.12 Total intercepted photosynthesis active radiation TPAR and radiation use efficiency (RUE) and the percentage of improved RUE in intercropping relative to sole cropping under two tillage systems: a) Morago and b) Paradys sites

a) Morago

DAE	TPAR (MJ)				RUE (TDM/TPAR, (g MJ^{-1})					RUE Improve (%)
	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Total M+B	
IRWH										
28	-	-	-	-	-	-	-	-	-	-
38	41.1	42.2	70.7	5.1	0.04	0.02	0.11	0.47	0.49	-89.5
50	146.3	198.9	155.0	102.8	0.22	0.02	0.15	0.19	0.21	-26.0
63	258.9	313.1	272.2	284.5	0.13	0.07	0.33	0.25	0.32	8.4
70	355.5	422.0	416.2	438.4	0.55	0.21	1.31	0.71	0.92	9.4
85	373.1	486.5	469.1	534.2	0.65	0.45	1.17	0.89	1.34	17.9
96	385.9	521.3	522.5	606.4	0.60	0.39	1.02	0.73	1.12	20.1
CON										
28	-	-	-	-	-	-	-	-	-	-
38	58.4	41.0	33.4	16.3	0.03	0.07	0.21	0.06	0.14	-27.9
50	167.5	302.5	122.2	202.6	0.01	0.01	0.10	0.01	0.02	81.8
63	316.2	494.1	298.3	365.0	0.03	0.05	0.16	0.03	0.07	46.4
70	410.7	554.7	446.7	585.6	0.07	0.14	0.18	0.16	0.29	31.1
85	456.4	568.7	500.8	705.5	0.50	0.27	0.33	0.46	0.74	34.4
96	534.0	611.8	577.1	800.4	0.47	0.39	0.74	0.56	0.95	28.2

b) Paradys

DAE	TPAR (MJ)				RUE (AGDM/TPAR, (g MJ^{-1})					RUE Improve (%)
	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Maize-Sole	Maize-Ic	Beans-Sole	Beans-Ic	Total M+B	
IRWH										
28	74.8	47.2	20.6	21.5	0.02	0.09	0.14	0.10	0.20	-9.5
38	220.5	145.2	66.9	111.9	0.06	0.07	0.19	0.08	0.15	10.8
50	432.1	277.5	178.4	287.3	0.10	0.25	0.27	0.10	0.35	9.1
63	532.5	398.5	337.8	413.1	0.24	0.25	0.33	0.26	0.51	1.9
70	549.8	488.6	498.4	466.2	0.39	0.14	1.07	0.52	0.66	-8.4
85	557.3	539.3	619.7	536.6	0.49	0.20	1.04	0.49	0.68	-10.5
96	525.1	582.0	655.9	604.0	0.59	0.25	1.13	1.10	1.35	-2.5
CON										
28	60.4	36.5	26.5	12.1	0.02	0.09	0.05	0.27	0.36	-50.7
38	131.8	153.0	106.0	95.1	0.01	0.02	0.02	0.03	0.04	2.9
50	250.4	237.9	218.3	186.6	0.04	0.10	0.05	0.02	0.12	0.2
63	316.5	334.4	314.6	369.5	0.09	0.24	0.09	0.22	0.46	11.4
70	332.0	374.7	382.3	425.6	0.73	0.44	0.63	0.38	0.82	8.7
85	368.6	429.7	430.6	498.9	0.72	0.59	0.62	0.51	1.10	12.2
96	381.9	452.0	471.9	521.4	0.75	0.60	0.61	0.52	1.12	9.1

5.3.9 Relationship of Radiation Use Efficiency (RUE) and Water productivity (WP)

Previous studies indicate a positive association between water use and radiation use under different management practices and environmental conditions. For example, Singh and Sri Rama (1989) reported a positive relationship between RUE of chickpea (*Cicer arietinum*) and extractable soil water content under stressed water conditions and constant RUE under conditions of non-stressed water. Tsubo et al. (2003) also found that in maize-bean intercropping systems the increase of RUE with an increase of WUE and explained as an advantage for yield and growth. In the study, the results of double-cropped wheat and soybean, Caviglia et al. (2003a) show the WUE was closely associated with radiation use efficiency and they concluded, as the impact of double cropping on resource capture was much larger for water than for radiation.

In this study, RUE (TDM/TIPAR) was plotted against WP (AGDM/P_g), for sole- and inter-cropping systems under two different tillages (CON and IRWH) as shown in Figure 5.10a and b. In all cropping systems under both tillages, RUE increased as WPg increased until radiation canopy interception reached the saturation level to produce biomass and then tended to be constant. Therefore, in agreement with the second hypothesis (Section 5.1), the water use of various treatments was related to radiation use in rainfed semi-arid areas of the study site for maize-bean cropping systems under different tillage systems. However, it is expected to vary the degree of associations for different tillage techniques (i.e. between CON and IRWH). By pooling all maize and beans data together, a comparison was made between CON and IRWH for solely grown crops (Figure 5.10a) and maize-bean intercropped treatments (Figure 5.10b). The coefficient of determination (R^2) of sole cropping shows higher values compared to intercropping which is 0.84 and 0.88 vs 0.67 and 0.82 for IRWH and CON, respectively. There were also significant differences ($P \leq 0.05$) between the two tillages in both cropping systems. Furthermore, in the analysis attempts were made to show the radiation saturation level with an increase of seasonal rainwater use for biomass production by the crops. The maximum RUE was calculated as an average of three highest RUE of each data set (IRWH-Sole-M, IRWH-Sole-B, CON-Sole-M, and C-Sole-B) and (IRWH-Ic-M, IRWH-Ic-B, CON-Ic-M, and C-Ic-B) while RUE between zero and the maximum values was determined as the slope of linear regression with the zero intercept (Figure 5.10a and b) and the results are also summarized in Table 5.13.

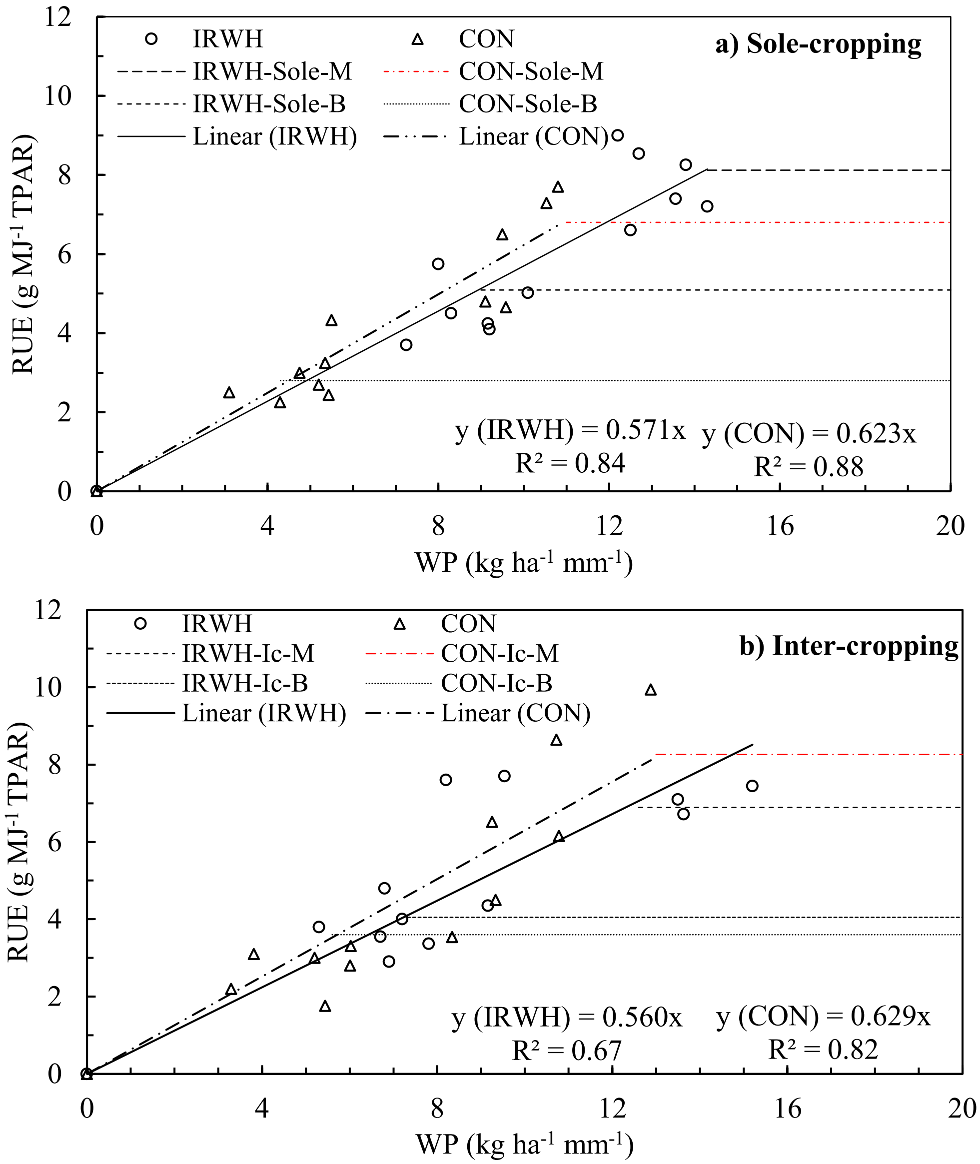

Figure 5.10 Relationship between water productivity (WP) and radiation use efficiency (RUE) among cropping systems under two different tillage systems (CON and IRWH); WP was derived as the slope of the regression of AGDM on cumulative water use during the growing season

Table 5.13 Summary of the results from Figures 5.11a and b showing maximum RUE, R^2, and the regression slope for different treatments with sole- and inter-cropping systems

Treatments	Sole-cropping			Treatments	Inter-cropping		
	Max. RUE ($g\ MJ^{-1}$)	R^2	Slope		Max. RUE ($g\ MJ^{-1}$)	R^2	Slope
IRWH-Sole-M	8.12	0.84	0.571	IRWH-Ic-M	6.89	0.67	0.560
IRWH-Sole-B	5.09			IRWH-IC-B	4.05		
CON-Sole-M	7.16	0.88	0.623	CON-Ic-M	8.46	0.82	0.629
CON-Sole-B	2.81			CON-Ic-B	3.60		

In sole cropping, the maximum RUE was found under IRWH for solely grown maize and beans, which is higher by 13% and 55% than the CON tillage, respectively. In contrast, for the inter-cropping system, the maximum RUE found lower for IRWH for only intercropped-maize (by19%) but the intercropped beans showed higher maximum RUE (by12%) compared to CON tillage. This relationship indicates the observed radiation by plants for photosynthesis is directly related to the transpiration rate until saturation occurs. Tsubo et al., 2003 described the high water requirement as a water deficit and proportional to lower RUE. Similarly, in this study, in sole cropping for maize and beans and intercropped beans, the CON showed the higher water deficit and lesser efficient in using the radiation available during the season compared to IRWH. However, despite the advantage of IRWH over the CON, the intercropped maize showed more water deficit compared to CON tillage, this could be due to higher competition of resources from the partner crop (beans) with shallow rooting structure for shallow soils in the study area. In general, in the IRWH the maximum RUE was higher in the sole-cropping system while in the CON tillage higher maximum RUE observed in intercropping system.

5.4 Discussion

Soil water is the most important environmental factor and directly determines productivity. The significance of IRWH system in improving soil water storage, and hence productivity in dryland ecosystems are well reported in the literature. However, the ecophysiological responses for maize-bean intercropping have not yet been comparatively studied under IRWH system.

The production of dry matter and grain depends on the ability of crops to capture resources. On a seasonal basis, cropping systems centred on solely grown crops waste large proportions of key inputs including incoming solar radiation and rainfall. In comparison to Maize-bean intercropping, both sole crops (maize and beans) decreased seasonal ET (ΔET) by 8% and 12% in CON and 5% and 16% under IRWH for maize and beans, respectively. The ET in IRWH increased by 42%, 31% and 37% compared to CON for sole maize, sole beans and maize-bean intercrop, respectively (Table 5.8a and b). This indicates that water losses as crop evapotranspiration were in proportion to seasonal runoff and soil evaporation occurred during the growing season. The unproductive water losses among treatments could be attributable to three main reasons. First, the ex-field runoff from the CON in both sole and intercropping with higher losses during occurrences of few rainstorms. Second, the water loss through ET, was higher in IRWH than CON, this could be due to higher infiltration in the IRWH compared to CON tillage. Thirdly related to PAR canopy interception. However, the PAR interception is always higher in intercropping compared to sole cropping in both tillage systems (CON and IRWH).

The results in Table 5.12 revealed the variation of TPAR and RUE maize-bean sole and intercropping under IRWH and CON tillages, Therefore, the RUE is another important factor for dry matter accumulation in addition to intercepted PAR. Radiation use efficiency was calculated based on biomass and was different across the crop growth stages in solely grown maize and beans and maize-bean intercropping (Table 5.12). The observed increase in RUE was consistent with the observed higher rate of increase in above-ground dry matter (Table 5.11). The maize RUE increased at each subsequent growth stage in both sole and intercropping but was different for different treatments. The RUE for sole bean was higher than for intercropped bean under IRWH tillage. This was inconsistent with the study conducted by Tsubo et al. (2004) in conventional tillage with irrigation where intercropped bean had higher RUE compared with sole beans.

Sole-crops had a lesser ability to intercept available PAR during the growing cycle than intercropping. Moreover, in Morago, the intercropping under IRWH showed lower in TPAR compared to CON. Results showed, that in Morago IRWH had less TPAR by 25% and 15% compared to CON, for intercropped beans and maize, respectively. Similarly, in Paradys the IRWH showed lesser TPAR by 15% and 28% compared to CON. This could be related to reduced PAR interception associated with the spatial arrangement of the canopy in the CON and IRWH tillage systems, and a reduced canopy size (leaf area and number) because of water deficit and shading. Studies from (Sinclair et al., 2005), intercropped could have higher water stress than sole crops because of increased evaporative demand of the canopies.

Water can be stored in the soil in different ways in CON and IRWH, thus differ the use of available resources and crop water demand. The capture of radiation is, in contrast, dependent on canopy structure and planting rows arrangements. For example, Hunt et al. (1990) have proposed that the resource capture model (dry matter production as a function of the efficiency of resource capture and the efficiency of resource utilization) is useful for all kinds of resources. Monteith (1994), however, pointed out that the model is more adequate for radiation and has some restrictions for storable resources. However, irrespective of the adequacy of the model, the contrasting responses for water and radiation, it is possible to develop alternative strategies for the benefit of efficient use of resources for smallholder farmers in semi-arid areas.

Based on TPAR and RUE estimations to improve seasonal water productivity in this study it is possible to consider other cultural practices into IRWH techniques. For example, mulching applications to minimize soil evaporation or growing cover crops to optimize resources use efficiency and suppress weeds, etc. The strong, positive relationship between RUE and WP indicates a better capture of radiation (Figure 5.10) in relation to the role of unproductive water losses, mainly by runoff and soil evaporation. There are studies on RUE (for example, Loomis and Connor, 1992) because RUE is the most widely used indicator of crop ability to use PAR to produce biomass. Close associations between RUE and WUE were reported for sunflower and spring wheat (Sadras et al., 1991) for wheat and soybean (Caviglia and Sadras, 2001) for maize-bean intercrop (Tsubo et al., 2003). Thus, the analysis of relating RUE and WP was useful to provide insight regarding how the intercropping system under improved tillages could increase seasonal productivity of water or radiation on dry matter basis through a significant increase in radiation interception. This result clearly showed that increasing radiation capture is an important avenue to improve water productivity.

5.5 Concluding Remarks

Increased smallholder farmers' rainfed crop production per unit area of their plot during the short rainy season is an important step towards food and nutrition security. Moreover, in semi-arid areas, the frequent occurrences of dry conditions (El Niño seasons) with long dry spell episodes and rain season shifting due to climate change effect, farmers seek alternative techniques to improve water productivity and efficient use of resources. More use of marginal land with the intervention of water harvesting techniques could also help to alleviate the pressure to produce grain in less productive, environmentally fragile agroecosystems (Sadras and Roget, 2004). Previous studies also described the ThabaNchu rural community facing the same challenge with low productivity and the necessities of improved techniques. Likewise, there is poor adoption of improved or alternative techniques and disorganized intercropping issues related to the scarcity of water in arid and semi-arid areas. These are the main concern for practicing efficient use of resources. There is a critical need therefore to devise alternative techniques accounting for increasing smallholders' productivity, which is based on improved ability to capture and use resources more efficiently. Thus, in this study, the efficient resource use or capture considered are water and radiation, although the soil nutrients not included the soils can benefit through legume N fixation ability. The relationships in Figure 5.10 indicate the links between the efficiencies in the use of radiation and rainwater remain when upgrading the CON to IRWH tillage and from solely grown crop to intercropping in a semi-arid environment. Through efficient use of resources, to improve WP under IRWH several options have been proposed including increasing harvest index, the proportion of transpired water and reducing vapour pressure deficit (VPD), however, the more adequate strategy to further increase the productivity of water on seasonal bases should be based on improved capture of radiation by crops in related to WP.

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CHAPTER 6: FARMERS INFORMED CHOICE: KNOWING THE IN-FIELD RAINWATER HARVESTING TILLAGE AWARENESS IN THABA NCHU

Abstract

A systematic engagement strategy was used to identify contextual factors preventing farmers in the Thaba Nchu area of Free State Province from accepting the in-field rainwater harvesting (IRWH) tillage system. The purpose of the qualitative study is to assess farmers' knowledge and attitudes, uptake and perceptions of the tillage system. To test the construct validity farmers' were engaged in interviews with questions drawn from the questionnaire. This study established two differing attitudes based on age the farmers' and experience of the IRWH tillage system. Results show that only less than a third (27%) made an informed choice although 89.6% had a positive attitude. The overall reflection of excellent knowledge (75%) about the IRWH tillage was high among farmers aged 41 and over (55.6%). Their narratives on the tillage usage showed their perceptions were linked to technical issues and climate change, whilst the other 40yr and under farmers were highly interested in gaining further tillage systems education and questioning the sustainability of the IRWH tillage system. Farmers' perception and narratives indicate their unique needs and experiences while providing an additional perspective on the use of the IRWH tillage as a climate-smart agricultural technology.

Keywords: Climate variability and change, Smallholder farmers, Farmer perceptions, in-field rainwater harvesting

6.1 Introduction

Following several sustainable initiatives to boost rainfed agriculture, food demands are exceeding supply globally in several regions. Some of these areas suffer droughts costing thousands of lives and causing severe socio-economic disruption (Speranza et al., 2008). Ensuring food security for households in arid and semi-arid areas remains a significant challenge. Subsistence farmers in sub-Saharan Africa (SSA) face challenges with restricted access to financial and agricultural extension and advisory support (Bedeke et al., 2019). Climate variability and change exacerbate these problems not only by reducing soil water storage but also by the changing frequency and duration of rainfall (Touhami et al., 2015). Frequent fluctuations in seasonal rainfall not only affect farming activities but can also increase variability in crop yields due to water stress during crop growth. Unpredictable rainfall exacerbates the vulnerability of farmers to climate change by limiting access to and availability of agricultural water, due to dry spells and increased conditions of drought pressure (Speranza et al., 2008; Gandure et al., 2013). The increase in drought frequency and intensity triggers an increase in the level of distress of farmers, especially to make informed choices; this hinders agricultural practices aimed at improving farmer's livelihoods such as the abandonment of rainwater harvesting. The result is a shift in the ability of farmers to engage in sustainable systems, hampering potential capacity for investment (Gandure et al., 2013). Also, these adverse effects of climate change will exacerbate poverty and malnutrition among subsistence farmers'.

Therefore, adaptation by subsistence farmers to impacts of climate change is of significant concern to various stakeholders worldwide and in South Africa. In the implementation of conservation practices, the potential for improving productivity in resource-constrained rainfed subsistence systems is in the continuously in focus. The Water Research Commission of South Africa (WRC) places particular emphasis on helping resource-constrained rainfed subsistence farmers develop their adaptive ability (Kahinda and Taigbenu, 2011). Projects were funded by the WRC, including the development of tillage techniques for in-field rainwater harvesting (IRWH) in the municipal area of Thaba Nchu, with the primary objective of transferring knowledge of this technology to local and surrounding communities (Botha et al., 2003). The initial deployment of IRWH technology, only started at six households in four farming communities during the initial stage of technology approval (2001/02 growing season) (Backeberg et al., 2010). Uptake expanded rapidly, due to the desirability of higher yields associated with IRWH tillage and dissemination of information. The increased take-up was as follows 108 farmers' homes in 6 villages (growing season 2002/03), 400 households in 37 communities (growing season 2003/04) and 1033 homes in 42 communities (growing season 2004/05); and 1033 homes in 42 communities (2004/05 growing season) (Backeberg et al., 2010). Several methods were used to disseminate knowledge and promote its use, including mass approaches via local television and radio stations, brochures, and training manuals (Backeberg et al., 2010). Demonstration plots on-station and capacity building actions with extension officers and youth were used in some of the group approach methods. However, after decades of efforts to implement and facilitate knowledge transfer about IRWH to the smallholder farmers in Thaba Nchu, there has been little sustained use of the IRWH methods by farmers.

Many innovations from different organizations (including NGOs and South African government departments) have been introduced to help resource-constrained rainfed subsistence farmers (Kahinda and Taigbenu, 2011). Technological products, especially enhanced plant varieties (drought-tolerant, high-yielding and disease-resistant) and mineral fertilizers were provided to increase productivity while addressing the risks of climate change (Baiphethi and Jacobs, 2009). Could the dissemination of such technological packages, however, have little complementarity with the IRWH tillage technique? When adopted jointly, these technologies can provide better productivity and improve social and economic status than used independently. Feder et al. (1985)

describe the receptiveness of subsistence farmers to new technological innovations. For Thaba Nchu, even in cases where participatory methods were used to implement the IRWH tillage, most farmers later abandoned the use of this tillage technology on their land. There is little knowledge about the underlying structural and community-level factors that influence the choices and attitudes of farmers towards the uptake. Participatory approaches using empirical inquiry techniques can, therefore, allow investigators to elucidate the underlying issues.

Farmers have informed agricultural conservation decision-making based on previous efforts to transmit information, one can infer that the Thaba Nchu society is knowledgeable “on” or “about” the IRWH tillage technology. A direct inquiry approach is a more convenient approach, rather than opinions of extension officers who are the farmers' sole provider of technical services (Mafongoya et al., 2016). Furthermore, comparing responses among farmers categorized by age groups to determine the effectiveness of transfer of knowledge is another approach to determine the information required for informed choices (Tittonell et al., 2012). Consequently, incentives can involve the transfer of knowledge from farmer to a farmer in the use of technology and are considered an effective method of agricultural extension (Franzel et al., 2001).

Knowledge correlated with the best results can be described as excellent knowledge. The first step in developing a knowledge measure is to agree on the appropriate content. Then have an extensive list of target related questions preceded by asking experts and other relat ed groups to select the important ones. Knowledge in developing countries is a weak determinant of technological adoption. Mafongoya et al. (2016), in a systematic review, found that farmers are aware of the associated outcomes of using conservation agriculture (CA) to increase their crop yields and conserve resources. However, high labour demands and additional expenditure (such as herbicides) are contributing factors that hamper uptake. More studies on CA farmers' awareness, behavior, and attitudes are necessary in evaluating the acceptance of CA practices by farmers and help to develop policies that increase uptake (Mafongoya et al., 2016). Having sufficient knowledge of a method of CA in subsistence farming is, therefore, not considered a prerequisite to making an informed choice. Farmers with low resources make a choice considering their socio-economic and financial values. It is crucial to understand farmers' views when encouraging technology uptake. Many studies have evaluated the socio-economic impact of IRWH tillage, but more attention is required on assessing its awareness and the related attitudes and perceptions that affect farmers' adoption. The objective of this study was to develop a tool for measuring informed choice about the IRWH tillage technique in the Thaba Nchu town of Free State Province, to assess any gaps in order to enable the provision of information necessary to promote its uptake.

6.2 Materials and Methods

6.2.1 Design of survey method to test informed choices

The qualitative and social aspect study was conducted in Thaba Nchu from October to November 2019. An analysis of previous information dissemination methods to adopt the IRWH tillage method enabled the design of the survey instrument (Botha et al., 2003). The aim was to inquire about the knowledge of farmers that could be coded as excellent and ineffective, while coding attitude as positive and negative, and uptake of IRWH tillage, coded as in-use, previously used, and potential usage. Several meetings with the extension officers and some researchers were important in helping to create the questionnaire and refining it. Some informal interviews with farmers in the Thaba Nchu area offered some feedback on understanding the scope of their expertise. Knowledge questions are organized with multiple choice of possible answers in a systematic manner (Table 6.1). To consider knowledge questions as excellent researchers agreed on a threshold of >5/8. Several meetings were scheduled with extension officers on the capacity of the measure to assess the knowledge and attitudes of farmers. To determine farmers' attitudes (beneficial / non-beneficial, important / unimportant, good / bad, advantageous / disadvantageous, and desirable / unwanted) questions were used. The attitude scale threshold was set to be positive 0-6, neutral 7-13, and negative 13-20. There were no neutral attitudes to respondents in this sample. Twelve farmers invited by the extension officers piloted the questionnaire. Mini-pilot interviews were also conducted by research assistants in mother tongue, which is Sesotho with a small group of farmers to determine the validity and reliability of the questionnaire's transparency.

6.2.2 Sampling and qualitative data collection

The study was investigating the knowledge of farmers based on previous WRC projects in its 42 villages. This exploratory, qualitative research activity was attended by a total of 48 farmers. Participants were drawn randomly from nine villages of Thaba Nchu, based on recommendations from extension officers. The farmers completed questionnaires in a face-to-face environment, followed by semi-structured interviews with questions drawn from the questionnaire of knowledge and attitude. The first survey meeting was attended by 16 farmers' households and 32 farmers in the second. The farmers' answers in these samples were pooled and analysed (n=48). Participants were asked to complete the questionnaire with the aid of enumerators. The researchers made presentations on the IRWH after the farmers completed the survey and interviews. Further discussions were conducted to investigate the reasons why the IRWH tillage was accepted or rejected. These discussions continued until everyone had made the contributions they wished to make, while a record of the values of farmers underpinning those perceptions was made.

Table 6.1 Overview of the 8 questions to test knowledge of IRWH tillage system

Knowledge questions	Reasons needed
1. What is the purpose of using the IRWH tillage?	To test general knowledge
2. Which equipment is required to construct IRWH tillage?	To test technical knowledge and practicality
3. What is the frequency of land preparation with IRWH tillage?	To test experience and uptake
4. What is the best purpose of basin making in IRWH tillage?	To understand the depth of knowledge and technicality
5. How does IRWH compare with conventional tillage?	To check if the farmers are realizing advantages
6. What can you say about drought when using IRWH tillage?	To confirm an understanding of adoption benefits
7. Is it important to continue using IRWH tillage?	To have a general farmer perception
8. Which of the definitions best describes drought?	Farmer awareness of drought

6.2.3 Data analysis

All data analyses were carried out using IBM Social Sciences Statistical Suite, SPSS version 24 (SPSS, Inc., Chicago, IL, USA) (SPSS Inc., 2015). Details of data analysis described in Chapter 4; section 4.7. The accuracy of the questions about knowledge and attitude was tested using the alpha of Cronbach. Alpha values ranging from 0.7-0.9 suggest a good internal accuracy measure. Descriptive statistics were created to reflect the opinions of farmers on informed choice with respect to different aspects of socio-economic demographics.

6.3 Results

6.3.1 Farmer and farm household characteristics

Table 6.2 provides a description of the demographic and socio-economic dimensions. It can be noted that 58.8% of those who completed the survey are men, and 45.8% of household heads are married. The household head age distribution shows that only 47.9 percent of household heads are older than or exactly 41 years, and 52.1 percent are less than 40 years old. Many households in the study (43.8%) have between 4 and 6 members in the household, while a small number of about 8.3% live as individuals. Most households (31.3%) are in the salary band R1501-2000 per month. High school education 45.8% is the highest level of literacy among heads of households, while 45.8% are unemployed.

The characteristics of the household farming system (Figure 6.1) evaluated by inferential statistics revealed that the highest number of farmers (80 percent) owns household gardens and are active in full-time for mixed crop-livestock farming. All part-time farmers (100%) irrespective of owning a household garden, outfield, or both were predominantly livestock only farmers. In contrast, all full time had higher percentages for practicing crop production only and none was livestock only farmers. Household heads with part-time farming status owning either a household garden (20%) or an outfield (20%) were the lowest. There was significant (R^2=5,82, DF=2, p<0,05) difference in crop production between farmers practicing on the household garden and the outfields.

Table 6.2 Demographic and socioeconomic profiles of the participants

Household participant characteristics		Frequency	Percentage
Sex	Male	28	58.3%
	Female	20	41.7%
Marital status	Married	22	45.8%
	Single	16	33.3%
	Divorced	5	10.4%
	Never married	3	6.3%
	Widowed	2	4.2%
Age groups	20-25	1	2.1%
	26-30	6	12.5%
	31-35	4	8.3%
	36-40	14	29.2%
	41 & above	23	47.9%
Household members	Live alone	4	8.3%
	1 to 2 people	7	14.6%
	2 to 4 people	10	20.8%
	4 to 6 people	21	43.8%
	6 & above	6	12.5%
Monthly income	Below R500	9	18.8%
	500-1000	4	8.3%
	1001-1500	6	12.5%
	1501-2000	15	31.3%
	2001-2500	5	10.4%
	2501-3000	1	2.1%
	3501-4000	5	10.4%
	4501 & above	3	6.3%
Educational level	Primary	13	27.1%
	High school	22	45.8%
	Diploma	8	16.7%
	Bachelor’s degree	5	10.4%
Employment status	Employed	13	27.1%
	Self employed	13	27.1%
	Not employed	22	45.8%

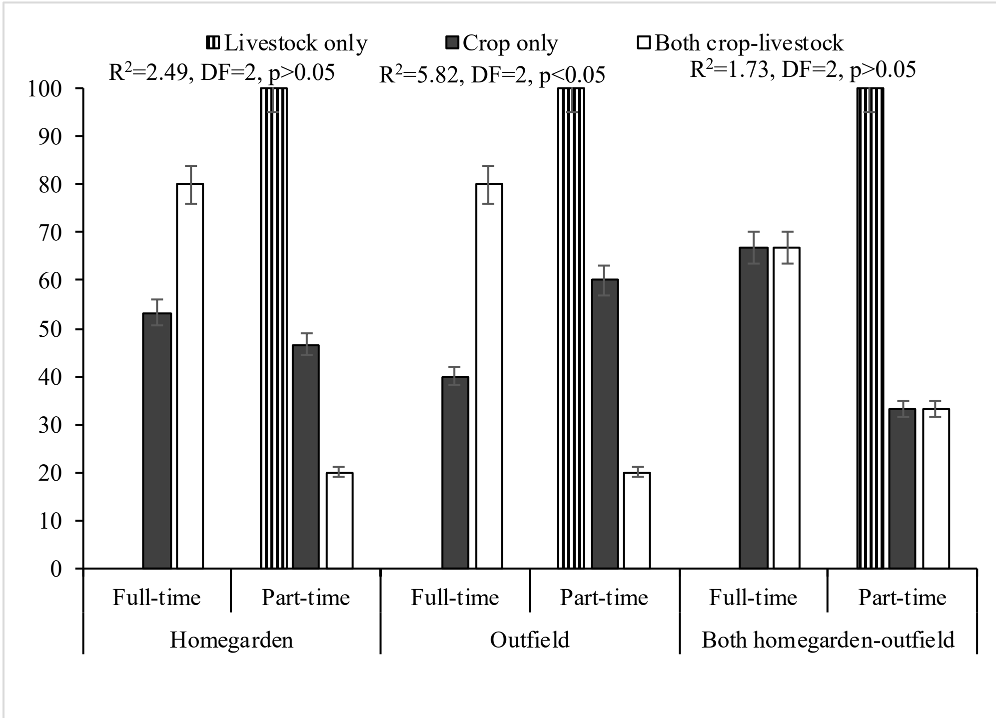

Figure 6.1 Relationships between employment status and mixed farming system versus land ownership among Thaba Nchu farmers

6.3.2 The percent of knowledge questions perceived as valuable

Farmers were divided into two classes by age (i.e. above 41 and below 40 years) to determine the percentage rating of questions which they viewed as essential and relevant. As shown in Figures 6.2 and 6.3, respectively, on the percentage of questions viewed as essential and necessary. Questions of knowledge 1, 2, 4, and 8 have been labelled as the key to the IRWH tillage. Farmers under the age of 40 had the most frequencies in knowledge questions 1 (65 percent), 2 (60 percent), and 8 (65 percent) perceived importance. Knowledge question 6 had the most frequency rating among farmers over the age of 41 (60%), showing the relevance of IRWH tillage system experience (Figure 6.2).

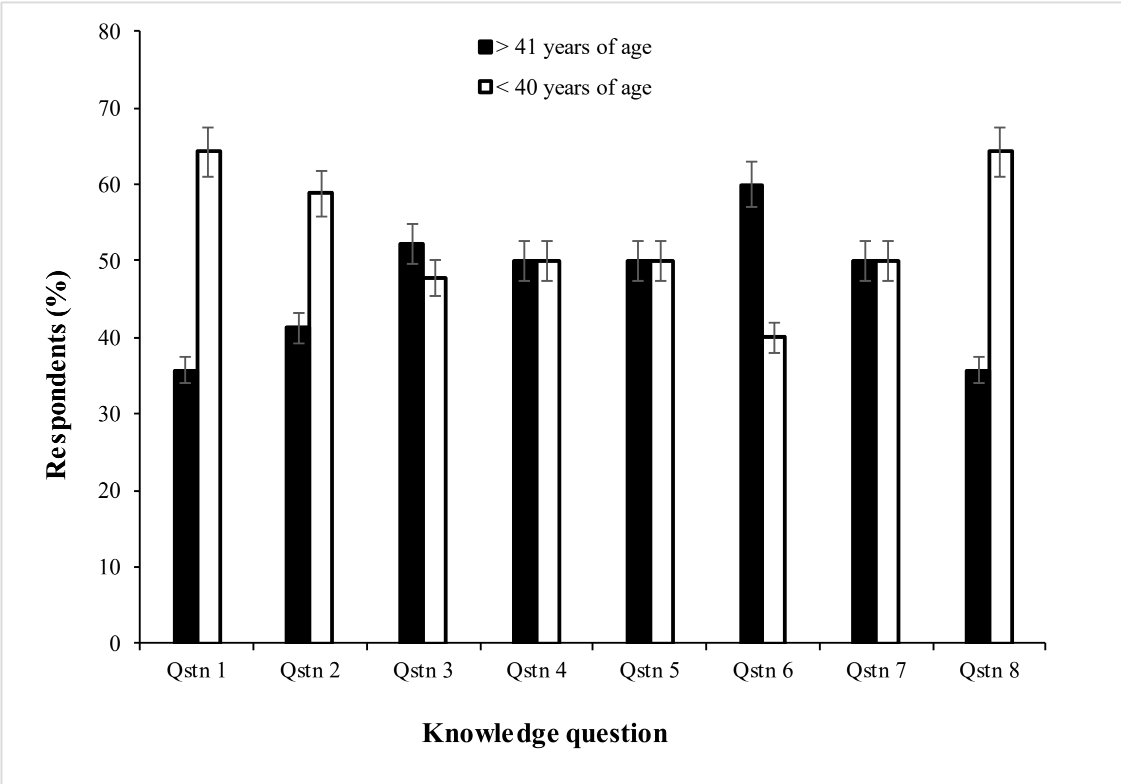

Figure 6.2 Differences in the rates of knowledge as highly important among farmers' age groups

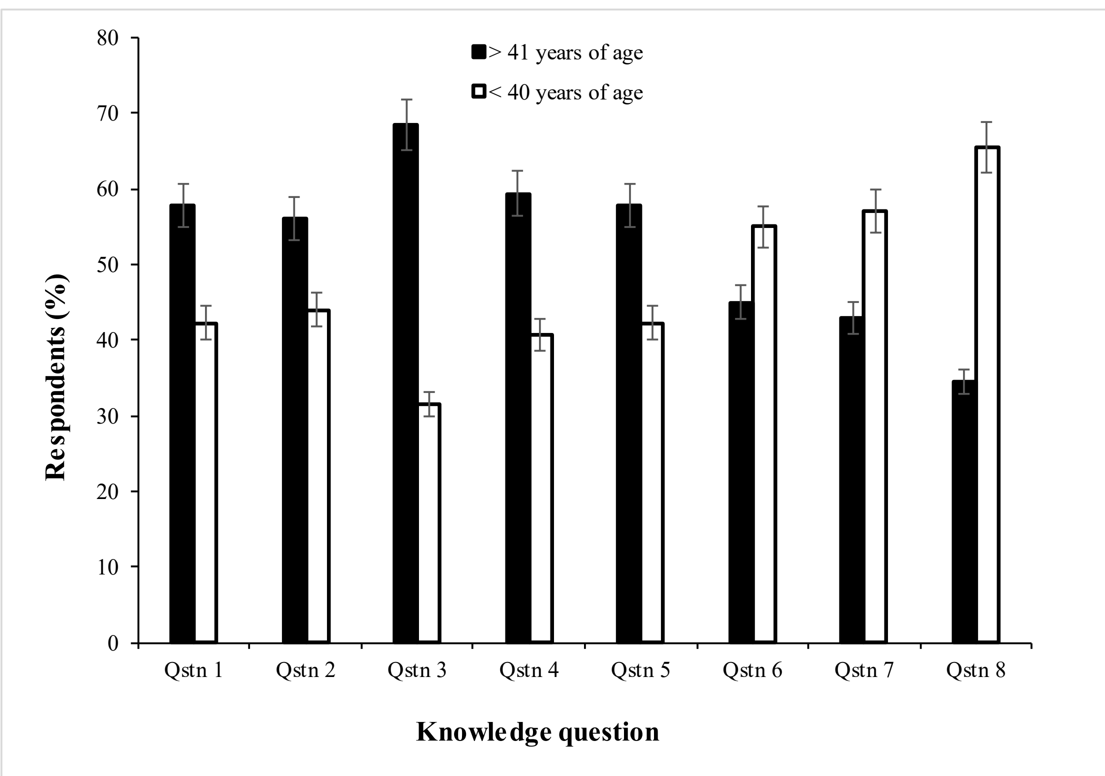

Figure 6.3 Differences on the rating of knowledge questions among the age groups of farmers

Of question 1 (57.7%), question 2 (56%), question 3 (68.4%), question 4 (59.3%) and question 5 (57.7%), the age group above 41 years had the highest percentage ranking as important. This indicates that the information provided was of particular importance, including some questions that could only be classified based on realistic experiences such as questions 3 and 5 (Figure 3). The younger farmers are highly aware of the drought and, as reflected in their rating of critical information questions, it is important.

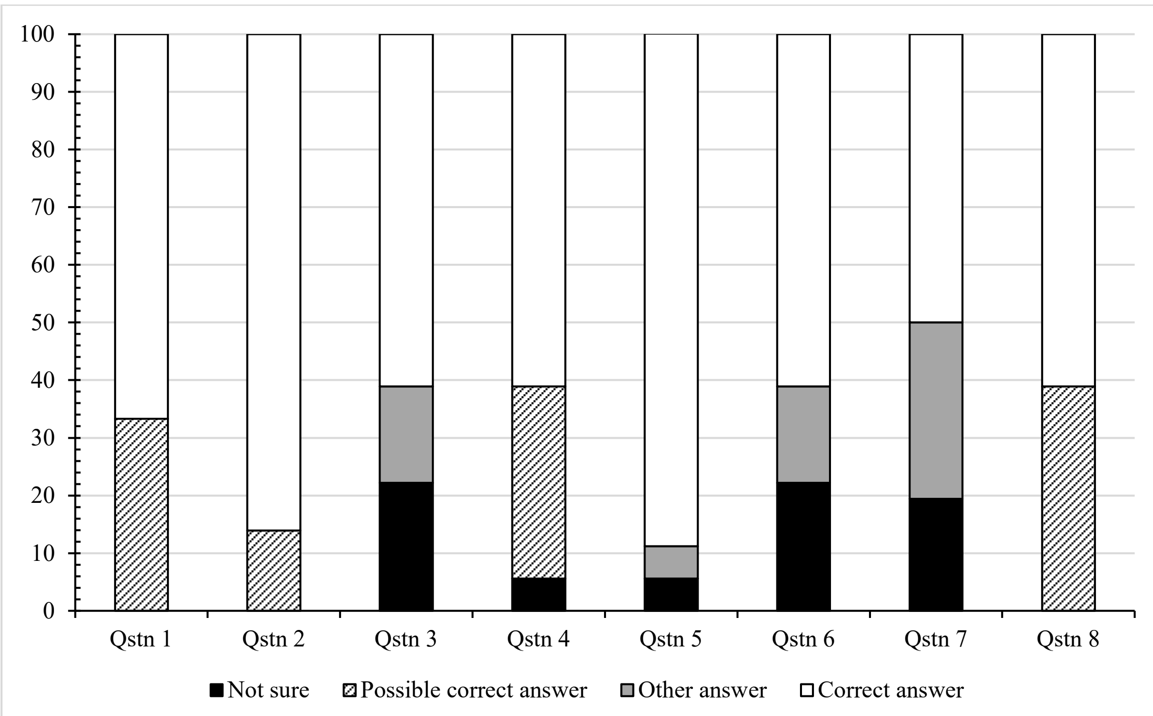

Figure 6.4 Distribution of farmers reacting to knowledge questions about content or knowledge with a correct answer, possible answer or indicating they are unsure.

The responses of farmers from the primary information questions have been evaluated (Figure 6.4). The information was required to highlight the percentage of farmers who did not have any idea about the IRWH tillage process. All possible responses to the question are correctly applied. Question 8 was the only question with excellent knowledge from the entire household heads this shows that farmers are highly aware about climate change and drought.

6.3.3 Internal reliability and construct validity

The summarized alpha coefficients showed internal accuracy for knowledge and attitude questions (Table 6.3). During instrument creation, twelve interviews were conducted with farmers to assess and explore awareness and attitude. Ten farmers were judged to have excellent knowledge (83%), and a positive attitude (67%) was agreed on by eight farmers. Table 6.4 provides examples of the knowledge and attitude of farmers. The informed choice interview analysis was then compared with the appropriate questionnaire. Overall, two (17%) anomalies have been reported, and knowledge relevant to these two was identified. The farmers failed to reach the necessary cut-off on the questionnaire, but during the interview, they showed adequate knowledge. For farmers over 41 years of age, the knowledge ratings were significantly higher and were considered to have excellent knowledge.

6.3.4 IRWH tillage and informed choice

A high percentage of household head willing to adopt the IRWH tillage system was 12 (25%) and included 10 males and 2 females under the age of 40 years. Table 6.5 summarizes the properties of the household to take up IRWH tillage. In the current use of the IRWH tillage method, farmers aged 41 and above had the highest frequency of 75 percent (n=12), and this was 56.2 percent (n=9) high among females compared to males. Females had higher frequency on the adoption of the tillage system that is indicated by the increase from 45% (once adopted) to 56.2% (currently adopting). Similarly, high school educated household heads have also continued to adopt the tillage system (Table 6.5). The highest frequency on the current adoption of IRWH tillage system is associated with unemployed household heads.

Table 6.3 Description of the questions on the instrument used to assess informed choice

Measures	Description	Questions	Relia bility	Range	Cut-off	Mean (SD)	Outcome
Knowledge	Knowledge of IRWH tillage assessed	8 questions, multiple choice answers	0.77	0-8	≥5 = excellent knowledge	0.42 (0.5)	Excellent knowledge: 58.3%
Attitude	Attitude towards adapting to IRWH tillage	Five 5-point Likert questions	0.87	0-20	0-6 = positive 7-13 = neutral 14-20 = negative	0.21 (0.62)	Positive: 89.6% Negative: 10.4%
Uptake	Whether farmer accepts or declines IRWH tillage	Choice of 3 options: currently using, once used and would like to use IRWH tillage	-	-	-	-	-
Informed choice	Excellent knowledge and positive attitude	Percentage of farmers with excellent knowledge, positive attitude and continued uptake	-	-	-	-	Informed choice: 27%

Table 6.4 Exemplary quotations of knowledge and attitude

Domains	Illustrative quote
1. Excellent knowledge	Local name "*Matangwane*" for the IRWH tillage system works very well since I started using the method; I have had good crop yields.
2. Inadequate knowledge	I would like to use the IRWH tillage system, but I do not know how it is designed and what equipment it needs.
3. Positive attitude	The extension officers should teach the IRWH tillage system
4. Negative attitude	I would like to use the IRWH tillage system as long as we are supported in implementing additional irrigation boreholes.
5. Neutral attitude	I was comfortable using the IRWH tillage system, but the problem is that my crops die in good rainy years, and I cannot get anything in very dry years as I rely solely on rainfall.

Table 6.5 Association of IRWH tillage uptake and household characteristics

Variables		Once adopted	Continued adoption
Age of household head	20-40	9 (45%)	4 (25%)
(R^2=0.80, DF=1, p>0.05)	41-95+	11 (55%)	12 (75%)
Sex of the household head	Male	11 (55%)	7 (43.8%)
(R^2=0.45, DF=1, p>0.05)	Female	9 (45%)	9 (56.2%)
Marital status of the head	Married	10 (50%)	9 (56.2)
(R^2=1.83, DF=4, p>0.05)	Single	4 (20%)	4 (25%)
	Divorced	3 (15%)	2 (12.5%)
	Never married	1 (5%)	1 (6.3%)
	Widowed	2 (10%)	-
People at household	Live alone	-	2 (12.5%)
(R^2=4, DF=4, p>0.05)	1-2	2 (10%)	1 (6.3%)
	2-4	6 (30%)	2 (12.5%)
	4-6	10 (50%)	9 (56.2%)
	6+	2 (10%)	2 (12.5%)
Household monthly income	Below 500	2 (10%)	3 (18.8%)
(R^2=3.63, DF=7, p>0.05)	R500-1000	2 (10%)	1 (6.3%)
	R1001-1500	2 (10%)	3 (18.8%)
	R1501-2000	6 (30%)	5 (31.3)
	R2001-2500	2 (10%)	2 (12.5%)
	R2501-3000	1 (5%)	-
	R3501-4000	3 (15%)	2 (12.5%)
	R4500+	2 (10%)	-
Education level	Primary	7 (35%)	4 (25%)
(R^2=5.64, DF=3, p>0.05)	High school	6 (30%)	10 (62.5%)
	Diploma	3 (15%)	2 (12.5%)
	Bachelor's	4 (20%)	-
Employment status	Employed	6 (30%)	3 (18.8%)
(R^2=1.64, DF=2, p>0.05)	Self employed	7 (35%)	4 (25%)
	Not employed	7 (35%)	9 (56.2%)

Twenty-seven percent (n=10) of farmers were assessed to have made an informed according to the survey instrument. Of the total sample, it was calculated that 58.3% (n=28) had excellent knowledge and that 89.6% (n=43) had a positive attitude (10.4% had a negative attitude). Of the 73% (n=26) that were perceived to have made an uninformed decision, 65.4% (n=17) had excellent knowledge, and 88.5% (n=23) had a positive attitude. There were no significant differences with demographic and socio-economic variables in the bivariate study of informed choice.

6.3.5 Knowledge, attitude and perceptions

A Kruskal-Wallis test showed significant differences in the scores based on age participants of knowledge and attitude survey. Age significantly affected knowledge scores ($H(7)=18.4$, $P<0.01$). One-way variance analysis (ANOVA) revealed that in comparison with the 41 and above age group, the 40 and below age group had significantly lower knowledge scores ($U= 79.3$, $P<0.0001$, $r= 0.25$). On the scale of attitude, there were no significant differences.

Table 6.6 Perceptions of farmers on the uptake of the IRWH tillage system

Perceptions	Strongly agree	Agree	Disagree	Not sure
1. The labour is demanding	43.8	20.8	10.4	25
2. Weed infestation is high	37.5	25	12.5	25
3. Lack of training	10.4	33.3	56.3	-
4. Lack of equipment	18.8	22.9	39.6	18.8
5.Reduces my plant population	52.1	16.7	6.3	25
6. There is not enough rainfall	63.3	16.7	-	-

Perceptions of farmers about the uptake of the IRWH tillage system (Table 6.6) collected from the questionnaire survey showed that the majority 63.3% strongly agree on the perception of drought hindering uptake. The perception on lack of training was disagreed by the majority 56.3% showing that the issue of knowledge on the IRWH tillage is not a factor limiting its adoption, unless other training needs are required. The condensed narratives of farmers ' perceptions obtained from interviews (Table 6.7) show that farmers raised concerns of being trained on the kinds of crop they can intercrop with IRWH and to be introduced to alternative conservation practices. Additionally raised perceptions from the interviews included that the older farmers are more concerned to their age and health when it comes to the intensive labour involved (Table 6.8). In addition, lack of commitment is also another concern to the majority of the farmers as raised by the interviews.

Table 6.7 The condensed narratives of farmers ' perceptions about IRWH tillage obtained from interviews

Perception	Farmers summarized narratives
1. Drought	➢ Lack of rainfall – the water production and plant harvest were excellent when I began using IRWH tillage in 2003, but now it has reduced a lot. ➢ The crop was decent back in the days – but now we are not even planting because the times it used to rain back then there's no rain these days. In addition, when we plant late when the rains come, we are back with crop yields are too low and our crops is damaged by frost.
2. Labour	➢ Labour is demanding – you do not have to be lazy. When you first introduce it in your field, it is very labour-intensive, but later, during each planting season, you will only change the basin area. ➢ People are lazy to spend their energies in the general continuation of plant cultivation because of droughts. Now when you're talking about IRWH tillage that has an additional work requirement.
3. Lack of commitment	➢ Only committed farmers can use it otherwise, other farmers won't turn researchers off because they know you're going to do all the work for them, from planting to harvesting. However, when researchers stop visiting the farmers, then most farmers also neglect the practice of the knowledge. I saw this happening in my village from 2004-2006 with my own eyes. ➢ In the past, government, extension officers and researchers have been working with us all the time; they have also invited us to talk to other interested farmers. To win prizes and certificates, we would compete with each other on harvesting more. The experts who introduced us to this system, however, disappeared and stopped supporting us, and most farmers lost interest in continuing to use it.
4. Health and age	➢ Compared to this young generation that relies on grocery shops. We, the elderly grew up farming and are committed to continue with farming. However, because I am old and sick, I stopped using the IRWH tillage, and when I hire young people to help me, they want a lot of money and they are not even interested in learning because all they want is cash.
5. Lack of training	➢ Could there be training on all kinds of crops that we can grow at the same time to maximize the harvesting advantage. We know that the main objective is to accumulate water for planting in the basin.
6. Reduces population	➢ We want to simultaneously plant more than two crops. The IRWH takes a lot of space to plant more crops in my field.
7. Damage to crop by pest and diseases	➢ There are plenty of pests and diseases that currently damage our crops and growing yields.

Table 6.8 The condensed farmers' narratives on the required interventions to improve IRWH tillage uptake

Intervention	Farmers summarized narratives
1. Government and extension support	➢ The government will spend and have time to come to our villages to see if IRWH tillage is still working now because there is no water. This could also help motivate our kids to learn as we did and start using IRWH tillage as I made a lot of money with IRWH tillage for lobola back in the days. ➢ The extension officers of today are not educating us about IRWH tillage relative to those back in the days. Extension officers should observe from researchers on other conservation methods same on the tillage of IRWH, come and urge us to continue using the tillage method of IRWH with new ideas. ➢ Government and extension officers can recognize engaged farmers who are already doing some farming and are willing to continue using the IRWH tillage. Otherwise, they will continue planting and giving resources to some of our friends who are not committed farmers.
2. Other conservation practices	➢ We are interested in trying different forms of tillage management practices and techniques for rainwater harvesting so that we can compare which ones we would like to continue to use other than just one method.
3. Incentives	➢ We used to get incentives, and that is why in the days when we were abandoned, most farmers continued to use it because we expected to get the prices. The government should give us agricultural awards if it wants us to keep farming, and I'm sure all of us in our villages will start using IRWH tillage because older men like me know it works.
4. Drought warning services	➢ Provide us with an early warning system for drought, so we know whether we are planting. Because we have invested a lot of money, energy, effort, and losses at the end.

6.4 Discussion

To our knowledge of the IRWH tillage, this is the first exploratory, qualitative research to apply the knowledge and the process of narrative inquiry to gain understanding and narratives of farmers based on their experience. This awareness, mindset, and perception evaluation of the continued use of technology are vital to the development of strategies to ensure continued use. Assessing the characteristics of farmers and farm households is essential in understanding the unequal receptivity of farmers to technology (Abebe et al., 2013). Recently introduced technologies are often defined as less well-known than earlier technologies (Lambrecht et al., 2014). In the case of IRWH tillage in Thaba Nchu, it is speculated that a more substantial fraction of households would have ensured continued adoption despite the introduction of new technologies in the area. The "discovery stage" is characterized as the time from the introduction of IRWH technology to farmers, whereas the "evaluation stage" is where farmers first try out using the technology on their own (Lindner et al., 1982). It is during the evaluation stage that the technology can be implemented by farmers and expect good returns. The farmers gain expertise by depending on their on-farm knowledge and being able to determine if the technology is viable for continued use or not. Linder et al. (1982) define this stage as a "trial," where continuing decisions about adoption are deeply dependent on perceptions. From a researcher's perspective, knowledge, or attitude of the effects of drought in crop cultivation will correlate positively with continued adoption. Still, with subsistence farmers, factors such as gender, education, and age should be considered.

Because of the supposed correlation between education and knowledge, the household head's education level has often been believed to affect adoption decisions (Yang et al. 2005). This study showed that higher responses were given by household heads who had obtained a high school education level (62.5%) for continued adoption of the IRWH tillage method. The study also showed a strong correlation between the older age group and excellent awareness and continued adoption (75%). This result may indicate that the experience of older-aged farmers is derived from the stages of exploration and assessment (Backeberg et al., 2010). Still, the skill and knowledge have not been passed to the younger generation. Such ambiguity poses potential impediments for possible continued adoption. It was noticed in this survey that the farmers' minority (27%) made an informed choice. These findings emphasize the importance of knowing expectations to improve the technology's continued acceptance through them. One possible reason for our sample's low rate of informed choice may be that older farmers with appropriate knowledge and experience are too elderly to participate in IRWH tillage's labor-intensive existence, as illustrated in their perceptions.

6.5 Concluding Remarks

The study examined how awareness, attitude, and perception affect the ongoing adoption of the IRWH tillage by smallholder farmers at Thaba Nchu, two decades after the technology implementation in the region through research and extension programs. We note that there is an immense knowledge among the elders about IRWH tillage; however, it seems to play no role in whether farmers have sustained continued adoption or whether they are behaving in line with their attitudes. Considering the role knowledge plays in the informed choice process, the results show that awareness was linked neither to continued adoption nor to views. This finding suggests the value of initiatives aimed at improving continued adoption by addressing the idea of informed choice to enable farmers to act following their attitudes effective than knowledge-improvement approaches.

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CHAPTER 7: FARMERS AND EXTENSION ENGAGEMENT

Abstract

Smallholder farmers in semi-arid area need many types of information to assess alternative techniques and make optimal management decisions. However, the lack of regular extension services makes it hard to consistently convince them to improve their management practices. The purpose of this work was to implement farmers and extension officer's engagement that provides a platform to enable stakeholders to communicate information on agricultural extension and collaborate on on-farm demonstration trials. Through the farmers' information-day messages of alternative techniques were conveyed and farmers showed their interest to implement the IRWH techniques. Participants expressed their satisfaction in visualizing the on-farm experiment on farmers' backyard and the opportunity to compare with the conventional (CON) tillages.

Keywords: Farmers' information day; Smallholder farmer; Extension services; Farmers engagement

7.1 Introduction

Agricultural extension is a fundamental tool in the agricultural sector as it facilitates knowledge transfer and enhances productivity by improving management practices. Improving smallholder farmers' access to agricultural services, especially in rural communities, is a central challenge facing governments in the arid semi-arid region where water is scarce and yet food insecurity is greatly impeding development (Bell, 2013). A more common understanding of smallholder farmers and extension officers could be achieved through conducting farmers' information day or through regular workshops to help them in keeping informed with technical implementation of on-farm trials. Traditional way of agricultural extension programs, for example (Waddington et al., 2014), include top-down approaches like training and visit or often focus on extended demonstration trial practices. However, the Bottom-up approaches focus on helping farmers to adopt alternative techniques and more sustainable practices through engaging farmers on the on-farm trials and conducting farmers field days and routing farm visits (Kondylis et al., 2017). During the information days farmers need to be well oriented with local languages and skills in transferring knowledge with current information on climate and other incidences (drought, pests, weeds, etc.).

For example, during the farmers' information day in Thaba Nchu on 8th march of 2018, the drought conditions was one of the topics farmers discussed on the event. According to (Asiedu-Darko, 2013) agricultural extension officers and farmers need regular in-service courses and workshops to help them keep abreast with the technical developments in farming. Farmers' information day approach should encourage active interactions between farmers, extension officers and researchers. In many researches, it is highly recommended that farmers be familiarised with various learning tools (such as preparing posters, picture, oral presentations, field visit and illustrations) which will accentuate information transfer. Teaching methods are fundamental tools for knowledge transfer, however, care must be taken in choosing a method that is suitable for effective content delivery. Therefore, in this study, continuous farmers engagement was employed, and a farmers' information day helped systematically illustrate the alternative management practices' advantages over the conventional tillages.

7.2 Farmers' Information Day

The stakeholder engagement workshop (farmers' information day) was organized on the 8th of March 2019 to share and discuss the progress of the project. The focus was to frame the perspectives of the stakeholders in the adoption of in-field rainwater harvesting and cropping system strategies for water-scarce semi-arid areas in Thaba Nchu. A pamphlet with the programme for the farmers' day was prepared with the theme: "*Innovative way to combat drought challenge and nutrition insecurity*" (See Appendix VIII). This message was reflected to tackle the current drought situation in Thaba Nchu through water harvesting technique application and advantages of maize legume intercropping for soil fertility and other nutritional benefits for a poor resource farming community.

Representatives from the two villages (22 farmers) were invited to participate in the stakeholders' engagement. Besides beneficiaries from the rural community, the extension officers, the village leaders / headmen, senior final year students and researchers were also invited. The farmers' information day was well represented by a variety of stakeholders and ensured gender inclusion from different backgrounds. The farmers included those with a knowledge of rainwater harvesting, small-scale backyard vegetable growers, marginal rainfed farmers, landless poor and female households.

7.3 The stakeholder engagement process

Following the general introduction of prayers, participants introduced themselves to motivate the engagement processes. Participant farmers shared their knowledge about rainwater harvesting practices in their village and neighbouring villages.

Session #1

In the first session, the headman of Morago village (Mr. Lengegeru) gave an opening speech focusing on adoption of rainwater harvesting and its advantages in dry and marginal areas. In his speech, he extended his gratitude for the effort done to work with the community and to identify the needs of the community towards improving productivity. Mr. Lengegeru is one of the few farmers we have observed in the village still practicing the IRWH technique in his backyard. He adopts the rainwater harvesting structures to grow maize and vegetables.

Session #2

Following the opening speech, the extension officer (Ms. Matekelo) explained the purpose of the farmers' information-day in the community project. She highlighted farmers' engagement for improved tillage and acknowledged the role of beneficiaries and contributions made during the project implementation processes. She also stressed the adoption of in-field rainwater harvesting in different villages in Thaba Nchu as a means of decreasing the risk of crop failure during the drought years. As the rain started late in the project season, farmers from the two villages were not motivated to sow their seeds on dry soils and almost all the arable lands and backyards remained uncultivated. The extension officer, Ms. Matekelo extended her advice to the participants (in particular to farmers) to consider the seasonal forecasting advisories and to choose the appropriate planting dates.

Highlights:

- Before a decade or so, there was an accelerated interest in IRWH techniques intervention in Thaba Nchu area. During this period (2001-2006), many communities in Thaba Nchu and researchers made a great effort and deployed large resources to increase awareness of the IRWH technology. However, due to many reasons, the adoption of the IRWH techniques showed a sharp decline, although the technology had yield benefits for smallholder farmers. Currently, the technique of IRWH is rarely practiced and only few farmers adopted the technology in the marginal land and in some farmers' backyard gardens.
- In rural farming communities and in semi-urban areas, the IRWH technique can serve as supplementary water source for rainfed crop production.
- There are some disadvantages to harvest the rainwater, because of dependency on climatic patterns (rainfall), soil storage capacity limitations (clay soil), labour required to construct and availability of implements for structure construction.
- These disadvantages of adoption can be minimized or avoided with proper planning and management and through incorporating advisories. For example, to initiate farmers' access to seasonal forecasting.

The flexibility and the many benefits associated with rainwater harvesting make it a farming community welcomed technique, which widely accepted, and is an increasingly promoted alternative for water storage in the soil profile during dry spells.

Session #3 (Communication and engagement)

From the project, team member Mr Andries Fourie presented the advantage of strong communication and engagement with farming communities during implementation processes. He said the communication should start engaging during the planning stage of the project. With changing environment, the farming community needs to adopt improved tillage techniques and requires new knowledge and skills through routine communication and engagement processes. In order to use their resource base and unique assets (land, implements, knowledge, information, markets, etc.), farmers need to develop communication skills, networking and active participation with other stakeholders, extension officers and researchers. In his presentation, he mentioned the partnership to prosper and to join hands by sharing resources, asking for help or advice from experts and extension officers, and copying improved practices from neighbours or researchers.

Highlights: observations:

- The farmer engagement session was well attended by members from the community and DRAR officials.
- The community members were eager to learn and obtain information. Questions were asked afterwards.
- The season's drought and late rain was not favourable – no other planting of cash crops (maize) was observed in the area except in that of the research project.
- Due to the dry conditions, there was a problem of germination and unfavourable seed emergence from the soil was noted. In particular, the beans planted in intercropping did not germinate very well.
- Some of the farmers were more "committed" to the project as was observed in how clean the planted areas were kept from weeds.

Session #4 (Briefing project activities to participants)

In this session, two poster presentations (by MSc. and Ph.D. students) were given and the floor was opened for discussions through viewing the posters. The MSc student presented about the technical field measurements performed by engagement and in collaboration with beneficiaries on their plots. The technical methods to measure various different micrometeorological (weather data, soil water and radiation interception by the crops) and agronomical parameters (germination, plant height, leaf number plant height and other yield parameters) were explained. The MSc. student elaborated on the scientific measurements and highlighted the expected data to be collected at different growth stages during the growing season.

Highlights (poster #1)

- Farmers recorded the rainfall amount after each rain event during the trial.
- Soil sample collection, site selection and plot layout design were performed in collaboration with farmers.
- Farmers participated during instrument installation and data collection.

The PhD student presented conservation tillage techniques such as IRWH-tillage and mulches to protect soil quality by reducing runoff and erosion, thereby improving soil water in dryland cropping. As an added value to the existing experiment, he discussed some new ideas by explaining agronomic benefits and opportunities that exist such as growing winter cover crops and returning the residues (mulch), which may enhance soil-plant water relations. He also highlighted the advantages of kraal manure application to improve the soil structure, enhance seed germination and promote seedling establishment in the early stage. The poor germination and seedling survival was one of the biggest challenges during the long dry spell after planting dates in January 2019.

Highlights (poster #2)

- Agronomic problems associated with bare fallow fields and possible benefits with the growth of cover crops.
- Winter cover crops are planted shortly before or soon after harvest of the main grain crop and are terminated before or soon after planting of the next grain crop.
- Crop residue left after harvest on the soil surface to serve as mulch.
- Leguminous winter cover crops can supply N in low N soils; however, they usually do not produce as much biomass as the small grains and their seed is relatively expensive.
- The IRWH tillage results in improved soil water, which promotes weed growth compared to CON.
- Germination and emergence trial was motivated on two different soils with mulch and manure application.

Session # 5

The project leader (Dr Weldemichael) presented details of the project progress up to date. This would help participants to have a full understanding of the community project running in their village's vicinity. During the meeting, the focus and rationale of the project was summarized as follows:

- General description of the two selected study areas (villages): like other rainfed cropping systems in semi-arid areas, the cropping systems are dominated by mono-cropping or disorganized intercropping systems and lack adoption of appropriate water conservation techniques.
- The unpredictability of rainfall and climate variability is the main cause for the negative impact on productivity. This leads to low crop productivity and inefficient water use, land use, poor crop performance and low resource use by crops.
- The effect of decline in soil fertility and increase in unproductive water loss through runoff and soil evaporation.
- The project targeted to improve nutrition security and sustainability through local adaptive practices of water conservation tillage and intercropping to create socially acceptable practices by the local community.
- Finally, briefing the two-fold project objectives: i) to evaluate intercropping and water harvesting techniques by smallholder farmers, and ii) engage smallholder farmers to enhance knowledge exchange.

Highlight (Oral presentation)

During this session, the following three main issues were discussed with participants:

i. Construction of rainwater harvesting structures

Land preparation and crop management illustrations within demonstration fields by engaging farmers were presented to show the participants how to systematically compare IRWH and CON tillage systems. The first step was to illustrate the implements employed to construct the IRWH structures. All the management practices used during the demonstration trials and set-up of the treatments were thoroughly discussed with participants. The whole process of harvesting and storing water in the basin area (in the root zone of intercropping) under IRWH and ex-field runoff of CON tillage was explained as visually as possible by means of pictures, photos and posters. After the farmers observed the pictures of the demonstration of IRWH and intercropping techniques, most of them understood the advantages of integration system and farmers asked some questions. For example, why choose beans for intercropping instead other vegetables. However, most farmers were convinced of the benefits of IRWH to store more water for production and over-dependence of a single crop. Some farmers suggest using vegetables or forage crops to intercrop with maize.

ii. Soil and radiation measurements

Practical scientific measurement of soil water (using soil moisture probes, runoff-tipper, AWS, etc.), radiation interception and all crop parameters measurement and instrumentations were illustrated during the field visit. This can provide to highlight the integration of scientific knowledge of measurements with the farmers indigenous knowledge and perception of water harvesting.

iii. Effects of current drought conditions during planting

The project leader emphasized the current drought challenge by elaborating the theme of the day "*Innovative way to combat drought challenge and nutrition insecurity*". This phenomenon was clearly visible in almost all the villages in Thaba Nchu during the current growing season (2018/19). The long-dry spells mainly affected the early growth stage of the crops before the crops established a deep rooting system. In general, the planting date was delayed or shifted to the first week of January as the rain only started in January. In Thaba Nchu areas including the project sites, the dry condition persisted during the emergence and during early growing summer season. The rain started more than a month late and the dry spell pattern was observed throughout the early stage and mid-season of the crops (until March). After the planting dates (7-15 January) of the demonstration trials, the dry spell continued from late-January through mid-February resulting in low germination rates and poor seedling establishment and performance. In some demonstration trials, poor germination with wilted and stressed seedlings was observed. However, there was relatively higher amount of rainfall in the last week of February up to mid-March compared to December and January.

The rainfall amount of the growing season was presented to the farmers in a simple tabulated form with comparison to the long-term averages. In all villages in Thaba Nchu, the dry conditions in early summer resulted in a sharp decline of the cultivation of summer crops (maize, beans and sunflower). In the later growth stages, widespread rain improved and the crops that survived the long dry spells recovered and were able to produce low grains. With long dry-spells and the delayed onset of rain, the weed infestation was the biggest problem and had a negative effect on the crops.

7.4 Demonstration Plot Visit and Discussion

The participants at the farmer's field day then went round each demonstration plot on both villages and talk to the implementing farmers about their experience, challenges and failure that they may have encountered while implementing particular interventions during the dry season with long dry spells. Farmers had also the opportunity to observe each demonstration plots carefully and ask for clarifications whenever applicable. They carefully observed the IRWH structures and implements used to construct the basin and runoff strips (Basin/runoff makers). Aspects of runoff and basin constructions and their efficiency on rainwater harvest against conventional tillages were also covered during the guided tours.

7.5 Concluding Remarks

Farmers need many types of information to assess new technologies and make optimal management decisions. In particular, extension services and training programs do not always reach farmers with the right information at the right time. Generally, farmers were very excited at the end of the farmers' information day event. They mentioned that they were especially pleased with the fact that they had learnt about the alternative technologies and farming techniques. Farmers requested the project to expand and reach more farmers. It is widely acknowledged that the small-scale farmers in Thaba Nchu need empowerment in particular female-headed households and young emerging farmers through extension services to achieve better management practices.

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CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1 General Conclusion

Being a former IRWH technology homeland, Thaba Nchu – rural communities regarded as a prime site for experimentation of food security and development projects in semi-arid areas of Free State, South Africa. Over the past and half-decade or so, the rural communities of Thaba Nchu experienced the introduction of IRWH and community gardening projects. The extension officers from DRAR in Thaba Nchu, during the project-launching meeting on May 2018 told to the project team, Thaba Nchu is a kind of experimental site for IRWH and representative and the same sentiment from scholars of the UFS and ARC. In short, the technique requires the creation of runoff strips leading to catchment basins, where rainwater stored and accessed by the plant root zone during drought and long dry spells. Besides farmers, own tacit knowledge of matched mixed cropping to minimize yield risk during adverse dry seasons and to maintain the soil fertility even though mainly practiced in a disorganized way.

The innovative idea of this study was in a systematic way, how to assess the uptake knowledge of the alternative practices through routinely engaging smallholder farmers and extension officers. The twofold goals of the project included in this study primarily in researching resource use (water and radiation) under IRWH and CON tillage systems to improve productivity in the water-deficit semi-arid environment; and secondly to integrate a qualitative study on how to assess farmers' knowledge and attitudes, uptake and perceptions of the tillage system.

Results from the study show that under the technique of IRWH from 2 m runoff strip, it is possible to harvest about one quarter (27%) of the amount rainfall, which could be a loss as ex-field runoff from the cropped field. In both project sites (Morago and Paradys), the maize total above ground dry matter (AGDM) and grain yield (GY) were significantly affected (at value $P \leq 0.05$) by the tillage and cropping systems. However, in general, the HI values were relatively low (0.26-0.39) compared to literature and could have been due to the effect of drought on the 2018/19 growing season and late-onset of the rain, as the harvest yield was below expectations. The PUE results indicate that the IRWH tillage was better at converting rainwater into biomass and grain yield compared to CON. The consideration of evapotranspiration in evaluating rainwater efficiencies may be able to show an advantage in practicing IRWH techniques for semi-arid climatic conditions. Water productivity (WP) as a function of the amount of rainwater during the growing season was considered a reliable estimation for this study.

In this study, results demonstrate that the close relationship between WP and RUE with higher R^2 values in solely grown crops compared to intercropping, which is 0.84 and 0.88 vs 0.67 and

0.79 for IRWH and CON, respectively. Furthermore, in the analysis the radiation saturation level demarcated with an increase of seasonal rainwater use for biomass production by the crops. The maximum RUE was found under IRWH for solely grown maize and beans, which is higher by 13% and 55% than the CON tillage, respectively. In contrast, for the inter-cropping system, the maximum RUE found lower for IRWH for only intercropped-maize (by19%) but the intercropped beans showed higher maximum RUE (by12%) compared to CON tillage. This relationship indicates the observed radiation by plants for photosynthesis is directly related to the transpiration rate until saturation occurs. In general, in the IRWH the maximum RUE was higher in the sole-cropping system while in the CON tillage higher maximum RUE observed in intercropping system. Through efficient use of resources, to improve WP under IRWH several options have been proposed including increasing harvest index, the proportion of transpired water and reducing vapour pressure deficit (VPD), however, the more adequate strategy to further increase the productivity of water on seasonal bases should be based on improved capture of radiation by crops in related to water productivity.

In conclusion, WU and RUE are closely related and greatly influence crop growth and yield. Appropriate crop management, especially proper water and nutrient management, and wise decision making are imperative to maintain crop yields under limiting conditions. Future research work is needed to further elaborate the nexus among WUE, NUE, and RUE, especially under drought stress. This will help devise strategies for better management of crops under such water-scarce environments to maintain productivity. Furthermore, from the findings noted that there is an immense knowledge among the elders about IRWH tillage; however, it seems to play no role in whether farmers have sustained continued use or whether they are behaving in line with their attitudes. Considering the role knowledge uptake plays in the informed choice process, the results show that awareness was linked neither to continued adoption nor to views. This finding suggests the value of initiatives aimed at improving continued adoption by addressing the idea of informed choice. Besides the study highlights several practical areas of concern regarding the adoption of technology such as basic implements, labour, attitude change, and the lack of continued formal extension provision. Although the complexity of technology uptake is portrayed, a need for future research in knowledge-improvement approaches is noted.

8.2 Recommendations and Further Research Motivation

Sustainable food production in smallholder's livelihoods in semi-arid tropical countries can be only achieved through efficient utilization of resources with improved management practices. Increasing water and radiation use efficiencies (WUE and RUE, respectively) are critical to enhancing crop production, in particular, to motivate further a climate-smart agricultural technology for the benefit of smallholders' livelihood. Thus, here is a critical need therefore to devise alternative techniques accounting for increasing smallholders' productivity, which is based on improved ability to capture and use resources more efficiently.

There was clear evidence in semi-arid areas of Thaba Nchu, the frequent occurrences of dry conditions with long dry spell episodes and rain season shifting due to climate change effect, farmers seek alternative techniques to improve water productivity and efficient use of resources. More use of idle backyard homestead gardens with the intervention of water harvesting techniques could also help to alleviate the pressure to produce grain and vegetables/forage crops in less productive, environmentally fragile agroecosystems. Though households seen not to apply the available manure in their backyard, it would be an advantage to ameliorate the clay soil nature of the project site in terms of structure and fertility.

As Thaba Nchu farming system is dominated by livestock rearing, this is an opportunity to integrate the in-field rainwater storage and livestock production. Thus, household homestead gardening using IRWH shows great potential for increasing nutrition and possibly income. This can have a big impact in the semi-arid environment such as rural communities in Thaba Nchu, where hunger and malnutrition are frequent. Future efforts toward crop improvement in the light of enhancing crop water and radiation use such as manure application, introducing green mulch (legume/forage as cover crops) along with optimal management practices lead toward higher productivity, which is critical in the context of a changing climate.

8.3 Lesson Learned

The findings of this research provide useful lessons in considering the efficient use of resources (water and radiation) and their interactions. Besides, the value of initiatives aimed at improving continued adoption, awareness, attitude, and knowledge-improvement approaches. Taking into consideration the range of biophysical, socio-economic and farmers motivation, constraints will assist to catalyse adoption, applicability and replication potential of the IRWH technique. During the post-project period (2019/2020) in both villages, beneficiary farmers have been seen to continue the technique of IRWH with a variety of mixed cropping (maize – with vegetables and legumes) systems without any follow-up of researchers and extension officers. This manifests the potential to acquire and transfer practical skills and knowledge of alternative management practices that enable smallholders to innovate and adapt new techniques.

In view of this, the following lessons are learned:

- The importance of participatory technology development and dissemination approach to accelerate replications and scaling-up of the alternative techniques
- Improving the technology by integrating various cultural management practices such as the application of manure, mulches and covers crops.

- Strengthening smallholders' awareness to access climate advisory support at least to identify the drought and wet season to plan the appropriate management practices
- Enhancing linkages with extension officers and researchers to help to fine-tune the commonly practiced techniques (IRWH) to increase efficiency in contributing sustainability.
- Promoting wide participation of smallholders with various age groups, experience, and gender to balance the contrasting challenges of technology transfer.
- Support smallholders (in a group/village) to equip them with low-medium technology (simple mechanized or manual ridge/basin maker implements) to motivate the transfer of the IRWH technology.
- In order to increase the chance of success in replicating and transferring cost-efficient technology to smallholders, consistent effort with the improvement of the technology will be needed.

APPENDICES

Appendix – I: Capacity Building and Publications

Capacity building

Muthianzhele R. (St. no. 20122066870)

The student has been registered for his MSc Degree in the agrometeorology section of the Department of Soil, Crop and Climates Sciences, University of the Free State, since March 2018. His MSc research project is in Thaba Nchu district as a case study to assess the integration of infield rainwater harvesting (IRWH) and intercropping systems. The student was involved in all field data collection, capturing, and analysis.

Dzvene AR. (St. no. 2017441813)

The student is a PhD candidate since May 2018, in the agrometeorology section of the Department of Soil, Crop and Climate Sciences, University of the Free State. The candidate involved in the project in the fieldwork and analysis of the data to support the MSc student. The student also leads the qualitative study to conduct the survey. The student also contributed towards preparing chapter 6. Besides, he is also involved in planning and conducting a pilot experiment on germination and emergence of seedling, after the research team noticed poor seedling establishment caused by long-dry spells in compacted clay soils.

Maleka PA. (St. no: 2014111153)

Ms Maleka participated in the project as a Hons. student in 2018 and she was actively involved in the project with a literature survey. She has submitted a literature review report for a senior project with a title: "Evaluation of cereal-legume under in-field rainwater harvesting (IRWH) in South Africa.

Nomalanga MM. (St. no: 201311770)

Ms Nomalanga is Hons. student in agrometeorology from Thaba Nchu, she is actively involved in field data collection and she helped to engaging the community. She was participated during planting and monitoring processes as she is speaking the local language of the community (Sesotho). The student also played a big role in collecting survey data through communicating with local language.

Sibiya LI. (St. no: 2013197229)

Sibiya is a final year student and presented a literature review in cover crops and intercropping for a senior project with a title: Benefits of cover crops on maize-bean intercropping under IRWH.

Famers and extension officers training

Various training of alternative techniques (including IRWH and cover crops techniques) were carried out for the beneficiary farmers (7) and extension officers (8) during the project period.

Publications

Article/thesis

- *Submitted article (Journal Climate services)*

Farmers informed choice: knowing the in-field rainwater harvesting (IRWH) tillage awareness and adoption in Thaba Nchu, South Africa

Dzvene*, AR., Tesfuhuney, W., Walker S, Fourie, A, Botha JJ.

- *Prepared draft article for submission to Journal (Agricultural Water Management)*

Water and radiation use efficiency in maize/bean intercropping under in the semi-arid area

Authors: Tesfuhuney*, W*, Ravuluma, Dzvene, AR, Zaid B. Walker S, Fourie, A.

- *Prepared draft for short communication article (Soil tillage)*

Dryland maize emergence, seedling growth and survival in response to soil organic matter amendments

Authors: Dzvene, AR*, Tesfuhuney, W, Zaid, B. Walker, S, Fourie, A.

Popular magazine *(Draft to submit to The Water Wheel)*

- Technology transfer of in-field rainwater harvesting (IRWH) and farmers' adoption
  Authors: Tesfuhuney, W*, Ravuluma, Dzvene, AR, Walker S, Fourie, A, Zaid B.

Conferences/Symposium Presentations

Posters

- Radiation use efficiency and biomass production in maize-bean intercropping under in-field rainwater harvesting. Presenter: Dzvene, AR., *35th Annual Conference of the South African Society for Atmospheric Sciences, SASAS (8-9 Oct. 2019), Pretoria.*
- Evaluation of integrated maize/beans sole- & inter-cropping under In-field rainwater Harvesting (IRWH): Presenter: Ravuluma M., on *35th Annual Conference of the South African Society for Atmospheric Sciences, SASAS (8-9 Oct. 2019), Pretoria.*

Oral Presentations

- Radiation and water use efficiency in maize-bean intercropping under in-field rainwater harvesting (IRWH): Presenter: Tesfuhuney W., on *20th WaterNet/WARFSA/GWP-SA Symposium (9-10 Nov. 2020), Johannesburg, South Africa.*
- Water Harvesting and Mini-catchment Runoff Farming (IRWH) and Intercropping: Presenter Tesfuhuney WA: on *4th Annual Free State Research Colloquium (18-19 Sep. 2019) Bloemfontein, South Africa.*

Appendix – II: Monitoring and Evaluation

Project Monitoring and Evaluation

Monitoring and evaluation (M&E) is an integral part of the project. It was performed in a collaborative manner with balanced participation and control during the process to achieve the objectives of the research and supported by both farmers (beneficiaries) and researchers/scientists. This can be performed as a complementary activity within an action research cycle to support decision-making and progress to sustain project effectiveness and outputs. Thus, the M&E plan needs to be drawn up and then implemented (Gervais et al., 2003).

Development of M&E Framework

The M&E involved stakeholders (smallholder farmers) together with researchers and extension officers in a collaborative working relationship. All M&E activities took place in all project aspects including data collection, farmer learning groups, on-farm demonstrations trials and dissemination/communication by extension officers and researchers. The M&E took place on a weekly, monthly, quarterly and annual basis. During the establishment phase of the project, indicators were identified to monitor each activity. This enabled selective and systematic observation. Processes and outputs were recorded, compared and communicated routinely while using them to steer and shape the project. The five strategic M&E areas that were included are relevance, effectiveness, efficiency, impact and sustainability (IFAD. 2000). Therefore, a monitoring framework of this project was developed with questions to address and form expected results. Indicators and information could be collected on a routine timeline and with some anticipated assumptions.

Implementation of M&E

Overview

The overall objective of the project, for which this M&E was prepared, was to increase agricultural productivity by intensifying cropping systems using intercropping and IRWH tillage techniques. Agricultural productivity would subsequently promote the nutrition security of smallholder farmers and improve natural resources management, thus reducing poverty and hunger in semi-arid areas of Thaba Nchu. The specific objectives of the implementation were to support the implementation of improved strategies for sustainable management and development of poor smallholder farmers to practice rainfed agriculture. Expected results and main activities of the project fell into four categories:

- *Result 1: Better improved cropping system adopted by small-scale farmers;*
- *Result 2: Increased uptake of alternative agronomic techniques (including IRWH and intercropping);*
- *Result 3: Simple support system tools for climate risk analysis developed; and*

- *Result 4: Data storage and management were formulated and documented for reporting and dissemination.*

Action plan for integration of IRWH and intercropping systems into a new research area (winter cover crop and manure/residue management practices) have been motivated to further incorporate and support the overall smallholder farmer's food security strategies under rainfed agriculture. This section of M&E provided the community project with guidelines on the key indicators of evaluation and to use the M&E checklist that was employed during the project implementation period and day-to-day management activities.

This report outlined how the project was monitored and evaluated, whether objectives were met and ultimately planning what should be achieved, based on the evaluation framework described herein. This could help stakeholders and project team members to be more accountable to those they work for and delivery partners. To measure the impact of the project, a set of indicators based on specific objectives are listed:

i. ***Key Indicators of overall objectives:***
   - *Adoption rate of new techniques increased by target groups;*
   - *Engagement of smallholder farmers (male and female farmers) promoted;*
   - *Decision support developed to advise farmers/extension officers through yield gap and climate risk analysis (not included in this study).*

ii. ***Key Indicators of specific objectives #1 and #2:***
   - *Data collected and results of demonstration trials compiled and summarized in tables and figures;*
   - *Target groups (beneficiaries and representative and extension officers) from two villages engaged / feedback and some capacity building activities implemented through informal meeting/group discussion / one-to-one meeting and farmers information day / farmers informed choice tested;*
   - *Data collected for yield gap and climate risk analysis (model outputs) (not included in this study).*

iii. ***Means / measurements for specific objective #1:***
   - *Site selection and land preparation/construction of basin and ridge performed;*
   - *Long-term climate data collected and analysed;*
   - *Crop management (planting, fertilization and weeding) practiced, routine data collection performed (leaf area, plant height, leaf number, biomass and yield harvest);*

- *Germination and emergence rate survey and pilot germination trials conducted on two different soils and with manure and mulch treatments. This action was taken after the long dry spell affected seedling emergence rate;*
- *Soil water content and radiation interception measured every 2-3 weeks and data collected from two demonstration plots from different treatments.*

Assumption

- o *Serious drought conditions occurred in early summer season and long dry spell at early growth stage affected germination, emergence and seedlings were stressed at the early growth stages;*
- o *During mid-February, the extreme rainstorms damaged instruments (runoff tipper data logger).*

iv. Means / verification for specific objective #2:

- *Meeting with extension officers and farmers. Selection processes conducted;*
- *Beneficiary selection completed. Seven backyards and two arable land areas identified;*
- *Involvement of farmers in land preparation, construction IRWH structures, planting and other movement practices;*
- *Developed learning-by-doing principle exercises and farmers participated in data recording;*
- *Engaged farmers through meetings. Information disseminated during farmers day and group discussions;*
- *Preparation for farmers information day (prepared programme, pamphlet, posters, presentation venue in Morago arranged);*
- *Farmers invited to the meeting and registration / attendance taken by students;*
- *Registration, pamphlet distributed, minutes taken and documented.*

Assumptions

- o *Difficulties in inviting large number of farmers from various villages / rural communities;*
- o *Farmers' active participation hindered by language barriers, etc.*

v. Means / verification for yield gap and climate risk (as further plan of action):

- *Long-term climate data collected from six stations around the project area;*
- *Baseline data collected from 109 farmers through data collection template;*
- *Model set-up to motivate extension officers and students.*

Assumptions

- o *Data availability, model calibration and validation;*
- o *Skills and tools manipulation and data management.*

vi. ***Expected results***

Output envisaged

- *Better cropping system that can be adopted by smallholder farmers to increase;*
- *Increased awareness about uptake of knowledge on the integration of IRWH and intercropping systems;*
- *Simple decision support system tool for climate risk to be introduced to extension officers and farmers in semi-arid areas using the collected data from the field and use long-term climate data / seasonal forecasts. (Not implemented in this project)*

Key indicators **(***to what extent the action achieved the expected results*)

- *Comparison of IRWH and CON on sole- and inter-cropping systems for crop growth / yield related parameters (emergence / survival rate leaf area, plant height, leaf number, yield and biomass);*
- *Soil water content, water use, radiation interception and radiation use by sole- and inter-cropping under IRWH and CON;*
- *Attendance and engagement at farmers' information day and feedback sessions;*
- *Conduct farmers' field day and demonstration trials;*
- *Open discussion with participants and documentation of farmers' views and suggestions. A record of farmers' interest / feedback;*
- *Application and motivation of decision support tool crop model – set-up, calibration and simulation;*
- *Determining whether students, extension officers and farmers understood yield gap analysis and climate risk / seasonal forecast, etc.*

Source of information

- *Field measurement using neutron probes, DFM, line quantum and laboratory measurement;*
- *Registration on farmers' day and documentation of farmers' interest / feedback;*
- *Data archiving and data feeding, analysis and application of data / statistical analyses.*

vii. Key activities

Activity # 1:

- *Identifying willing farmers / beneficiaries and sign consent for participation*
- *Distribution of rain gauges, rainfall record sheets, knapsacks, seeds, fertilizer and herbicides*
- *Conduct demonstration trials in seven farmers' backyards (two villages on arable land)*
- *Conduct germination and emergence / survival rate pilot trials on different soils and surface treatments*
- *Collect field data, install and capture data during the growing season (Jan-May)*
- *Analyse data, produce summary tables and graphs as well as interpretation of results and findings*

Intervention / means

- *Participation of technicians, farmers. extension and students /researchers;*
- *Soil sampling collection and analysis, crop sampling and laboratory analysis.*

Activity # 2:

- *Farmers learning-by-doing on the experimental demonstration trials*
- *Consistent engagement of beneficiaries in all activities*
- *Visualization of the results / feedback from the farmers on the farmers' field day and feedback sessions*
- *Distribution of pamphlets and poster presentations during the information day*
- *Discussion during the field visit during information day*

Intervention / means

- *Prepare popular pamphlets;*
- *Informal training of farmers;*
- *Group and individual discussions with farmers.*

Activity # 3:

- *Model set-up, input data into the model*
- *Run the model and analyse model output*
- *Produce summary tables and figures to present results for farmers and extension officers*
- *Create linkage between seasonal forecast and climate risk (support tool)*

Intervention / means

- *Computer desktop model application and model installation;*
- *Data processing, statistical programme packages;*
- *Collect long-term climate data and use data from AWS;*
- *Use field data for calibration and parametrization.*

Activity # 4:

- *Data storage and management*
- *Formulate indicators and create systematic quantification*
- *Develop matrix for evaluation*
- *Monitoring progress, report writing to funding organization (deliverable reports)*

Intervention / means

- *Central data storage, data sharing between project team;*
- *Regular commination between partners and target groups, field visit records, workshops and documentation.*
- *Publication in scientific journals, popular articles, oral and poster conference presentation – dissemination.*

References

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Appendix – III: Data Management Plan and Standard Protocols

Templates prepared for data collection

- Rainfall record sheet (distributed to farmers) to measure rainfall
- Field notebooks for recording dates of field operations (land preparation. planting emergence coverage. weeding, etc.)
- Soil sample template sheet used to record data from the field soil survey after site selection
- Crop sampling template to record DAP / DAE measurements
- Template for soil water content measured by neutron probe (DAP) at 0-18 cm depth at 2 demonstration trials
- Template for recording radiation interception at top and beneath crop canopy
- All data collected from the field transferred to Excel sheets under separate file names

Downloaded data arrangement

- Hourly data from AWS in Paradys (T_{max}, T_{min}, RH, Rad, wind, rainfall). Continual soil moisture measurement using DFM at four depths and hourly soil temperatures downloaded regularly. Data exported to Excel sheets
- Data analysis protocols
- Folder for each type of measurement created (named Crop, Soil water, Radiation, Weather, Long-term)
- Data analysis files created, and data organized according to each treatment
- Data summarized in tables and graphs plotted according to various treatments
- Long-term climate data calculated on monthly averages and summarized in tabulated format
- Data arranged to feed into statistical programmes (SAS / SPSS statistical package)

Meeting and engagement information collection

- Consent template created and signed by beneficiaries
- Attendance prepared and signed, registration taken during meetings and farmers' information day, pamphlet prepared and distributed
- Progress, documentation and reporting writing performed

Appendix – IV: Pilot Experiment (for Short communication article)

Title: Dryland maize emergence, seedling growth and survival in response to soil organic matter amendments

Abstract

Early crop establishment in rainfed farming systems is particularly difficult due to low and variable rainfall constraints coupled with soils with a tendency to crust development. This pilot study was investigated the impact of organic matter amendments on the emergence and survival of maize (*Zea mays* L.) seedlings in rainfed conditions. The experiment was set-up using a randomized complete block design with two organic amendments (sheep kraal manure and residues from maize crops) and control (control had no organic modifications and the soil crust was broken manually). The findings indicate significant differences ($P<0.05$) in germination rate, germination index and mean germination time associated with soil type. The sandy loamy soil resulted in the greatest germination percentage (88.3%) compared to that on the clay loam soil (79.1%). Further studies should be undertaken to explore the optimum rate of organic materials required to stimulate the emergence and growth of maize under the Sustainable Development Goals (SDGs) for food security.

Keywords: Dryland, Maize, Seedling emergence, Soil crust, Soil organic matter

Introduction

Seasonal and annual rainfall fluctuations are responsible for problems such as low soil moisture, soil crusting and erosion in shallow soils during the rainy summer season. During heavy rainfall storms of short length, soil crust formation is exacerbated on bare soil surfaces and this often leads to increased runoff, reduced infiltration and low soil water storage and ultimately poor emergence and reduced seedling survival (Colin et al., 2010; Laker and Nortje, 2019). Soil crusting has been a serious problem, which has hindered crop uniformity in many crops such as flax and turnips, potatoes, wheat, and beans (Mas et al., 2017). Moreover, a crust was responsible for decreased seedling emergence in oats, grain sorghum and soybeans (Bullard et al., 2018). The crust (dry state) or seal (wet state) will adversely affect the emergence of seedlings and leads to the poor establishment of crop stands (Anzooman et al. 2018; Mas et al. 2017). A standardized stand of desired density needs to be successfully developed in crop production. Modification in soil organic matter indirectly boost crop productivity in the long run by increasing soil organic carbon (SOC) fraction, which plays a key role in soil functioning. Short-term direct benefits of organic amendments are associated with measurements of soil physical properties such as increased infiltration rate, moderated temperatures, reduced runoff and evaporation, which are derived from the mulching benefits.

More precisely, the associated effect of raindrop splash on soil compaction is of critical importance for seedling emergence.

Quantification of the effects of organic matter applied to soil is restricted to long- and short-term benefits regardless of the mode of application, i.e. surface application as manure or mulch or mixing into the top surface of the soil layer (0-20cm). Therefore, the study focused on organic matter mode of application in the backyard gardens of smallholder farmers and proposed that maize germination and seedling survival in soil treated with amendments would be higher. This was because an increase in organic matter absorbs raindrop dissipating energy, which causes crusting, and thus improves seed emergence, encouraging infiltration and conserving soil moisture in rainfed conditions. The problem in rainfed farming is that, when rainfall is erratic or heavy and temperatures are very high, unfavourable soil conditions are experienced that hinder seedling growth and survival. Hence, seedling emergence can be delayed, or survival will be low, resulting in a low and non-uniform plant population. Therefore, the purpose of this pilot study is to observe manure and crop residue amendment effect on seedling emergence in soils of different physical properties.

Methodology

Measurement and data collection

The pilot study was carried out on two different soils (Sandy loamy and clay loamy soils) in homestead back yard gardens in Thaba Nchu during the growing season 2018/19 (on 8-30 March). The soils of the region, in general, underpinned by dolomitic parent materials that give rise to clay soils prone to crusting and deep cracking (Akwensioge 2012). There were three treatment plots of 4 m^2 in area treated with sheep kraal manure (M) or maize crop residue (R) at levels equal to 2 t ha^{-1} and a control (C). In each plot, the mulching materials were applied to the 0-20 cm top of the soil (Figure 1). Treatments of four replicates were structured in a randomized complete block design (RCBD) with 10 rows. In each row, 10 maize seeds were planted, and first germination after three days was observed and tested daily until the eighth day when the final germination was obtained. The number of seed germinations from 10 seeds sown per row was recorded for each treatment and the overall plot germination percentage was calculated.

Figure 1 Surface treatment preparation with the application of manure and crop residue by engaging farmers (left) and seedling emergence (right).

Germination measurements

Parameters of the measured percentage of germination included mean germination time (MGT), germination index (GI), relative seed germination (RSG), relative root elongation (RRE) and seedling vigour index (SVI). The GI, RSG and RRE values were determined from the measurements take as shown in equations 1-3:

$$\text{GI}\ (\%) = \frac{\%\ \text{seed germination} \times \%\ \text{root elongation}}{100} \qquad (1)$$

$$\text{RSG}\ (\%) = \frac{\text{Number of seeds germinated in the treatment}}{\text{Number of seeds germinated in the control}} \times 100 \qquad (2)$$

$$\text{RRE}\ (\%) = \frac{\text{Mean root elongation in the treatment}}{\text{Mean root elongation in the control}} \times 100 \qquad (3)$$

The mean germination time was determined (equation 4) as follows:

$$\text{MGT} = \frac{\sum(\text{fx})}{\sum \text{x}} \qquad (4)$$

Where x = number of newly germinated seeds on each day and f = number of days after seeds were set to germinate.

Seedling growth was assessed after 21 days by harvesting three individual seedlings per treatment and different growth parameters including shoot length and root length (Figure 2). Dry matter accumulation is an indication of seedling health, whilst low MGT indicates seed vigour and uniform seedling sizes. The seedling vigour index (SVI) was determined as follows (equation 5):

$$\text{SVI} = \frac{\text{Dry weight per seedling}}{\text{MGT}} \times 100 \qquad (5)$$

Statistical analysis

The data reported included the means of four replicates (n=4). The results were subjected to analysis of variance (ANOVA) and where significant differences were observed, the means were separated using the least significant differences (LSD) test at $P \leq 0.05$. All statistical analyses were conducted using the SAS statistical package (SAS Institute Inc., Cary, NC, USA).

Results and discussion

Results presented in Tables 1 indicate the mulching effect of maize residues, and sheep kraal manure on the germination of maize was significantly affected by soil type ($P<0.05$). No significant differences ($P>0.05$) were observed on germination parameters of maize seedlings with mulching materials (Table 1). The number of days taken for the first seed germination was not affected by either mulching material or soil type. Singh and Jolly (2008) studied the effects of wheat straw mulch, farmyard manure and crust breaking under simulated rainfall conditions and found that the results on soybean germination were similar. However, in the present study significant differences observed with soil type on maize germination characteristics indicates that soil crusting and moisture availability are a function of soil type. Significant differences in germination percentage ($P<0.0033$), germination index (GI) ($P<0.02$) and mean germination time (MGT) ($P<0.0037$) were observed. The sandy loamy soil resulted in the greatest germination percentage (88.3%) compared to that on the clay loam soil (79.1%). The sandy soil resulted in a lower MGT value of 9.9 compared to that of clay soil, which was higher at 11.1 (Table 2).

Figure 2 Seedling emergence measurements from samples of crop residue and manure treatments

No significant differences ($P>0.05$) were observed on the seedling growth of maize seedlings after 21 days of sowing in a sandy loamy or clay loamy soil (Table 3). However, in Table 4 mulching treatment showed significant differences (P<0.05) for shoot length (P<0.03), biomass (P<0.07) and seedling vigour index (SVI) (P<0.07). The control had the highest shoot length (16.2 cm), biomass weight (3.27 g) and a higher seedling vigour index of 32.1.

Table 1. Summary analysis of variance (ANOVA) results for residue effect on germination parameters of maize seedlings in a sandy loamy or clay loamy soil

SV		No. of days taken for 1st seed germination	Germination percentage (GP)	Germination index (GI)	Mean germination time (MGT)
Treatment	*F*	0.34	0.55	0.45	0.48
	P	ns	ns	ns	ns
Soil	*F*	2.85	11.7	6.49	11.33
	P	ns	<0.0033	<0.02	<0.0037

*ns=not significant (P>0.05)

Table 2. Effect of soil type on the germination of maize seedlings. Each value is a mean of four replicates

SV	GP	GI	MGT
Type of soil			
Sandy loamy soil	88.3	45.9	9.9
Clay loamy soil	79.1	36.0	11.1
LSD (0.05)	5.7	8.22	0.72

Table 3. Summary analysis of variance (ANOVA) results for organic matter effect amended in a sandy loamy or clay loamy on seedling growth after 21 days

SV	Shoot length	Root length	GI	RSG	RRE	SVI	Biomass
Treatment							
F	4.35	0.3	0.45	00	00	4.57	3.05
P	<0.03	ns	ns	00	00	<0.03	<0.07
Soil							
F	0.34	2.48	6.49	00	00	2.89	0.28
P	ns	ns	<0.02	00	00	ns	ns

ns=not significant (P>0.05)

Table 4. Effect of soil type and residue treatment on seedling growth of maize seedlings after 21 days of sowing. Each value is a mean of four replicates

SV	Shoot length	Biomass	SVI
Treatment			
Control	16.2	3.27	32.1
Maize residue	15.4	2.61	24.3
Sheep manure	14.8	2.46	23.8
LSD (0.05)	0.97	0.73	6..51

Seedling growth and survival under rainfed conditions can be encouraged or hindered by direct water availability or stress (Wijewardana *et al*., 2019), as well as by non-meteorological factors such as soil type or quality (Soureshjani et al., 2019), which can cause significant disadvantages. In this study, sandy soil provided the highest percentage of germination. Sandy soil has a loose texture, making it possible for water to infiltrate and seed plumes to emerge

(Jawayria et al., 2018). As a result, the comparatively lower emergence value observed for the clay soil type may be due to the compact nature of the clay soil resulting in reduced germination.

Concluding remarks

Poor emergence in subsistence farming systems is a major problem especially for maize production under dryland conditions. Sowing is achieved with the start of summer rains in November. Nevertheless, rains before the crop emerges result in the development of a crust, resulting in poor emergence. Farmers typically use crop residues as livestock feed, and in some cases as fuel, hence the evaluation of the treatments chosen. The present study has shown no improvements with mulching materials. However, if adopted in the end, the use of maize crop residues or animal manures as mulch may as well boost the emergence characteristics and seedling vigour index in maize by retaining soil moisture.

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Appendix – V: Informed Consent Form

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

INFORMED CONSENT

Project Name: WRC project Water utilization in Agriculture (K5/ 2821)

I hereby agree to participate in research regarding……………………………………………….. I understand that I am participating freely and without being forced in any way to do so. I also understand that I can stop this participation at any point should I not want to continue and that this decision will not in any way affect me negatively.

I understand that this is a research project whose purpose is not necessarily to benefit me personally.

I have received the telephone number of a person to contact should I need to speak about any issues which may arise in this project participation.

I understand that this consent form will not be linked to the research studies, and that my answers will remain confidential.

I understand that if at all possible, feedback will be given to my community on the results of the completed research.

Signature of participant: ………………. **Date**: ……………………………

I hereby agree to the tape recording of my participation in the study

Signature of participant: ………………….. **Date**: ………………………………

Signature of responsible researcher (UFS): ______________________________

Date: ______________________________

Appendix – VI: Questionnaire/Survey

UNIVERSITY OF THE FREE STATE

UFS·UV

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

IN VERITATE SAPIENTIAE LUX

PROJECT:

UPTAKE OF KNOWLEDGE, TECHNOLOGY AND PRACTICES FOR IMPROVING WATER PRODUCTIVITY IN RAIN-FED CROPPING SYSTEM USING IRWH

Survey Questionnaire on:

Farmers' informed choice: understanding knowledge in the context of in-field rainwater harvesting tillage uptake in Thaba Nchu, South Africa

Demographic and socio-economic status

1. **Gender**

Male		Female	

2. **Marital status**

Married		Single		Divorced		Never married	

3. **Age**

20-25		26-30		31-35		36-40		40 & above	

4. **How many people live with you?**

Live alone		1 to 2		2 to 4		4 to 6		6 & above	

5. **What is your monthly income?**

Below R500		R500-1000		R1001-1500		R1501-2000		R2001-2500	
R2501-3000		R3001-3500		R3501-4000		R4001-4500		R4501 & above	

6. **What is your highest education level?**

Primary		Higher		Diploma		Bachelor's degree	

7. **Please indicate your current employment status**

Employed		Self employed		Not currently employed	

8. **What type of farmer are you?**

Fulltime		Part-time	

9. **What is your main farming practice?**

Livestock		Crops		Both	

10. **How many hectares of farmland do you have?**

Home-garden		Cropland		Both	

11. **What are the crop types grown?**

Maize		Beans		Cabbage		Spinach		Sorghum	
Other (Please specify)									

Farmer characteristics

A. Answer the following questions one by one.

12. What is the purpose of using in-field rainwater harvesting (IRWH) tillage? (tick one answer only)

Reduce soil erosion	
Improve soil water	
Better crop growth	
All of the above	
Not sure	

13. What equipment is needed for construction of the IRWH tillage? (tick one answer only)

Tractor	
Spade	
Rake/harrow	
All of the above	
Not sure	

14. How many times do you have to prepare the land for IRWH tillage? (tick one answer only)

Every year	
Only once	
Not sure	

15. What is the purpose of making basins in IRWH tillage? (tick one answer only)

The basin stores water for the crops	
The basin stops water from leaving the field and reduces soil erosion	
All of the above	
Not sure	

16. How does IRWH tillage compare with conventional tillage practices? (tick one answer only)

It has less advantage	
It has the same advantage	
It is more advantageous	
Not sure	

17. What can you say about using IRWH tillage (tick one answer only)

There is no risk of drought	
There is a risk of drought	
Not sure	

18. Do you have to use the IRWH tillage? (tick one answer only)

Yes, all farmers have to use IRWH in drought	
No, it is my choice whether or not to use IRWH	
Not sure	

19. What is Drought? (tick one answer only)

Lack of rainfall	
Crops dying because of water stress in the field	
All of the above	
Not sure	

Indicate whether each of the eight knowledge items were essential. Based on your own experience, please tick to show whether you think each is essential, helpful, or not helpful when deciding to use IRWH tillage.

Essential	Helpful	Not helpful

1. What is the purpose of using in-field rainwater harvesting (IRWH) tillage?			
2. What equipment is needed for IRWH tillage construction?			
3. How many times do you have to prepare the land for IRWH tillage?			
4. What is the purpose of making basins in IRWH tillage?			
5. How does IRWH tillage compare with conventional tillage practices?			
6. What can you say about using IRWH tillage			
7. Do you have to use the IRWH tillage?			
8. What is Drought?			

Circle the number of three of the items above "the most important things for a farmer to know when deciding to use the IRWH tillage".

B. For each of the following five questions, please circle the number from 0 to 4 on the scale that best describes how you feel at the moment.

13. For me, using IRWH tillage would be:

Beneficial	0	1	2	3	4	Non-beneficial

14. For me, using IRWH tillage would be:

Important	0	1	2	3	4	Unimportant

15. For me, using IRWH tillage would be:

A good thing	0	1	2	3	4	A bad thing

16. For me, using IRWH tillage would be:

Reassuring	0	1	2	3	4	Not reassuring

17. For me, using IRWH tillage would be:

Desirable	0	1	2	3	4	Undesirable

C. Uptake

18. Which option best applies to you regarding IRWH tillage? Only one option.

a) I once used the IRWH tillage	
b) I am currently using the IRWH tillage	
c) I would want to use IRWH tillage	

What can you say when it comes to use of IRWH? I don't want to use IRWH because, please tick to show if you agree, strongly agree, or disagree. Only one answer per item.

	Agree	Strongly Agree	Disagree
1. The labour is demanding			
2. Weed infestation is high			
3. Lack of training			
4. Lack of equipment/ implement			
5. It makes my field small/ reduces the crop to grow			
6. There is not enough rainfall			

Appendix – VII: Soil Land Type Description

Table 1 Soil and terrain form inventory of land type data Dc17 (Land Type Survey Staff, 2002)

LAND TYPE : Dc17
CLIMATE ZONE : 46S
Area : 239080 ha

Occurrence (maps) and areas:
2826 Winburg (4750 ha) 2926 Bloemfontein (234330 ha)

Inventory by:
J.F Eloff & A.T.PBennie
Modal Profiles:
P605 P607

Estimated area unavailable for agriculture: 4080 ha

Terrain unit	1	1(1)	2	3	3(1)	4	5
% of land type	6	12	1	12	40	20	9
Area (ha)	14345	28690	2391	28690	95632	47816	21517
Slope (%)	2-8	1-2	90-150	12-45	2-3	0-2	0-3
Slope length (m)	50-500	100-700	100-400	100-600	300-1000	250-800	50-300
Slope shape	Z-Y	Z-Y	Z	X	Z-Y	Z	X-Z
MB0, MB1 (ha)	0	27255	0	0	92763	47816	18505
MB2 - MB4 (ha)	14345	1434	2391	28690	2869	0	3012

Soil series or land classes	Depth	MB	1 ha	1 %	1(1) ha	1(1) %	2 ha	2 %	3 ha	3 %	3(1) ha	3(1) %	4 ha	4 %	5 ha	5 %	Total ha	Total %	Clay content (%) A	E	B21	Hor	Texture Class	Limiting material
Soil-rock complex :	(mm)																							
Rock		4:	10042	70			2391	100	18648	65							31080	13						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36,	100-250	3:	2152	15					4304	15							6455	2.7	10-20		15-25	A	LmfiSa-SaLm	R,so
Milkwood Mw11, Glengazi Bo31 Rashseni Bo21, Glendale Sd21	250-350	3:	1148	8					2869	10							4017	1.7	25-50		35-55	A	fiSaClL m-SaCl	R,vp,vr
Swartland Sw31, Sterkspruit Ss26,	100-250	3:	1004	7					2869	10							3873	1.6	10-20		40-50	B	fiSaCl	Vp,pr,
Swartland Sw31,Nyoka Sw41, Omdraai Sw42	100-250	0:			14345	50					33471	35	16736	35	3443	16	67994	28.4	15-30		40-60	B	fiSaCl-Cl	Vp
Shepperdvale Va42,Lidley Va 41, Arniston Va31	100-300	0:			7172	25					19126	20	14345	30	3443	16	44086	18.4	15-30		45-60	B	fiSaCl-Cl	Vp
Milkwood Mw11,Grythorne Mw21	300-600	0:									19126	20	9563	20	3873	18	32563	13.6	40-55			A	fiSaCl-Cl	R
Glengazi Bo31,Bonheim Bo41	250-400	0:									9563	10	3347	7	2582	12	15492	6.5	40-55		45-60	A	fiSaCl-Cl	Vp
Estcourt Es36,Enkeldoom Es33	200-350	0:									4782	5	2391	5	646	3	7818	3.3	12-25	10-20	45-60	E	LmfiSa-SaLm	Pr
Sterkspruit Ss26,	100-300	0:			5738	20					1913	2					7651	3.2	15-30		45-60	A	fisaLm-SaClLm	Pr
Gelykvlakte Ar20	400-900	0:									4782	5	1434	3	1076	5	7292	3.1	40-60			A	fiSaCl-Cl	R
Mispah Ms10,Williamson Gs	100-300	0:			1434	5					2869	3					4303	1.8	10-15			A	fisaLm-SaClLm	R,so
Dundee Du10, Limpopo Oa46,	600-1200	0													3443	16	3443	1.4	15-35		25-35	B	fiSaClL m	
Stream beds		4													3012	14	3012	1.3						

MB = Mechanical limitations, MB0 = no limitation, MB1 = many stones but ploughable, MB2 = large stones and boulders, unplaughable, MB3 = very shallow soils on rock, MB4 = lack of soil
Slope shapes: X = concave, Y = convex, Z = straight
Depth limiting material: vp = pedocutanic B horizon, pr = prismacutanic B horizon, R = rock, so = saprolite

Terrain type A4 Geology: Sandstone, shale and mudstone of the Beaufort group with dolerite intrusions.

Terrain form sketch

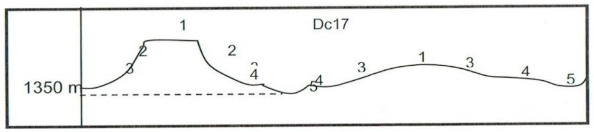


Table 2 Soil and terrain form inventory for Land Type Db37 (Land Type Survey Staff, 2002).

LAND TYPE / *LANDTIPE* .... : **Db37**

CLIMATE ZONE *KLIMAATSONE* .... : 46S

Area *Oppervlakte* .... : 94220 ha

Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 2220 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte :*
2826 Winburg (65720 ha) 2926 Bloemfontein (28500 ha)

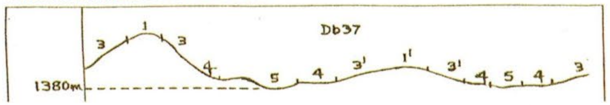
Inventory by *Inventaris deur :*
J F Eloff & A T P Bennie

Modal Profiles *Modale profiele :*
P472 P473 P474 P475 P476
P608 P609 P610
48 49 50

Terrain unit *Terreineenheid*	1	1(1)	3	3(1)	4	5
% of land type *% van landtipe*	1	11	3	52	23	10
Area *Oppervlakte (ha)*	942	10364	2827	48994	21671	9422
Slope / *Helling (%)*	1 - 2	0 - 2	6 - 35	1 - 3	0 - 2	0 - 1
Slope length *Hellingslengte (m)*	200 - 700	20 - 50	500 - 1500	50 - 300	400 - 1000	50 - 300
Slope shape *Hellingsvorm*	Z-Y	Z-Y	Z	Z	Z	Z-X
MB0, MB1 (ha)	0	10364	0	48994	21671	8009
MB2 - MB4 (ha)	942	0	2827	0	0	1413

Soil series or land classes *Grondserles of landklasse*	**Depth** *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Soil-rock complex																						
Grond-rotskompleks:																						
Rock/Rots		4	659	70			1979	70							2638	2.8						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36	100-250	3	188	20			424	15							612	0.7	10-25		15-30	A	LmfiSa-SaClLm	R,so
Glendale Sd21, Milkwood Mw11, Glengazi Bo31	250-400	2	94	10			424	15							518	0.6	20-45		35-50	B	fiSaCl	R,vp
Sheppardvale Va42	100-250	0							19598	40	14086	65	1413	15	35097	37.3	20-30		55-65	B	Cl	vp
Lindley Va41, Arniston Va31	100-250	0			5182	50			17148	35	2601	12	471	5	25402	27.0	12-25		40-55	B	fiSaCl-Cl	vp
Nyoka Sw41, Omdraai Sw42, Swartland Sw31	100-200	0							4899	10	3251	15	754	8	8904	9.5	12-30		40-65	B	fiSaCl-Cl	vp
Rietvlei We12	300-450	0			4664	45			1470	3					6134	6.5	12-30		20-35	A	fiSaLm-SaClLm	sp
Dundee Du10, Jozini Oa36	>1200	0											4711	50	4711	5.0	15-45			A	fiSaLm-SaCl	
Bluebank Kd16, Kroonstad Kd13	450-600	0							2940	6	1084	5	283	3	4306	4.6	15-25	10-20	40-60	E	fiSaLm	G
Milkwood Mw11, Glengazi Bo31	300-450	0							2450	5	650	3	377	4	3477	3.7	35-50		40-55	A	fiSaCl	R,vp,sp
Soetmelk Av36	500-700	0			518	5			490	1					1008	1.1	12-25		20-35	B	fiSaClLm	sp
Stream beds/Stroombeddings		4											1413	15	1413	1.5						

Terrain type /*Terreintipe* : A3
Terrain form sketch /*Terreinvormskets*



Ter verduidelliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Sandstone, shale and mudstone of the Beaufort Group, with dolerite intrusions.

Geologie Sandsteen, skalie en moddersteen van die Groep Beaufort, met dolerietindringings.

Appendix – VIII: Meetings / Framers' day

Farmers Information day training and presentations

Information Day Theme

Innovative way to combat drought challenge & nutrition insecurity

UPTAKE OF KNOWLEDGE, TECHNOLOGY AND PRACTICES FOR IMPROVING WATER PRODUCTIVITY IN RAINFED CROPPING SYSTEM

Project Team:

WA. Tesfuhuney
S. Walker
A. Fourie

Students:

1. D. Admire
2. R. Muthianzhelem
3. P.A. Maleka
4. M.M. Nomalanga

Farmers Participation (6)

Extension officers

- Mrs. Matokelo

DEPARTMENT OF AGRICULTURE & RURAL DEVELOPMENT

FARMER ENGAGEMENT : BENEFITING AS A TEAM

ANDRIES FOURIE

08 March 2019

www.fs.gov.za

Pamphlet for farmers' information day (08 march 2019)

Information Day Theme

08 March 2019

Innovative way to combat drought challenge & nutrition insecurity

Program Information day

ThabaNchu In-field Rainwater Harvesting & Intercropping Project (WRC K5/2821)

08 March 2019

·ductory Speech

– 8:50	Opening	Mr. Lengegeru
– 9:00	Purpose / information-day	Mrs. Matokelo
- 9:10	Communication / engagement	Mr. Andries

·ct Activities / Implementation

– 9:30	Student research project Presentation	
	• Ph.D. Research	Mr. Admire
	• MSc. Research	Mr. Ravuluma
- 9:50	Project aims and progress	Dr. Weldemichael

·ers / Extension Engagement

– 10:00	Representative farmer	Mr. Muzamu
) – 11:00	Discussion / Feedback session / Interaction	

·onstration plot visit

) – 12:00	Visit demonstration plots (Morago village)
) – 01:00	Refreshment and travel to Paradyse village
) – 01:45	Visit demonstration plots (Paradyse village)
5 – 02:00	Closing remarks

In-field rainwater harvesting

With in-field rainwater harvesting (IRWH) rainfall runoff is promoted on a 2 m wide strip between alternate crop rows and stored in basins. Water collected in the basins infiltrates deep into the soil beyond the surface evaporation zone. After the basins have been constructed no-till is applied and a crust forms on the runoff strip which enhances runoff. Mulch can be placed in the basins to further reduce water losses through evaporation from the soil surface (Es) and to create a cooler cropping environment. The stored rainwater is used productively to grow a variety of grain and vegetable crops for household consumption.

Benefits

- Empowers people in rural communities to fight food insecurity and poverty
- Increases yields by 30 – 110 %
- Decrease risk of crop failure by 43 – 63 %
- 48 – 54% higher probability to break even
- Socially acceptable (Increases income, promotes education, improves social well-being, improves health status, reduces crime, increases crop diversity)
- Easy to implement with low maintenance cost
- Simple duplicatable technique

Farmers' information day and demonstration-plot visit

Farmers and extension officers engagement and technology transfer data collection

Post project period (2019/20 season) farmers motivation/adoption of the technology (Intercropping maize – vegetables under IRWH tillage system)