SUSTAINABLE TECHNIQUES AND PRACTICES FOR WATER HARVESTING AND CONSERVATION AND THEIR EFFECTIVE APPLICATION IN RESOURCE-POOR AGRICULTURAL PRODUCTION THROUGH PARTICIPATORY ADAPTIVE RESEARCH

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Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

1 INTRODUCTION

Rainwater harvesting (the accumulation and storage of rainwater) is already widely used throughout the world as a method of utilising rainwater for domestic and agricultural use. Although it has wide application for the provision of drinking water, water for livestock and water for irrigation, the percentage of households using rainwater harvesting in rural areas of South Africa is low. However, with increasing populations and high unemployment there is more pressure on agriculture to provide food. Rainwater harvesting has the potential to improve food production for communities who have a high dependence on agriculture.

One of the areas where this potential can be realised is the Umlazi River catchment, situated in the eastern region of KwaZulu-Natal near Pietermaritzburg. There is no piped water in this area and the rural communities are entirely dependent on rainwater. The aim of this project was to select and implement water harvesting and conservation techniques that would assist the communities in this catchment area to improve their livelihoods by increasing their food production.

2 PROJECT OBJECTIVES

The specific objectives of the project were:

- To do a baseline study to determine the status quo of crop and livestock production systems.
- To conduct on-station experiments at the Zakhe Agricultural College to introduce/implement and test one or more promising (existing/new) water harvesting and conservation techniques.
- To evaluate the impact of the selected water harvesting techniques on the crop and livestock production systems.
- To measure the impact of increased water use efficiency on the crop and livestock production systems.
- To measure the technical feasibility, risk, economic viability, social acceptability (including gender issue), environmental impact of the selected water harvesting and conservation techniques.

3 STUDY AREA

The study sites where detailed water harvesting experiments were undertaken were situated in the Umlazi River catchment, approximately 20 km south-east of Pietermaritzburg. Four rural communities live within this catchment: Ntembeni, KwaMncane, Hopewell and Baynesfield.

The annual rainfall of the region, which ranges from 800 mm to 1000 mm, falls mostly in summer. Winters are dry with an average rainfall of 12.5 mm. The region has a temperate climate, with a mean January maximum temperature range of 24.8-26.0°C and a mean July minimum temperature range of 4.4-7.6°C. Opportunities for extending the growing season of crops in the area are in April to May when temperatures are favourable and additional moisture can still be obtained, either through soil conservation measures or water harvesting techniques.

The planning of water harvesting techniques needs to account for the appropriate "design" rainfall, according to which the ratio of catchment or “run-on” to planted or “run-off” area will be determined (FAO, 1991). Design rainfall analyses for Zakhe and KwaMncane showed that for Zakhe the seasonal rainfall amount for a probability of exceedance of 66% (two out of three years) was only 600 mm and for 33% (one out of three years) 800 mm. For the same probabilities of exceedance for KwaMncane the rainfall amounts were approximately 900 and 1100 mm for the 66 and 33% exceedance levels respectively. These data showed the importance of recognising the site differences in design rainfall amounts, even in sites situated relatively closely together (<15 km). For an equivalent crop area and water use the “run-on” area at Zakhe would need to be 33% larger than at KwaMncane.

The vegetation is grassland of low grazing value with *Aristida junciformis,* an unpalatable grass, being the dominant species. Livestock production is therefore limited by the low quality of natural veld.

The land use of the area has a high potential, mainly because of its favourable climate and high potential soils.

4 BASELINE SOCIO-ECONOMIC STUDY

4.1 Introduction

One of the critical factors affecting the productivity in farming at the household and community level is the shortage of water. The main aim of this baseline study was to describe the socio-economic situation in relation to how households and communities manage their water supplies and the potential impact of improved water harvesting on food security. In particular, the study focused on determining the following:

- The structure and composition of households and the role of gender and generation in agricultural production;
- The effect of seasonality on agricultural activities;
- The current practices and techniques used in water harvesting and conservation;
- The attitudes and constraints of households concerning water harvesting and conservation;
- Opportunities available to support socio-economic development.

4.2 Methods

The socio-economic survey was an applied, descriptive study employing both qualitative (focus group discussions, key informant interviews and transect walks) and quantitative (questionnaires) research techniques (n=37 for Ntembeni, n=43 for KwaMncane).

4.3 Results

Households in Ntembeni and KwaMncane communities are headed mainly by women (76-95%). The region is characterised by extreme poverty with 68-74% of the households earning <R1000 per month and 34-37% having 6-10 dependents. Increased food production through water harvesting is therefore likely to have a major impact on livelihoods.

Factors that may impact negatively on the participation of community members in the project are the low level of education (34% have no education), long distances (up to 5 km) to facilities and poor access to media.

The land is under common property and is controlled by the traditonal authority (tribal council). The majority of the residents (91.9%) have land-use rights for cultivation and have been allocated less than a hectare of land for agricultural production. However, only 70.3% of the residents use this land for farming. Individual homestead gardens are mainly used for summer production due to water unavailability in winter. There are 32.4% of the residents who use less than one hectare of the land for communal gardens. The main vegetable crop grown is potatoes.

The main source of water supply for agricultural production to the majority of the farmers (70.3%) is the Umgeni pipe system, followed by streams, which are used by 10.8% of the farmers. Fifty one percent of respondents stated that shortage of water is a result of poor supply systems.

Participants of the water-harvesting project indicated that their greatest expectation was profit (43.2%) followed by a good harvest (10.8%).

5 THE EFFECT OF SELECTED WATER HARVESTING AND SOIL CONSERVATION TECHNIQUES ON SOIL WATER AND CROP YIELD

5.1 Introduction

There are two major forms of water harvesting that are generally recognised in agriculture: (1) Micro-catchment (In-field rainwater harvesting), collecting rainfall on the surface where it falls, and (2) Macro-catchment (ex-field water harvesting) which is a system that involves the collection of run-off originating from rainfall over a surface elsewhere. The focus of this study was on in-field rainwater harvesting for vegetable production at Ntembeni community and at Zakhe farm in KwaZulu-Natal. The project team investigated the effect of raised seedbeds, ridges and infield run-on/off plots on available water for production of cabbage and Swiss chard at the two sites.

5.2 Methods

5.2.1 Climate monitoring (automatic weather station)

Measurements of precipitation, air temperature, relative humidity and incoming solar radiation were recorded at Zakhe in 2005 and 2007, and at the community vegetable garden in 2006 using an automatic weather station (AWS).

The watermark system was selected as an appropriate technique for the measurement of soil matric potential for plots where continuous measurements were required. All sensors were wired via a Campbell AM416 multiplexer to a Campbell CR10X data logger programmed to record soil water potential every 12 minutes.

5.2.2 Effects of mulching at Zakhe

In June 2005, an experiment to evaluate the effect of mulching on soil water content was carried out at both the Zakhe Agricultural College and the Ntembeni community garden. The contours at Zakhe were disked to incorporate residual material and fertiliser into the top 0.30 m of soil. Four blocks per contour were marked out. Each plot measured 1 m x 2 m. Soil collected from within the contour was added to each plot such that the height of the bed was raised by 0.20 m. In total, 96 individual plots were created comprising four blocks of 12 plots on a high and low contour planted to peas, peas with mulch, cabbage, cabbage with mulch, spinach and spinach with mulch. Grass was used as the mulch cover. Access tubes for the weekly measurement of soil water content, using the Diviner 2000 system of measurement, were installed across the two contours. A similar experiment was repeated at Ntembeni.

5.2.3 Run-on plot experiment

In November 2005, a new summer experiment was undertaken where the focus was to harvest rainwater in a field plot. The technique was designed to increase run-off from the adjacent slope making this additional water available for the crops. A suitable contour strip was selected at the Ntembeni community garden for this trial. This contour was then divided into four sections. In section one run-off and field plots were set up, section two included the control plots and sections three and four were a repeat of the winter experiments with raised and flat beds.

Both the experimental plots and the control plots were instrumented with 12 Diviner 2000 access tubes to a depth of 1 m. Soil water content was recorded at 0.10 m intervals. Watermark sensors to monitor the matric potential were also installed and connected to the automatic weather station to record soil moisture every 12 minutes.

5.2.4 Micro-catchment water harvesting (the in-field runoff plots – modified Free State method)

In May 2006, a new trial was designed to test the applicability of micro-catchment water harvesting (Free State in-field run-off plot, Hensley et al., 2000) technique in the Ntembeni community garden. Cabbage and Chinese cabbage seedlings were planted in a completely randomised field experiment. The treatments were two water harvesting techniques: ridged planting and the run-off system. Ridged planting consisted of planting seedlings on 0.20 m ridges and the run-off plots consisted of two rows planted at 0.50 m spacing, with 1 m run-off spaces on both sides. Flat beds were used as a control treatment. Mulching (straw) was superimposed as a sub-plot on the land modification treatments (ridging and run-off plots) and the flat beds. The experiment was replicated three times and the crops were grown in separate but adjacent blocks.

5.3 Results

5.3.1 Climate

The climate data showed wet and dry seasonal trends with the summer being wet and humid and the winter dry. Regular rain events were recorded in summer. January to March was characterised by small rainfall events, with totals seldom exceeding 10 $mm.day^{-1}$. Only 328 mm of rain was recorded between January and September 2006, showing that conditions were relatively dry when compared with the long term mean of 475 mm. Average daily temperatures in summer often exceeded 25°C and were indicative of the hot dry conditions experienced late in the 2005/06 summer season.

5.3.2 Soil water studies

5.3.2.1 Soil water measurements at Zakhe

During summer the matric potential of the soil remained fairly low and rarely decreased to below -70 kPa. From late April, a progressive decrease in soil matric potential occurred and by the end of May to early June the soil was probably at its driest. Individual winter rainfall events generally have little influence on the soil water content of the deeper layers. These results are important in that they suggest the timing of rainwater harvesting practices should be during summer when water can be "harvested" for its use later in the season.

5.3.2.2 Effects of mulching

The experiment to evaluate the effect of mulching on soil water content showed that the surface soil was generally wetter than at depth, owing mainly to the irrigation of the plots. As winter progressed, the water content near the surface decreased progressively, presumably in response to the direct uptake of water by the increasing root system of the crop. From the results it was evident that adding mulch maintained higher water contents in the soil from a depth of 0.2 m to 0.5 m due to its role in decreasing evaporative losses. From a depth of 0.5 m downwards, for both the mulched and no mulch plots, the water content ranged between 0.32 $m^3.m^{-3}$ and 0.35 $m^3.m^{-3}$. Mulching as a technique of soil water conservation is, therefore, a useful strategy in sustaining soil water contents within the root zone.

5.3.2.3 Run-on plot measurements

Establishment of plants on all plots was completed on the 20/12/2005, but due to a severe hailstorm in the area all the crops (with the exception of the cabbages) were replanted. It was found that in the winter months the run-off plots tended to have higher soil moisture than the control plots. Recharge events were evident when either irrigation or rain occurred. On average the run-off plots had 10-20 mm more water (15% of plant available water content) in the upper 500 mm soil profile than the control plots.

5.3.2.4 Micro-catchment technique – the in-field run-off plots (modified Free State method)

The introduction of the micro-catchment (Free State) run-off technique showed that mulching improved the soil water content by 50 mm when compared with the control plot. The run-off mulched plot had the highest water content with approximately 200 mm in the top meter of the soil profile. However, the run-off plot with no mulch showed very poor soil water retention. Comparison of the various treatments without mulch showed that the method of having ridges and troughs increased the total profile soil water content (1 m profile) to 125 mm compared to the control plot that had an average of 90 $mm.m^{-1}$. The run-off plot without mulch had the lowest water content. It was also evident that the ridge mulch treatment had the highest total profile water content (> 200 mm) when compared to other treatments (generally < 150 mm). A comparison of the various treatments with mulch showed that the method of having ridges and troughs increased the surface soil water content (<0.1 m) to 33%, compared to the control plot that had a surface soil water content of 20%. The run-off plot also performed better than the control plot with a surface soil water content of approximately 25%.

5.3.3 Plant growth (Free Sate adopted method) – May 2006

5.3.3.1 Leaf number and plant height

For both cabbage and Chinese cabbage leaf number and plant height were improved by all the water harvesting techniques. However, there were no significant differences between the various water harvesting techniques.

5.3.4 Yield

For cabbage, water harvesting techniques increased the yield by 50-60% and mulching increased the yield by a further 10-20%. For Chinese cabbage, there was a 40-50% increase in yield due to water harvesting and mulching caused a further 10% increase.

5.3.5 Gravimetric soil water content (upper 0.15 m soil layer)

Both ridges and run-off treatments improved soil water content regardless of the crop grown. Mulching improved the soil water content in the flat beds (control- vs. control + mulch) by approximately 37% in cabbage and 12% in Chinese cabbage. The soil water contents in both the run-off and ridge water harvesting treatments were 5-15% higher than the control throughout the growing period.

5.4 Conclusion

The rainwater harvesting (RWH) techniques that were implemented to increase water availability included raised seedbeds, ridges and run-off plots. In addition, the study demonstrated the effectiveness of the micro-catchment (modified in-field RWH) technique that was adopted from the Agricultural Research Council at Glen in the Free State. The comparative study between the control (flat), ridged and run-off plots showed that the soil moisture profile for the run-off plots was consistently higher when compared to the control plots. On average, the run-off plots had about 10-20 mm more water (15% of the plant available water content) in the upper 500 mm soil profile. Adding mulch also maintained higher water contents in the soil from a depth of 0.1 m to 0.3 m due to its role in decreasing evaporative losses. The soil moisture in the top 0.2 m of the mulch plots was about 30% compared to the no mulch plots (13%.). This is an important soil conservation strategy as vegetable crops mainly have roots in the top 0.2 m to 0.3 m of the soil layer. Mulching as a technique of soil water conservation is therefore a useful strategy in sustaining soil water contents within the root zone.

The studies also showed that, regardless of the crop used, micro-catchment techniques or in-field water harvesting using ridges increased biomass. For example, water harvesting techniques increased the yield of cabbage by 50-60% and mulching increased the yield by a further 10-20%. For Chinese cabbage, there was a 40-50% increase in yield due to water harvesting and mulching increased yield by a further 10%.

6. APPLICATION OF WATER HARVESTING TECHNIQUES IN RANGELAND/LIVESTOCK PRODUCTION SYSTEMS

6.1 Introduction

When the quality of natural forage falls below the level required to maintain bodyweight, animal production declines. Cattle kept by the communities in the study area are dependent on the rangelands for forage. Shortage of fodder is a major constraint to livestock production in the study area. The aim of this study was to determine the effect of water harvesting techniques on fodder production for communal livestock systems. The specific objectives were:

- To carry out a baseline study to determine the status quo of livestock production systems.

- To determine whether Dolichos, a fodder legume, can be grown and utilised in the Ntembeni communal production system using water conservation techniques.
- To examine the effect of mulching and soil preparation on the germination, survival, dry matter production, and infestation by weeds of Dolichos.

6.2 Methods

6.2.1 Veld condition

The veld condition was assessed by comparing the species composition at the Ntembeni and KwaMncane study sites to that of a benchmark in which the veld is considered to be in optimal condition. The benchmark site selected was Moist Midlands Mistbelt. The relative frequency of the above-ground species in each of the wards was estimated using the descending point technique (Levy and Madden, 1933).

6.2.2 Fodder production

Dolichos was grown in experimental plots in a randomised block design. The two factors (basin size and mulching), each at two levels, were replicated three times resulting in four treatments and twelve plots. Each plot comprised two 1 x 1 m subplots, 2 m apart, which were cleared of all above-ground vegetation. Plots were positioned along a fence (that was approximately perpendicular to the contour of the land) to maximise production from marginal land. The land was contoured, giving rise to nearly level ridges separated by steep contour banks. Plots were located only on the ridges.

For factor 1 (basin size), the first level was large basin size in which the soil across the whole subplot was loosened with a pick and spade, and shaped to form a large open basin designed to dam water following rain. For level 2, small basin size, only a small area (approximately 20 x 20 cm) was loosened but not shaped.

For factor 2 (mulching) the first level comprised entire subplots which were mulched with hay to a depth of approximately 15 cm and the second level comprised plots which were not mulched.

6.3 Results

6.3.1 Veld condition

In the baseline survey, both fodder shortage and animal diseases were highlighted by the Ntembeni community as major constraints to livestock keeping. Fodder shortage was due to the absence of palatable Decreaser species at the study sites and the dominance of low quality Increaser II species (14.0-74.5%) when compared to the benchmark value (5%). The poor veld condition (30.3-63.4%) indicates that livestock owners need to supplement their livestock with additional forage to prevent the animals declining in productivity.

6.3.2 Fodder production

The experimental results indicated that Dolichos can be successfully established in community gardens. Livestock control was sufficient to ensure that animals did not eat the young plants. The average length of mulched plants was higher (74 mm) than that of no mulch plants (53 mm), although the effect was not significant (P=0.19).

The infestation of weeds (all species) was significantly lower on mulched (1.5/5) than on no mulch (2.4/5) plots (P=0.024). The number of allelopathic *Cyperus* plants in each plot was significantly lower on mulched than on no mulch plots (P<0.001). Hole size had no significant effect on weed infestation or plant length.

6.4 Discussion

Hole size and mulching did not have a statistically significant effect on the size of plants. This indicates that plants grown in relatively hard soils next to boundary fences can achieve (initial) growth rates similar to that of plants in cultivated soil. This is highly relevant to the communities in the study area where there is a shortage of land for growing vegetables and fodder. In many production systems, the area immediately adjacent to the boundary fence is unproductive, so this provides an opportunity to make better use of resources.

Mulching proved an effective way of reducing competition from weeds and, therefore, will save costs in terms of labour input to keep the plants weed-free while they are young and susceptible. Since some weeds can compete directly with plants through allelopathy, particularly the nutsedges (*Cyperus* species), mulching was effective against these weeds which were highly abundant around no mulch plants.

Although the dry-matter production of the Dolichos was too low to run a feeding trial, the results indicate that water conservation techniques have the potential to increase fodder production.

7 SOCIO- ECONOMIC IMPACT ASSESSMENT

7.1 Introduction

The three communities in the study area (Ntembeni, KwaMncane and Baynesfield) were trained in rainwater harvesting and soil conservation techniques to improve their livelihoods through vegetable production. The main objective of this study was to assess the socio-economic impact of the project on the participating farmers, non-participating community members and the buyers of the produce from the community gardens. This study adopted the socio-economic impact assessment framework developed by the Commonwealth of Australia (SEIA, 2005). A semi-structured questionnaire and focus group discussions were used for data collection.

7.2 Results and Discussion

The questionnaire survey indicated that 75% of the respondents (n=18) were convinced that the community garden was the solution to alleviate poverty and promote food security. The majority of farmers (75%) cited that they had become more food secure at household level since the introduction of the project. The other 25% stated that the main hindrance to the success of community gardens was inadequate water supply for irrigation. At least 50% of the participants were involved in project activities including design, planning, decision making and assessment.

At the end of the study adoption of water harvesting techniques and practices by the farmers involved in the project was high (70-100%). All farmers adopted the use of a cropping calendar and application of fertilisers to their crops. Use of certified seed, recommended plant populations, integrated pest management and keeping of financial records were adopted by the majority (95%) of farmers. Seventy percent of farmers noted an improvement in the management of water when they adopted timely irrigation. Before the introduction of the project, most farmers used to irrigate at any time of the day, even when it was too hot. The adoption of correct time of planting by 80% of the farmers resulted in increased production when compared to planting at any time depending on convenience.

The survey showed that currently 75% of the farmers spend more time in the field compared to the previous three years, with 55% farmers working full time. This time commitment is an indication of the success of the project.

The majority of farmers (75%) marketed their produce as individuals, while only 25% practised group marketing. All farmers (100%) cited lack of formal contracts as a major hindrance to marketing their produce. Regarding access to input suppliers, 25% acknowledged an improvement while the other 75% did not witness any improvement in input suppliers since the inception of the project in 2003.

The project had a positive impact on regulatory institutions. In 2005, the management structure of the farmers was almost dysfunctional (no meetings were planned and scheduled project meetings were not honoured). After the baseline study in 2005, the project team facilitated the formation of a farmers' committee to coordinate all activities. In 2008, 85% of farmers stated that regular attendance of meetings resulted in the strengthening of their organizational structures. However, the other 15% were not convinced that meetings were bearing as much fruit as anticipated. Positive initiatives resulting from the organizational development were the organisation of training courses, collaboration and co-operation between farmers to establish markets and liaise with buyers and hawkers, the organisation of tractors for land preparation and the exchange of knowledge and skills on gardening activities and general farming.

The majority of respondents (80%) indicated that there was an improvement in economic well-being. In addition, their agricultural skills had improved. Evidence for improved skills was that they sold produce and bought seeds, they earned more money, had access to more land and gained better knowledge in water harvesting techniques. The respondents who cited that they had not gained any skills since the introduction of the water harvesting techniques (WHT) project attributed this to lack of adequate resources. For instance, they cited that they could not adopt correct times to irrigate due to lack of adequate water for irrigation. The survey revealed that 85% of farmers had adopted financial record-keeping in order to ascertain whether they were making a profit or loss. With respect to farming inputs, 65% of the farmers indicated that their farm input expenditure (e.g. the purchase of fertiliser, chemicals and seed) had increased since 2005. All respondents indicated that there was not much change regarding hiring labour due to financial constraints.

In 2008 there was a significant drop (40%) in farmers buying food from the urban market compared to the baseline in 2005. This was attributed to a significant improvement in the number of farmers producing their own food (cabbage, potatoes, spinach, beetroot, carrots, onions and beans). Fifty-five percent of the respondents indicated that there was evidence of positive changes in terms of using various water harvesting techniques after the training offered to them. Farmers mentioned that Zakhe Agricultural College had played a significant role by providing pipes to facilitate in watering their gardens. This led to a conclusion that rural development can be meaningful when the farmers have the right attitude to learning and implement the concepts they have learned.

This change in attitude was apparent in the 2008 survey which showed that farmers had acquired more land (up to 75%) for cultivation. Factors that motivated farmers to obtain more land were the success in farming (which was associated with profit making and other gains) and training which equipped farmers with new knowledge. Previously, farmers used to cultivate very small garden plots averaging less than 1000 square metres. According to the respondents, farmers now had the desire to increase their land holding to increase their production and profits.

With respect to farmers' information days, 40% of the respondents said that they had learnt a lot from the events. As a result, they were keen to be involved in growing vegetables and later join the farming community. However, 60% of the respondents indicated that they were not aware of the farmers' information days because of not being updated by the farmers. This may be due to long distances to communication facilities which were highlighted as a constraint in the baseline study. The majority (80%) of respondents indicated that it was not easy to join the community garden if one did not know someone who was already participating in the project. Another constraint was the joining fee of R100 which was not affordable to many respondents.

Although the majority of respondents (70%) indicated that the poverty levels had decreased as compared to 2005, it was apparent from this unaffordability constraint that poverty was a major limiting factor for the project. It is, therefore, recommended that farming subsidies be re-introduced to enable farming to become more profitable.

The majority of the respondents (95%) confirmed that the community gardens at Ntembeni and KwaMncane had positively affected the surrounding communities. The community benefited by obtaining food (vegetables) from the gardens as well as limited employment. They were able to access vegetables as part of their payment. Other positive factors were reasonable prices for vegetable buyers and hawkers, good quality vegetables and sharing of ideas regarding farming. Some of the surrounding community members observed that although they had homestead gardens they could not produce as much as their counterparts at the community gardens because they lacked skills to produce more vegetables and had no fences to prevent cattle from consuming their crops.

The main buyers of the vegetables were the local Thabethe, Nkabini and Happy stores and two stores in Pietermaritzburg, Evergreen and Southgate Spar. Other main buyers were hawkers from the surrounding community. The buyers stated that the general quality of produce was good except for onion which was fair. The wide scope of crops contributed to the improvement of the market.

During interviews, these buyers reaffirmed their desire to support the farmers at Ntembeni and KwaMncane by buying their produce. However, problems that they had encountered with the farmers included insignificant supplies, poor capacity to supply constantly and high prices. It is apparent that further development of the marketing and irrigation strategies for the farmers is required to produce food throughout the year and to plan, fix prices and control the marketing of vegetables.

8 CAPACITY BUILDING AND TECHNOLOGY EXCHANGE

8.1 Community

- Two workshops were conducted; an initial stakeholder planning workshop at Zakhe to introduce the project followed by workshops in each community to engage both the participating and non-participating community members.
- Four farmer information days were held in 2004-2007 in each of the two communities to give a total of eight.
- Educational tour: 12 project participants were exposed to best practices in different provinces (Gauteng and Limpopo) in the initial implementation of the project in 2004.
- The community benefited from learners through technology transfer whereby the Zakhe learners went to nearby communities to demonstrate skills learnt during the implementation of the project.
- The child of a KwaMncane participating farmers, the Khenisa family, became interested in water management issues and ended up pursuing a degree in Hydrology at the University of KwaZulu-Natal.

8.2 Staff

- The project team went to the University of the Free State to learn from Prof Leon van Rensburg who had successfully completed a similar project in water harvesting.
- Zakhe staff who acted as junior researchers were mentored on scientific methods of data collection by the senior research team.

8.3 Zakhe Learners

- Zakhe learners were introduced to basic research principles and different water harvesting techniques.
- Learners learnt to volunteer and transfer knowledge to the community.

8.4 Zakhe Agricultural College

- Financial resources helped in the development of Zakhe as an organisation.
- Learner exposure to scientific research methods instilled in them the desire to love farming and working with the community. As a result, many boys were employed on commercial farms as farm workers, with some developing into farm managers when they obtained their Matric certificates. Two learners are currently farm managers and four are assistant managers on commercial farms.
- Production at Zakhe improved significantly due to the involvement of the learners in the project.

9 RECOMMENDATIONS FOR FUTURE RESEARCH

Mulching may not always be a feasible technique as the residues used have greater value for other uses such as animal fodder or thatching (Rockstrőm and Steiner, 2003). The labour inputs required for collecting mulching material, as well as the increase in insect pest populations, bacterial and fungal diseases may in the long-term bring unanticipated crop losses. These aspects require further investigation.

Another area not investigated by the project team was the role of conventional versus minimum tillage. Besides the beneficial water holding impacts of minimum tillage, further research is required on its effect on increases in soil organic carbon. This has the potential to have positive impacts not only on sustainable food production but also on global climate change.

10 DATA

All processed data have been catalogued and stored at UKZN, BEEH, P/Bag X01, Scottsville, 3209.

Contact person: Prof CS Everson.

These data are held on non-flexible diskette. All data can be supplied to researchers and managers on CD-R diskettes.

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ACRONYMS

ANOVA	Analysis of variance
AWS	Automatic weather station
CBOs	Community-based organisations
DAEA	Department of Agriculture and Environmental Affairs
DLL	Field capacity
DRWH	Domestic rainwater harvesting
DUL	Drained upper limit
FAO	Food and Agriculture Organization
FGD	Focus group discussions
Ha	Hectare
IAEA	International Atomic Energy Agency
IRWH	In-field rainwater harvesting
KZN	KwaZulu-Natal
NDA	National Department of Agriculture
NGOs	Non-governmental organisations
PAWC	Plant available water content
PRA	Participatory rural appraisal
RETC	Retention Curve Program for Unsaturated Soils
RWH	Rainwater harvesting
RWH&CT	Rainwater harvesting and conservation techniques
SEIA	Socio-economic impact assessment
WRC	Water Research Commission
XRWH	Ex-field rainwater harvesting

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CHAPTER 1 INTRODUCTION

Rainwater harvesting (the accumulation and storage of rainwater) is already widely used throughout the world as a method of utilising rainwater for domestic and agricultural use. It is a method which has been used since ancient times and is increasingly being accepted as a practical method of providing potable water in development projects throughout the world (Critchely and Siegert, 1991). Although it has wide application for the provision of drinking water, water for livestock and water for irrigation, the percentage of households using rainwater harvesting in rural areas of South Africa is low (Kahinda et al., 2009). However, with the increase in the population and high unemployment there is more pressure on agriculture to provide food. Rainwater harvesting has the potential to improve food production for communities who have a high dependence on agriculture.

One of the areas where this potential can be realised is the Umlazi River catchment situated in the eastern region of KwaZulu-Natal (KZN) near Pietermaritzburg. There is no piped water in this area and the rural communities are entirely dependent on rainwater. One of the communities in this area had been assisted by the KZN provincial Department of Agriculture and Environmental Affairs (DAEA) to establish a community vegetable garden and several homestead gardens. Further, linkages were established between the community and the Zakhe Agricultural College to improve vegetable production. However, farmers experienced difficulties in operating these gardens because of water shortages. The aim of this project was to select and implement water harvesting and conservation techniques that would assist the communities in this catchment area to improve their livelihoods by increasing their food production.

The specific objectives of the project were:

1. Conduct a literature review of techniques and practices for water harvesting and conservation in Saharan, West-Asian and North-African countries and also capture the existing knowledge of individual experts in South-Africa. Use this information to describe different farming systems based on water harvesting and conservation with particular reference to techniques and context.

2. Organise a project specific workshop and field trip to share, capture and distil knowledge on water harvesting conservation, to select the study area(s) and appropriate techniques for field trials according to specific criteria.
3. Obtain endorsement of stakeholders in the proposed study area(s) to conduct the research project.
4. Determine the institutional arrangements (rules of the game with reference to land management).
5. Describe the agro-ecology (including indigenous practice) of the selected study area).
6. Do a baseline study to determine e.g. the status quo of crop production systems, livestock production systems and production data (yields, etc.) by means of appropriate and reliable data collection methods to produce quantitative data.
7. Select, introduce/implement and test one or more promising (existing/new) water harvesting and conservation techniques on-farm for each crop and rangeland/livestock production system, following a participatory approach. Conduct on-station experiments for fine-tuning of the techniques.
8. Evaluate the impact of the selected water harvesting techniques on the crop and livestock production systems.
9. Measure the impact in terms of increased water use efficiency in the crop and livestock production systems.
10. Measure the technical feasibility, risk, economic viability, social acceptability (including gender issue), environmental impact of the selected water harvesting and conservation techniques.

In order to maintain consistency between WRC reports we have followed the definitions and terminology proposed by Denison and Wotshela (2009) in a report entitled: Indigenous Water Harvesting and Conservation Practices: Historical Context, Cases and Implications. In this report, the definition of rainwater harvesting (RWH) is adopted from Oweis et al. (1999), where RWH is defined as 'the process of concentrating rainfall as run-off from a larger catchment area to be used in a smaller target area. This process may occur naturally or artificially. The collected run-off water is either directly applied to an adjacent agricultural field (i.e. stored in the soil-rootzone) or stored in some type of on-farm storage facility for domestic use and for supplemental irrigation of crops'.

The definition of soil conservation is adopted from Woyessa et al. (2006) as 'A reduction in run-off which results from practices that successfully increase the infiltration capacity of the soil, increase the contact time, and/or reduce surface sealing. It is commonly accepted that covering the soil with a mulch, for example, with a crop residue, will achieve these goals and will also reduce evaporation from the soil surface'.

Soil water conservation in this study is, therefore, interpreted as promoting the additional retention of water within the soil profile through practices such as covering the soil with organic material (mulch), stones and cover crops. The specific aim of these practices is to reduce evaporation from the bare soil during the fallow period or reduce crop evapotranspiration (soil and plant) during the growing period and prevent deep percolation below the root zone.

Internationally and locally there have been numerous attempts to categorise rainwater harvesting and conservation techniques (RWH&CT). A full review of these techniques is presented in Appendix 1. We have followed the simple and pragmatic categorisation of RWH&CT (Figure 1.1) as recommended by Denison and Wotshela (2009) adjusted from the FAO 2003 categorisation. The classification is based on a scale and storage descriptor and adjusted for South African conditions (i.e. annual rainfall > 300 mm). The relationship between the type of water harvesting, rainfall and scale (size) is shown in Table 1.1. The research component of this project focused mainly on the scale of micro-catchment water harvesting, while the scale of rooftop water harvesting was a component of the community water harvesting (Figure 1.1, Table 1.1).

Table 1.1 Ratio of catchment, field size and flow type for water harvesting and conservation systems (taken from Denison and Wotshela, 2009)

Type of WH	Kind of flow	Annual rainfall	Treatment of catchment	Size	Ratio
Micro-catchment	sheet and rill flow	> 200 - < 300 mm	treated or untreated	- 1000 m	1:1-10:1
Macro-catchment	turbulent runoff + channel flow	> 300 mm	treated or untreated	1000 m - 200 ha	10:1-100:1
Floodwater harvesting	flood water	> 150 mm	untreated	200 ha - 50 km^2	100:1-10,000:1

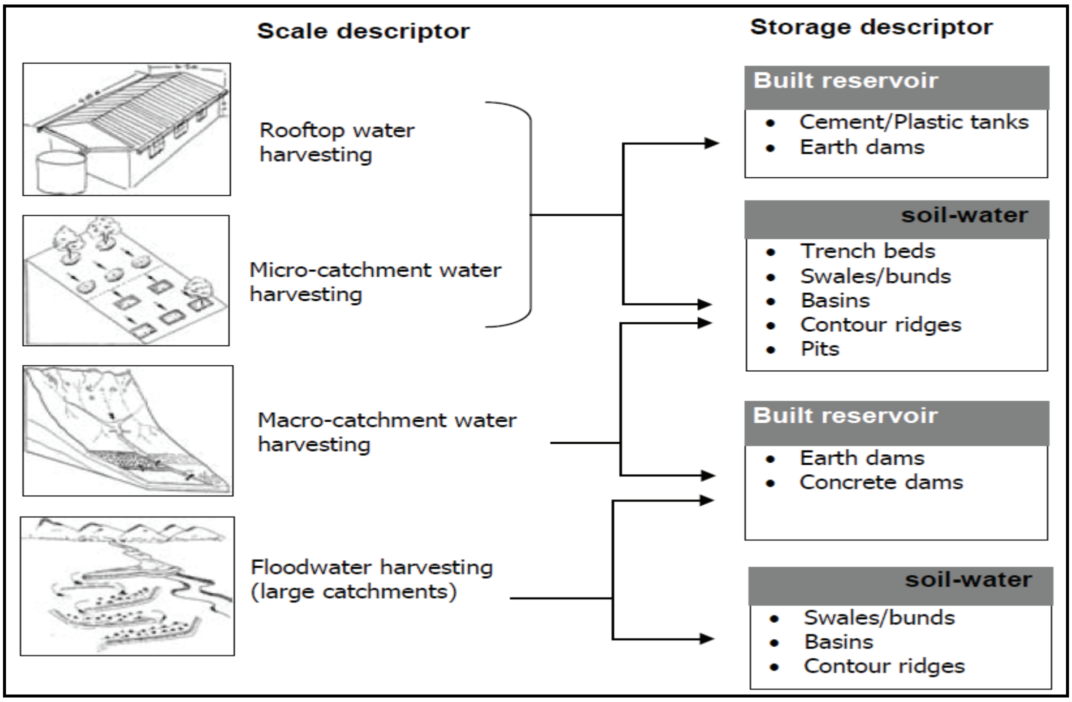


Figure 1.1 Categorisation of rainwater *techniques (after Denison and Wotshela, 2009)*

Many kinds of rainwater harvesting techniques are practised throughout the world. Below is a summary of the different techniques outlined by Kahinda et al. (2008):

a) *In-field* rainwater *harvesting (IRWH) (micro-catchment)*

In IRWH, surface water is retained on the soil surface by use of RWH earthworks, which are designed to act as barriers and control run-off flows to allow for longer infiltration time and storage. The IRWH systems, also known as micro-catchments, are where RWH uses part of the catchment area as the target area (the catchment area and the target area are directly adjacent to each other). IRWH is linked to farming practices and is specifically related to food production and food security.

A specific in-field rainwater harvesting technique (IRWH) developed by researchers from the University of the Free State combines the advantages of water harvesting, no-till, basin tillage and mulching (Hensley et al., 2000). This technique promotes run-off from strips between alternate crop rows which collects in basins and infiltrates the soil where it is stored in the soil profile.

b) Ex-field rainwater *harvesting (XRWH) (macro-catchment)*

Rainwater is harvested from a catchment located at an appreciable distance external to the cropping area. XRWH is also known as macro-catchment RWH; the catchment area is usually not cultivable. Water is diverted from the external catchment and can either be applied directly to the cropping area or it can be stored in a storage facility such as a farm, dam or pond and used at a later stage. These systems may also help in flood control and erosion prevention by holding storm water in reservoirs and discharging at a controlled rate.

c) Domestic rainwater *harvesting (DRWH)*

For domestic RWH practice, rainwater is collected from rooftops, courtyards, natural features such as rock outcrops, compacted or treated surfaces and it is stored in RWH tanks and used for domestic purposes. Storage tanks can be located underground or above ground. It may be household based or community based.

The adoption of techniques by the community will depend not only on the physical and ecological factors, but also on their socio-economic requirements. As these factors will affect the success or failure of the technique implemented, the socio-economic factors will also be evaluated in this project.

CHAPTER 2 NATURAL RESOURCE BASE OF THE STUDY AREA

2.1 General

The study was undertaken in the Baynesfield and Taylors Halt areas approximately 20 km south-east of Pietermaritzburg in KwaZulu-Natal, South Africa (Figures 2.1 and 2.2). The study area falls into the Moist Midlands Mistbelt (Bioresource Unit 5) under subgroup 3 which is found in the area stretching from Cedara to Richmond (Camp, 1999). Lying at an altitude range of 900 m to 1400 m above sea level, the area is characterised by broken and rolling terrain with steep to moderately steep slopes. The agricultural potential is reasonably uniform throughout the area. The area is a communally farmed area, producing mainly maize.

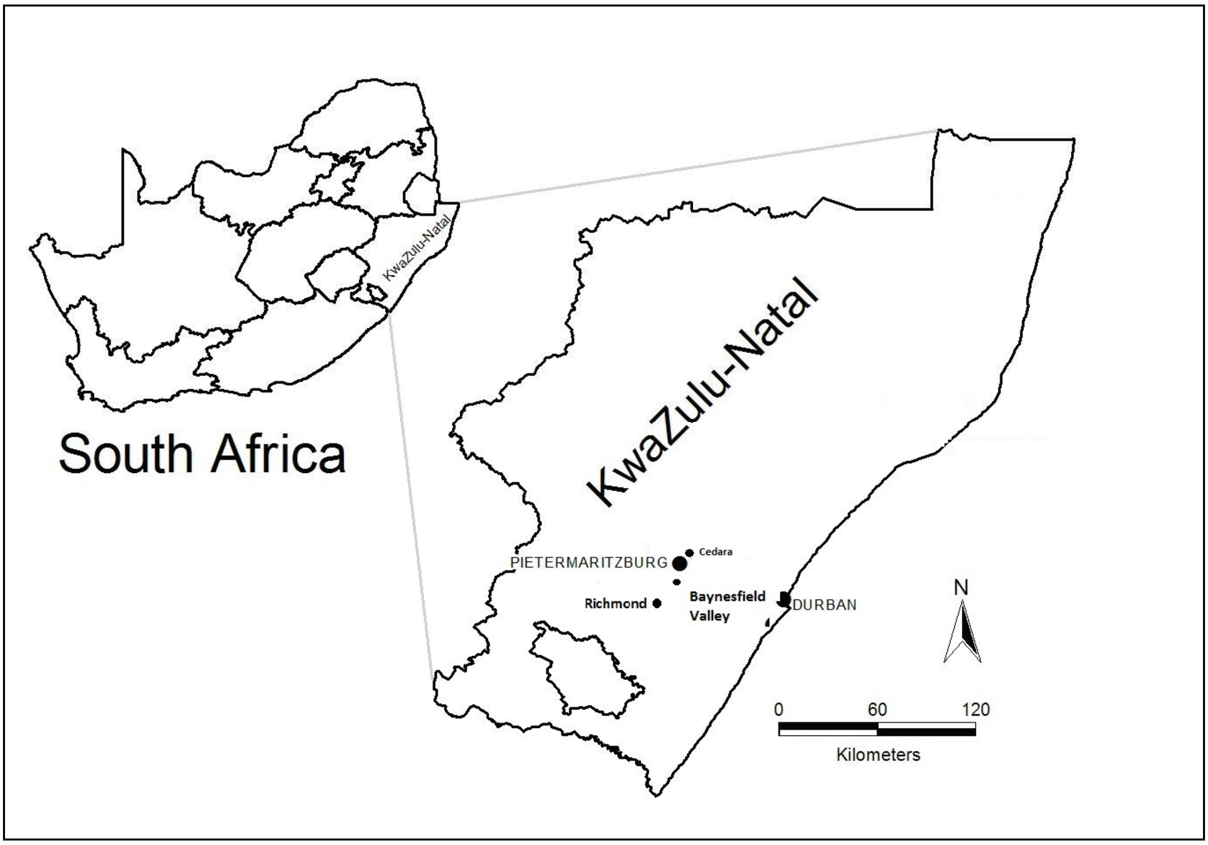


Figure 2.1 The location of the water harvesting study sites in KwaZulu-Natal, South Africa

Figure 2.2 The location of Zakhe Agricultural College, Ntembeni community garden and KwaMncane near Pietermaritzburg, South Africa

2.2 Climate

The region has a temperate climate, with an annual rainfall ranging from 800 mm to 1000 mm (Camp, 1999). Heavy mists are a common and an important feature providing additional moisture. Much of the rain comes in the form of cold front activity, mainly in the spring and early summer. Thunderstorms are common in summer and autumn. The mean annual temperature range is 16.0-17.3°C. The mean January maximum temperature range is 24.8-26.0°C while the mean July minimum temperature range is 4.4-7.6 °C. Moderate to severe frost occurs in frost pockets, with light frost elsewhere. The area is, therefore, classed according to the Köppen System (Peel et al., 2007) as Cwa, being mild mid-latitude (C) with a dry winter (w) and hot summer (a) (Figure 2.3). These climates have an average temperature above 10°C in their warmest months and a coldest month average between −3°C and 18°C. The second letter indicates the precipitation pattern – (w) indicates dry winters (driest winter month average precipitation less than one-tenth wettest summer month average precipitation). The third letter indicates the degree of summer heat – (a) indicates warmest month average temperature above 22°C with at least four months averaging above 10°C.

Climate hazards include occasional droughts, usually of short duration, occasional hail, frost, which varies from slight to severe, and excessive cloudiness during the summer growing season. Hot, north-westerly ("berg") winds, followed by sudden cold temperatures or cold fronts make for unpredictable conditions, particularly in the spring and early summer. The mean annual evaporation range is from 1635-1696 mm (Camp, 1999).

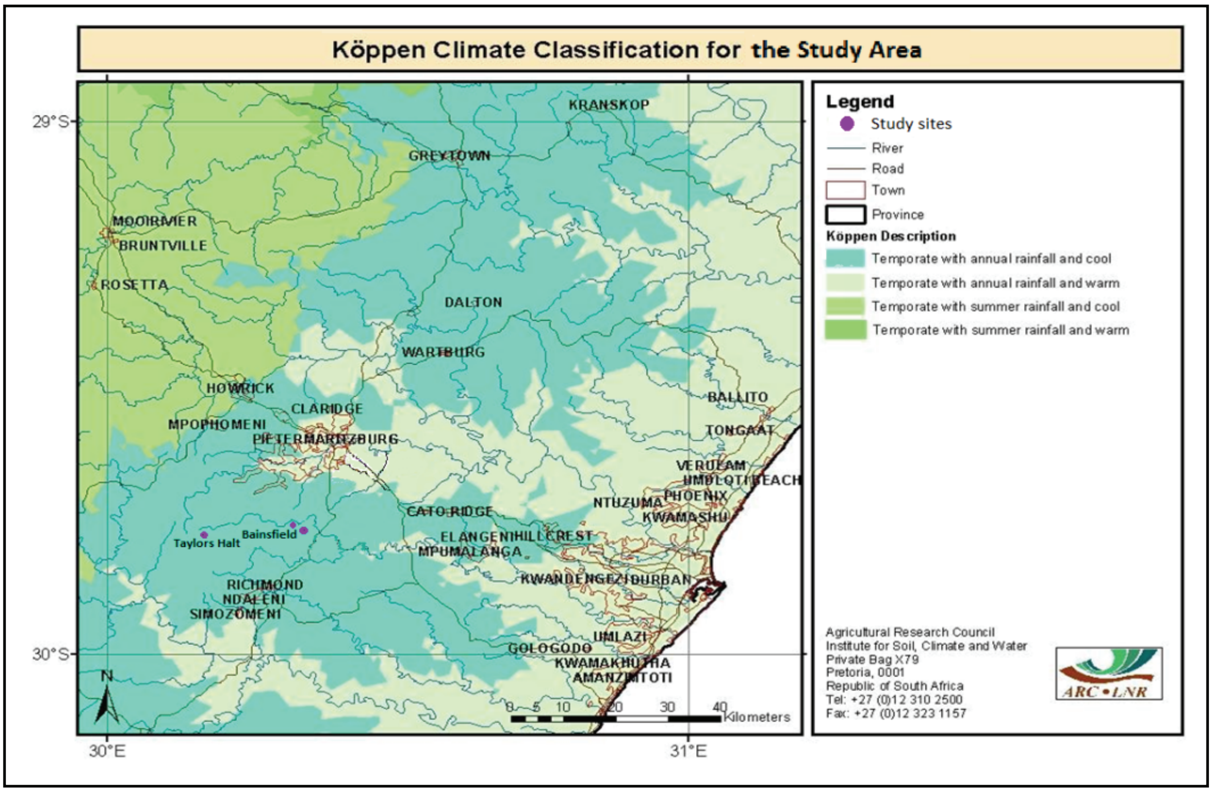


Figure 2.3 Köppen climate classifications for the KwaZulu-Natal Midlands

2.3 Vegetation

The Bioresource Units included in the area are Wc30, Wc32, Xc14, Xc15, Yc14, Zc5 and Zc7 (Figure 2.4) with a combined area of 100067 ha (18% arable and 15% with high potential soils) (Camp, 1999). The general pattern of vegetation is grassland of low grazing value with *Aristida junciformis*, or Ngongoni grass, being the dominant species. On some of the cooler, south-facing aspects which receive more moisture and protection from fire, there are remnants of indigenous forest. A feature of these forests is the abrupt margins where fire has destroyed the ecotone or forest margin comprising, shrubs and young trees. These margins are of great importance in the biodiversity of forests. The contribution of forests to the conservation of water resources needs greater recognition. Most forests have been extensively exploited and *Podocarpus* species, in particular, were felled for building timber in the past. The main danger now exists in the form of uncontrolled fires and further exploitation destroying these remaining forests. Indicator species include *Aristida junciformis* and *Buddleja salviifolia, Greyia sutherlandia* and *Leucosidea sericea* at the upper altitudinal limits. *Pteridium aqualinum* grows mainly on moist south-facing aspects.

A major problem in the area is the invasion of alien weed species into plantations and, to a lesser extent, lands and veld. These weeds are *Rubus cuneifolia* (American bramble), *Solanum mauritianum* (bugweed), *Chromolaena odorata, Pereskia aculeata, Psidium guajava, Lantana camara* and *Acacia mearnsii* (black wattle). Poisonous plants of the area include *Moraea* species on bottomland sites, *Senecio retrorsus* and *Lantana camara* (Camp, 1999). The Working for Water Programme has been active in the area and extensive invasions of black wattle have been removed. The continued removal of alien invasive species which consume large amounts of water is essential for conservation of water resources.

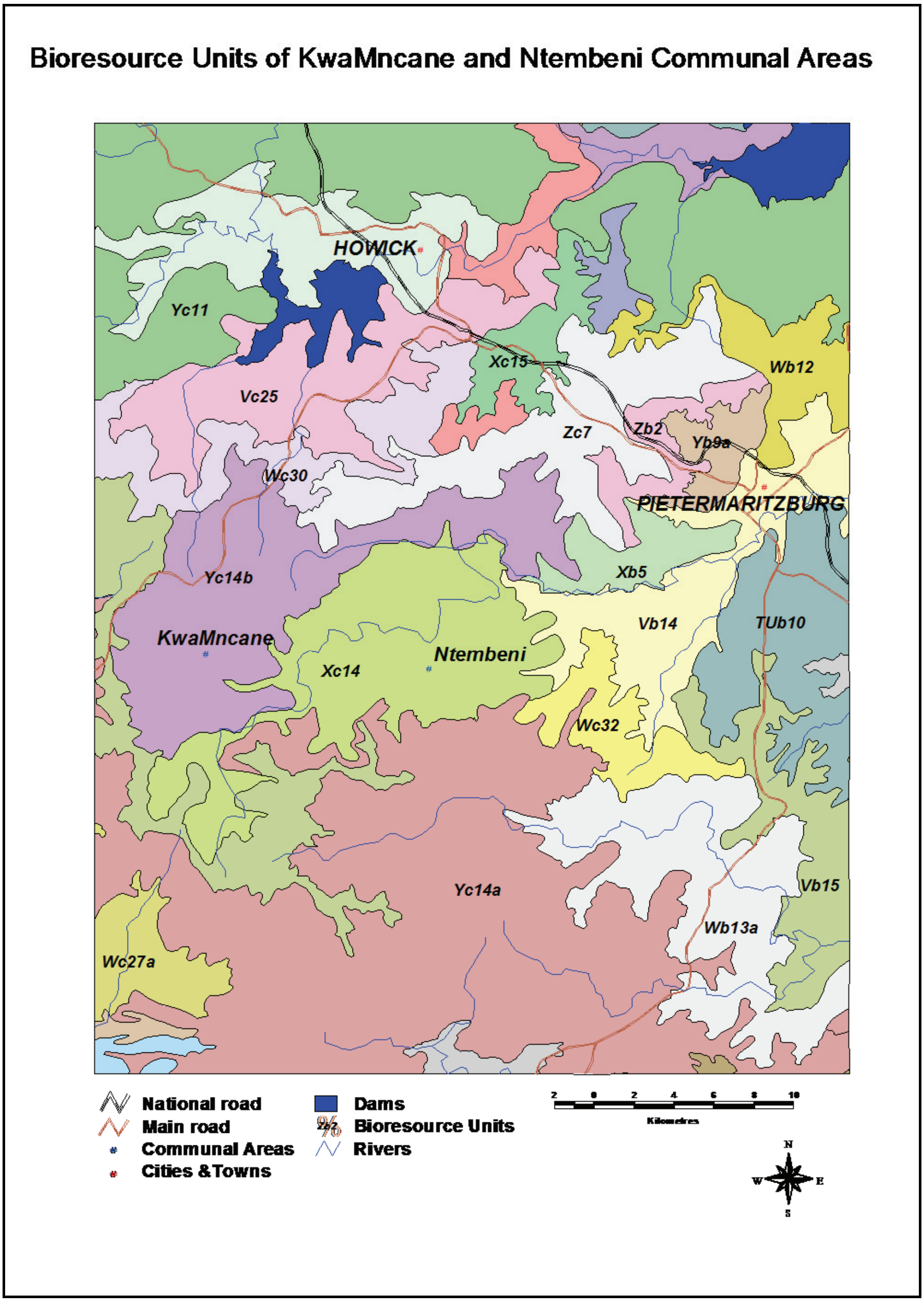


Figure 2.4 The Bioresource Units represented in the greater study area (Camp, 1999)

Veld management in the area is poor. Management practices such as excessive burning, particularly during the season of active grass growth, followed by continuous selective over-grazing has resulted in the destruction of the former *Themeda triandra* grassland. The palatable grass species have been replaced by hardy pioneer species such as *Aristida* *junciformis, Eragrostis plana, Sporobolus africanus* and *Hyparrhenia hirta. Aristida junciformis*, or Ngongoni grass, is a densely tufted and strongly rooted grass with a wiry leaf and is particularly dominant. This grass is grazed only in the very early stages of growth following fire, when the grazing animal is able to pull the entire leaf from the plant. In the late summer the ripening inflorescence is eaten. In many cases where veld appears to be completely dominated by Ngongoni, many palatable species are present, but are in a state of low vigour. A season's rest could improve the grazing value of the veld considerably. Resting of veld is an essential strategy to apply in order to maintain the quality of veld, but is virtually never practised.

2.4 Soils

Proper knowledge of soils and their distribution is essential for the management and design of any agricultural activity and is key to sustainable agriculture. According to Hensley et al. (2006), it is generally accepted that soil quality describes its capacity to sustain plant production, maintain environmental quality and promote both animal and human health. Soils also play a major role in the hydrological cycle and are clearly an important factor in the planning of any water harvesting activities in a region.

In South Africa soils are recognised by their "form" which represents a specific sequence of diagnostic horizons and is the broadest group of the South African classification system (Soil Classification Working Group, 1991). The distribution of South Africa's soil is mapped as "land types" at a scale of 1:250 000 (Land Type Survey Staff, 2004). A land type represents an area displaying a marked degree of similarity with respect to terrain form, soil pattern and climate. The land types are subdivided into nine broad categories, each characterised by a particular soil distribution pattern (Hensley et al., 2006). The soils of the study area are dominated by land type group A, represented by map units Ab (red dystrophic and /or mesotrophic soils) and Ac (red and yellow dystrophic and/or mesotrophic soils) (Figure 2.5). These soils are characteristic of red-yellow apedal, freely drained soils without water tables and belonging in one of the following soil forms: Inanda, Kranskop, Magwa, Hutton, Griffin and Clovelly. The majority of the study area falls within the Ac class of soils. The agricultural potential of these soils is high, in spite of the fact that the nutrient status is very low. The fact that the soils are well-drained and highly leached results in aluminium toxicity and poor phosphorus fixation. Adding lime to the soils in the area is therefore normally recommended.

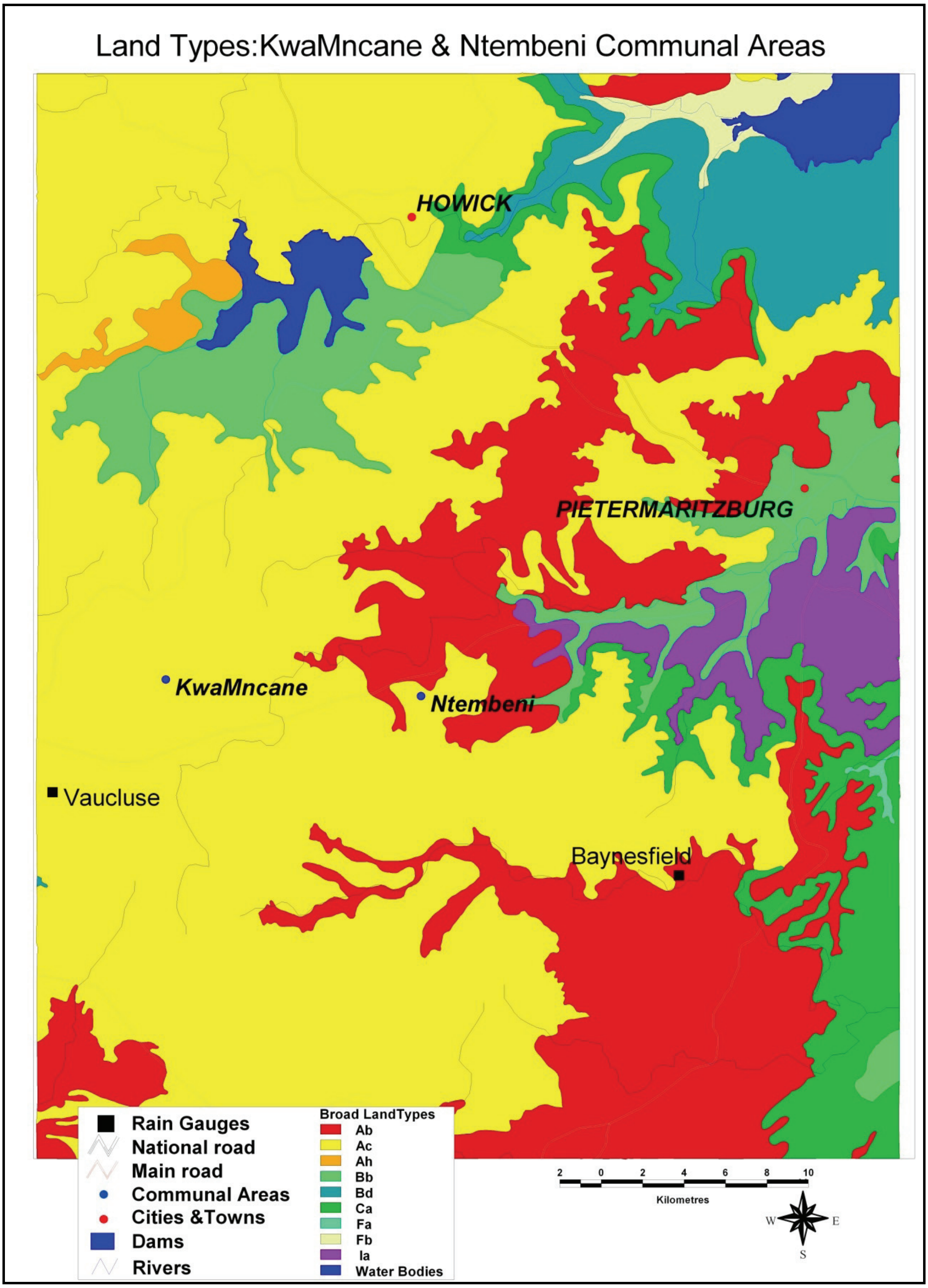


Figure 2.5 The distribution of land type groups A, B, C, F and I in the study area

2.5 Water Resources

The area is characterised by streams rising in the south-facing hills. These streams are a most important source of water for the lower lying areas that they feed and it is essential that planning water harvesting for water conservation takes these into account. Although Umgeni Water has made water accessible for household use, most households cannot afford to use it for food production. Water harvesting, therefore, has the potential to provide affordable water for food security. There is also a great need for spring protection and supplementary irrigation for provision of water for homestead and community gardens.

2.6 Land Use and Potential

The area has a high potential, mainly because of its favourable climate and high potential soils. Most of the area is farmed with annual crops such as maize. Vegetable production is carried out in community and homestead gardens, where there is a high diversity of vegetables including butternut, spinach, Taro (amadumbe), chillies, onions, beans, tomatoes, cabbage, sweet potatoes and beans. In some of the gardens drip irrigation is carried out. However, this is not extensive and it is evident that water harvesting and supplementary irrigation can play an important role in crop production and food security in the region. Other crops suitable for the study area include tea production and avocados that can be grown on deep, well-drained soils. Sugar cane can be grown on sites where the drainage of cold air is good, ensuring that no frost or only light frost occurs.

The veld is of a very poor quality and supplementary feeding is necessary for any livestock enterprise. Maize stover and cabbage leaves from vegetable gardens are fed to livestock in winter. Increased vegetable production through water harvesting will have a positive effect on livestock farming.

Forestry is ecologically suitable for the area and is the most widespread land use form in the adjacent areas owned by Mondi. The most common species grown are gum, pine and wattle. Since trees can be grown successfully in the area, agro-forestry has a potential role to play in agricultural production.

2.7 The Study Sites

The study sites where detailed water harvesting experiments were undertaken were situated in the Umlazi River catchment, in the eastern KwaZulu-Natal province (see section 2.1). Four rural communities live within this catchment: Ntembeni, KwaMncane, Hopewell and Baynesfield. The Ntembeni and KwaMncane communities are located at the headwaters of the Umlazi River and the Umsunduzi River respectively, 50 km from Pietermaritzburg. The two other communities, Baynesfield and Hopewell, are situated in the lower part of the catchment. Pietermaritzburg (35 km from Baynesfield) is the biggest and nearest town which provides supplies to these local communities.

For the selection of the water harvesting techniques and sites a number of important criteria were considered at the outset of the project. Firstly, the nature of the rainfall of the area is critical for the design and selection of the various water harvesting techniques. Although the study sites are relatively close to each other, the hilly nature of the area results in variable annual rainfall amounts at each of the experimental sites (Figure 2.6). The data showed that Baynesfield (Zakhe) in the bottom of the valley (650-750 mm) is much drier than either Ntembeni (950-1050 mm) or KwaMncane (850-950 mm). This trend was also found in the annual temperature variation (Figure 2.7) with Baynesfield (annual average 17°C, altitude 838 m) being 2°C warmer than KwaMncane, which is situated at the top of the mountain (annual average 15°C, altitude 1400 m). The Ntembeni site was in between with an annual average temperature of 16°C.

Although the annual average rainfall and temperature are informative, it is the seasonal distribution of rainfall and temperature that determine the success or failure of a crop. The long term means of monthly rainfall and temperature (1950-1999) for Baynesfield and KwaMncane (Figures 2.8 and 2.9) showed the typical trend found in the summer rainfall regions of South Africa. Winters are cool (average temperature in July 12.9 and 11.1°C at Baynesfield and KwaMncane respectively) and dry (rainfall <10 mm and <15 mm per month at Baynesfield and KwaMncane respectively). Summers are hot and wet (average temperature in January >26°C and rainfall >120 mm (December to February) at Baynesfield and KwaMncane respectively) (Figures 2.8 and 2.9). Opportunities for extending the growing season of crops in the area are in April to May when temperatures are favourable and additional moisture can still be obtained either through soil conservation measures or water harvesting techniques.

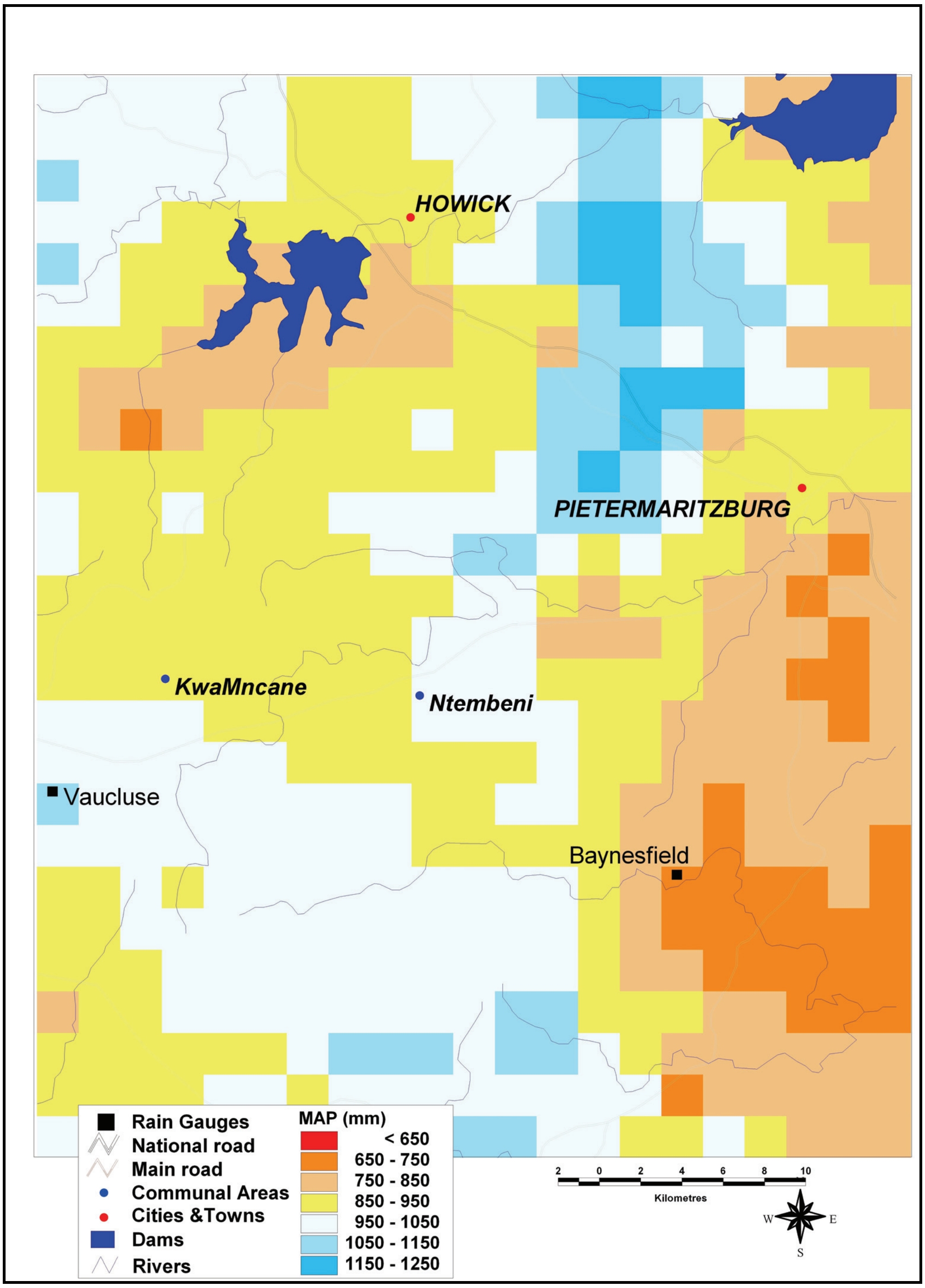


Figure 2.6 The spatial distribution of mean annual precipitation across the three main study sites (Baynesfield, Ntembeni and KwaMncane) (Camp, *1999)*

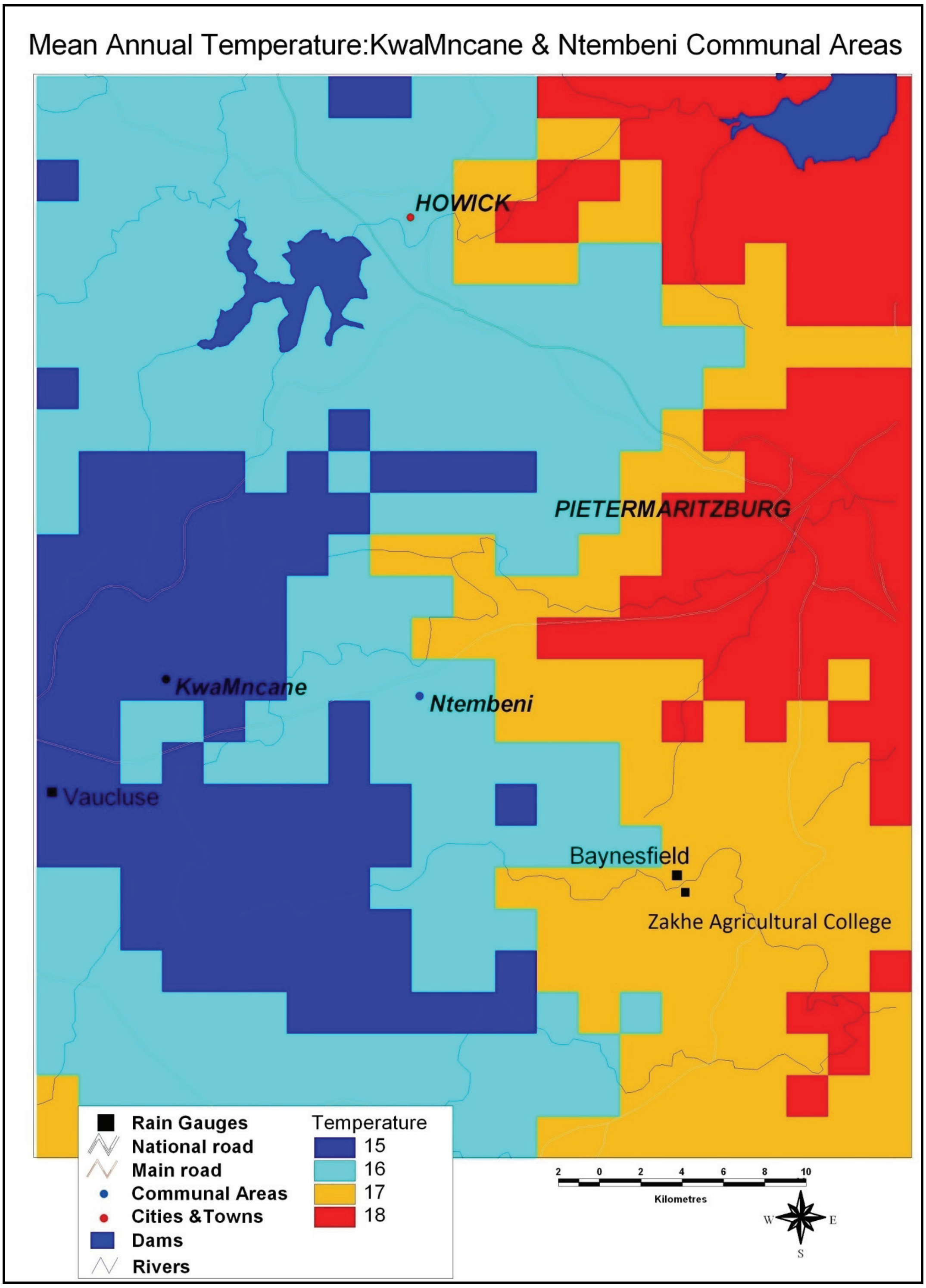


Figure 2.7 The spatial distribution of annual temperature across the three main study sites (Baynesfield, Ntembeni and KwaMncane) (Camp, 1999)

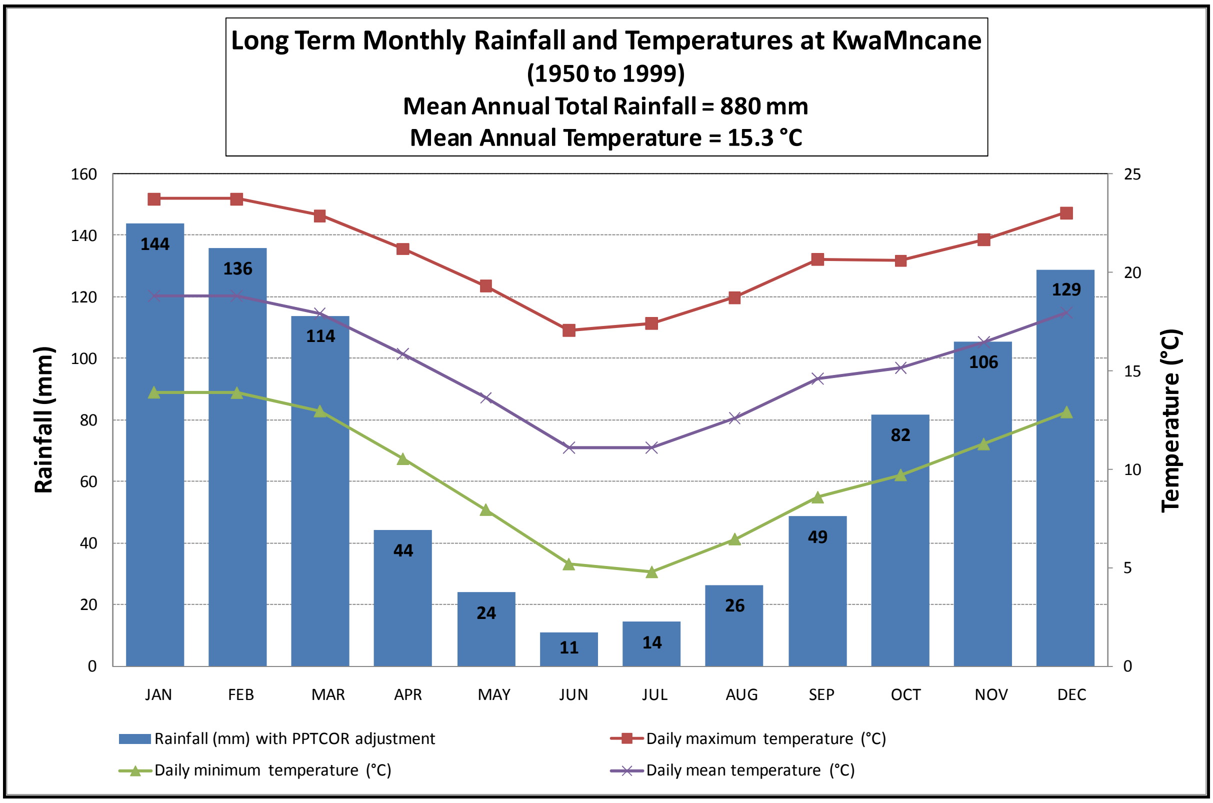


Figure 2.8 The long term (49 year) monthly rainfall and temperature at the KwaMncane study site

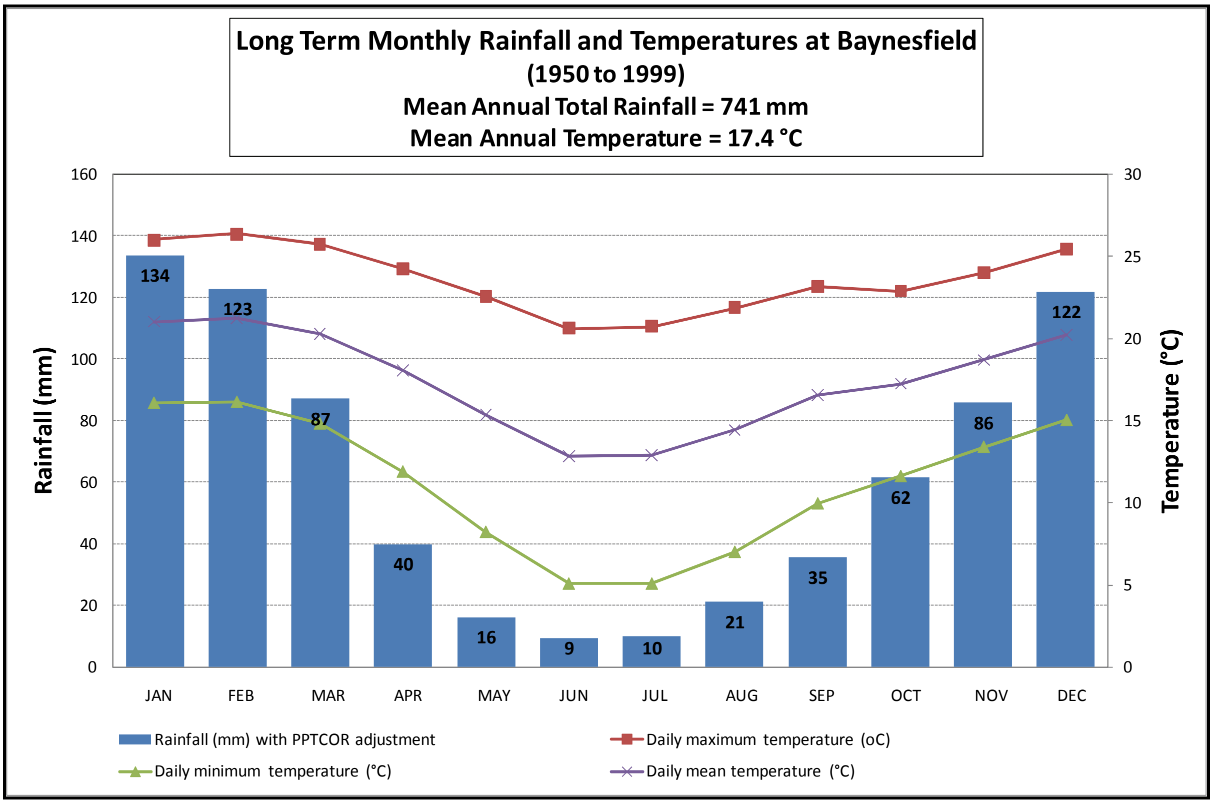


Figure 2.9 The long term (49 year) monthly rainfall and temperature at the Baynesfield study site

Rainfall in the study region is, therefore, both spatially and seasonally variable across the study sites. In summer rainfall is normally associated with convective thunderstorms. The rate at which rain falls ($mm.h^{-1}$), is termed the rainfall intensity. The intensity of rainfall is normally inversely proportional to its duration (FAO, 1991). The statistical characteristics of high-intensity, short-duration, convective rainfall are essentially independent of locations within a region and are statistically similar in many parts of the world (Critchely and Siegert, 1991). Analysis of short-term rainfall data suggests that there is a reasonably stable relationship governing the intensity characteristics of rainfall. Studies suggest that, on average, around 50% of all rain occurs at intensities in excess of 20 $mm.h^{-1}$ and 20-30% occurs at intensities in excess of 40 $mm.h^{-1}$ (Critchely and Siegert, 1991). This relationship appears to be independent of the long-term average rainfall at a particular location.

The planning of water harvesting techniques, therefore, needs to account for the appropriate "design" rainfall, according to which the ratio of catchment or “run-on” to planted or “run-off” area will be determined (Critchely and Siegert, 1991). According to the FAO (1991) “Design rainfall is defined as the total amount of rain during the cropping season at which, or above which, the catchment area will provide sufficient run-off to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be plant moisture stress. If the actual rainfall exceeds the design rainfall, there will be surplus run-off which may result in damage to the structures” (referring to the water harvesting structures).

In this study, the design rainfall was determined for both Baynesfield and Zakhe by means of a statistical probability analysis program (Smithers and Schulze, 2000). This program implements procedures to estimate design rainfall in South Africa and was run with annual data for the study area sites and surrounding areas, and can be used for designing water harvesting techniques in the study region (Table 2.1). To determine the probability of exceedance of the annual rainfall totals for Zakhe and KwaMncane, a graphical procedure of ranking the annual rainfall totals against their probability of occurrence and plotting on normal probability paper was applied to the long term rainfall data (109 and 112 years respectively) (Figures 2.10 and 2.11). Long term data series were required to make the data representative of the long term rainfall patterns of the two selected study sites. The probability of occurrence P (%) for each of the ranked observations was estimated from the equation (Critchely and Siegert, 1991):

$$P(\%) = \frac{m-0.375}{N-0.25} * 100 \qquad \text{eq. 2.1}$$

Where P = probability in % of the observation of the rank m, m = the rank of the observation and N = total number of observations used.

Logarithmic and second order polynomial regression lines were fitted to the KwaMncane and Zakhe data respectively (Figures 2.10 and 2.11). From these curves it was possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability. The design rainfall is usually assigned to a certain probability of occurrence or exceedance. If, for example, the design rainfall with a 67% probability of exceedance is selected, this means that on average this value will be reached or exceeded in two years out of three and therefore the crop water requirements would also be met in two years out of three.

Design rainfall analyses for Zakhe and KwaMncane showed that for Zakhe the seasonal rainfall amount for a probability of exceedance of 66% (two out of three years) was 600 mm and for 33% (one out of three years) 800 mm. For the same probabilities of exceedance for KwaMncane, the rainfall amounts were approximately 900 and 1100 mm for the 66 and 33% exceedance levels respectively (Figures 2.10 and 2.11). These results illustrate the importance of recognising the site differences in design rainfall amounts, even in sites situated relatively closely together (<15 km). For an equivalent crop area and water use, the “run-on” area at Zakhe would need to be 33% (600/900*100) larger than at KwaMncane.

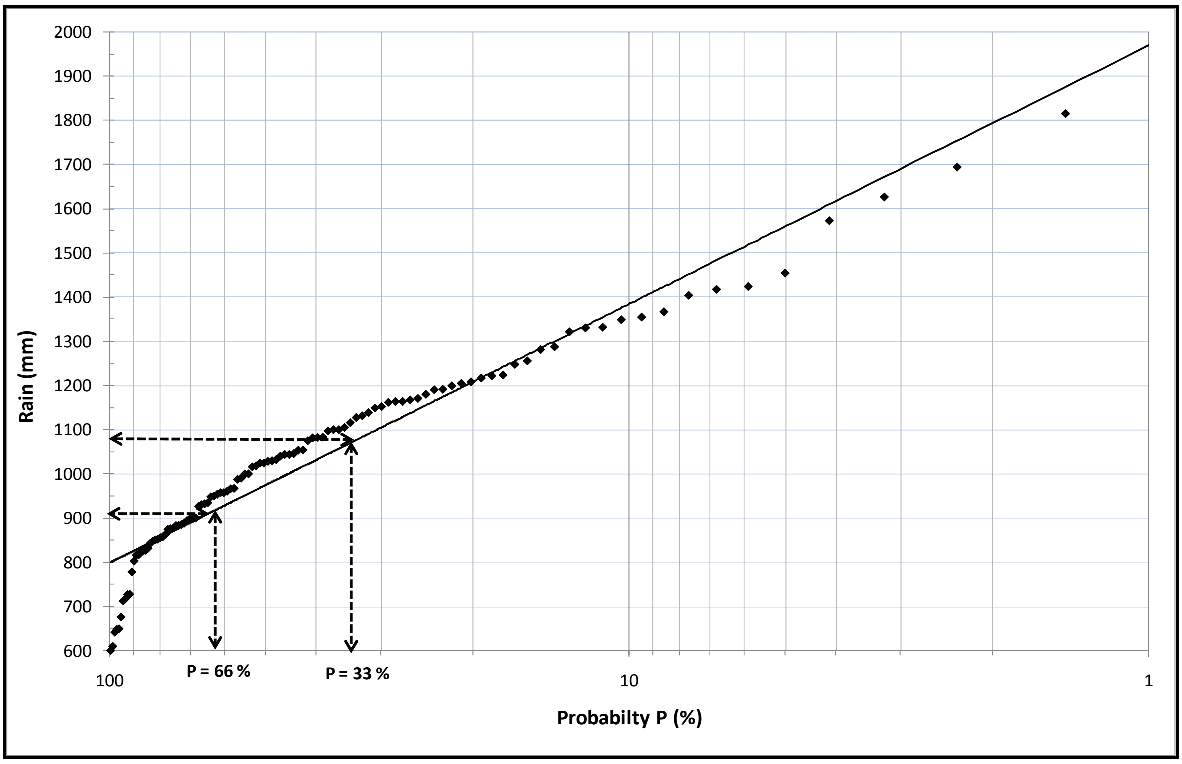


Figure 2.10 Probability diagram with regression line for an observed series of annual rainfall totals – KwaMncane

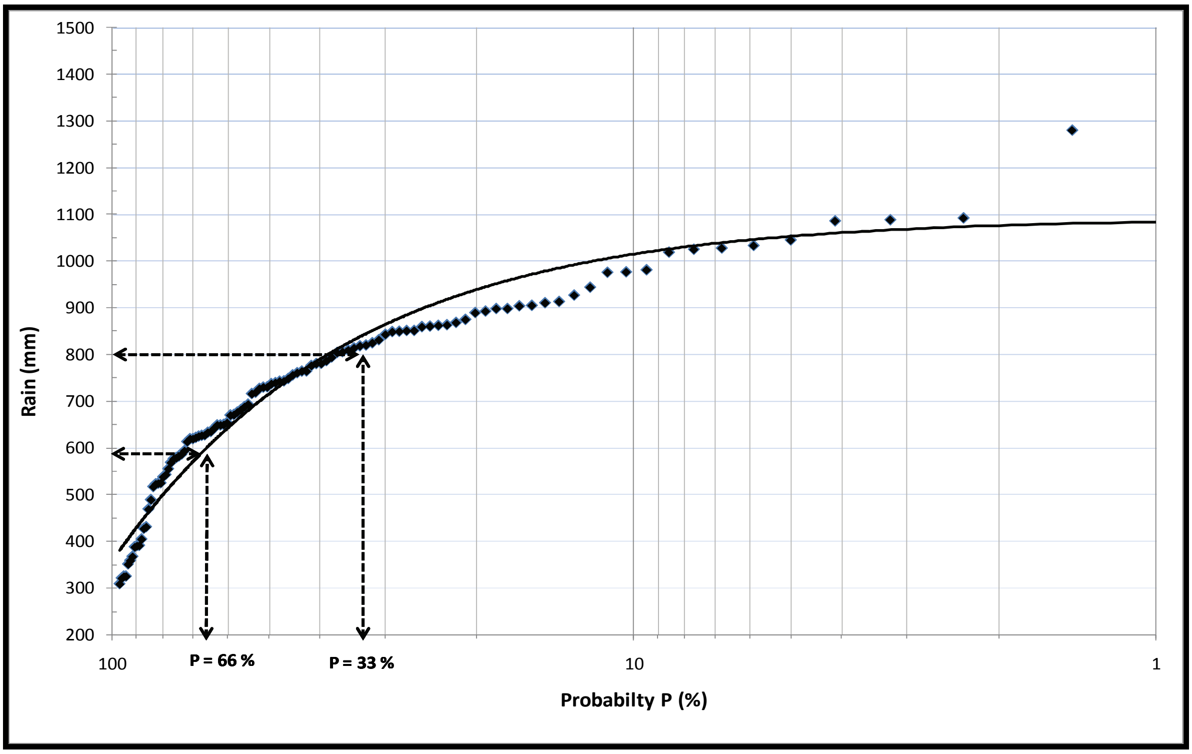


Figure 2.11 Probability diagram with regression line for an observed series of annual rainfall totals –Zakhe

Table 2.1 Design rainfall for the study sites and adjacent rainfall stations

[illegible]

CHAPTER 3 BASELINE SOCIO-ECONOMIC STUDY

3.1 Background

Agriculture in South Africa has a key role in building a strong economy by increasing incomes and employment opportunities for the poor (NDA, 1995). Although agricultural production makes a small contribution to household income, over one third of rural households continue to engage in agricultural production. This makes agriculture the third most important livelihood strategy used in rural areas after wages and remittances (May, 1998). A livelihood is secure if strategies result in improved food security, more income, increased well-being and secure rights to water and land resources (Ellis, 2000). Although agriculture is one of the essential livelihood strategies in rural areas, poor water supplies pose a major constraint for rural households (Schuh, 2000).

For most regions of the South African provinces there are little available data that link agriculture and food security. An understanding of the direction and nature of socio-economic changes among rural households is the foundation of all agricultural and rural development initiatives. Thus, a socio-economic survey was the first step in this project to develop sustainable techniques and practices for water harvesting and conservation to improve agricultural production for resource-poor households. The survey gave a comprehensive description of assets and resources that exist within the community to enhance rural livelihoods. This was carried out with the active involvement of the community itself for the purpose of developing an action plan to improve rural livelihood security.

Different individuals, households and social groups have varying levels of interest in agricultural production, livestock, management of common property resources, non-agrarian production and domestic and agricultural water uses. Combinations of water use will determine the form of people's stake in these resources. Sustainable water resource management must be part of a broader agricultural production programme where a balance between technical, economic and social intervention is needed. Water harvesting and conservation are key aspects to sustainable agriculture and the viability of many rural livelihood systems.

A prerequisite to enhancing the contribution of water resources to sustainable livelihoods is an institutional context which helps to create conditions whereby the resource-poor households can gain access to the resources on a sustainable basis. More action-oriented socio-economic research is needed to understand specific forms of rural livelihoods in relation to water resources. This is important because people's access to water in rural areas affects their agricultural production and food security substantially. Solutions must therefore be found that focus on promoting the active role of rural-poor households in food production and income generation as a way to empower them to overcome the many barriers linked to poverty and managing water supplies.

3.2 The Problem

In baseline studies, socio-economic factors need to be addressed at both household and community level. One of the critical factors affecting the productivity in farming at the household and community level is the shortage of water. Many rural communities do not have access to adequate water supplies for household use and agricultural activities. Rural areas are in desperate need of water for irrigation. A piped water supply system is usually the best option, but in poor and scattered communities in rural areas it is too expensive and maintenance can be a problem. The main aim of the study was to describe the socio-economic aspects of how households and communities manage their water supplies and the potential impact of water harvesting on food security.

3.3 Research Objectives

The specific objectives of the socio-economic study were to:

- Determine the structure and composition of rural households in terms of role of gender and generation in division of labour (power and authority).
- Determine household livelihood indicators, namely assets and resources and income and expenditure.
- Determine the effect of seasonality on agricultural activities.
- Identify practices and techniques used in water harvesting and conservation.
- Identify water supply sources for agricultural production and households.
- Determine gender and generation roles in agricultural production.

- Identify methods of agricultural production used in crop and animal husbandry.
- Evaluate attitudes of households concerning water harvesting and conservation.
- Identify constraints in villages and communities pertaining to the implementation of the water harvesting and conservation project.
- Identify interactive components determining local food security and institutional arrangements.
- Assess resources of people.
- Identify opportunities available to support socio-economic development.

The technology of rainwater harvesting systems is known, but "what is most needed is the moral acceptance of the technology and the political will to implement the systems" (Gnadlinger, 2000).

3.4 Study Design

The socio-economic survey was an applied descriptive study employing both qualitative and quantitative research techniques. It was found necessary not only to quantify the socio-economic variables, but also to find explanations of behaviour pertaining to agricultural production and the related constraints. Qualitative techniques were directed towards gaining an understanding of the meaning of people's everyday lives from their point of view. Participatory rural appraisal (PRA) techniques were used because they made it possible to build close working relationships with communities and they were cost-effective. In order to improve accuracy of data, triangulation became important. For this reason it was necessary to use more than one method of data collection for validation.

A purposive sample was selected using non-probability techniques. Hence clusters of homesteads were selected in each area. In a cluster, 33% of homesteads were sampled. Clusters in areas with high potential for water harvesting to enhance agricultural activities were given priority. Forty households were included in the sample of Ntembeni and 50 at KwaMncane.

3.5 Methods

3.5.1 Focus group discussion (FGD)

Qualitative data were collected from FGDs. Interview guides were used to interview groups organised around gender, generation and agricultural activities. Focus group discussions comprising men, women, mixed men and women, the youth and vegetable gardening members were conducted.

Three FGDs were conducted in each area. The first FGD comprised members of the community gardening group. The second was formed by a group of men and women who were not members of the gardening group and the third one comprised the youth. The FGDs comprised small groups of 10-15 people led by a facilitator to cover a minimum range of topics in the discussion guideline. Participants of the FGDs provided information that was specific to direct the discussions towards concrete and detailed accounts of their experiences. The FGDs fostered interaction that explored participants' feelings and opinions in some depth.

3.5.2 Key informant interviews

Key informant interviews were used to collect qualitative data from knowledgeable people about the area, water harvesting methods and agricultural activities. Four community key informants and one agricultural extension officer in each area were interviewed.

3.5.3 Transect walks

The researcher, community members and assistants systematically walked through the study area along water courses to observe, discuss and identify local technologies for water harvesting. The community leaders decided on the most interesting routes through the villages for transect walks. They were asked to point out along the way everything that was relevant to water resources and farming (e.g. crops that were grown, the type of soil, community gardens and different types of water sources and technologies used to conserve water). Together with the group, the community leaders looked at the problems encountered by farming households and individual farmers and discussed possible solutions. The first transect walk took place in May 2003.

3.5.4 Household survey

Homestead visits were done to provide an opportunity for discussion of real problems and means of coping with inadequate water supply and how to harvest and conserve water. A questionnaire was designed to collect the quantitative data and covered basic socio-economic variables (gender, age, household size, education, income, household and farm assets, land ownership, livestock). There were also questions on water harvesting, crop production, irrigation, livestock and constraints to agricultural production. The questionnaire was pre-tested among community members in the study area. The comments of interviewees and the experience of the interviewers were used to revise the questionnaire before its administration.

Twenty questionnaires were administered to households within two clusters of the sub-ward that were conveniently selected on the basis of accessibility in 2005. Households were approached on the basis of the availability of the head of household or *de facto* head of household to respond to questions. An effort was made to ensure representativeness of the community.

3.6 Results – Ntembeni

3.6.1 Demographics

Interviews were conducted in 37 households at Ntembeni. Households in this community are composed and/or headed mainly by women (76%) and pensioners (46%) as shown in Table 3.1 and Table 3.2 respectively. The reason may be that most of the male members of the family are migrant workers who only come to their families when they are on vacation leave, weekends or public holidays.

Table 3.1 Gender of respondents at Ntembeni

Demographics	Numbers	Percentage
Female	28	75.7
Male	9	25.3
Total No. of Respondents	37	100

Table 3.2 Age of household head of Ntembeni respondents

Age breakdown (years)	Numbers	Percentage
18-5	4	11
36-45	6	16
46-60	8	22
Above 60	17	46
Age unknown	2	5
Total	37	100

3.6.2 Infrastructure

The access road to the community is gravel; however the road is usable for the whole year. The majority of the respondents (57%) have access to public telephones with 16% owning cellular phones or having a landline in the house. It takes 20-30 minutes by foot for 41% of the respondents to get to the nearest communication facility. Furthermore, 76% of the respondents have access to the post office. The following schools shown in Table 3.3 are found in the area.

The average distance travelled by residents to any one of the facilities in Table 3.3 is approximately 5 km. There are no adult education centres in the area, nor are there tertiary institutions situated in the area. There is no library, however a number of residents have access to the media sources shown in Table 3.4.

There is no hospital in the area; however there is one clinic, one mobile clinic and one medical practitioner that serve the area. It takes approximately 30 minutes to one hour for the majority (40.5%) of average residents, travelling by public transport, to get to any one of the health facilities.

The majority of the households (62.2%) are equipped with electricity and wood is the main (40.5%) source of fuel used in the household.

3.6.3 Household water and sanitation

The main type of water source used by the community is public tap (86.5%) and few households use boreholes, springs, and wells. The entire community is equipped with pit toilets.

Table 3.3 Educational facilities near to Ntembeni

Educational facility	Numbers
Pre-primary schools	2
Lower primary school	2
Higher primary school	1
High school	1

Table 3.4 Members of the community with access to media sources

Media source	Percentage
Television	56.8
Newspapers	16.2
Newsletters	2.7
Library	0
Non response	24.3

3.6.4 Socio-economic profile of Ntembeni

The main source of income for most households (51%) is the state old age pension. Another source of income is the child benefit received by unmarried women from the state (22%). As the unemployment rate in the area is high, it was found that household members in the economically active ages tended to depend on relatives who received a state pension. In addition, there are many children who are born out of wedlock or to unmarried mothers. Most of the unmarried mothers depend on their parents for livelihoods. Illegitimate children add to the number of household dependents. Food shortages were reported in households with many dependents.

Income received by households (Table 3.5) indicates that most households receive income that is below the poverty line. Furthermore, most of the households have a high number of dependents that cannot be sufficiently supported by this income. Only 16% of households earn an income above R1000 per month.

Table 3.5 Household income per month for Ntembeni

Income category	Numbers	Percentage
Less than R200	5	13.5
R200-R500	5	13.5
R501-R1000	17	46
Above R1000	6	16
Income undefined	4	11
Total	37	100

Table 3.6 Number of dependents per household in Ntembeni

Dependents category	Number	Percentage
1-5	7	19
6-10	14	38
11-15	3	8
16-20	1	3
Undefined	12	32
Total	37	100

The average household size in Ntembeni is eight. Thirty eight percent of respondents had between 6-10 people per household as indicated in Table 3.6. In many households pensioners are responsible for the well being of grandchildren. The high number of dependents has a negative effect on livelihood security of households in the area. Food shortages were reported to be prevalent in most households.

Table 3.7 Educational level of head of households

Educational level	Number	Percentage
No Education	12	32
Grade 1-	21	57
Grade 8-12	4	11
Post-school	0	0
Total	37	100

The majority of the heads of households are semi-literate having dropped out of formal education between Grade 1 and Grade 7. Table 3.7 indicates 57% in this category. Furthermore 32% of them have never been to school. Adegboyega et al. (1997) state that improving economic conditions plays an essential role in reducing illiteracy. A high level of illiteracy in Ntembeni has an impact on the socio-economic status of numerous households.

3.6.5 Community activities

There are no home industries or any form of household employment in the Ntembeni area. The most common type of community based organisations currently operating in the area are gardening clubs. The membership gender of these clubs is dominated by males (78.4%). However, 64.9% of females hold positions in the school governing bodies and 2.7% in tribal authority council.

Adult basic education is one of the government development projects currently taking place in the area. There are also agriculture and rural development extension programmes operating. 5.4% of the respondents stated that these programmes are an opportunity for the community to enhance the quality of life for their households in the area. The water harvesting project run by Zakhe Training Institute is the only non-governmental project present in the area.

Respondents made a list of constraints the community is facing with regard to development (Table 3.8). High unemployment (78.4%) is the major problem facing people in the Ntembeni community. Unemployment is much higher than the norm for South Africa (25.2%) (Stats SA, 2010) indicating that the project has the potential to have a high impact on people's livelihoods.

Table 3.8 Community constraints to development

Constraints	Percentage of respondents
Unemployment	78.4
Lack fencing and other inputs for the gardens	8.1
Shortage of water	5.4
Lack of public transport	5.4
Theft	2.7

3.6.6 Land ownership and land use

The total area of land is under common property and is controlled by the traditional authority (tribal council). The majority of the residents (91.9%) have land-use rights for cultivation and have been allocated less than a hectare of land for agricultural production. However, only 70.3% of the residents use this land for farming. Individual homestead gardens are mainly used for summer production due to water unavailability in winter. There are 32.4% of the residents who use less than one hectare of the land for communal gardens. The communal vegetable garden was allocated to the project beneficiaries by the local authority (Induna). The community garden was divided into small plots by the committee of the vegetable garden and each member was allocated a plot that they had rights to use. However, some people with rights to use the plots did not use them, resulting in unproductive plots in the communal garden.This caused some conflict as these fallow plots were perceived to be breeding sites for pests and diseases. Through negotiations, some of the non-users (mainly the old people who could not work the land) offered their fallow plots to active producers. However, no disciplinary measures were taken to those who did not use their plots. The main reason attributed to this was fear of the tribal authorities. With more inputs given to them through the project as a result of the implementation of the water harvesting techniques, more land was acquired from the Induna, and the garden was extended. The project team had to report to both the local and traditional authorities on all aspects of the communal garden. One of project‘s successes was its intervention to empower the committee to request the “owners” of fallow plots in the communal garden to hand over their user rights to others. There were some positive responses as some “owners” started to use their fallow plots and some gave their user rights to others.

The type of vegetables and crops grown in the home and communal gardens are shown in Table 3.9. The peak season for land cultivation is summer, the rainy season. Therefore, most agricultural activities take place in summer. Modern agriculture has been practised in the area as 57% of the farmers engaged in agricultural production used inorganic/chemical fertilisers and 32.4% used powered equipment such as tractors, harvesters and threshers.

Approximately 24.3% of households use their agricultural produce for consumption at home, whereas 21.6% use their produce for both home and commercial use. There is no formally established market for agricultural produce in this community.

Table 3.9 Vegetables and crops grown in home and communal gardens at Ntembeni

Vegetable/crop	Garden location	Percentage of respondents
Potatoes	Home	13.5
Sweet potatoes	Communal	13.5
Vegetables (cabbages, carrots, chillies, etc.)	Home	13.5
	Communal	18.9
Peas and cabbages	Communal	13.5
Potatoes and vegetables	Home	10.8
Potatoes and beans	Home	2.7
Maize	Home	2.7
Other		10.9

3.6.7 Water supply and water use

The main source of water supply for agricultural production for the majority of the farmers (70.3%) is the Umgeni pipe system followed by streams, which are used by 10.8% of the farmers. The main problems associated with water supply are listed in Table 3.10 according to the highest percentage of occurrence.

Table 3.10 Problems with water supply at Ntembeni

Problem with water supply	Percentage
Shortage of water	51.4
Sharing of water pipes	21.6
Blocked pipes	8.1
Shortage of water + blocked pipes	2.7
Sharing of pipes + shortage of water	2.7
Other	13.5

Only 43.2% of the residents have participated in water harvesting activities. Dams and tanks were suggested by 35.1% of the residents as improvements that are needed for water harvesting compared to 13.5% and 8.1% for dams only and tanks only respectively.

Although the supply of water for the community garden at Ntembeni was not enough, there were no rules and regulations on how to use the scarce resource which resulted in conflicts. To resolve this, the project team divided the garden into two portions: upper and lower. Beneficiaries in the upper portion could use water on Mondays and Tuesdays, while Wednesdays and Thursdays were exclusively for the lower portion beneficiaries. Fridays and Saturdays were open to everyone. This initially worked, but in winter when there were very low levels of water and high water demand, more conflict was experienced as the two days was not be enough for each group. Eventually, the beneficiaries chose two men who were empowered to monitor and make sure everyone abided by the rules.

When the project started, a communal garden committee was present but not functional. No meetings were held and hence no decisions were taken. One of the tasks of the project team was to empower the committee. This resulted in the election of new members and regular meetings every Tuesday. The committee was then tasked by the members of the garden to manage the water. The committee also started to discipline people who were not using plots. However, this was not entirely successful as some people ignored these actions. Although the committee was advised to report this to the Induna, this did not happen.

Participants of the water-harvesting project indicated their expectations after the project (Table 3.11). Although 43.2% expected rainwater harvesting to increase their profit, a high percentage (32.4%) had no expectations, a factor which must be considered by the project.

Table 3.11 Expectations of the participants after the projects at Ntembeni (2008)

Expectations	Percentage
Profit	43.2
Good harvest	10.8
Improvement in the gardens	8.2
Food security	2.7
Plenty water	2.7
None	32.4

3.7 Results – KwaMncane

3.7.1 Demographics

Interviews were conducted in 43 households at KwaMncane. The number of females who are heads of households is slightly higher than the number of males in this community (44.2 vs. 34.9%). Most households are composed of or headed by mature adults rather than pensioners as shown in Tables 3.12 and 3.13. Only 7% of the respondents have completed tertiary education at college or university level.

Table 3.12 Gender of respondents in KwaMncane

Demographics	Numbers	Percentage
Female	41	95.3
Male	2	4.7
Total no. respondents	43	100

Table 3.13 Age of household head in KwaMncane

Age Breakdown (Years)	Numbers	Percentage
18-35	3	7.0
36-35	12	27.9
46-60	21	48.8
Above 60	5	11.6
Age unknown	2	4.7
Total	43	100.0

3.7.2 Infrastructure

The road leading to KwaMncane is gravel; however the road is usable for most of the year. There are public telephones in the area with 28% of the respondents owning either a landline in the house or a cell phone. It takes an average of 20 minutes for other residents to get to the nearest communication facility. There is one post office in the area. There is no library and no newsletter that comes to the area. Only 2.3% of the respondents read newspapers, whereas 51.2% of the households own a television set. The majority of the households (69.8%) are equipped with electricity. Wood is the main source of fuel (65.1%) used in the household, followed by paraffin.

There are six schools in the area (Table 3.14), but no adult education centres nor tertiary institutions situated in the area. There is no hospital or mobile clinic but there is one clinic and two private medical practitioners that serve the area. The average distance travelled by residents to any one of the health facilities is approximately 4 km.

Table 3.14 Educational facilities near KwaMncane

Educational facility	Numbers
Pre-primary schools	2
Lower primary school	2
Higher primary school	1
High school	1
Total	6

3.7.3 Household water and sanitation

The main types of water sources used by the community are the combinations of public taps, spring water and rainwater and a few households use boreholes, springs and wells. The entire community is equipped with pit toilets.

3.7.4 Socio-economic profile of KwaMncane

The main sources of income in order of importance at KwaMncane are shown in Table 3.15. Income received by households (Table 3.16) indicates that most households receive income that is below the poverty line. Furthermore, the high number of dependents per household (Table 3.17) indicates that this income is unlikely to be sufficient to support these dependents.

Table 3.15 Source of income for respondents at KwaMncane

Sources of income	Percentage
Temporary jobs	25.6
Old-age pension	23.3
Husbands' salaries	14.0
Traders	14.0
Children's support grants from the state	7.0
Saving's club	7.0
Children's contribution	4.7
Pension and temporary jobs	2.3
Agriculture	2.1

The low contribution of agriculture to household incomes (2.1%) supports a more detailed analysis by Van Averbeke (2008) which showed that from 1996 to 2003, farming contributed 6-12% of household income on rain-fed or dry land settlements. This indicates that rainwater harvesting has the potential to increase agricultural production and rural household incomes.

Table 3.16 Household income per month for KwaMncane

Income category	Numbers	Percentage
Less than R200	12	27.8
R200-R500	7	16.3
R501-R1000	10	23.3
Above R1000	3	7.0
Income undefined	11	25.6

Table 3.17 Number of dependents per household for KwaMncane

Dependents category	Numbers	Percentage
1-5	14	32.6
6-10	16	37.2
11-15	3	7
16-20	1	2.3
Undefined	9	20.9
Total	43	100.0

3.7.5 Community activities

There is only one home industry for sewing in the area and no household employment. The types of community-based organisations present in the area are shown in Table 3.18. The membership in these organisations is well balanced with 32.6% of membership composed of both genders in any one organisation. However, 11.6% of women have positions in school governing bodies. There are no government development projects or agriculture and rural development programmes currently taking place in the area. The water harvesting project run by Zakhe Training Institute is the only non-governmental project present in the area. Planting and harvesting crops was indicated by respondents (2.3%) as the only opportunity that the community has to enhance the quality of life of the households in the area.

Table 3.18 Types of community based organisations at KwaMncane

Type of organisation	Numbers
Women and youth	5
Gardening	4
Youth	3
Youth and gardening	3
Women	2
Women, youth and gardening	1
Youth gardening and cooperatives	1
Total	19

Table 3.19 shows the constraints faced by the community with regard to development. As in Ntembeni, the unemployment rate (65.1%) is much higher than the norm for South Africa (25.2%) (Stats SA 2010), indicating that the project has potential to have a positive impact on the livelihoods of the KwaMncane community.

The residents expressed their most important needs (Table 3.20) for their households in particular and their community in general. The greatest need (37.2%) was shortage of land for crops indicating that this will be one of the major challenges facing the project.

Table 3.19 Community constraints in KwaMncane

Constraints	Percentage
Unemployment	65.1
Child care	7.0
Shortage of water	4.6
Diseases	2.3
Poor road conditions	2.3
Other	18.7

Table 3.20 Household and community needs in their order of importance at KwaMncane

Households/community needs	Percentage
Land for planting crops	37.2
Job opportunities	34.9
Improved infrastructure	7.0
Recreational facilities	9.3
Social facilities	7.0
Land for grazing	2.3
Improved housing	2.3

3.7.6 Land ownership and land use

The land ownership of KwaMncane is the same as Ntembeni with the traditional authority governing land use and user rights. The majority of the residents (90.7%) have user rights to land for agricultural purposes. However, only 72.1% of residents use this land (<1 ha) for agricultural production. There are about 7% of the residents who use 1-2 hectares of land for communal gardens.

The peak season for land cultivation is summer, the rainy season. Therefore most agricultural activities take place in summer. There is a low application of modern agricultural practice in KwaMncane since only 11.6% of the farmers engaged in agricultural production used synthetic/chemical fertilisers and only 2.3% used powered equipment like tractors, harvesters and threshers. The type of vegetables and crops grown in the home and communal gardens are shown in Table 3.21.

The majority of the households (74.4%) use their agricultural produce for consumption at home, whereas only 7% use their produce for both home and commercial use by selling it to the neighbours. There is no formally established market for agricultural produce in this community.

Table 3.21 Vegetables and crops grown in home and communal gardens at KwaMncane

Vegetable/Crop	Garden location	Percentage
Potatoes	Home	2.3
Sweet potatoes	Communal	11.6
Vegetables (cabbages, carrots, chillies, etc.)	Home	37.2
	Communal	7.0
Peas and cabbages	Communal	13.5
Potatoes and beans	Home	20.9
Other		7.5

3.7.7 Water supply and water use

The few residents at KwaMncane who are engaged in agricultural production (2.3%) obtain their main source of water supply from the stream. A pipe system with communal taps is the main water management system for the community. There appear to be few residents who encounter problems associated with this water supply (Table 3.22).

When the water harvesting project was initiated, the area around the individual homesteads was the main land used for agriculture. The project team tried to get a group of six homesteads to work together as a group, but this was a challenge because of different levels of interest. Only one family, the Khenisa family, was interested in producing vegetables, while the rest wanted to use the water for domestic purposes. Institutional arrangements for water management were set by the six homesteads in terms of paying the Khenisa family (who owned the pump) for electricity for pumping water, the use of water, a production plan, input supply by the project team and exposure to water harvesting techniques. The project then bought a cable to supply electricity to pump the water. A rate was set to be paid monthly to the Khenisa family towards electricity, but the five families did not honour this. Although the project team tried to resolve the matter, the five households eventually pulled out. However, Khenisa allowed them to continue getting water for household use. The Khenisa family were partly compensated by receiving the first batch of seedlings from the project.

Only 2.3% of the residents of KwaMncane have participated in water harvesting before. Dams and tanks were suggested by 11.6% of the residents as improvements that are needed for water harvesting. Participants of the water-harvesting project indicated low expectations that the project will impact on their lives (Table 3.23).

Table 3.22 Problems with water supply in KwaMncane

Problem with water supply	Percentage
Shortage of water	51.4
Sharing of water pipes	21.6
Blocked pipes	8.1
Shortage of water + blocked pipes	2.7
Sharing of pipes + shortage of water	2.7
Other	13.5

Table 3.23 Expectations of the participants after the project in KwaMncane

Expectations	Percentage
Profit	43.2
Good harvest	10.8
Improvement in the gardens	8.1
Food security	2.7
Plenty of water	2.7
Other	32.5

3.8 Discussion

The results of the baseline survey outline the situation that affects households, community agricultural activities and water harvesting in the study area. This study regards the household as the unit of analysis because it is the most important component in which rural people live. It is a basic unit of society where individuals both cooperate and compete for resources. The household is a social unit that combines production, distribution, transmission and reproduction. There are three dimensions of household livelihood, namely residence, family and resource management which are critical in satisfying primary needs of households. The household structure includes composition, gender, age, division of labour, patterns of power and authority, kinship linkages, availability, access and distribution of resources. All of these impacted on the implementation of the project. Gender and age are important factors in the structure and processes of the households and community at large. In both communities of the study area, namely Ntembeni and KwaMncane, the majority of households sampled (75.7-95.3%) were headed by women. These are either de facto heads of households in the absence of men who are mostly migrant workers or de jure heads of households as a result of death of spouses, desertion and those who were never married. These high numbers are significantly higher than the norm for South Africa (56.5%) reported by Backeberg and Sanewe (2010). The high number of female-headed households in the study area may have a positive influence on sustainable rural livelihoods because numerous studies show that women who have power and authority to make household decisions spend resources on enhancing food and nutrition security and general welfare of the household (Mokgope 2000). However, the restrictions on women in terms of access to land and other resources means that their 'right to make agreements for access to land, to transfer or dispose of it and to use land for entrepreneurial purposes is marginal' (Cross 1999:13). This was apparent in the current study where women were not able to negotiate with the tribal authority for access to garden plots not used by members who had user rights to the plots.

This study indicates that households with women heads have the potential to play a positive role in adopting new appropriate technologies for water harvesting and agricultural practices. They are likely to ensure food security and rural livelihood security through their participation in the project. The age structure in the study area is the result of a dynamic process involving fertility, mortality and rural-urban migration. Generally, young people in rural areas migrate to find employment in cities or other areas. However, this trend is diminishing with the high national unemployment rate. In both communities of the study area the highest proportion of the population is the elderly as many people return from urban areas to retire in rural homes. Another cause could be the impact of HIV/AIDS on the youth resulting in premature deaths. There is a high rate of dependency of children and young adults on the elderly for livelihoods. The majority of household heads who are mostly women have no education at all or were only educated up to Grade 7. In general, women in rural areas are not educated to the same level as men. Therefore, participants in the water harvesting project should be given access to appropriate non-formal education opportunities. These should include functional literacy as well as education and training in agriculture and water harvesting.

Division of labour in the study area is still based on traditional gender roles. Women's main responsibilities entail the care and maintenance of the households and its members. This includes bearing of and caring for children, preparing food, collecting water and fuel, housekeeping and health care of household members. This type of work was described to be time consuming and labour-intensive. Consequently, women's overload of work can impact negatively on their participation in agricultural activities. However, the water harvesting project might have a positive impact in making water supplies for agricultural activities more accessible than at present. Most women fetch water from communal taps or rivers. Girls, too, get involved in household work from an early age. They help carry water and gather fuel wood. Boys tend to be active in feeding and caring for the livestock and helping with repair and maintenance work.

Men and women involve themselves in productive work, such as agriculture. However, in the study area, women form the majority of those involved in agricultural activities, particularly in community and homestead gardening. Some men in the area are involved in wage-paying employment and others depend on old age pensions and disability grants for a livelihood. Many households in the study area diversify their livelihoods because they have different income sources. Agriculture or farming is not the primary means of rural survival. This supports other studies which show that agriculture does not contribute significantly to rural livelihoods due to factors such as shortage of arable land, drought and low rainfall, and high input costs (Mokgope 2000, Van Averbeke 2008). For risk-related reasons, households are forced to adopt a diverse portfolio of activities such as agriculture, informal trading, wage employment, state support and sometimes illegal activities.

Both men and women are involved in activities to improve the community. However, gender division still prevails in community work. Men are primarily responsible for community politics as they take part in decision-making at tribal authority level. Most of the men are not paid for the work undertaken for community development, but they benefit indirectly through improved status, power and recognition. Contrary to the men's role in community politics, women are primarily involved in community-managing activities in relation to the running of the household unit. They are responsible for ensuring the provision and maintenance of scarce resources which everyone uses, such as water, health care and education. Women's work is often voluntary, unpaid and not given the full recognition it deserves. At household and community level, men have more power and authority than women.

In the study area, kinship linkages are important in determining access, provision and distribution of resources. Land for housing and agricultural activities is communally owned and accessed according to local rural norms. Most of the time kinship linkages are taken into consideration. Therefore, for planning and implementing the water harvesting based projects, kinship linkages of households in the community should be considered and respected. The rural household remains an important micro unit of analysis for community projects in the area.

This study identified essential sustainable rural livelihood indicators that are important for this project as household food security, cash income, human and social capital, health status, gender and natural capital. These indicators can be used to monitor and evaluate the water harvesting project.

All households in the study are confronted with seasonality as an inherent feature of their livelihoods. Since there are no irrigation systems, production cycles of crop and livestock are determined by the onset of rains, their duration, the length of the growing season, temperatures and variations across the calendar year. For the past few years, drought has had a negative effect on agricultural activities. As a result of seasonal fluctuations, diversification from farming has become a logical answer to uncertainties caused by seasonality.

Some of the water harvesting practices that have been practised in the areas use, for example, dams, tanks and corrugated iron roofs to collect rainwater. The concept of water harvesting is therefore not new. However, poor previous experiences may have resulted in few community members expecting to benefit from the project. There was a low expectation of improved vegetable and crop harvests, household food security, cash income from agricultural activities and improved water supply in the study area. Another reason for this low expectation may be due to the common property land tenure. As people do not own land their use- rights are not secure and there is no incentive to invest in water harvesting. One of the challenges of the project is therefore to ensure that water harvesting has a positive impact on people’s lives in the study area, and creates incentives for people to make productive use of the land.

Water supply sources are mainly rivers, dams, rainwater, springs and public taps. Shortage of water supply and lack of maintenance is a problem in the area. Thus, this study concludes that an improvement in provision and conservation of water is a priority for agricultural development. Therefore, measures to ensure sustainability of the project were considered at the initial stage. The households and communities need training on how to harvest and conserve water and to maintain and repair water harvesting systems in the area.

Households in the study area still use traditional and primitive methods of agriculture. Therefore, they need training on appropriate methods for crop and animal production. This study concludes that people in the study had a positive attitude towards the water harvesting project.

This study identified some of the main constraints that can have a negative impact on the implementation of the water harvesting and conservation project in relation to agricultural development. These constraints are caused by limited access to physical, human, social, financial and natural resources. The roads, particularly access ones, are very poor in both communities and are not properly maintained. Telecommunication facilities are very limited hence dissemination of information and communication is problematic. Access to public transport within the study area is scarce and leads to time being wasted walking from one point to another. Both communities experience a severe shortage of water, particularly in the dry season. The general infrastructure of the study area needs improvement to provide an enabling environment for the implementation of the water harvesting project for agricultural development activities. As a result of high illiteracy rates in the study area, building the capacity of local households through training in agriculture, nature and water conservation, health, nutrition, and business management skills will improve household food security, cash income and sustainable use of natural resources.

Social relations and networks among households by which they informally share work does affect household food security and nutrition. The social entitlements of households were identified to be under great stress as a result of drought and lack of cash resulting from unemployment. The households will play a significant role in decision-making pertaining to participation in agricultural activities and water harvesting initiatives. The role of government is very important in the form of investments such as roads, water points, health and education centres. These infrastructures need improvement. Furthermore, agricultural, veterinary and natural resource management extension services are very limited and should be enhanced through partnerships with non-governmental organisations (NGOs), community-based organisations (CBOs) and other relevant provincial government departments and local municipalities.

Generally, both communities have limited assets and resources but they can make use of what they have provided they get training on water harvesting, conservation of natural resources and agricultural production. Because the majority of households have less than two hectares of land, promotion of production of high value commodities is recommended. If supplied with water, commercialisation of communal vegetable gardens could enhance household cash income, and homestead gardens could contribute to household food security. However, the whole food value chain from production to consumption should be well investigated before commercialisation of agricultural activities is undertaken in order to properly integrate the farmers in the market place. The involvement of the community and professionals from different sectors, including the private sector would open more opportunities to support socio-economic development.

CHAPTER 4 THE EFFECT OF SELECTED WATER HARVESTING AND SOIL CONSERVATION TECHNIQUES ON SOIL WATER AND CROP YIELD

4.1 Introduction

In South Africa, soil water conservation strategies and in-field rainwater harvesting under rain-fed conditions have been the focus of numerous studies (Hensley and Bennie, 2003). However, the majority of these studies have been undertaken in the more arid regions of South Africa. Rainwater management strategies can be classified into the following categories (Rockström, 2002):

- Systems that prolong the duration of soil moisture availability in the soil (e.g. mulching practices).
- Systems that promote the infiltration of rainwater into the soil (e.g. pitting, ridging/furrowing and terracing).
- Systems that store surface and sub-surface run-off water for later use (e.g. rainwater harvesting systems with storage for supplementary irrigation).

According to Mpungwa (2006), smallholder farmers in southern Africa already employ tillage practices with the aim of accomplishing several short-term goals, including seedbed preparation, weed control and rainwater retention (Waddington, 1991; Morse, 1996; Twomlow and Bruneau, 2000). In order to assess the benefits of RWH&CT it is clear that a knowledge of the soil water and crop yield changes brought about by these practices need to be measured and understood. The aim of this project was, therefore, to test one or more promising RWH&CT by monitoring the soil water and crop yields in a wetter region of South Africa where few previous studies have been undertaken. The focus was on micro catchment (in-field) rainwater harvesting for vegetable production at the Ntembeni community in KwaZulu-Natal. At the Zakhe Agricultural College a number of different techniques were installed and used primarily as demonstration plots for the Zakhe students and the local community. A full description of these sites was presented in Chapter 2.

The Zakhe site comprised a vegetable garden with seven plots which were planted with different vegetables during the winter and summer seasons. The harvesting or conservation of water at Zakhe was through the use of mulch as well as different in-field techniques. These trials were considered to be "demonstration" as in the early phase of the project the focus was on the implementation of RWH&CT rather than experimental research. The demonstration trials at the Zakhe College were based on harvesting rainwater from roads, roofs and in-field structures. The demonstration field covered an approximate surface area of 0.2 ha and was divided into seven plots by swales of Vetiver grass. A reservoir was built at the top of the field to collect the water from the roads. The crops grown were spinach, broccoli, lettuce, cabbage, peas. The treatments were mulch and no mulch, with three different configurations: ridges, flat and raised beds.

The Ntembeni site ("on farm") was a community vegetable garden that was used by nine households for vegetable production. The production of crops throughout the year through the harvesting of supplementary water from the local river was used by these community members to extend the traditional summer growing season into winter.

The project team investigated the effect of raised seedbeds, ridges and in-field run-on/off plots on water harvesting for production of cabbage and Swiss chard at the two sites. In the summer of 2005, an experiment to enhance water harvesting (laying plastic sheets in the area just above and contiguous to a seedbed) was initiated using both ridged and raised seedbeds. In addition to this, in 2006 the project research team visited the University of the Free State to attend a workshop on water harvesting, organised by the Department of Soil, Crop and Climate Sciences. At that workshop, the researchers were introduced to the use of a micro catchment or in-field run-off system for water harvesting for maize production. This system was then adapted for vegetable production and compared with ridge planting at Ntembeni and Zakhe.

The on-farm trials were statistically designed and were intended to be farmer-managed. However this was not fully achieved as the farmers did not always follow the research recommendations. The trials were therefore continued with a focus on participatory action research and rigid statistical results were not always possible. Participatory action research involves practitioners in the research process from the initial design of the project through data gathering and analysis to final conclusions and actions arising out of the research (Whyte, 1991).

4.2 Materials and Methods

4.2.1 Automatic weather station

Measurements of precipitation, air temperature, relative humidity, wind velocity (windspeed and direction) and incoming solar radiation were recorded at a height of 2 m above the ground surface at Zakhe in 2005, 2007 and at the community vegetable garden in 2006 (Figure 4.1).

The weather station instruments, linked to a Campbell CR10X data logger, recorded the following measurements:

i) Rain using a Texas Instruments tipping bucket raingauge (0.1 mm tip).
ii) Solar radiation measured with a Kipp solarimeter.
iii) Windspeed and direction using a Met-One wind sensor.
iv) Temperature and relative humidity were measured with a Campbell CS500 probe.

All sensors were averaged or totaled at 60-minute intervals and daily summaries stored at midnight. A Falcom modem and Campbell telemetry equipment were installed to allow remote access and downloading to computer for data analysis.

Figure 4.1 ***The automatic weather station at the Ntembeni community garden on the left and at Zakhe on the right***

4.2.2 Soil physical properties

Soil factors required for understanding the soil water measurements included the soil physical properties, soil matric potential, saturated hydraulic conductivity and the total soil porosity (Kumar et al., 2008). The curve showing the unique relationship between the matric potential and volumetric water content of a soil is termed the soil water characteristic curve. Differences in the soil water characteristic curve are attributed primarily to the variations in pore size distribution among soils, which in turn are a function of particle size distribution. The soil water characteristic curves are sensitive to the changes in bulk densities brought about by compaction and tillage practices.

Field and laboratory investigations were carried out to determine the soil moisture retention characteristics at Ntembeni. A total of 20 undisturbed soil samples were collected from two soil pits at five depths (0-0.3 m, 0.3-0.6 m, 0.6-0.9 m, 0.9-1.2 m and 1.2-1.5 m) in the community garden. Soil bulk density, particle density and porosity were measured for each soil sample. Retention data were obtained through pressure plate apparatus.

The Retention Curve Program for Unsaturated Soils (RETC) was used for describing the hydraulic properties of the Ntembeni soil (van Genuchten et al., 2009). The soil water retention and hydraulic conductivity are key parameters in any quantitative description of water flow into and through the unsaturated zone. The Program was used to fit several analytical models to the observed water retention data. RETC uses the parametric models of Brooks and Corey (1964, 1966) and van Genuchten (1980) to represent the soil water retention curve, and the theoretical pore-size distribution models of Mualem (1976) and Burdine (1953) to predict the unsaturated hydraulic conductivity function from observed soil water retention data. A nonlinear least-squares optimisation approach was used to estimate the unknown model parameters from the observed retention data.

Due to the shallow soil at Zakhe, soil physical properties studies were confined to the Ntembeni community garden site. Compared with the Zakhe site, the soil at Ntembeni was significantly deeper (in excess of two metres), of the Hutton form (having been derived from a dolerite dyke that runs through the site) and had a distinctly red colour with well drained properties.

To model the retention and movement of water in the unsaturated zone, it was necessary to know the relationships between soil water pressure (*h*) and volumetric water content (θ). It was convenient to represent this function by means of a simple parametric expression. The problem of characterising the soil hydraulic properties was solved by estimating the parameters using the RETC model.

The measurements of θ(*h*) from the undisturbed cores obtained through the pressure plate data were fitted to the desired soil water retention model, where θ (*h*) was the soil water pressure head (also known as the matric potential). This variable was taken to be negative and expressed in cm of water and was the van Genuchten pressure head scale parameter. For the van Genuchten (1980) model, the water retention function is given by:

$$S_e = (\theta_v - \theta_r)/(\theta_v - \theta_r) = [1 + (\alpha_v \ |h|)^n \ ]^{-m} \quad \text{for } h < 0$$
$$= 1 \quad \text{for } h \geq 0 \qquad \text{eq. 4.1}$$

where, θ_r is the residual water content, α_v and n are the dimensionless van Genuchten (1980) model parameters and are related by m = 1 – 1/*n*.

In the present study, parameters α_v and *n* of the soil moisture retention function and hydraulic conductivity function were obtained using the RETC model (van Genuchten et al., 2009). The saturated moisture content (θ_s) was assumed to be equal to the measured saturated water content at 0.01 kPa. Rearranging eq. 1, then, allowed conversion of matric potential values into volumetric water content (θ_V) using the following equation:

$$\theta_v = \theta_r + [(\theta_s - \theta_r)/[1 + (\alpha h)^n]^{1-1/n}] \qquad \text{eq. 4.2}$$

The topsoil had a silt clay loam texture typical of the Hutton soil type (Table 4.1). The bulk density was low in the soil profile while there was a high hydraulic conductivity in the top 0.06 m of the soil profile with a sharp decrease in hydraulic conductivity from 0.90 m down to 1.5 m. Organic matter decreased down the soil profile with 2.88% on the surface and only 0.04% below 1.2 m. The movement of clay down the soil profile, termed clay illuviation, is a process often encountered in several of the deep well-drained red soils that are common within this region. Table 4.1 provides clear evidence of this process as the clay content at a depth of 1.2 m was approximately three times higher than that of the topsoil. Soil bulk density also increased with depth but remained within the range normally encountered in un-compacted soils of this type.

Table 4.1 Soil properties for Ntembeni community garden

Sample Depth (cm)	% Clay	% Silt		% Sand				% Organic Matter	Saturated hydraulic conductivity ($mm.h^{-1}$)	Bulk density $g.cm^{-3}$	Total Porosity
		Fine	Coarse	Very Fine	Fine	Medium	Coarse				
0-30	20.31	23.35	17.34	11.33	9.08	5.51	10.2	2.88	102.87	1.078	0.593
30-60	21.45	25.3	21.85	11.43	5.83	3.47	8.61	2.05	119.93	1.050	0.604
60-90	55.39	25.35	7.42	3.81	2.43	1.23	2.84	1.52	45	1.045	0.606
90-120	63.12	21.33	7.32	3.43	2.17	0.76	1.06	0.81	19.3	1.190	0.551
120-150	66.75	19.92	7.16	3.00	1.90	0.69	0.54	0.04	5.5	1.194	0.549

It is generally accepted that at field capacity (-10 kPa), where all pores > 29.2 µm are drained, soils with an air filled porosity of around 12-15% would tend to limit root development due to inadequate aeration. From Figure 4.2, it can be seen that none of the soils have an air-filled porosity below this critical limit.

The air-filled porosity of the B-Zone soil ranged in the order of 0.24-0.65 $m^3.m^{-3}$ at field capacity. At a matric potential of -100 kPa, when all pores > 2.92 µm are drained, approximately 90% of the total pore space was air-filled which was indicative of a well-structured soil exhibiting good drainage characteristics. Readily available water contents for the B-Zone soil ranged between 0.061 and 0.043 $m^3.m^{-3}$ while the plant available water was in the order of 0.165-0.117 $m^3.m^{-3}$. The average soil parameters from site A and B derived using the RETC model are shown in Table 4.2 and can be used for converting matric potential to volumetric water content or vice versa.

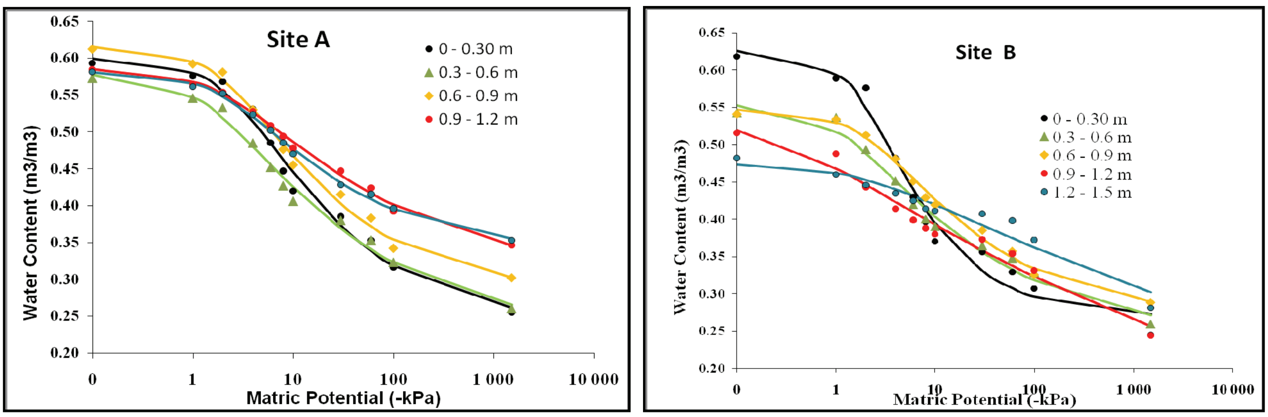


Figure 4.2 Observed (symbols) and fitted lines using the van Genuchten (1990) parameters for the soil characteristic curves for sites A and B for five depth intervals for the Ntembeni community garden

Table 4.2 Mean soil parameters from Sites A and B at Ntembeni determined using the Retention Curve Program for Unsaturated Soils (RETC) program (see text for variable definitions)

Variable	Depth Interval (m)				
	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	1.2-1.5m
θ_S	0.612	0.565	0.581	0.552	0.527
θ_r	0.251	0.229	0.271	0.145	0.166
α	0.039	0.064	0.038	0.150	0.046
n	1.542	1.313	1.399	1.173	1.220
Goodness of fit (R^2)	0.981	0.985	0.993	0.983	0.969

4.2.3 Soil water studies

4.2.3.1 Soil water measurements

The changes in soil water content brought about by the establishment of water harvesting techniques provided important insights into the changed dynamics of the water budget at the Zakhe experimental site in 2005. This required knowledge of the soil water content preceding and following the implementation of the techniques.

Two contoured fields on which water harvesting techniques were tested were selected for this experiment. The fields, each approximately 15 m wide, were separated from each other by a 0.4 m wide swale that spanned the length of the contour. The swale was planted with Vetiver grass which was in good condition (Figure 4.3).

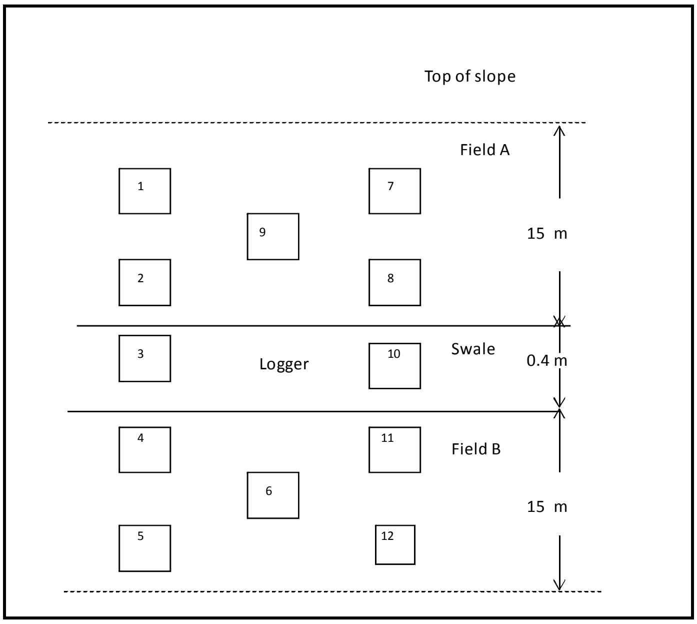


Figure 4.3 Schematic layout of the soil water sensors at the Zakhe site

The soil at the site was shallow owing to the presence of a dolerite sill that was marked by weathered rock at an approximate depth of 0.30-0.35 m below the surface. Due to this depth limitation, it was only possible to establish a soil water monitoring network for the topsoil.

The Watermark system was selected as an appropriate technique for the measurement of soil matric potential. Twelve sensors were installed in the upper 0.25 m of the soil. A schematic representation of the field layout is shown in Figure 4.3. Six sensors (1, 9, 7, 5, 6 and 12) were positioned at the centre of the fields whilst sensors 2 and 8, and 4 and 11 were sited immediately upslope and downslope of the swale respectively. An additional two sensors (3 and 10) were located within the swale. This sensor layout was adopted with the aim of determining the influence of the swale on the movement of soil water down the slope. To install the sensors, a 30 mm diameter shaft was augured to a depth of 25 mm. A slurry containing the recently excavated soil was prepared and poured down the shaft before installing the sensor. This was necessary to minimise the risk of air gaps between the sensor and surrounding soil. All sensors were wired via a Campbell AM416 multiplexer to a Campbell CR10X data logger programmed to record soil water potential every 12 minutes.

4.2.3.2 Mulching at Zakhe

In June 2005, an experiment to evaluate the effect of mulching on soil water content was carried out at both the Zakhe Agricultural College and the Ntembeni community garden. Although it is well known that mulches improve soil water conservation, this aspect is not always recognised or understood by the local communities. The contours at Zakhe were disked to incorporate residual material and fertiliser into the top 0.30 m of soil. Figure 4.4 shows pictures of the experimental site. Four blocks of 12 plots per contour were marked out. Each plot measured 1 m x 2 m with approximately 0.40 m spacing between individual plots. Soil collected from within the contour was added to each plot such that the height of the bed was raised by 0.20 m. In total 96 individual plots were created. The four blocks on the higher contour were planted to peas, cabbage and spinach. Each crop included a mulch treatment (where grass was used as the mulch cover) and a no mulch treatment.

Figure 4.4 ***The experimental site at Zakhe Agricultural College***

Immediately following the planting of the plots, 16 (2 per block) access tubes for the measurement of soil water content, using the Sentek Diviner 2000 system of measurement, were installed across the two contours. Water content was measured across the two contours weekly for the duration of the winter experiment. The Diviner 2000 probe (Figure 4.5), which uses the dielectric properties of the soil (dependent upon water content), was lowered into the access tube and measurements were taken at every 10 cm depth by "swiping" the probe in and out of the access tube.

Figure 4.5 ***The Sentek Diviner 2000 system of soil water content measurement was used in this study. The left picture shows an access tube installed within a bed, whilst the right picture shows the Diviner 2000 instrument***

To convert the Diviner 2000 readings into values that represent absolute volumetric soil water content, a specific calibration must be performed. Sentek Pty Ltd (2001) provides default calibration equations for converting the raw sensor counts into estimates of soil water content. This is often more convenient as calibrating for absolute readings is a time-consuming and expensive procedure. Sentek Pty Ltd (2001) recommends the use of their default calibration equations that have been calculated based on a range of different soil types and which can be used to show "relative" soil water changes.

Many data sets collected from various soil types and crops around the world have shown that relative changes in volumetric soil water content based on the default calibration can be used to show the most important soil water trends in relation to optimum plant production (Alva and Fares, 1988 and 1999; Paltineanu and Starr, 1997; Starr and Paltineanu, 1998; Tomer and Anderson, 1995). As the project was mainly concerned with the relative changes in soil water dynamics for understanding the impact of the different water harvesting techniques the "relative" approach was adopted for converting the raw Diviner 2000 data into volumetric water content. According to Sentek Pty Ltd (2001), research has shown that the "relative" values obtained can be used to obtain a clear picture of the soil-water dynamics for most soil types around the world, particularly with continuous monitoring. In this way even relatively minor changes in soil moisture can be distinguished and key indicators such as drainage and the onset of crop stress can be readily detected. In addition, Sentek Pty Ltd (2001) cautions users on the risks of utilising inaccurate or misleading data obtained by inexperienced researchers conducting volumetric soil water calibration, since the calibration errors can significantly exceed the error in the Diviner 2000 instrument, resulting in inaccurate soil moisture determinations.

The Diviner 2000 provides a standard "default" calibration equation based on combined data from sand, sandy loam and an organic potting soil and has the following form:

$$y = Ax^{B} + C \qquad \text{eq.4.3}$$

Where y = Scaled Frequency, x = volumetric soil water content (mm), A, B, C = calibration coefficients. The Scaled Frequency (y) is defined as:

$$\mathrm{y} = \frac{(\text{Air count} - \text{Field count})}{(\text{Air count} - \text{Water count})} \qquad \text{eq. 4.4}$$

According to Sentek (2001) the standard default calibration equation provides an R^2 value of 0.9985.

4.2.3.3 Mulching at Ntembeni

In view of the challenges faced in establishing a scientifically defensible trial at Zakhe, a further attempt at evaluating the effect of mulch on soil water content was attempted, this time at Ntembeni (Figure 4.6).

Figure 4.6 The Ntembeni trial showing the cabbage no-mulch plots in the foreground

The upper contour of the community garden at Ntembeni was disked before five blocks, each comprising 24 individual plots per block, were laid out (Table 4.3). Three crop types were used: peas, cabbage and Swiss chard. The second block was planted with cabbage and was treated with mulch using bean residues from earlier in the season (see Table 4.3 for plot numbers and treatments). As was done at Zakhe access tubes were installed to a depth of 1.20 m within each block to measure the water content of the soil. The Ntembeni community garden was equipped with a flow meter (Figure 4.7) that was fitted on the main irrigation pipe line. This irrigation pipe line was gravity fed from a small dam, about 3 km up-stream from the community gardens. The irrigation was carried out with the use of garden sprinklers which were moved manually around the garden. One of the community members recorded the flow meter readings on a daily basis. These readings were then collected weekly by one of the researchers and graphed. Furthermore, the same set of measurements that were recorded at Zakhe was also recorded at the Ntembeni site.

Table 4.3 Table of plot numbers showing the layout of field plots at Ntembeni where Diviner 2000 measurements were taken. Key: M- = no mulch, M+ = mulch

Pea(M-)			**Cabbage(M-)**			**Cabbage(M+)**			**Swiss Chard(M-)**			**Peas (M-)**		
1	9	17	25	33	41	49	57	65	73	81	89	97	105	113
2	10	18	26	34	42	50	58	66	74	82	90	98	106	114
3	11	19	27	35	43	51	59	67	75	83	91	99	107	115
4	12	20	28	36	44	52	60	68	76	84	92	100	108	116
5	13	21	29	37	45	53	61	69	77	85	93	101	109	117
6	14	22	30	38	46	54	62	70	78	86	94	102	110	118
7	15	23	31	39	47	55	63	71	79	87	95	103	111	119
8	16	24	32	40	48	56	64	72	80	88	96	104	112	120

Figure 4.7 The installation of the flow meter at Ntembeni community gardens

4.2.3.4 Run-on plot experiment

In November 2005, a new summer experiment was undertaken where the focus was to harvest rainwater in a field plot. The technique was designed to increase run-off from the adjacent slope making this additional water available for the crops. A suitable contour strip was selected at the Ntembeni community gardens for this trial. This contour was then divided into four blocks. In block 1, run-off and field plots were set up, block 2 included the control plots and blocks 3 and 4 were a repeat of the winter experiments with raised and flat beds. Blocks 1 and 2 were further divided into four sub-plots to make four replicates for each treatment. The treatment plots in block 1 were nine square meters while the run-on plots were eight square meters in size. The upper portions of the run-on plots were lined with plastic sheeting to make a run-off area, allowing the direct run-off to flow onto the down-slope field plot. Ridges and troughs were also used to increase infiltration. There were six ridges and troughs in the plot with a break in the centre of each ridge to allow water to pass from one trough into a lower trough. The photographs in Figure 4.8 show an example of the plots in block 1.

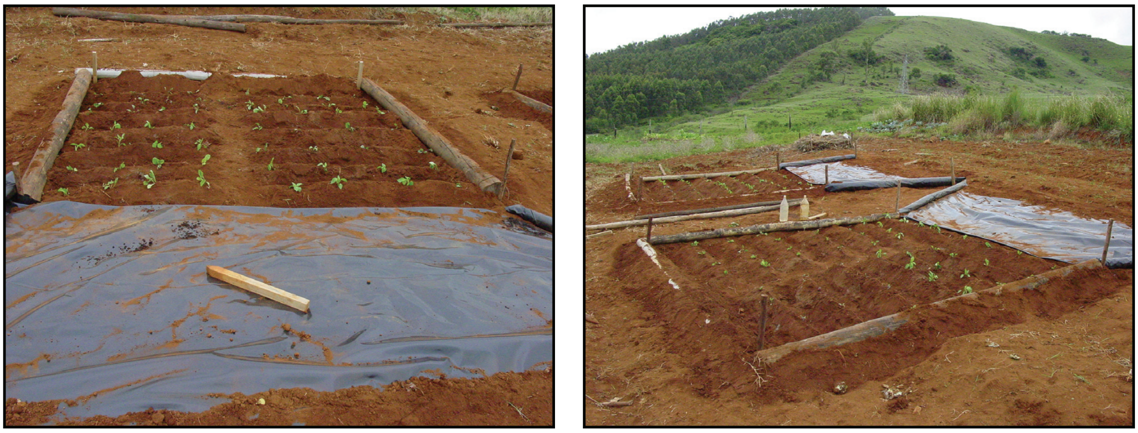


Figure 4.8 ***A run-on plot at Ntembeni in 2005 showing the plastic run-off area at the top of the plot. The ridges and furrows are clearly visible***

Crops were planted on the top of each ridge with a spacing of 0.4 m between plants and 0.45 m between ridges. Three crops were planted: spinach, green pepper and beetroot. The position of each crop type was selected during planting using a randomisation scheme. Figure 4.9 shows a diagrammatic representation of the layout of the plots in block 1.

The control plots where established in section two on the contour. These control plots were the same size as the experimental plots and did not have ridges and troughs. The traditional planting method is pitting which was used to plant these crops (Figure 4.10). The crops were planted in rows with eight plants per row and at the same planting density as in the treatment plots. Once again, there were four repetitions as in the treatment plots (Figure 4.9).

Plot 1		Plot 2		Plot 3		Plot 4	
S	S	B	B	P	P	S	S
S	S	B	B	P	P	S	S
P	P	S	S	B	B	P	P
P	P	S	S	B	B	P	P
B	B	P	P	S	S	B	B
B	B	P	P	S	S	B	B

Key	
Spinach	S
Green Pepper	P
Beetroot	B

Figure 4.9 Layout of plots in each block at Ntembeni in 2009

Figure 4.10 The control plots (pitted) that were planted at the community garden at Ntembeni in 2005. The planting pits are clearly visible

Both the treatment and control plots were instrumented with 12 Diviner 2000 access tubes to a depth of one meter. Soil moisture readings were recorded at 0.10 m intervals. Watermark sensors to measure matric potential were installed and connected to the automatic weather station to record soil water potential every 12 minutes.

The watermark sensors (connected to the CR10X datalogger of the automatic weather station) contained two concentric electrodes embedded in a granular matrix with known pore size distribution. These sensors measured the electrical resistance of the soil which was dependent upon the water content and temperature (Thompson and Armstrong, 1987). The water potential was obtained through first normalising the resistance measurement to 21°C and then applying the non-linear equation of Thompson and Armstrong (1987) to obtain more precise readings in the 0-10 kPa range. Since this relationship is temperature dependent, a measure of this parameter was also made using a type T (Cu/Co) thermocouple buried at the same depth as the Watermark sensors. The advantage of this system was that once installed, it required very little maintenance apart from regular checks of battery voltage. In addition to the watermark sensors, 1.0 m long access tubes were installed in each plot. These were located within the troughs of the run-on plots. Soil water content measurements were taken fortnightly with the Diviner 2000 probe.

In January 2006, raised and flat bed land preparations were repeated to observe the performance of the crops under dryland conditions. However, these plots were reduced from 25 m^2 to 4 m^2. These experiments were carried out on the same contour as the run-on plots. The diagram in Figure 4.11 shows the layout of the raised and flat bed plots.

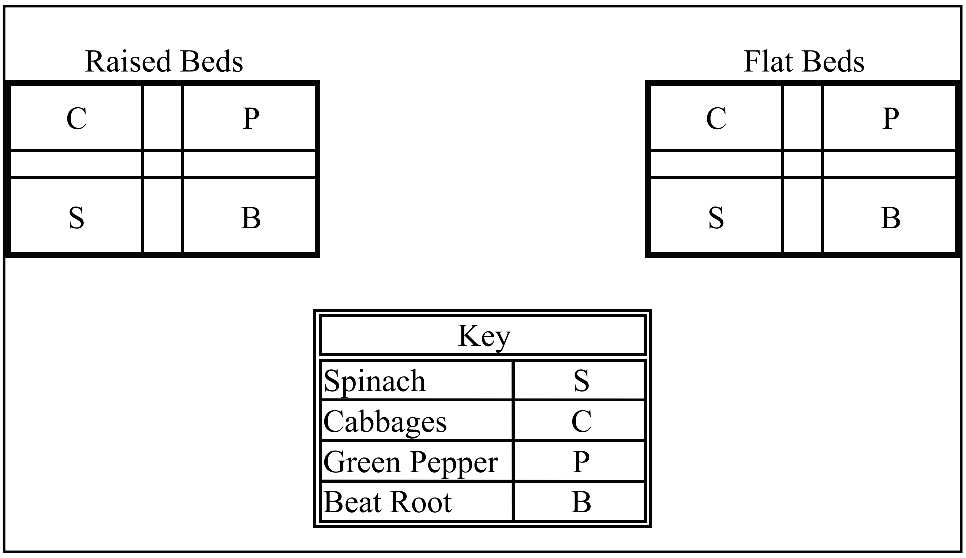


Figure 4.11 Diagram showing the layout of the raised and flat-bed plots at Ntembeni in 2006

All the field plots had the same agronomic practices, namely:

- No irrigation.
- Weeding every 2 weeks.

- Application of pesticides only if required.

4.2.3.5 Micro catchment water harvesting (in-field run-off plots – modified Free State method)

Following a water harvesting workshop which the research team attended in April 2006, a new trial was designed in May 2006 to test the applicability of the micro catchment water harvesting technique (developed in the Free State province) in the Ntembeni community garden. The land was prepared and planted on 16 May 2006. The crops had to be replanted on 26 May 2006 due to hail damage that occurred on 22 May 2006.

The choice of crops for this study was influenced by the farmers who wanted cabbage because it is a popular vegetable in the community. The second crop that was originally chosen was kale, another popular vegetable. However, kale seedlings were damaged by a hailstorm and the use of Chinese cabbage was successfully negotiated by the researchers to introduce a new crop in the community.

Cabbage and Chinese cabbage seedlings were purchased from a local nursery and planted in a completely randomised block experiment. Seedlings were planted at 0.50 m between plants and 0.50 m between rows in 2.5 m^2 plots. The treatments were two water harvesting techniques: ridged planting, which was previously reported, and the run-off system. Briefly, ridged planting consisted of planting seedlings on the ridge of approximately 0.20 m and the run-off plots consisted of two rows planted at 0.50 m spacing with 1 m spaces for run-off on both sides. Flat beds were used as a control treatment for soil modification. Mulching (straw derived from natural stands in the garden where the experiment was undertaken) was superimposed as a sub-plot on the land modification treatments (ridging and run-off plots) and the flat beds. The mulch was applied to cover the soil surface completely throughout the period of plant growth. The treatments were:

1. Ridge + = Ridging with mulch
2. Ridge - = Ridging with no mulch
3. Run-off + = Run-off with mulch
4. Run-off - = Run-off with no mulch
5. Control + = Flat bed with mulch
6. Control - = Flat bed with no mulch

Four rows per plot were planted and the sampling unit consisted of the four middle plants surrounded by border rows. For the run-off plots, the border rows were planted at the edges of the 1.0 m^2 run-off areas around the sampling area. The experiment was replicated three times and the crops were grown in separate adjacent blocks. The experimental plot layout is illustrated in Figure 4.12.

The crops were irrigated manually using a hosepipe fitted with a sprinkler head as the farmers would normally irrigate using water drawn from a nearby spring. Irrigation occurred twice a week, on Thursdays and Tuesdays, in the afternoons. Rain gauges were placed randomly in the experimental plots to estimate the amount of irrigation per week, which was found to average 23 mm (± 4 mm). Determination of irrigation amount was done by one of the farmers who lived across the road from the community garden where the experiment was undertaken.

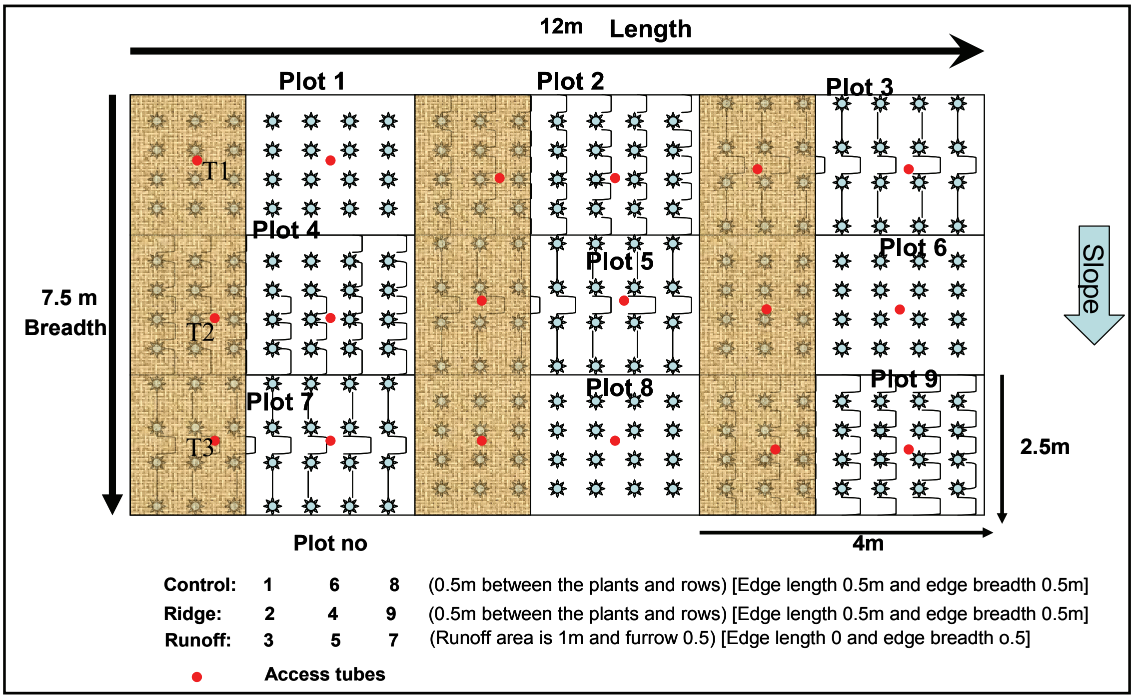


Figure 4.12 Plot layout at the community gardens – Ntembeni

Plant height and leaf number were measured weekly on Tuesday mornings, for the first eight weeks after planting. At the same time as plant growth was determined, soil samples were taken from the top 0.15 m of the soil approximately 0.05 m from the plant and gravimetric soil water content ($\%_w$) was determined by:

$$\%_w = ((\text{Wet mass} - \text{oven-dry mass}) / \text{oven-dry mass})*100 \qquad \text{eq. 4.5}$$

Yield (above-ground biomass per plant) was determined at harvest maturity, 12 and 16 weeks after planting for Chinese cabbage and cabbage respectively.

Measurement of soil water availability was measured using a Diviner 2000 probe. Eighteen access tubes were placed at a 1 m depth, two in each plot except for the mulched and no mulched treatments where only one was placed. The soil moisture was measured every two weeks. Figure 4.13 shows a student taking soil moisture measurements from one of the access tubes in the community gardens. A comparison of the crop growth after two weeks and two months is shown in Figure 4.14. Figure 4.15 depicts the placement of the access tubes in the modified Free State technique.

Figure 4.13 Student taking soil moisture readings with the Diviner 2000 at Ntembeni

Figure 4.14 Community gardens at Ntembeni (left photo taken 2 weeks after planting; right photo taken 2 months after planting)

Figure 4.15 An example of the location of access tubes in each of the cabbage plots

Following the project success at the Ntembeni community gardens in 2006, the project team decided to repeat the 2006 experiment again in 2007. The experiment in 2007 was carried out on part of the farm at the Zakhe Agricultural College. This decision was taken to allow researchers to have better control over the trial site. At the end of April 2007, the trial site was established with soil preparation and planting finished in mid-May. Diviner 2000 access tubes were installed in each plot (Figure 4.16).

Figure 4.16 Photograph showing the completed field trial setup at the Zakhe Agricultural College at the beginning of June 2007

In addition to this experiment, the project team also decided to repeat the plastic run-on plot experiment (Figure 4.17) as this experiment was carried out over a very short period in 2005. Diviner 2000 access tubes were also installed in these plots. The soil moisture was measured on a weekly basis with the Diviner 2000. The field site was also equipped with manual raingauges across the plots. These raingauges were installed just above the crop to measure all irrigation the crop received when the field irrigation system was operating. A student from Zakhe College recorded the amount and duration of irrigation.

Figure 4.17 Photograph showing the completed run-on plots setup at the Zakhe Agricultural College at the beginning of June 2007

4.3 Results and Discussion

4.3.1 Climate

The climate data showed the wet and dry seasonal trends in the measured climatic variables from January 2005 to October 2007 (Figures 4.18-4.20). Generally the summers were wet and humid and the winters dry. Regular rain events were recorded in summer (November to December). However, dry summer periods were recorded. For example in 2006, January to March was characterised by small rainfall events with totals seldom exceeding 10 mm.day^{-1}. The maximum single event (36 mm) was measured on 11 April 2006. Only 328 mm of rain was recorded between January and September 2006 showing that conditions at the site were relatively dry. Average daily temperatures in summer often exceeded 25°C and were indicative of the hot dry conditions experienced late in the 2005/06 summer season.

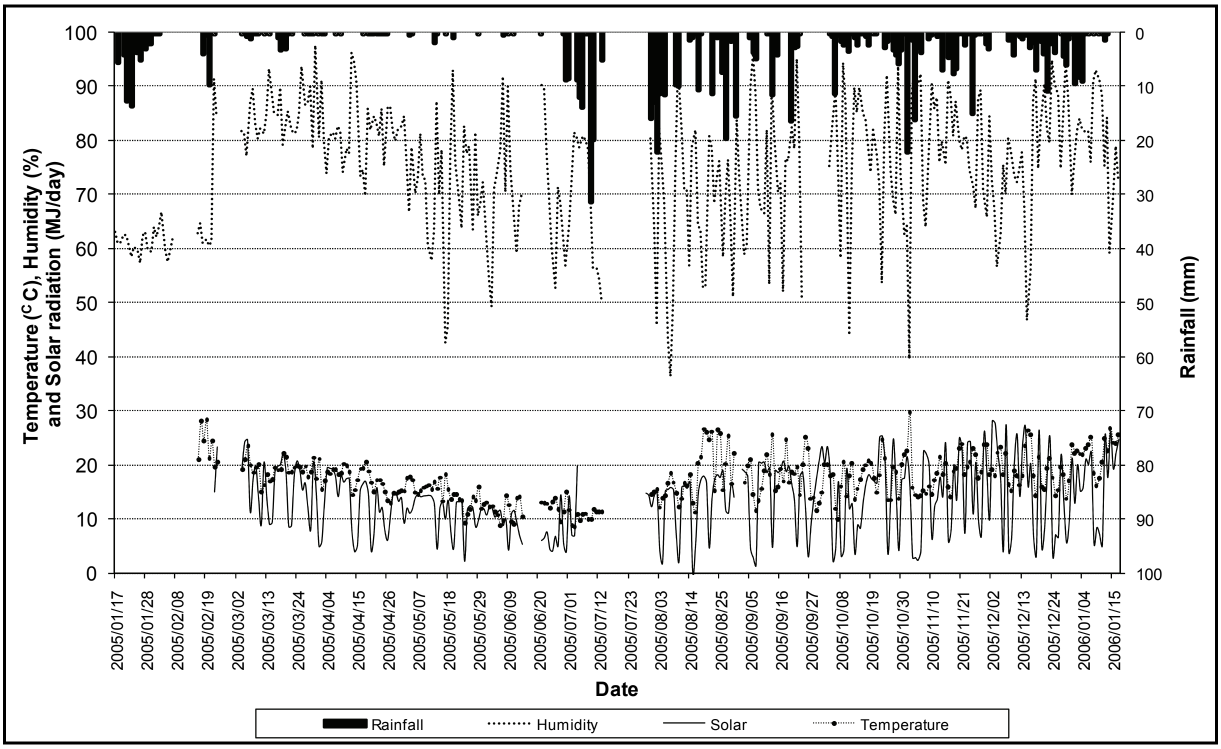


Figure 4.18 Measured meteorological conditions at Zakhe for 2005

In comparison to the climate at Ntembeni in 2006, Figure 4.20 shows the climatic data and wet and dry seasonal trends at the Zakhe Agricultural College from January 2007 to the end of September 2007. The measured climatic variable trend displayed in 2006 was also evident in 2007 data with a wet and humid summer and a dry winter. Once again, most of the rainfall occurred during the summer season with a total rainfall of 120 mm from August to October. During winter, rainfall events occurred very seldom producing 0.6 mm.day^{-1} on average. The maximum single event (16 mm) was measured on 07 September 2007. A total of only 211 mm of rainfall was recorded between January and October 2007, showing that conditions at the site were much drier in comparison to the Ntembeni site that had a total rain of 328 mm for this same period in the previous year. An average daily summer temperature of 25°C was experienced while the temperature during winter dropped to an average 13°C.

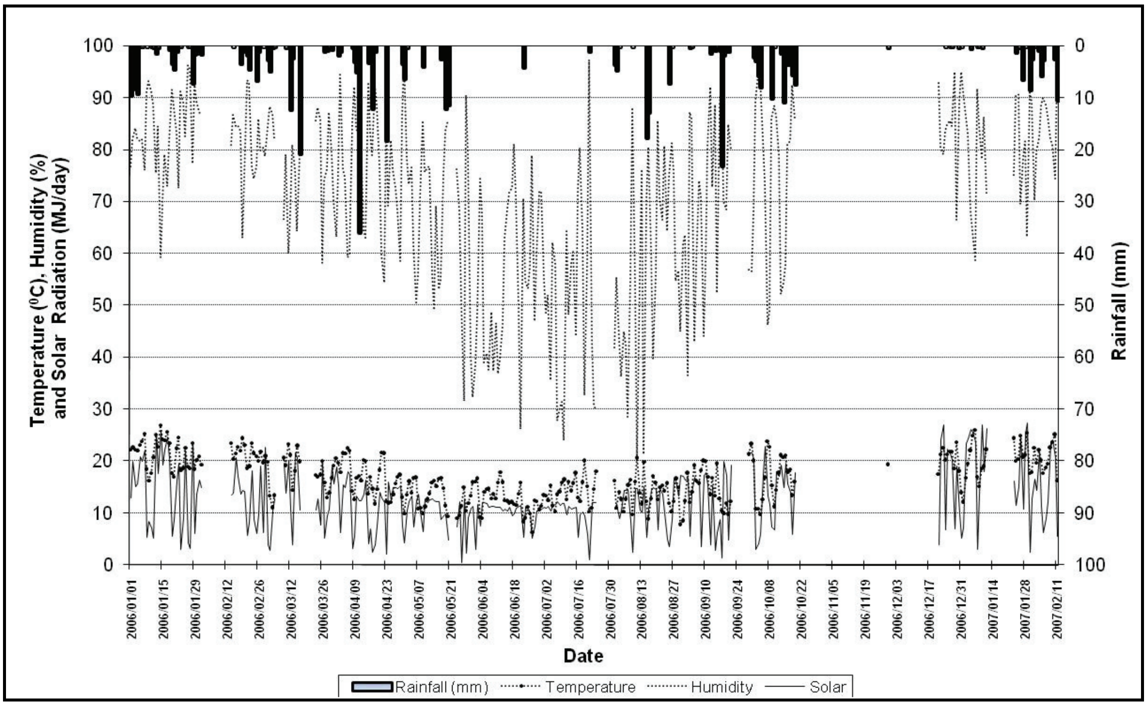


Figure 4.19 Measured meteorological conditions at Ntembeni for 2006

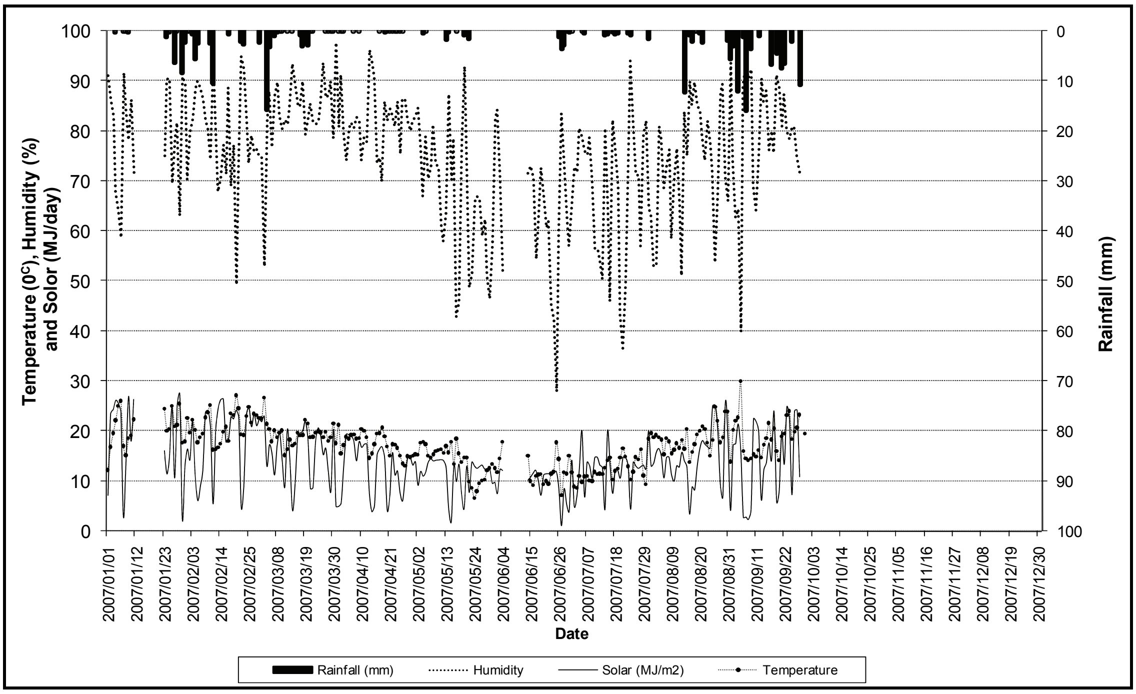


Figure 4.20 Measured meteorological conditions at Zakhe for 2007

4.3.2 Soil water studies

4.3.2.1 Soil water measurements at Zakhe

During summer, which is typically the rainy season, the matric potential of the soil remained fairly low and rarely decreased to below -70kPa (Figure 4.21). Individual recharge events (e.g. 20/02/2005 and 24/03/2005) when more than 10 mm rain fell, were denoted by a rapid decrease in matric potential followed by a more gradual increase after the rainfall event due to evaporative drying and soil water drainage. From late April, which is typically the end of summer (and therefore the rainy season), a progressive decrease in soil matric potential occurred and by the end of May the soil was at its driest (Figure 4.21). Individual winter rainfall events generally had little influence on the soil water content of the deeper layers. When winter rainfall was received at the site, a marginal decrease in soil water potential was noted but this did not last for very long and the soil soon returned to its pre-rainfall condition. The matric potential in the mid swale position showed the driest conditions of all sites. We ascribed this to the high leaf area index and high root density of the Vetiver grass growing on the contour bund in comparison with the surrounding area.

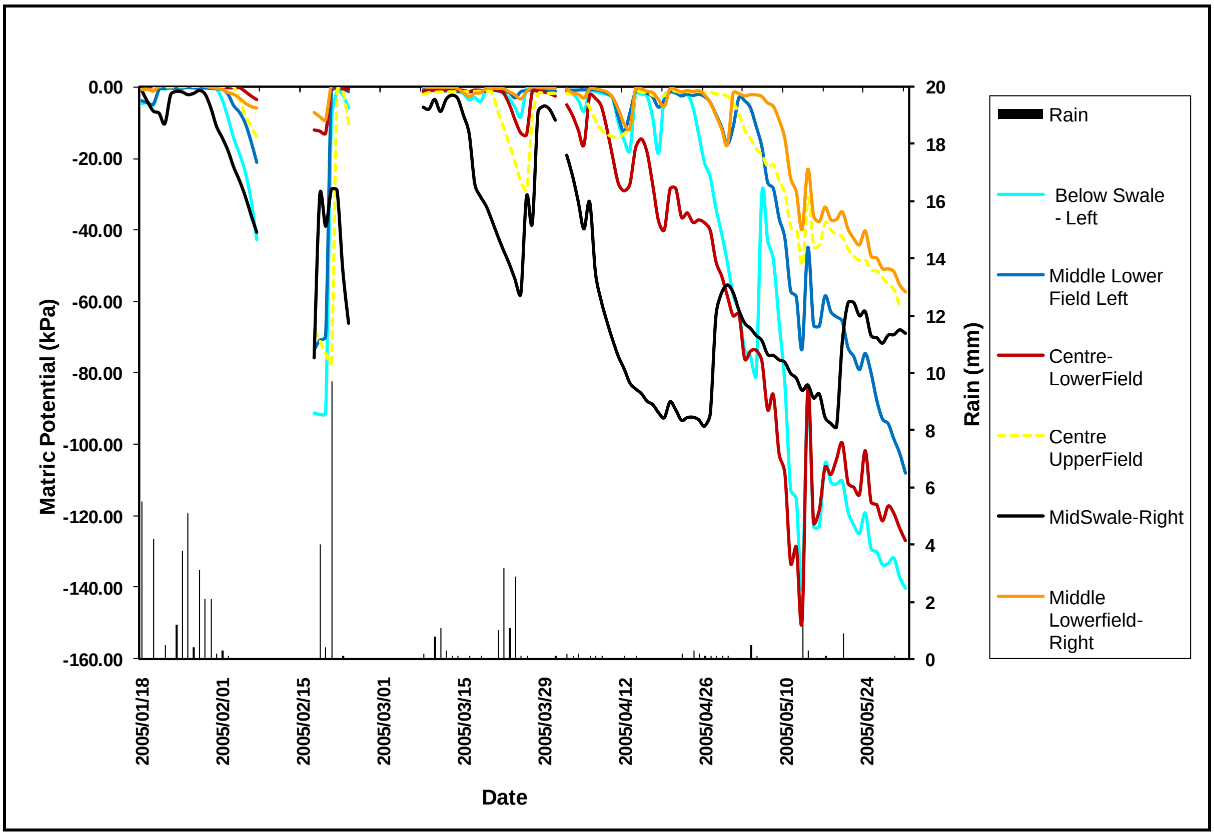


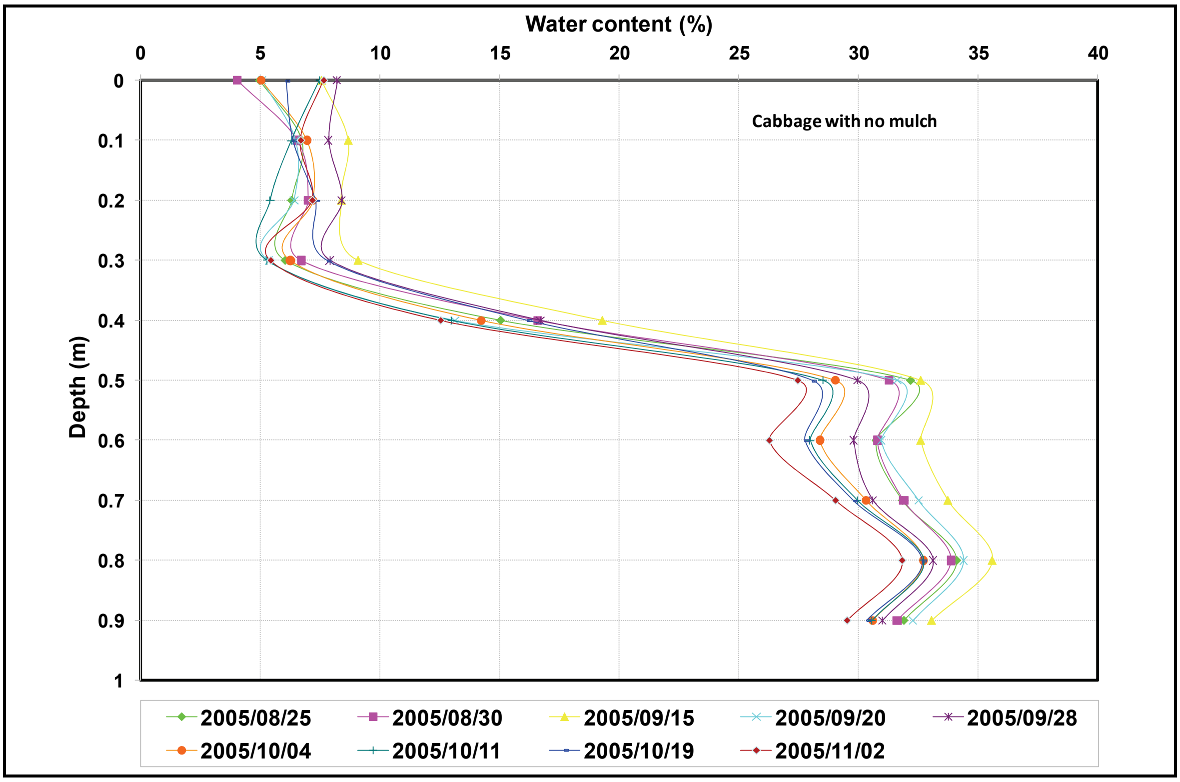
Figure 4.21 Soil water potential record at the Zakhe site during February to June 2005

The results of Figure 4.21 are important in that they allow for some comment on the timing of potential rainwater harvesting practices. During summer, when water is abundant, most of the effort should be expended on the collection of water for its use later in the season, i.e. from late May or early June when soil water potentials start dropping to below the -60 to -70 kPa range. Instead of run-off being allowed to cause erosion, it should be harvested and utilised. In the semi-arid, drought-prone areas where it is already practised, water harvesting is a productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method.

4.3.2.2 Effects of mulching at Ntembeni

Three trials were established at the Ntembeni community garden in 2005. The Ntembeni site was partially irrigated and representative of the community's access to irrigation water in winter. The trial was therefore a combination of irrigation and IRWH. The aim of these experiments was therefore to maximise rainfall use efficiency with supplemental irrigation.

The general trend of a progressive decrease in soil water content across all treatments as the season progressed was similar to that observed at Zakhe, although this was interrupted briefly by irrigation. Figure 4.22 compares the water content of the cabbage plots without and with mulch respectively. The difference in water content is clearly shown in Figure 4.22 where access tube T5 was installed in a cabbage with no mulch plot while T8 was installed in the cabbage mulch plot. From the results, it is evident that adding mulch maintains a higher water content in the soil from a depth of 0.2 m to 0.5 m due to its role in decreasing evaporative losses.



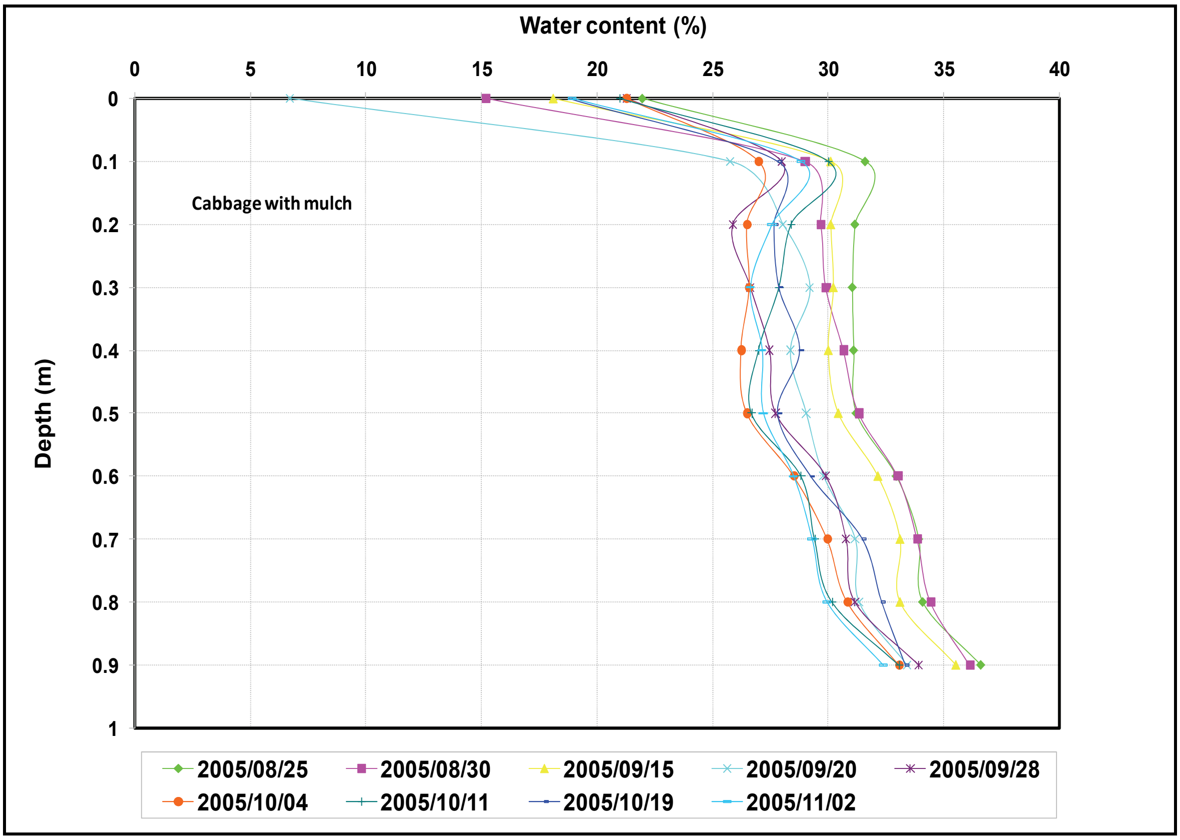


Figure 4.22 Depth profile of soil water content (%) from Ntembeni showing access tubes T5 (cabbage, no mulch) and T8 (cabbage, mulch) from 25 August to 2 November 2005

A similar trend was also observed for the other access tubes in the mulch plots (for brevity these data are not presented here). From a depth of 0.5 m downwards for both the mulch and no mulch plots the water content ranged between 0.32 $m^3.m^{-3}$ and 0.35 $m^3.m^{-3}$. Mulching as a technique of soil water conservation is, therefore, a useful strategy in sustaining soil water contents within the root zone. It must be recalled that the Diviner values used here are "relative" and therefore it was not possible to determine the soil characteristics from these data. This can be done from the laboratory studies which showed that the mean plant available water content (PAWC) (the difference between field capacity and permanent wilting point) was 273 mm for the 1.5 m profile (Table 4.4). In the upper 0.60 m, where most of the roots were distributed, the PAWC was only 134.72 mm. It is in this upper zone where IRWH activities need to be focused to increase plant production. Despite there being increased available water in the upper zone of the mulch treatment, there was also evidence of deep drainage beyond 1.5 m as shown by the high water content values at 0.9 m (Figure 4.23). This increased drainage in the mulch treatment when compared to the no mulch treatment could be a result of the high bare soil evaporation in the latter treatment.

Table 4.4 Soil characteristics showing the plant available water capacity (PAWC) as defined by the drained upper limit (DUL) and field capacity (DLL) for sites A and B at Ntembeni

	Site A		Site B		Site A	Site B	Mean
Depth (m)	FC (DUL)	PWP (DLL)	FC (DUL)	PWP (DLL)	PAWC		
0.00-0.30	0.45	0.26	0.39	0.27	55.23	36.54	45.88
0.30-0.60	0.58	0.27	0.55	0.27	93.41	84.27	88.84
0.60-0.90	0.47	0.30	0.43	0.29	49.38	40.97	45.18
0.90-1.20	0.58	0.32	0.41	0.29	78.48	36.08	57.28
120-1.50	0.48	0.36	0.42	0.30	36.44	35.26	35.85
Total Profile PAWC (mm)					312.94	233.12	273.03

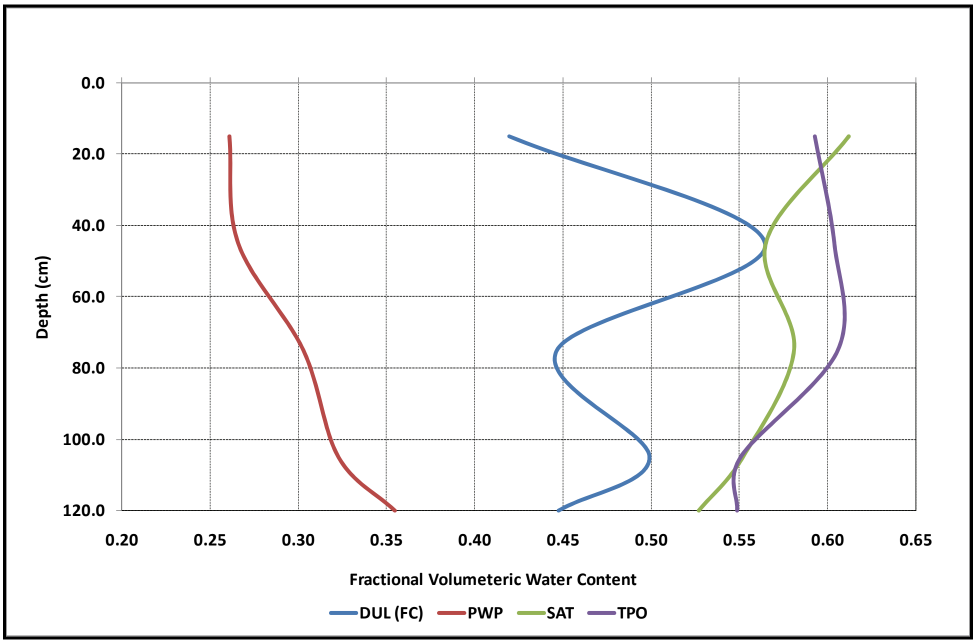


Figure 4.23 ***The storage profile showing the potential water storage of the soil, plant available water content, as defined by the drained upper limit (DUL), drained lower limit (DLL), saturation (SAT) and total porosity (TPO)***

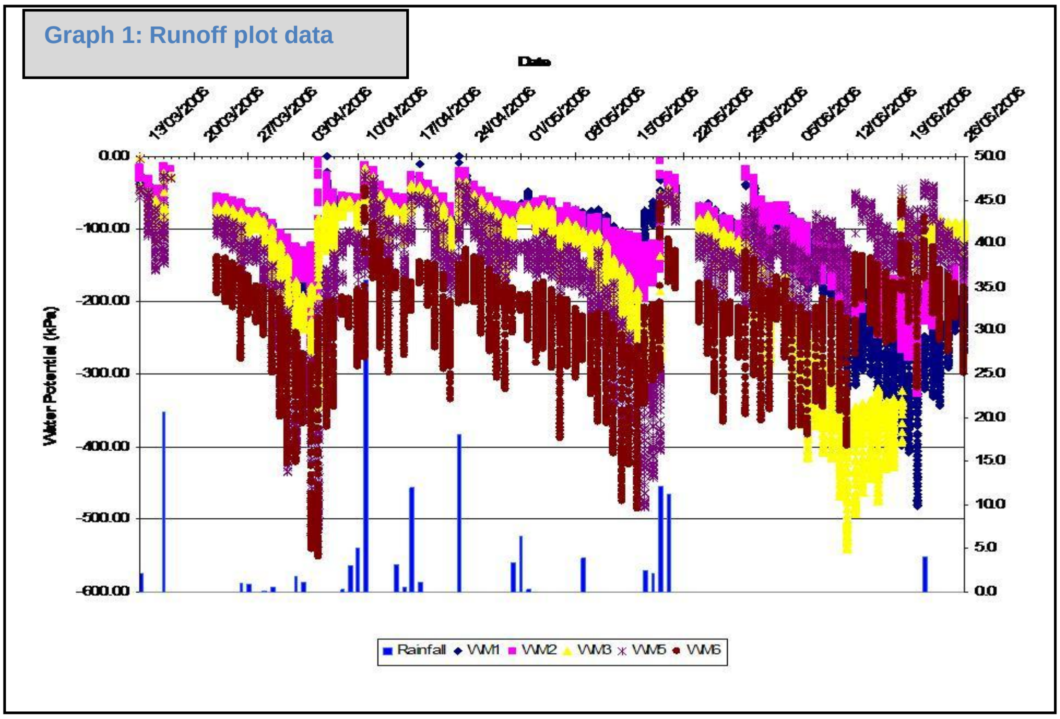
4.3.2.3 Run-on plot measurements

Establishment of plants on all plots was completed on 20/12/2005, but due to a severe hailstorm in the area on 23/12/2005, all the crops, with the exception of the cabbages, had to be replanted on 11/01/2006.

This experiment, unfortunately, did not run for as long as was originally planned as the community members were not convinced of the importance of not irrigating these plots, despite communication by the project team on the relevance of a control plot in the experimental framework. Plants received water when the farmers detected the onset of stress when the plants appeared wilted. By doing this, the rigidity of the experimental framework was compromised such that the comparative estimates of water use were lost. A decision was then taken to cease the monitoring of this site in mid June 2006. However, some valuable soil moisture data was collected during this period and is reported upon below.

Figure 4.24 compares the soil matric potential between the run-on and pitted plots for the uppermost, middle and bottom of the plots, i.e. sensors no 1 and 8, 3 and 9, and 6 and 12. These results showed differences in the soil moisture ranges for the run-on and pitted plots. For example, the control plot has a larger range, especially during the month of June when rainfall was at its lowest. During this period, the soil moisture for the run-off and control plots reached a maximum of -600 kPa and -1000 kPa respectively. One of the difficulties in interpreting this data set is that, during the early stages of this trial, the community members irrigated the control plot. Hence, when doing a comparative study of the data from March to May, we found that the control plots generally had higher soil water content.

Figure 4.25 shows the comparative results between the run-off plots and the control plots. Sensors 1 and 8 were at the top of the slope in the run-off and control plots respectively, while sensors 6 and 12 were at the bottom of these plots. The rest of the sensors were between these two sets of sensors on the middle slope. Similar results were obtained from the watermark sensors going down the slope, indicating similar soil water conditions down the contour (graphs in Figure 4.25). Importantly, we found that in the winter months the run-off plots tended to have higher soil moisture than the control plots. Recharge events were evident when either irrigation or rain occurred. For instance, if we take the 35 mm rainfall event that occurred on 11 April 2006, there was also a concomitant increase in soil moisture.



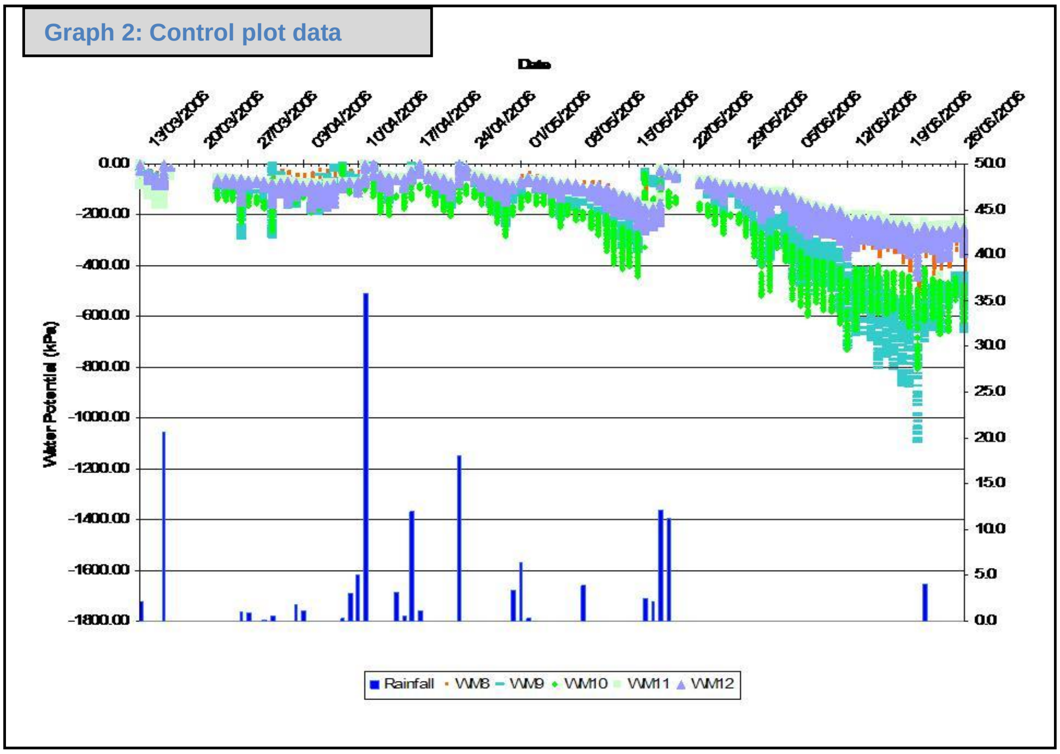


Figure 4.24 (Graph 1 & 2). Data collected from the watermark sensors at Ntembeni (Graph 1- run-off plot & Graph 2 – control plot)

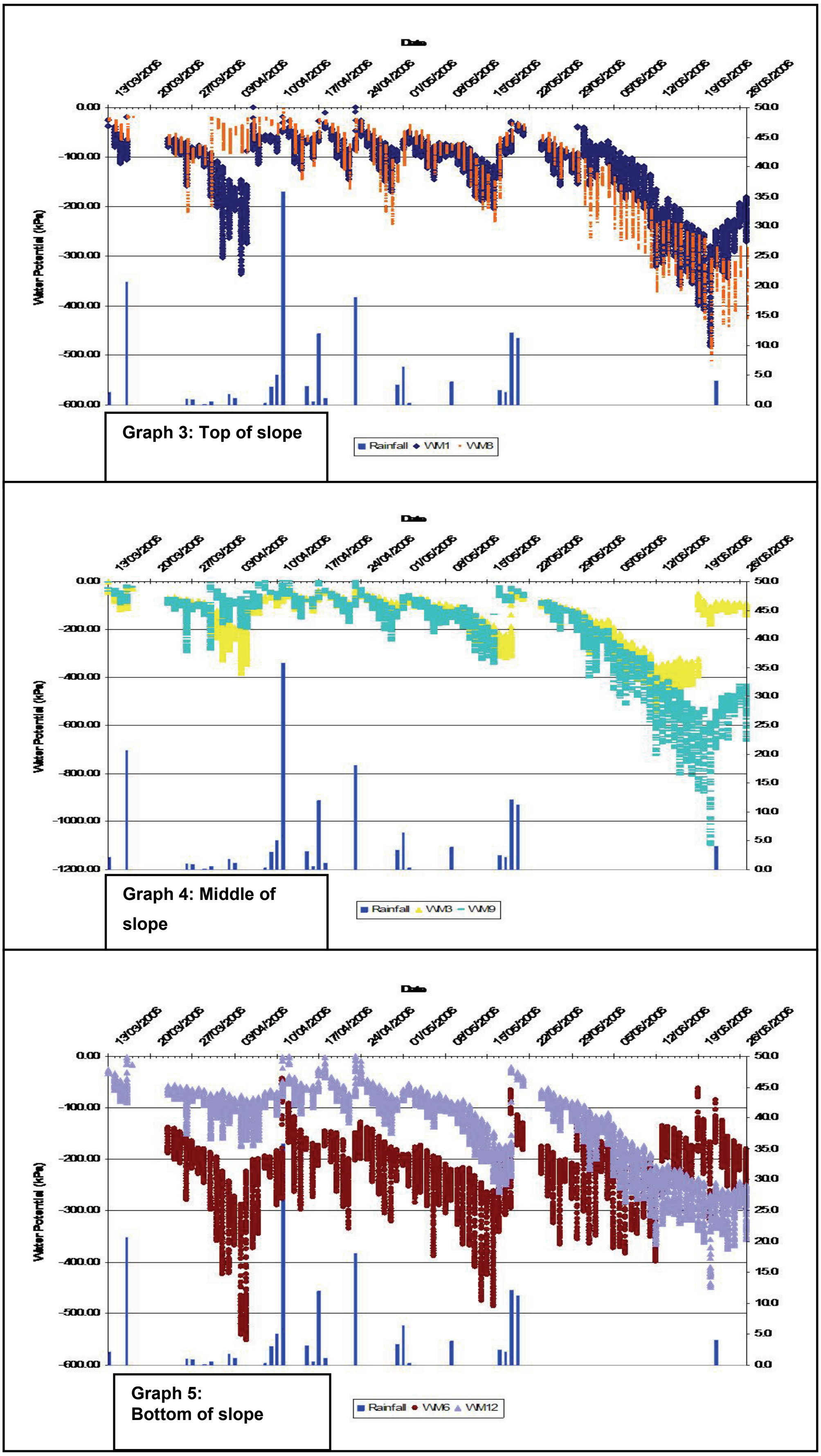


Figure 4.25 Comparative results between the run-off plots and the control plots

In addition to the Watermark sensors in these plots, there were Diviner access tubes installed in a trough at the centre of each plot. Soil moisture readings were taken fortnightly with the Diviner 2000 probe. A general trend between these two study plots can be established where the run-off and control plots follow the same time series pattern with a higher soil water content found in the run-off plots compared to the control plots. On average, the run-off plots had about 10-20 mm more water in the upper 500 mm soil profile.

The installation of the flow meter gives information on the amount of water used for irrigation on the community gardens during the winter season. From the time of installation there was a sharp increase in water abstraction during the winter months, typically from May to October each year. This trend was shown in the accumulated flow in Figure 4.26. Also shown in Figure 4.26 is the mean daily flow in litres. We found that the average amount of water used for irrigation was between 50-80 litres per day for the study site during the winter season while approximately 10 000 litres were used between June and October 2005.

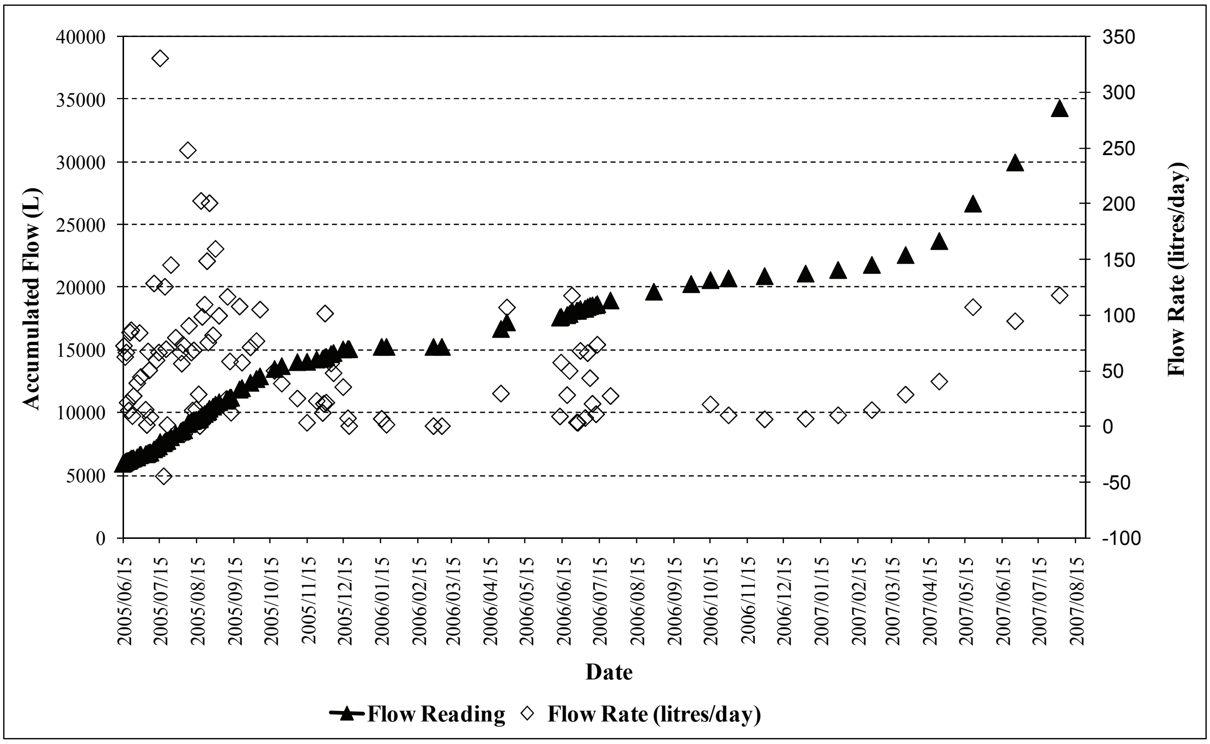


Figure 4.26 Accumulated flow and mean daily water consumption from the flow meter at Ntembeni

The measurements of the flow meter data were problematic during the project as the person that recorded the flow data moved away from the area and it was difficult for the project team to find a responsible person to take daily readings. As a result, team members recorded flow readings when they visited the study site weekly.

The repeat of this experiment in the winter of 2007 showed that the run-on plot with mulch had higher soil moisture compared to the plot with no mulch (Figure 4.27). In addition to this, the run-on plots had a higher soil moisture percentage for the upper 0.10 m to 0.30 m of soil. In the mulched plot, the soil water content was as high as 37% at the surface.

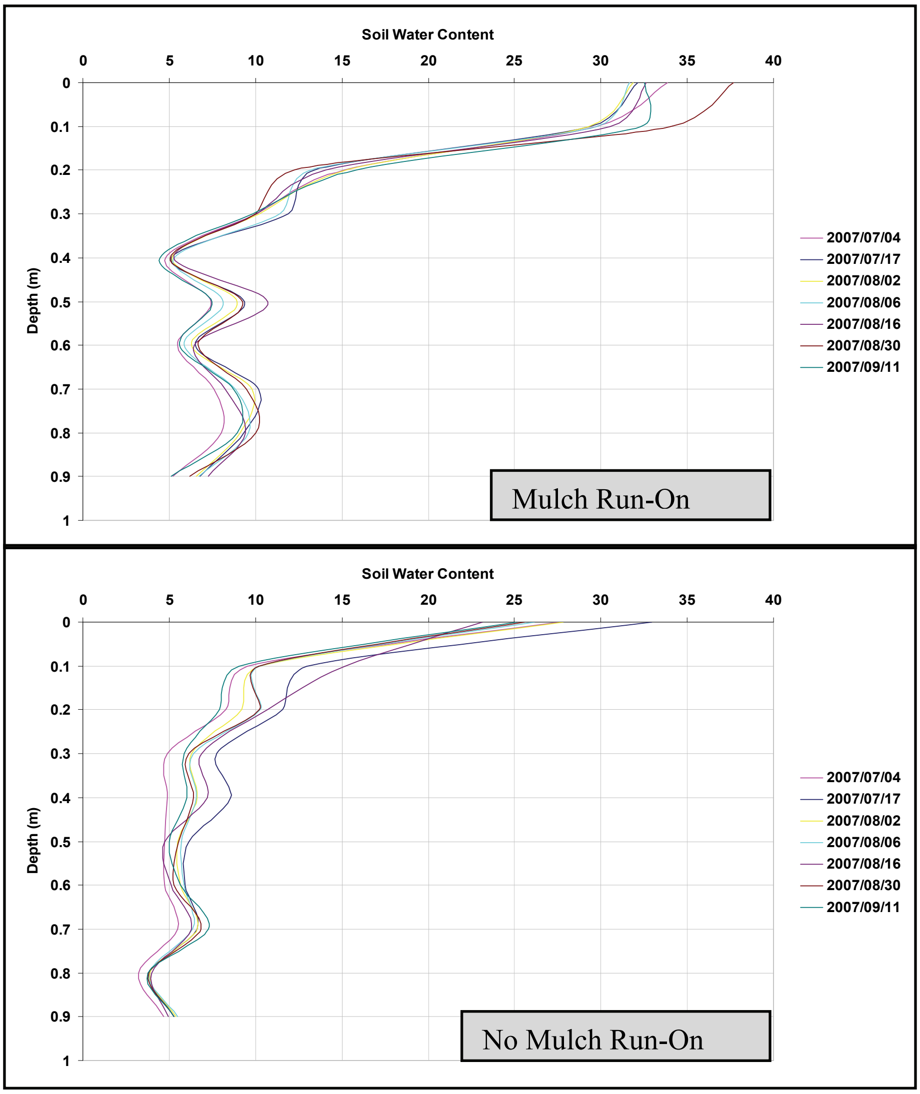


Figure 4.27 Soil water profile comparison between mulch and no mulch run-on plots for access tubes T25 and T26 respectively

4.3.2.4 Micro catchment water harvesting (modified in-field run-off plots – Free State method)

The introduction of the micro catchment water harvesting technique, specifically developed in the Free State and modified for the local conditions in this project, has also been successful. It was evident from the results that mulching improved the soil water content by 50 mm when compared with the control plot (Figure 4.28). The run-off mulch plot had the highest water content with 200 mm in the top meter of the soil profile. However, the run-off plot with no mulch showed very poor soil water retention. Comparison of the various treatments without mulch showed that the method of having ridges and troughs increased the total profile soil water content (1 m profile) to 125 mm compared to the control plot that had an average of 90 mm. The run-off plot with no mulch had the lowest water content.

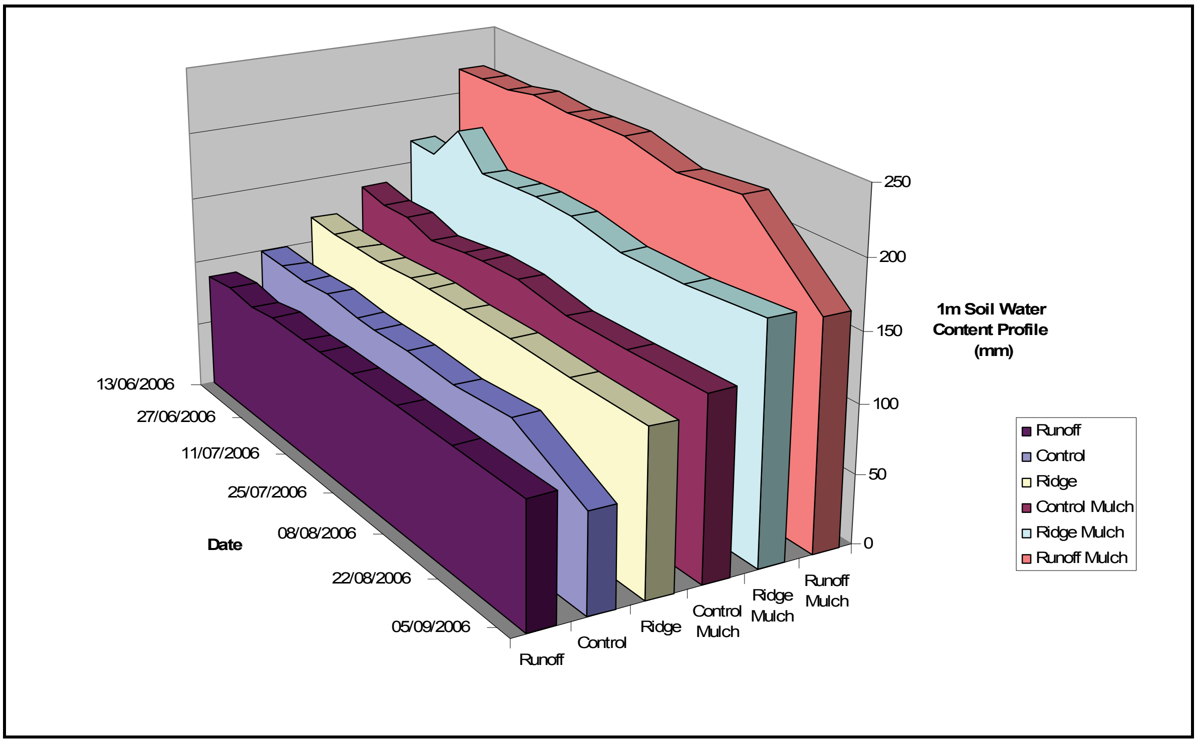


Figure 4.28 Comparative results of the various water harvesting and conservation techniques used at Ntembeni

In May 2007, the project team repeated the winter 2006 experiment at Zakhe Agricultural College. The results (Figure 4.29) indicated a progressive decrease in soil water content across all treatments. This trend in seasonal soil water decrease was similar to that observed in the subsequent years at Zakhe and Ntembeni, although this was interrupted briefly by irrigation. It is also evident that the ridge mulch treatment had the best performance when compared to other treatments.

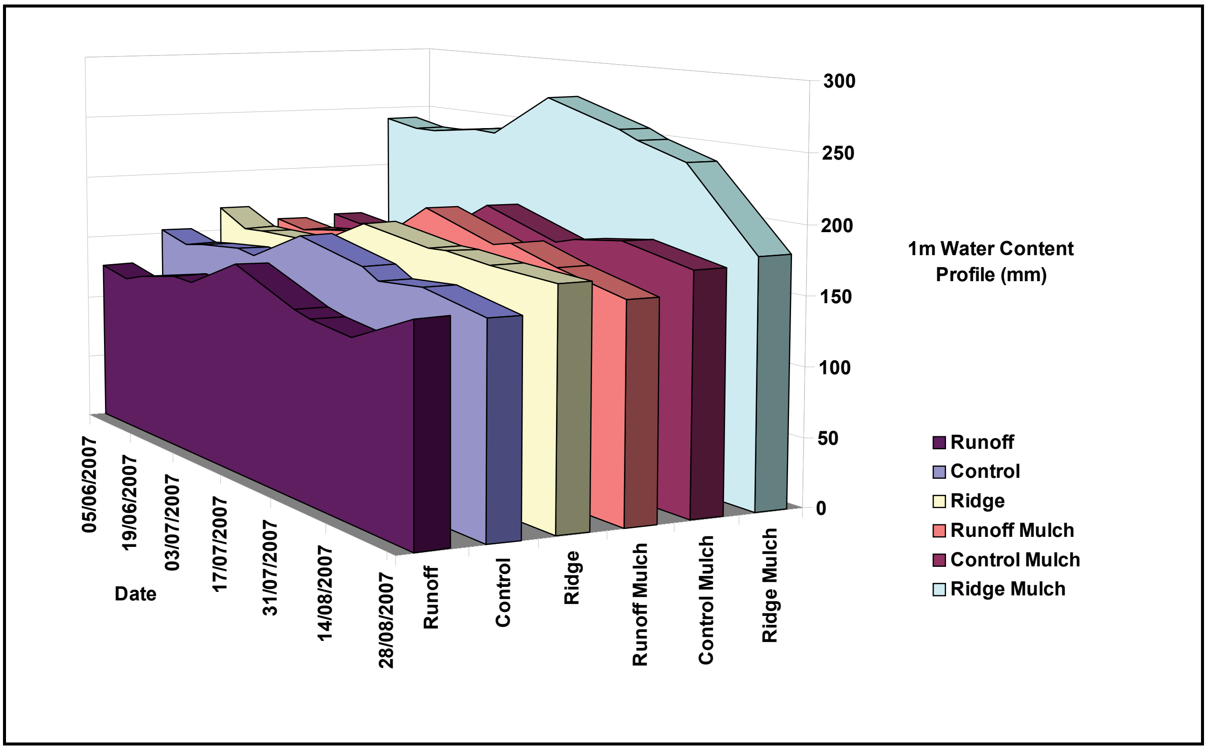


Figure 4.29 Comparative results of the various water harvesting and conservation techniques used at Zakhe for 2007

A closer comparative study was then carried out to focus on mulching versus no mulching. This study clearly showed the differences in soil water content (Figure 4.30) where access tube T8 was installed in a cabbage with no mulch plot while T14 was installed in the cabbage mulch plot. From the results it was evident that adding mulch maintained higher water content in the soil from a depth of 0.1-0.3 m due to its role in decreasing evaporative losses. The soil moisture in the top 0.2 m of the mulched plots was about 30% compared to the no mulch plot (13%.) A similar trend was also observed for the other access tubes in the mulch plots. This soil moisture is important in this study as the crops that are used in these experiments mainly have their roots in the top 0.2-0.3 m of the soil layer. Mulching as a technique of soil water conservation is, therefore, a useful strategy in sustaining soil water contents within the root zone.

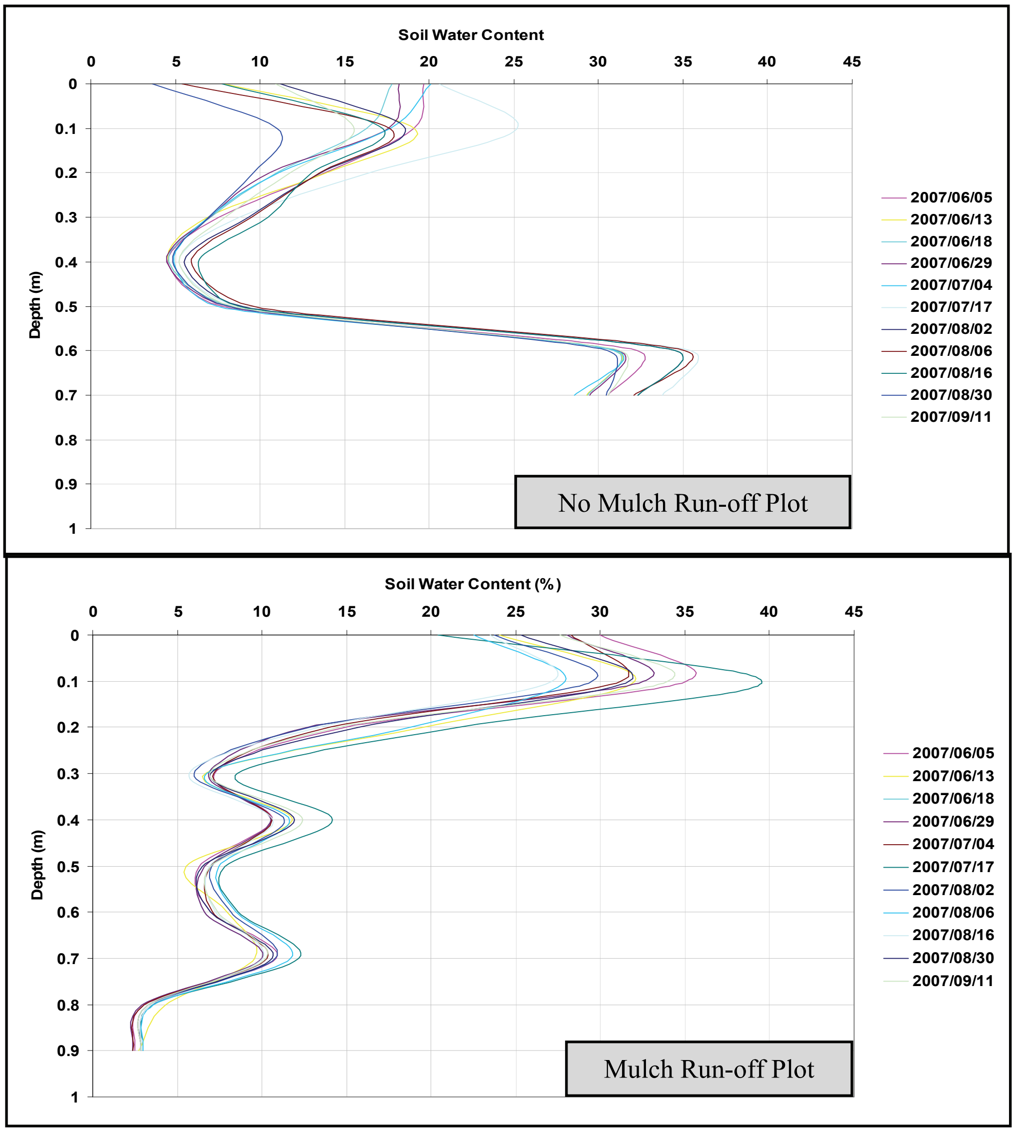


Figure 4.30 Soil water profile comparison between mulch and no mulch run-off plots for access tubes T8 and T14 respectively

A second comparative study between the control, ridged and run-off plots was also carried out. The modified Free State run-off technique proved to be most successful in improving soil moisture conditions. Since the results in Figure 4.30 showed that mulching improved the soil water content, in this study only mulch plots were compared. The ridge mulch plot had the highest water content with approximately 250 mm in the top meter of the soil profile, while the run-off plot and control mulched plots had an average of 170 mm (Figure 4.31). A comparison of the various treatments with mulch showed that the method of having ridges and troughs increased the total profile soil water content to 33% compared to the control plot that had soil water content 20% (Figure 4.13). The run-off plot also performed better than the control plot with a soil water content of 25%.

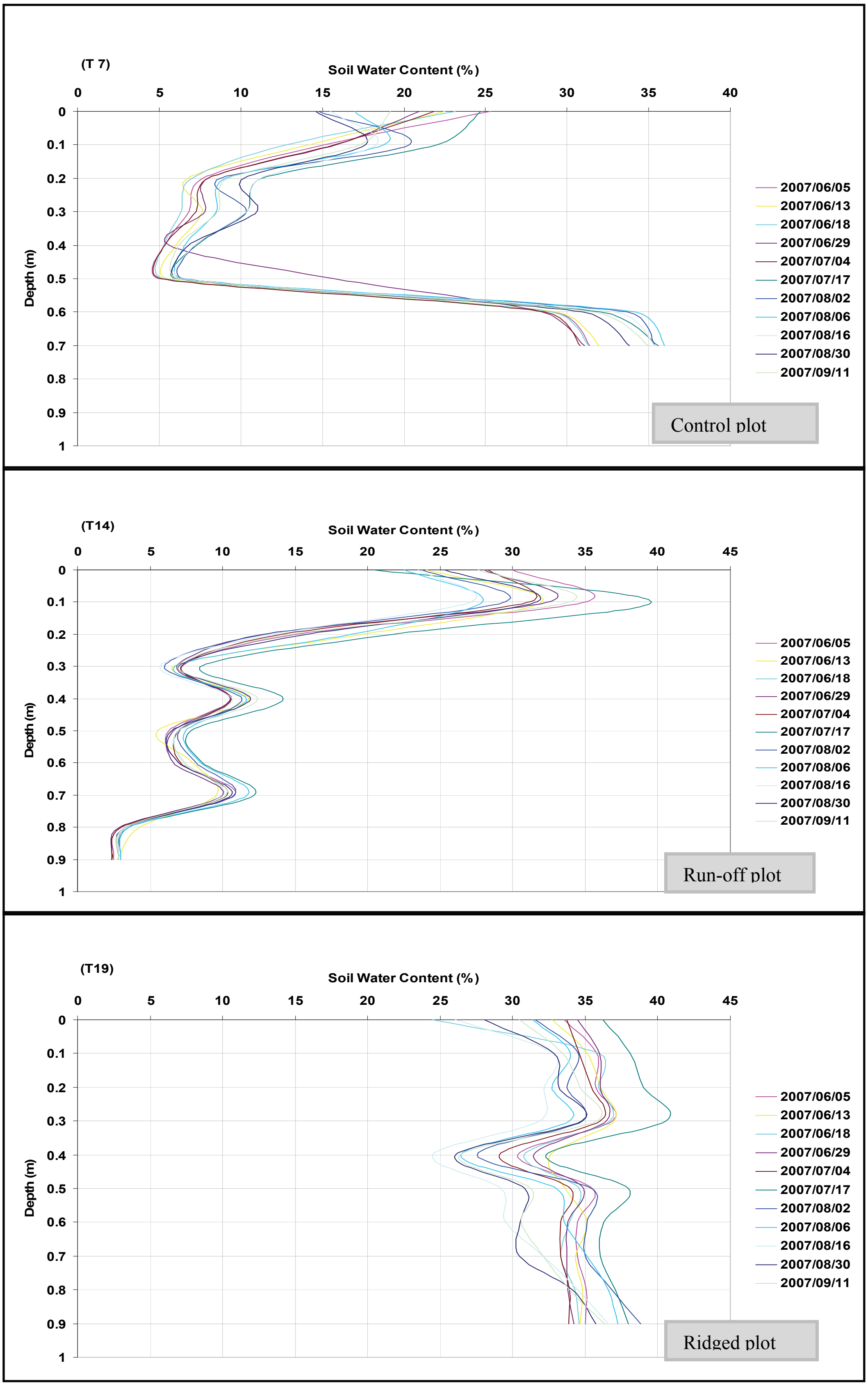


Figure 4.31 Soil water profile comparison between the three treatments (control, ridged and run-off plots) for access tubes 7, 14 and 19

4.3.3 Plant growth (micro-catchment Free Sate adopted method), May 2006

4.3.3.1 Leaf number and plant height

For both cabbage and Chinese cabbage, leaf number and plant height were improved by all the water harvesting techniques (Figures 4.32-4.35). However, there were no significant differences between the water harvesting techniques. The use of mulch did not result in the control plots having a similar effect as the water harvesting techniques with respect to plant growth. Although mulching had no effect on leaf number, it increased plant height in the flat beds so that they were comparable to those grown in ridged and run-off plots.

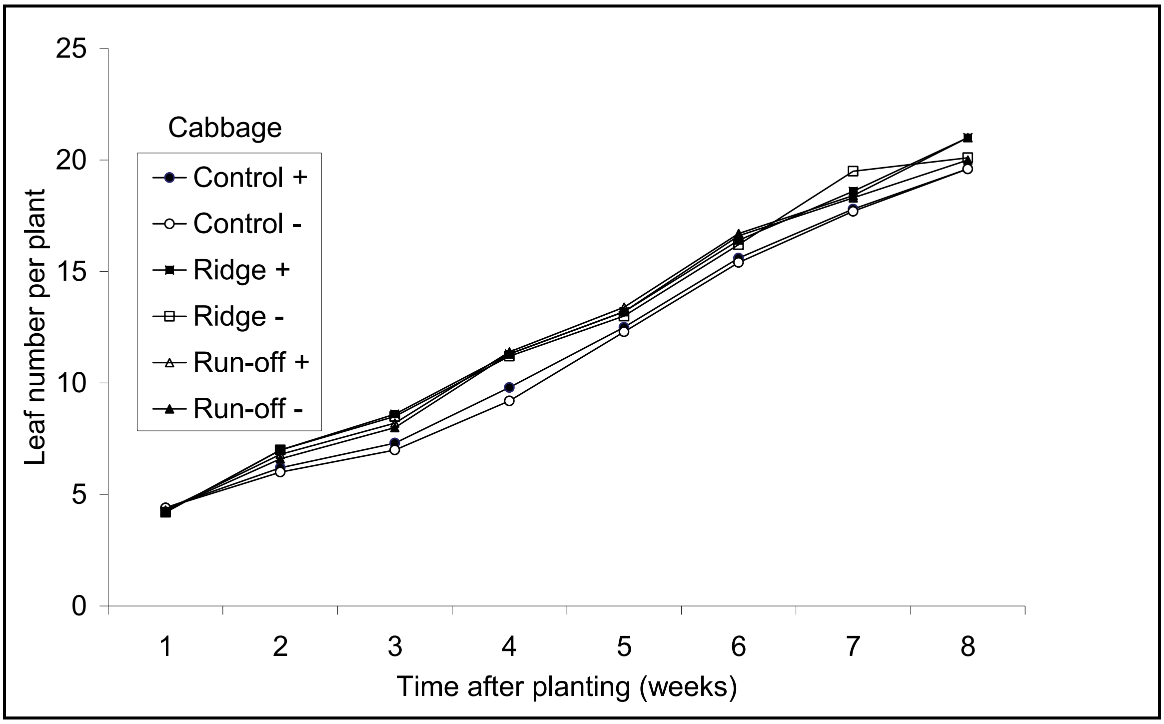


Figure 4.32 ***Comparison of water harvesting techniques (ridged and run-off plots) for effects on cabbage leaf number in the presence (+) or absence (-) of mulch during the first eight weeks of growth. Control plants were grown on flat plots. SED (0.05) (Techniques) = 3.3; SED (0.05) (Tine) = 1.7***

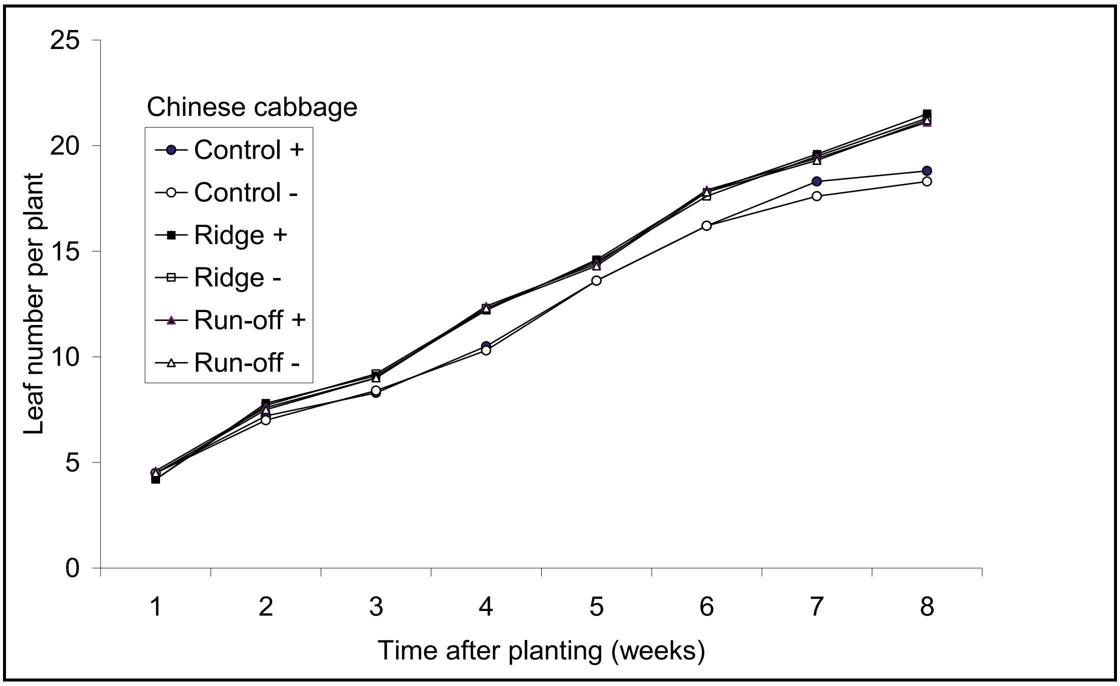


Figure 4.33 ***Comparison of water harvesting techniques (ridged and run-off plots) for effects on Chinese cabbage leaf number in the presence (+) or absence (-) of mulch during the first eight weeks of growth. Control plants were grown on flat plots. SED (0.05) (Techniques) = 3.8; SED (0.05) (Tine) = 2.1.***

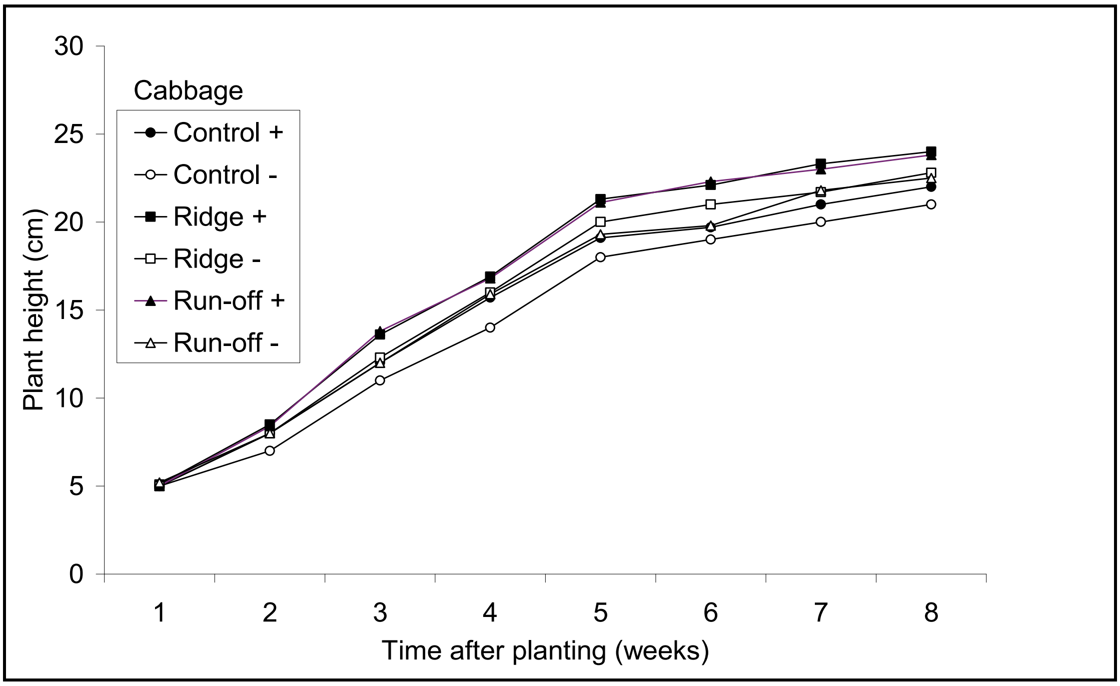


Figure 4.34 ***Comparison of water harvesting techniques (ridged and run-off plots) for effects on cabbage plant height in the presence (+) or absence (-) of mulch during the first eight weeks of growth. Control plants were grown on flat plots. SED (0.05) (Techniques) = 3.7; SED (0.05) (Tine) = 2.8***

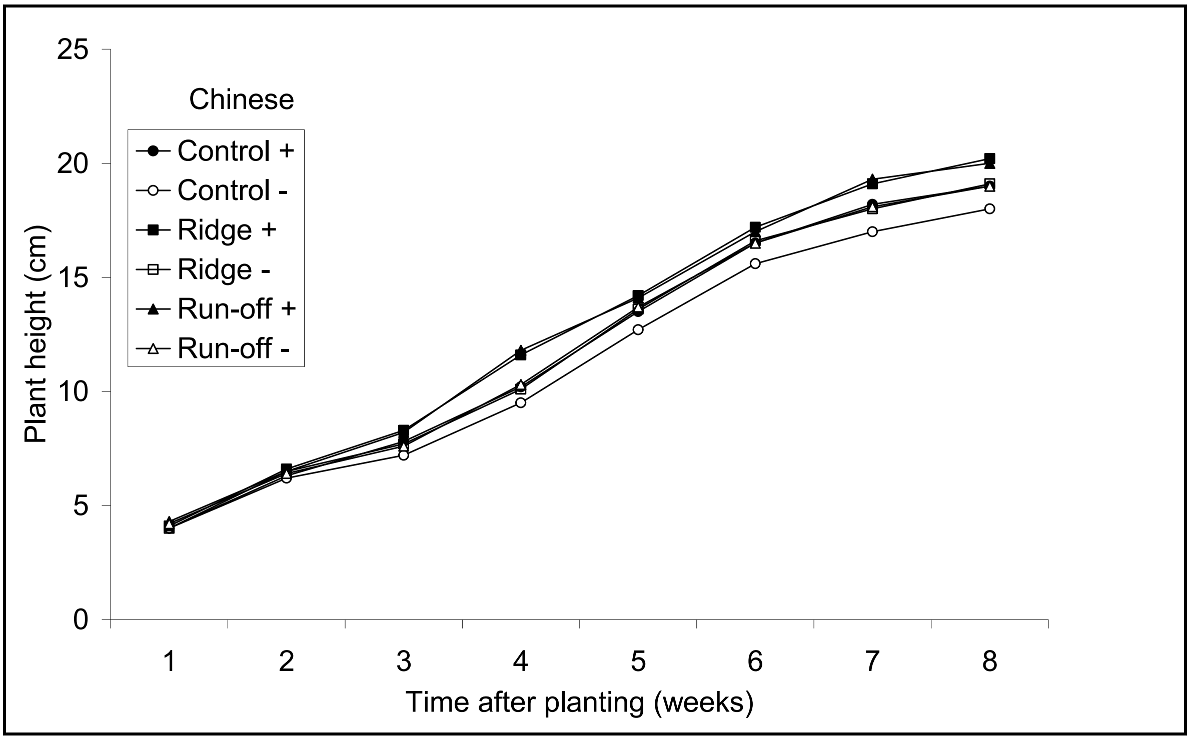


Figure 4.35 Effect of water harvesting techniques (ridged and run-off plots) on Chinese cabbage plant height in the presence (+) or absence (-) of mulch during the first eight weeks of growth. Control plants were grown on flat plots. SED (0.05) (Techniques) = 4.2; SED (0.05) (Tine) = 3.6

4.3.3.2 Crop yield

For cabbage, water harvesting techniques increased the yield by 50-60% and mulching increased the yield by 10-20% (Figure 4.36). For Chinese cabbage, there was about 40-50% increase in yield due to water harvesting and mulching caused about 10% increase (Figure 4.36). The effect of water harvesting on the harvested crop is shown in the photograph in Figure 4.37.

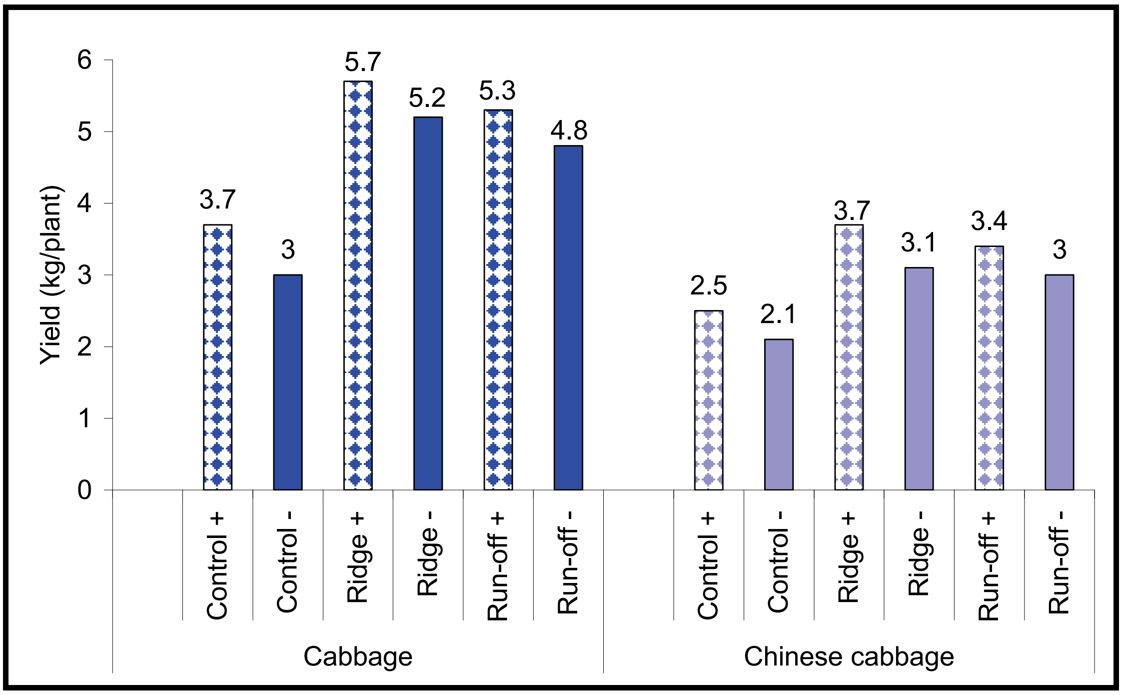


Figure 4.36 ***Yield of cabbage and Chinese cabbage in response to two water harvesting techniques (ridged and run-off plots) compared with flat beds (control) in the presence (+) or absence (-) of mulch. LSD (0.05) (Techniques, Cabbage) = 0.5; LSD (0.05) (Techniques, Chinese) = 0.3***

Figure 4.37 ***Mature Chinese cabbage plant grown using ridging (left) as a water harvesting technique compared with a control plant (right) grown on flat beds. Both plants were grown using grass/straw mulch (+)***

4.3.4 Gravimetric soil water content (upper 0.15 m soil layer)

Both water harvesting techniques (ridges and run-off) improved soil water content regardless of the crop grown (Figures 4.38 and 4.39). Mulching improved the soil water content in the flat beds (control- vs. control+) by approximately 37% in cabbage and 12% in Chinese cabbage (i.e. the effect of mulching with no water harvesting) (Figures 4.38 and 4.39). Both water harvesting treatments showed improved soil water compared to the flat bed control (no mulch) where soil water content values were higher throughout the season by 5% (run-off-) to 15% (ridge+) by week six for both crops (Figures 4.38 and 4.39). Under both cabbage and Chinese cabbage, soil water content decreased for the first four weeks of crop growth by approximately 3% and then it increased with plant age by about 5% in all treatments (Figures 4.38 and 4.39). The difference between treatments was shown as early as one week after planting and there was a general consistency in treatment effects for the duration of eight weeks (Figures 4.38 and 4.39).

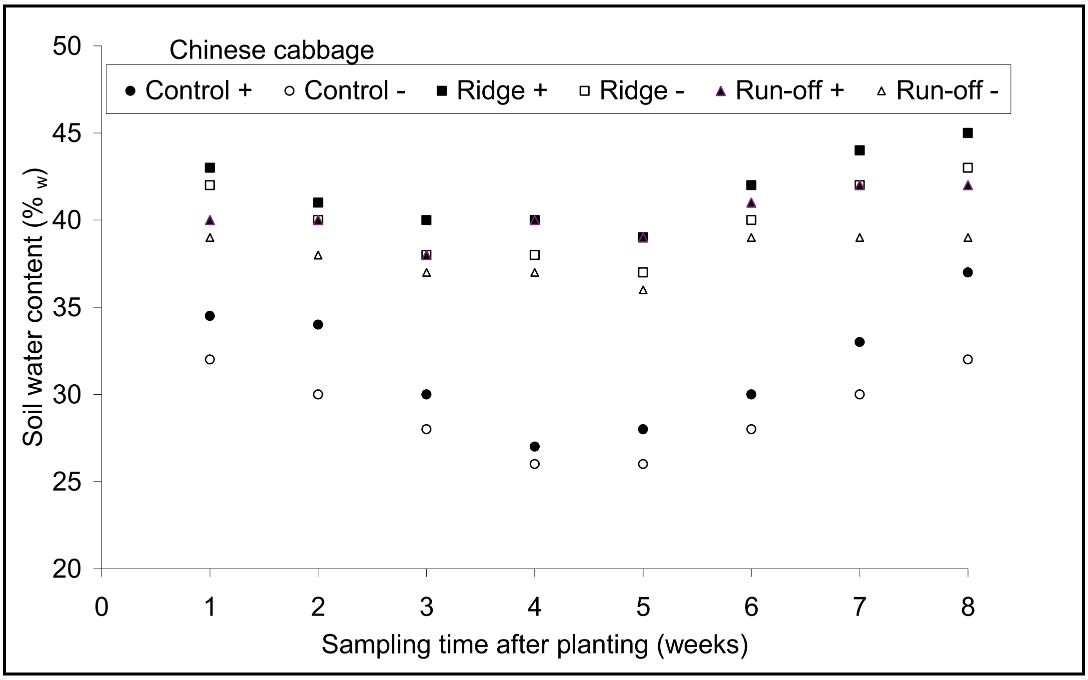


Figure 4.38 ***Pattern of gravimetric soil water content in the top 15 cm of soil sampled from the root zone of cabbage during the first eight weeks of growth. LSD (0.05) (Techniques) = 2.3; LSD (0.05) (Time) = 5.2***

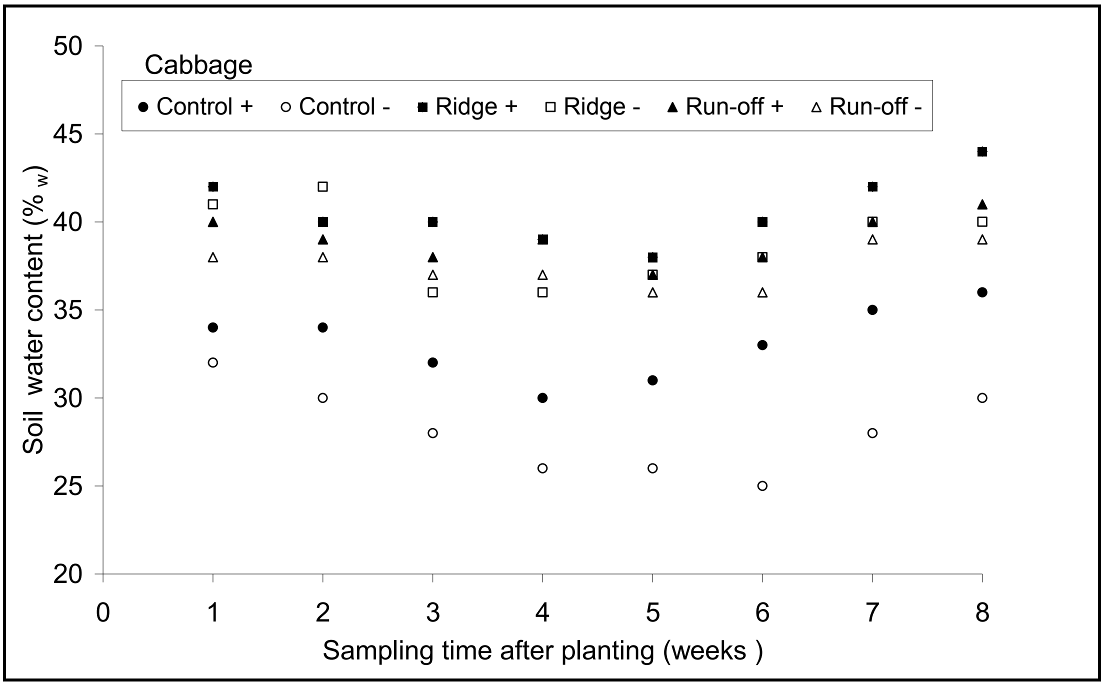


Figure 4.39 Pattern of gravimetric soil water content in the top 15 cm of soil sampled from the root zone of Chinese cabbage during the first eight weeks of growth. LSD (0.05) (Techniques) = 3.1; LSD (0.05) (Time) = 7.1

4.4 Conclusion

The research team determined the effect of different water harvesting and conservation techniques (raised seedbeds, ridges and in-field run-on/off plots) on the production of cabbage, Chinese cabbage and Swiss chard at the Zakhe Agricultural College and Ntembeni community garden. The studies showed that, regardless of the crop used, in-field (micro catchment) water harvesting using ridges increased soil water content and biomass. In addition, the effectiveness of a water harvesting technique was strongly influenced by soil type and structure. For example, in the winter season of 2006 the technique that produced the highest soil water content was the run-off plots, while in the winter of 2007 the findings were reversed as a result of differences in soil type and structure. The mean plant available water content was 273 mm for the 1.5 m profile in the Ntembeni soil profile. In the upper 0.60 m, where most of the roots were distributed, the plant available water content was only 134.72 mm. It is in this upper zone where IRWH activities need to be focused to increase plant production.

Adding mulch maintained higher water contents in the soil from a depth of 0.1-0.3 m due to its role in decreasing evaporative losses. The soil moisture in the top 0.2 m of the mulch plots was about 30% compared to the no mulch plots (13%.). This is an important soil conservation strategy as vegetable crops mainly have roots in the top 0.2-0.3 m of the soil layer. Mulching as a technique of soil water conservation is, therefore, a useful strategy in sustaining soil water contents within the root zone.

The comparative study between the control, ridged and run-off plots showed that the soil moisture profile for the run-off plots was consistently higher when compared to the control plots. On average, the run-off plots had about 10-20 mm more water (15% of the PAWC) in the upper 500 mm soil profile.

This study has clearly demonstrated that RWH and soil conservation techniques can play an important role in improving the sustainability of food production in the Midlands region of KwaZulu-Natal by improving soil water storage, crop yields and extending the growing season into the dry winter months. The implementation and adoption of these techniques will, however, require careful planning and economic support from both the National and Regional Departments of Agriculture and Environmental Affairs. Ongoing, effective information campaigns on the benefits of RWH&C techniques through participatory meetings with farmers, extension officers and researchers will be required to create the necessary awareness and subsequent adoption of these techniques.

Several studies on rainwater harvesting have shown that techniques such as mulching (Hensley et al., 2000; Botha et al., 2003), pitting and ridging (Mandiringana et al., 2003), and the modified Free State run-on plots (Hensley et al., 2000; Botha et al., 2003) are effective in arid (<300 mm) and semi arid regions (<700 mm). The results of this study showed that these techniques are also effective when applied in a high rainfall region (>800 mm).

CHAPTER 5 APPLICATION OF WATER HARVESTING TECHNIQUES IN RANGELAND/LIVESTOCK PRODUCTION SYSTEMS

5.1 Background

Livestock production is an important component of agricultural systems in rural areas of South Africa. Rangelands are the main and cheapest source of fodder for South Africa's animal production sector (DOA, 2009). However, increasing degradation of rangelands is occurring worldwide both in developed and developing countries (Scoones, 1992; Darkok, 1998; Wessels et al., 2007). In many communal areas of South Africa, rangeland is in poor condition which has a negative effect on animal production (Everson and Hatch, 1999). Previous rangeland improvement programmes and strategies in the communal areas of South Africa (e.g. the betterment scheme) have focused on de-stocking. However, these initiatives were socially unacceptable as they ignored the fact that livestock ownership is a multi-faceted strategy whereby benefits are multiple and cattle also have cultural and spiritual significance (Salomon, 2006).

Peden (2007) identified a livestock water productivity framework which enables a better understanding of livestock-water interactions. The framework identifies four basic livestock development strategies that can lead to more productive and sustainable use of water resources:

- improving the sourcing of animal feeds;
- enhancing animal productivity (products, services and cultural values) through better veterinary care, genetics, marketing of animal products and value-added enterprise;
- improving watering and grazing practices to avoid degradation of land and water resources; and
- providing quality drinking water.

One of the problems with applying this framework to communal rangelands is that there is a complex set of biophysical, social and economic considerations that need to be taken into account (Gross et al., 2005). In each specific case an understanding of these factors and their interactions is necessary before any interventions can be made.

In the case of Ntembeni, cattle kept by the community are dependent on the rangelands for forage. In summer, grazing is largely confined to the top of the hills although with increasing theft more and more cattle are kept closer to the homestead. In winter, the livestock have free access to the lower areas and feed on the maize stover and natural veld. However, fodder is extremely short and some community members cut and carry cabbage leaves and stover from the community garden to feed their livestock in winter. Water harvesting techniques have the potential to increase alternative fodder supply which will directly benefit livestock production. The objectives of this study were to:

1. Carry out a baseline study to determine the status quo of livestock production systems.
2. Select or introduce a water harvesting and conservation technique and test its effectiveness on a fodder flow plan for rangeland/livestock production systems using a participatory approach.

5.2 Baseline Survey

5.2.1 Methods

5.2.1.1 Site visits and community meetings

Site visits were conducted to meet the farmers and communities and view the study area. Community meetings and a workshop were held with the Ntembeni community to develop an understanding of current grazing practices, needs and constraints.

5.2.1.2 Map available resources (transect walks with community)

A participatory mapping exercise was carried out to determine the allocation of resources for grazing and access to water.

5.2.1.3 Veld condition

Veld condition assessments were carried out at Ntembeni and KwaMncane, the two wards in Baynesfield. Ntembeni is one big ward and KwaMncane has four sub-wards (3 & 4 and 6 & 7). The livestock for sub-wards 3 & 4 graze in the same area whereas livestock from 6 & 7 graze in their designated area. In total, four veld condition assessments were carried out by assessing the relative frequency of the plant species.

The relative frequency of the above-ground species in each of the wards was estimated using the descending point technique (Levy and Madden, 1933). A Levy bridge, comprising 10 pointed rods spaced 150 mm apart, was randomly placed at each site 20 times. At every location each rod was lowered and the species nearest to the lowered point recorded and identified. Two hundred observations were made at each site and the frequency of each plant species was expressed as a proportion of the total number of observations for the sample site. To estimate basal cover, distance measurements (cm) were taken from 50 random points to the nearest living tuft and the basal diameter of the tuft was measured (cm).

The veld condition was assessed by comparing the species composition data to that of a benchmark site in which the veld is considered to be in optimal condition. The benchmark site selected was Moist Midlands Mistbelt as described in The Bioresource Groups of KZN (Camp, 1999), where the optimal species composition and their relative abundance is given. The species were allocated into their respective ecological groups, namely Decreasers, Increaser I, Increaser II and Increaser III species (adapted from Van Wyk and Oudtshoorn, 2006):

- Decreasers: These species are generally palatable and decrease in relative abundance in veld which is over grazed or under-utilised.
- Increaser I: These species are not abundant in veld which is in good condition, but increase when veld is under-utilised.
- Increaser II: These species are not abundant in veld which is in good condition, but increase when veld is over-utilised.
- Increaser III: These species increase in abundance with selective grazing.

The relative abundance of each species was then calculated and recorded (Table 5.1). Each grass species was allocated a grazing value, depending on their nutritional quality in terms of digestibility and palatability. The relative abundance was then multiplied by this grazing value to give a sample site score for each species. The benchmark percentage and benchmark score were calculated for each species. The veld condition score was calculated using the following equation:

$$\text{Veld Condition Score} = (\text{total sample score} / \text{total bench mark score}) * 100 \qquad \text{eq. 5.1}$$

5.2.2 Results

5.2.2.1 Constraints to cattle management

During the meetings and workshop the community outlined a number of constraints to cattle management:

- **Veld burning** – there are no proper plans when burning the veld. Everyone in the community burns the grasses when they want to with no consultation or planning. The community would like to be trained on how and when to burn.
- **Lack of dipping tanks** – this issue was brought forward as a cause for concern. The community say they do not have the money for curing diseases and wounds caused by the ticks and they feel that a dipping tank will benefit their livestock. They also think that crush pens are important and will help reduce the number of diseases.
- **Lack of fencing of the camps** – the community see the need for their area to be re-fenced. The area was fenced before but the fence is in poor condition and in some areas has been destroyed. Some of the fence was stolen and they think the people behind these actions are community members. There is a boundary dispute between the Ntembeni community (cattle owners) and Mondi Forest. The community say that the expansion of forestry has reduced the amount of grazing land. Cattle are causing a lot of problems in the fields. The community feels that fencing will allow them to practise their agriculture freely and reduce the conflicts among the community members. One community member asked whether goats could be included in this grazing system as they also cause problems in the fields.
- **Water shortages** – Shortage of drinking water for livestock is one of the problems at Ntembeni. Cattle use the springs, catchments and streams for drinking water. The community feel that they should find a certain mechanism to improve their springs or use the unused tanks for the supply of water.
- **Livestock theft** – the community is experiencing theft of their cattle. This normally occurs when their cattle have been impounded. The community see the need for branding their cattle but since this has been attended to they hope theft will decrease.

- **Fodder shortages** – the community has a major problem with fodder shortage. They attributed this to the planting of trees (Mondi Forests) which has reduced their grazing area and has contributed to water shortages in the area.
- **Unemployment** – there is a high rate of unemployment. The youth that have completed grade ten are also not employed.

5.2.2.2 Mapping exercise

The community nominated one of the community members, Phelelani, to draw the layout of the Ntembeni sub-ward on the white board. The community helped him with the drawing. The following features were shown on the map: the mountain (Deyi) where livestock graze, the primary school (Kwa-Msinga), homesteads of the community, streams and rivers (Lubhidi the main stream), the water tanks in the area, the hall (community hall), the road (from the garden to Tafuleni), the boundaries separating Ntembeni from Mondi forest and Mafunze sub-ward. The map was then used by the community to highlight the problem of the shortage of water in the area and the long distances people have to travel to work in the community gardens and to attend to their livestock grazing needs.

5.2.2.3 Veld condition and management

The veld in both wards was in poor condition ranging from 30.3-54.1% in Ntembeni and from 35.4-63.4% in KwaMncane. There has been a marked decrease in the palatable Decreaser species on the slopes and ridge tops (0-13%) when compared to the benchmark site (50%) which is grassland that is in optimal condition. The high percentage of Increaser II species (44-89%) when compared to the benchmark (21%) indicates long term over-grazing. The dominant Increaser II species are the unpalatable *Eragrostis plana* and *Eragrostis curvula* species. The low species diversity and high numbers of forbs is a further indication of the poor condition of the veld. The high value of Increaser III species such as *Aristida junciformis* (10-53%) when compared to the benchmark value of 4% indicates that over-grazing has been selective and that the stocking rate is high. *Aristida junciformis* is a tough, unpalatable grass with zero grazing value. Since selective overgrazing has taken place this grass forms dominant stands which are virtually impossible to eradicate with normal veld management practices. The potential for any form of livestock production on this veld is extremely limited.

5.2.2.4 Organisational capacity of the community to introduce a fodder flow plan

A discussion was held with the community about the importance of the livestock committee in the implementation of a fodder flow plan. The current livestock committee was elected to attend to all livestock related issues and problems. It consisted of five people from the community. However, it had not been functional for some time. A new committee was elected by the community at a meeting held on 24/01/2004.

5.2.2.5 Timeline exercise

A timeline exercise was done in the form of a discussion with the entire group to get a background on grazing management interventions in the area. Deteriorating animal health due to diseases was the main issue and was given top ranking. The Ntembeni community have been subjected to many projects but little change has occurred in grazing management. The area never had formal grazing management till the mid-90's when Mondi tried to address grazing problems. The Mondi liaison officer facilitated the project. A livestock committee was formed and dipping tanks were planned to be established but due to lack of funding from Mondi, the entire project never progressed. However, the community acquired some land under Mondi Forest. Mondi suggested that they should hire a herder to look after their cattle. This was done and then the community hired another two herders due to the increase of livestock. Each livestock owner/household paid R30 to the herders per month. Approximately 700 cattle graze in this Mondi area. According to the community, the veld in the Mondi area is in a better condition than the communal veld. The livestock owners who can't afford to contribute to the herding fund take their cattle to graze on the mountains.

5.2.2.6 Livestock management

The community reported that cattle graze on the mountains where there was a fence and are kraaled at night at home. Other livestock graze in the area acquired from Mondi Forest. Livestock remain in these areas for the rest of the year, whereas some owners collect their cattle in autumn for feeding on maize stover. There is no rested veld in the area. Mondi tried to co-ordinate a dipping tank construction project. This failed due to lack of funding. Every livestock owner takes care of his/her own cattle for dipping and other health related practices.

5.2.3 Conclusion

The use of water harvesting to improve rangeland and fodder production is relatively rare (Critchley and Siegert, 1991). The main reason for this is that rangeland users and other stakeholders, such as extension staff and policy-makers, are faced with a complex set of biophysical, social and economic considerations (Gross et al., 2005). During the baseline study to determine the current status of livestock production systems, a number of issues arose which highlight the complex nature of livestock management in the area. Many of the issues are beyond the scope of this project (e.g. fencing of grazing camps, provision of dipping tanks, implementation of veld burning programmes). However, the water harvesting project has the potential to address the issues of animal health and fodder shortage. The introduction of legume fodder species with high tannins to reduce parasites will not only improve animal health, but will also address the problem of fodder shortage which is evident from the poor veld condition.

Table 5.1 Species composition and veld condition of the study sites

Moist Midlands Mistbelt		Grazing	Benchmark		Entembeni (Site 1)		Entembeni (Site 2)		KwaMncane (Site 1)		KwaMncane (Site 2)	
Group	**Species**	**Value**	**%**	**Score**	**%**	**Score**	**%**	**Score**	**%**	**Score**	**%**	**Score**
Increaser	*Alloteropsis semialata*	3	2	6	0	0	0	0	0	0	0	0
I	*Digitaria tricholaenoides*	6	1	6	1.5	9	0	0	0	0	0	0
	Eulalia villosa	3	1	3	0	0	0	0	0	0	0	0
	Setaria nigrirostris	5	1	5	0	0	0	0	0	0	0	0
	Hyperthelia dissoluta	0	2	0	0	0	0	0	0	0	0	0
	Digitaria natalensis	0	18	0	0	0	0	0	0	0	0	0
	Tristachya leucothrix	9	0	0	2.5	22.5	0	0	0	0	0	0
	Cymbopogon excavatus	1	0	0	1.5	1.5	0	0	0	0	0	0
	Digitaria sanguinalis	2	0	0	0	0	0	0	0	0	0	0
	Paspalum notatum	3	0	0	0	0	0	0	0	0	0	0
	Sub Total		**25**	**20**	**5.5**	**33**	**0**	**0**	**0**	**0**	**0**	**0**
Decreaser	*Brachiaria serrata*	3	1	3	0	0	0	0	0	0	0	0
	Diheteropogon amplectens	8	2	16	0	0	0	0	0	0	0	0
	Monocymbium ceresiiforme	6	2	12	0	0	0	0	0	0	0	0
	Themeda triandra	10	45	450	8.5	85	0	0	0	0	0	0
	Heteropogon contortus	6	0	0	4.5	27	0	0	0	0	0	0
	Diheteropogon amplectens	8	0	0	0	0	0	0	0	0	1	8
	Setaria incrassata	0	0	0	0	0	0	0	0	0	0	0
	Panicum deustum	10	0	0	0	0	0	0	0	0	0	0
	Sub Total		**50**	**481**	**13**	**112**	**0**	**0**	**0**	**0**	**1**	**8**
Increaser	*Eragrostis capensis*	2	2	4	0	0	0	0	6	12	9.5	19
IIa	*Harpochloa falx*	3	2	6	2	6	1	3	0	0	0	0
	Heteropogon contortus	6	3	18	0	0	0	0	0	0	0	0
	Sub Total		**7**	**28**	**2**	**6**	**1**	**3**	**6**	**12**	**9.5**	**19**
Increaser	*Eragrostis curvula*	5	1	5	15	75	0	0	17.5	87.5	9	45
IIb	*Eragrostis plana*	3	1	3	1	3	6	18	26	78	24.5	73.5
	Eragrostis racemosa	2	1	2	2.5	5	4	8	0	0	0.5	1
	Hyparrhenia hirta	5	1	5	0.5	2.5	0	0	20	100	0	0
	Sporobolus africanus	3	1	3	3	9	4	12	8	24	11.5	34.5
	Sub Total		**5**	**18**	**22**	**94.5**	**14**	**38**	**71.5**	**289.5**	**45.5**	**154**
Increaser	*Microchloa caffra*	1	1	1	0	0	0	0	0	0	0	0
IIc	*Paspalum scrobiculatum*	3	1	3	0	0	0	0	0	0	0	0
	Forbs & Sedges	0	7	0	12.5	0	14	0	0	0	32	0
	Paspalum dilatatum	7	0	0	7.5	52.5	18	126	4.5	31.5	2	14
	Paspalum notatum	3	0	0	0	0	0	0	5.5	16.5	0	0
	Aristida schirensis	6	0	0	0	0	0	0	0	0	0	0
	Sub Total		**9**	**4**	**20**	0	**32**	**0**	**10**	**48**	**34**	**14**
Increaser	*Aristida junciformis*	0	2	0	37.5	52.5	53	126	12.5	0	10	**0**
III	*Diheteropogon filifolius*	0	1	0	0	0	0	0	0	0	0	0
	Elionurus muticus	0	1	0	0	0	0	0	0	0	0	0
	Sub Total		**4**	**0**	**37.5**	**52.5**	**53**	**126**	**12.5**	**0**	**10**	**0**
	Total		100	551	100	298	100	167	100	349.5	100	195
	Veld Condtion Score %			**100**		**54.1**		**30.3**		**63.4**		**35.4**

5.3 Fodder Flow Experiment

5.3.1 Introduction

When the quality of natural forage falls below the level required to maintain bodyweight, animal production declines. The absence of palatable Decreaser species at the study sites and the dominance of low quality Increaser II species (14.0-74.5%) when compared to the benchmark value (5%) indicates that livestock owners need to supplement their livestock with additional forage during winter to prevent the animals losing condition, declining in productivity and possibly dying. Such supplementation takes the form of crop by-products, such as maize stover. However, such supplements are often of relatively low quality, whereas forage crops have the potential to provide better nutrition, especially if they are high in protein (e.g. legumes).

Another problem in any livestock production system is the ever-present threat of internal parasites, such as worms. Such parasites can debilitate animals, even in the presence of good quality forage. Worm infestations can be treated using commercially available anthelmintics, but in communal areas this option is often precluded owing to a lack of financial resources.

In the baseline survey, both fodder shortage and animal diseases were highlighted by the Ntembeni community as major constraints to livestock keeping. *Dolichos lablab* (Dolichos) is a legume that is often grown as a forage crop for livestock and has the potential to address these constraints. Both the plant and, especially, the seed are high in protein and digestible carbohydrates and can be stored to provide supplementary forage when natural forage is unavailable. Additionally, it has been suggested that Dolichos may provide some protection against internal parasites. Therefore, Dolichos may be a useful crop in these communal production systems. The aim of this study was to investigate whether Dolichos can be grown and utilised in the Ntembeni communal production system using water conservation techniques. The objective of the study was to examine the effect of mulching and soil preparation on the germination, survival, dry matter production and infestation by weeds of Dolichos, a common fodder crop.

5.3.2 Methods

The experiment was established at the Community Garden on 16 January 2007. Dolichos does not tolerate very high temperatures, although it can tolerate cool conditions. Therefore, seeds were planted towards the middle of summer so that most growth (and the critical fruiting time) would take place under relatively cooler conditions.

5.3.2.1 Experimental design

The experiment was a randomised block design, with two factors each at two levels replicated three times, resulting in four treatments and twelve plots (Table 5.2). Each plot comprised two 1x1 m subplots, 2 m apart, which were cleared of all above-ground vegetation. Plots were at least 4 m, but less than 6 m, apart and positioned along a fence that runs approximately perpendicular to the contour of the land. The land was contoured, giving rise to nearly-level ridges separated by steep contour banks. Plots were located only on the ridges, but did not necessarily follow the block structure of the design (Figure 5.1).

5.3.2.2 Factors

Factor 1 was basin size. For level 1, the soil across the whole subplot was loosened with a pick and spade, and shaped to form a large open basin designed to dam water following rain. For level 2, only a small area (approximately 20x20 cm) was loosened, but was not shaped.

Factor 2 was mulching. For level 1, entire subplots were both mulched with hay to a depth of approximately 15 cm. For level 2, plots were not mulched.

Table 5.2 Experiment design. See Figure 5.1 for details of 'ridge'

Plot	Code	Block	Ridge	Details
1	SN	1	1	Small basin, no mulch
2	SM	1	1	Small basin, mulch
3	BN	1	1	Large basin, no mulch
4	BM	1	2	Large basin, mulch
5	BN	2	2	Large basin, no mulch
6	SN	2	3	Small basin, no mulch
7	BM	2	3	Large basin, mulch
8	SM	2	3	Small basin, mulch
9	BM	3	3	Large basin, mulch
10	SN	3	4	Small basin, no mulch
11	SM	3	4	Small basin, mulch
12	BN	3	4	Large basin, no mulch

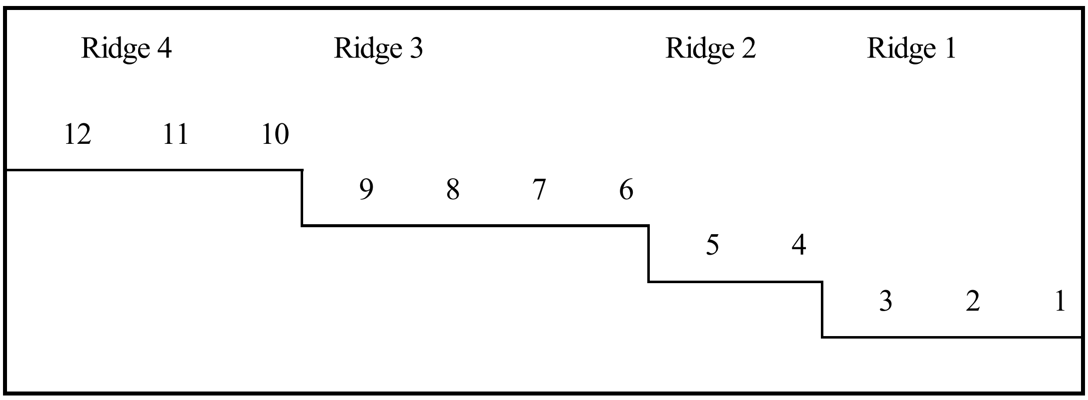


Figure 5.1 Physical layout of plots

5.3.2.3 Establishment

Dolichos seeds were planted (5 per subplot) on 16 January 2007. Fertiliser containing the macro-elements nitrogen, phosphorous and potassium in the ratio of 2:3:2 was incorporated into the soil at planting. Seeds were inoculated with an appropriate inoculant.

5.3.2.4 Data collection

The following data were collected at the site on 6 March 2007 (data were pooled across subplots):

- Number of established plants.
- Length of each plant.
- Comparative aphid infestation (1 = none; 2 = very sparse; 3 = medium density; 4 = high density; 5 = debilitatingly high density).
- Number of *Cyperus* plants (allelopathic weeds that can significantly reduce crop yields).
- Comparative infestation of weeds (1 = none, 2 = light, 3 = medium, 4 = high, 5 = very high).

5.3.2.5 Statistical analyses

The following statistical tests were carried out to determine the effects of mulching and hole size on:

- Germination (logistic regression).
- Average plant length (ANOVA).
- Aphid infestation (ANOVA).
- Number of *Cyperus* plants (Poisson regression).
- Weed infestation (ANOVA).

5.3.3 Results

Fifty-seven plants from the 120 seeds (47%) that were planted successfully established. There was no effect of either mulching or hole size on the likelihood of survival (P=0.60). At least one plant established in each of the subplots. There were no significant effects of either mulching or hole size on the length of plants, although the average length of mulched plants was higher than that of no mulch plants (74 vs. 53 mm; P=0.19).

The infestation of weeds (all species) was significantly lower on mulched (1.5/5) than on no mulch (2.4/5) plots (P=0.024). The number of allelopathic *Cyperus* plants in each plot was significantly lower on mulched than on no mulch plots (P<0.001). Hole size had no significant effect of weed infestation.

Some plants were heavily infested with aphids, but this was not related to block, hole size, or mulching. There was no relation between plant length and aphid infestation, probably because aphid infestation was estimated at the subplot level, while plant length was measured at the individual plant level.

5.3.4 Discussion

The experimental results indicate that Dolichos can be successfully established in community gardens. Livestock control was sufficient to ensure that animals did not eat, and thereby kill, the young plants.

Hole size and mulching did not have a statistically significant effect on the size of plants. This indicates that plants grown in relatively hard soils next to boundary fences can achieve (initial) growth rates similar to that of plants in cultivated soil. In many production systems, the area immediately adjacent to the boundary fence is unproductive, so this provides an opportunity to make better use of resources.

Mulching proved an effective way of reducing competition from weeds. This would presumably lower labour input to keep the plants weed-free while they are young and susceptible. At a later stage Dolichos would likely be able to smother and out-compete any weeds. Some weeds can compete directly with plants through allelopathy, particularly the nutsedges (*Cyperus* species). Mulching was effective against these weeds, which were highly abundant around no mulch plants. Aphids were present on some of the plants and these plants appeared to have been damaged by the insects. Therefore, prudent insect control is probably necessary.

Although the dry-matter production of the Dolichos was too low to run a feeding trial, the results indicate that water conservation techniques have the potential to increase fodder production. Improving animal feeds will ultimately reduce the grazing pressure on the rangeland and reduce degradation of land and water resources. More in-depth studies are required to develop livestock development strategies in degraded communal rangelands that can lead to more productive and sustainable use of land and water resources.

CHAPTER 6 SOCIO-ECONOMIC IMPACT ASSESSMENT

6.1 Introduction

The rainwater harvesting (RWH) project was implemented at Ntembeni, KwaMncane and Baynesfield (Zakhe Agricultural College) communities under the jurisdiction of uMgungundlovu Municipality in KwaZulu-Natal province. The aim of the project was to find ways of assisting the three communities on techniques to improve agricultural productivity through water harvesting and conservation techniques. The focus was on rainwater harvesting, a process of concentrating rainfall as run-off from an area for use in target areas. Prior to the introduction of water harvesting techniques in Ntembeni, KwaMncane and Baynesfield communities, farmers experienced the following challenges:

- Problems of insufficient water for vegetable production, particularly in the winter season.
- Lack of relevant skills and techniques on farming.
- Lack of techniques for utilising rainwater.

After identifying these setbacks, it was imperative to introduce techniques that would assist in addressing these socio-economic constraints in the three communities. The objective of the project was to identify and implement water harvesting and conservation techniques that would assist the targeted communities to improve their livelihoods through vegetable production. In order to achieve this objective, the project focused on improving farming operations by introducing practices that would help farmers improve their crop production, marketing strategies and management of their agricultural activities.

The main objective of this study was an overall assessment of the socio-economic impact of the RWH project established at Ntembeni, KwaMncane and Zakhe Agricultural College. The aim was to ascertain the impact of RWH interventions on people's livelihoods. The specific objectives of the study were to:

- Assess the impact of the RWH project on social status of the farmers at the three communities.
- Assess the impact of the RWH project on economic status of the farmers at the three communities.
- Assess the impact of the RWH project on the socio-economic status of the surrounding communities.
- Assess the uptake of the water harvesting and soil conservation techniques by the communities.

6.2 Methods

6.2.1 Framework of analyses

This study adopted the socio-economic impact assessment (SEIA) framework developed by the International Atomic Energy Association (IAEA, 2005). The method provides a range of options for assessing social and economic impact on a project and it offers advice on appropriate methods for each particular situation. The IAEA (2005) asserts that SEIA is a useful tool to help understand a potential range of impacts of a proposed change and the likely response of those affected upon if the change occurs. It can be used to assess impacts of a wide range of types of change. Two methods, a socio-economic survey using a semi-structured questionnaire and focus group discussions, were used for data collection.

6.2.2 The social survey

This initially involved the recruitment and training of four enumerators (research assistants) to conduct interviews. The questionnaire was pilot-tested and found to be feasible. The study population consisted of all farmers from Ntembeni and KwaMncane who were involved in the trials and demonstrations. The study units were individual farmers and buyers of the farmers' produce.

Data were collected from 18 farmers at Ntembeni and KwaMncane communities. In 2005, a baseline study (Chapter 3) was carried out amongst 25 farmers and the aim for this investigation was to interview the same farmers. However, only 18 of them could be interviewed. The rest were either not available during the time of the interviews or were no longer involved with the project. In addition to the 18 farmers involved with the project, 15 buyers of the farmers' vegetables were also interviewed. One of these buyers was Southgate Spar Supermarket in Pietermaritzburg where Zakhe Agricultural College supplied its vegetables, while the rest were hawkers.

6.2.3 Focus group discussions

Focus group discussions were used to obtain data from the farmers who were not directly involved in the implementation of the trials and demonstrations but attended the meetings and other gatherings of the project. Krueger (1994) defines a focus group discussion as a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment, where participants share and respond to comments, ideas and perceptions. Ghauri & Gronhaug (2002) also state that by focus group, they mean a small group of people interacting with each other to seek information on a small (focused) number of issues.

The aim of the focus group discussions was to understand the farmers' views regarding the agricultural activities directly affecting their lives. The same method was used to obtain information from the surrounding communities of Ntembeni and KwaMncane. A total of 23 farmers and community members from the aforementioned communities attended the focus group discussions with the research team. The intention was for these people to give their independent views, since they were not directly involved with the project.

6.2.4 Analysis and interpretation of data

The data were captured and processed using Microsoft Excel and analysis was limited to descriptive statistics. The codes were developed into themes by reading through transcripts and listing concepts, ideas, beliefs, perceptions, attitudes and knowledge. Qualitative analysis of the data was based on the notes taken during the focus group discussions.

6.3 Results and Discussion

6.3.1 Gender and age distribution of the respondents

Respondents consisted of 80% females and 20% males from Ntembeni and KwaMncane. The gender distribution in this case can be attributed to the significant role played by women in food security at the household level. With respect to age, the majority of the respondents fell in the age groups 40-50 and 61-70 years (Figure 6.1).

6.3.2 Impact of the rainwater harvesting project on social status of households

6.3.2.1 Farmers' awareness of the project and its objectives

The majority (95%) of respondents indicated that they were aware of the project and demonstrated their awareness of the project activities. Only 5% expressed ignorance of the project objectives.

The socio-economic survey indicated that 75% of the respondents were convinced that the community garden was the solution to alleviate poverty and promote food security. The other 25% did not think the community garden was going to help in poverty alleviation, food security and overall community development. One issue they cited as a hindrance to the success of community gardens was inadequate water supply for irrigation.

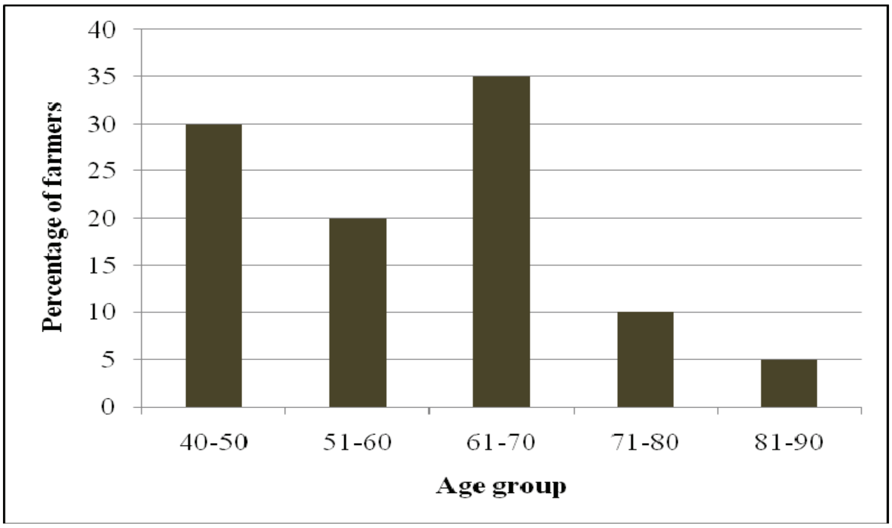


Figure 6.1 Age distribution of respondents interviewed

6.3.2.2 Relationship between the rainwater harvesting project participants and the research team

The majority (95%) of the respondents indicated that their relationship with the project team was cordial. Some of the reasons for advanced cordial relations with the project team as indicated by the respondents were:

- The team is friendly.
- The team supplies us with seedlings and inputs.
- The team has taught us water-harvesting techniques in vegetable production.

Fifty percent of the participants stated that they had participated in the designing and planning of the project, while the other 50% declined having participated in the exercise at all. In terms of decision-making, 60% mentioned that they had participated in the process of decision making for the project activities. As for involvement in planning the assessment of the project, 60% acknowledged that they actually took part, but 40% said they did not take part. With regard to involvement in the identification of socio-economic indicators, 50% agreed that they took part, while the other 50% said they were not part of the exercise. These responses are summarized in Table 6.1.

Table 6.1 Participant responses to project planning and designing activities

Activity	Yes (%)	No (%)
Participation in project design and planning	50	50
Participation in project decision making	60	40
Participation in planning the assessment of the project	60	40
Involvement in the identification of socio-economic indicators	50	50

It is imperative that initial planning of the agricultural development to take place in the area brings together the research team and farmers, as well as other stakeholders, in order to create a sense of ownership of the project by the farmers.

6.3.2.3 Impact of technologies and practices introduced on farmers

The RWH project team introduced a number of technologies and practices at Ntembeni and KwaMncane communities during its life from 2005 to 2008. The technologies and practices introduced, as well as the proportion of farmers who adopted, them are shown in Table 6.2.

Table 6.2 Farmer adoption of technologies introduced by the rainwater harvesting project team

Practice	Adoption (%)	Non-adoption (%)
Best times to irrigate gardens	70	30
Use of a cropping calendar	100	0
Application of fertilisers	100	0
Correct planting time	80	20
Use of certified seed	95	5
Correct planting populations	95	5
Integrated pest management	95	5
Keeping of financial records	95	5

All farmers adopted the use of a cropping calendar and application of fertilisers to their crops. Use of certified seed, recommended plant populations, integrated pest management and keeping of financial records were adopted by the majority (95%) of farmers as shown in Table 6.2. An improvement was noticed in the management of water as reflected by the fact that 70% of farmers adopted timely irrigation (Table 6.2). Before the introduction of the RWH project, most farmers used to irrigate at any time of the day, even when it was too hot. The RWH team discouraged this practice and the farmers adopted the habit of irrigating in the mornings and late afternoons. The other 30% could not adopt best times to irrigate because of inadequate water supply in the gardens. The adoption of correct time of planting by 80% of the farmers was a move in the right direction, given that prior to the introduction of the RWH project farmers planted at any time depending on convenience.

According to Mkhabela (2005), developing and adopting new production techniques could improve productive efficiency. In addition, the vegetable-based cropping systems could maintain their economic viability by improving the efficiency of existing operations with given technology. On the other hand, Botha et al. (2007) acknowledge that water conservation technologies that have shown great potential for decreasing poverty and food insecurity have been developed through research over the years. Unfortunately, low adoption of these techniques occurred in rural communities. However, Twomlow and O'Neill (2003) claim that a household's ability to adopt different crop management options depends on a range of socio-economic and biophysical factors. Twomlow and O'Neill (2003) further anticipate that if research and development do not consider these factors, households will not adopt innovative techniques.

According to Smyth and Dumanski (1993) the five pillars of sustainability of crop production are:

- Appropriate use of crop system and agricultural inputs supporting those activities.
- Improvement in agronomic productivity.
- Reduction in production risk.
- Conservation of the natural resources base.
- Economic viability and social acceptability.

With regard to engagement in the garden, 55% confirmed that they worked on a full-time basis, while 45% were part-time farmers. In terms of working on a daily basis (except during weekends) in the garden, 70% said they did not work every day, and only 30% agreed that they worked daily. Sixty percent of the farmers worked 2-3 days a week while the other 40% worked 4-5 days per week. The survey also revealed that 75% of the farmers spent more time presently in the field as compared to the previous three years.

A change was noticed in the area of marketing. Findings indicated that 75% of the participants demonstrated knowledge of marketing, which was not the case in 2005. Asked if they were using the chain stores, local hawkers or outside hawkers, results indicated that the majority of respondents used the local hawkers (Figure 6.2).

The majority of farmers (75%) marketed their produce as individuals (local and outside hawkers), while only 25% practised group marketing. All farmers (100%) cited lack of formal contracts as a major hindrance to marketing their produce. Regarding access to input suppliers, 25% acknowledged an improvement while the other 75% did not witness any improvement in input suppliers since the inception of the RWH project in 2003. Vermeulen et al. (2008) states that adverse market conditions and poor access to markets are major problems for farmers in Africa.

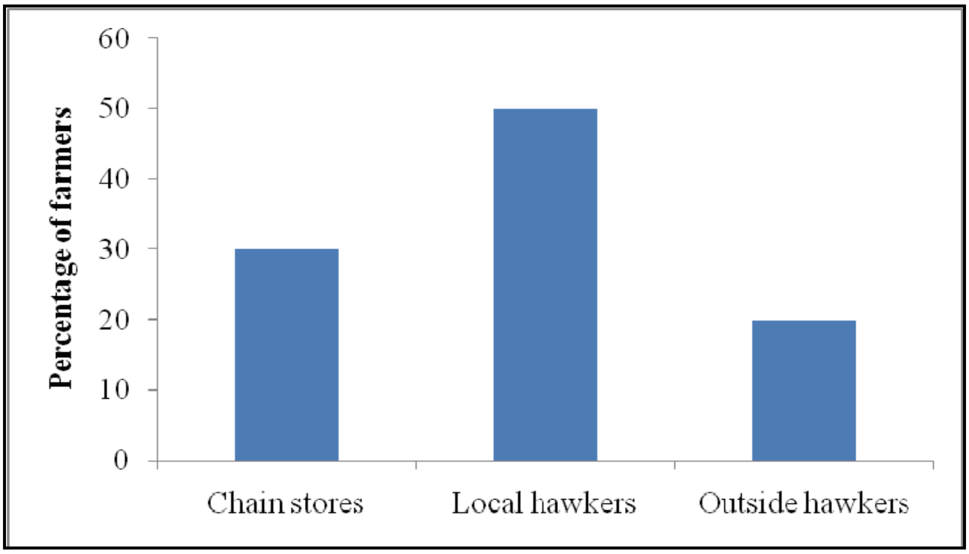


Figure 6.2 Marketing channels used by the farmers to sell their produce

6.3.3 Impact of the rainwater harvesting project on farmers' organisational structures

6.3.3.1 The management structure

The RWH project had a positive impact on organisational structure and regulatory institutions. In 2005, the management structure of the farmers was almost dysfunctional such that no meetings were planned and held whatsoever (Chapter 3). The farmers only used to meet when the RWH project team was visiting the projects. Scheduled meetings were not honoured, with each farmer giving different reasons for not attending. After the baseline study in 2005, the RWH project team managed to facilitate the formation of a farmers' committee to coordinate all activities, resulting in a great improvement in institutional development among the project participants.

Of the farmers interviewed in 2008, 85% confirmed that meetings were being conducted on a regular basis. They cited that the attendance to meetings had resulted in the strengthening of their orgnisational set-up. However, the other 15% were not convinced that meetings were bearing much fruit as anticipated. Asked if their organisation was legal and had a registered structure, 65% agreed but 35% did not remember processing the registration of their organisation. However, they mentioned that both political and tribal leadership played a significant role in the area in that they were both supportive of the farmers' contribution to the socio-economic well-being of the population.

On the subject of facilitation of the formation of the committee, the majority of the community members (75%) agreed that there was facilitation of the formation of the RWH project committee. Moreover, it was unanimously agreed that minutes had always been taken during meetings and that they had been read during the subsequent meetings. All respondents concurred that there was a code of conduct during meetings, while 75% of the respondents also mentioned that the community was represented in the umbrella body and that the committee had a constitution. However, 25% of the respondents were not sure of the constitution. With respect to committee meetings, 65% of the farmers confirmed that the committee met regularly. All farmers confirmed that the RWH project committee existed. Findings indicated that the majority (65%) of farmers prepared their land on an individual basis while 35% worked collectively.

Regarding outside contractors for land preparation, 75% cited that there were written contractual agreements while the other 25% had none. Further, asked what means of equipment the farmers used for land preparation, the entire group mentioned that they had been using tractors from Zakhe Agricultural College and the surrounding communities. According to the respondents, organisational development had both positive and negative effects on them (Table 6.3).

Table 6.3 Effects of organisational development initiatives on the farmers

Positive	Negative
Use of tractors made land preparation easy	Selling as a group was challenging because of family responsibilities
Farmers gained skills in producing vegetables through the training courses offered	Shortage of water and leaking pipes still a hindrance to adoption of best times to irrigate
Meetings were very helpful as they allowed exchange of knowledge and skills regarding their gardening activities and general farming	Problems of accessing markets to sell vegetables

As with organisational development, adoption of new practices as introduced by the RWH project team at household level resulted in both positive and negative effects (Table 6.4).

Table 6.4 Effects of the new practices as introduced by the rainwater harvesting project team on the farmers

Positive	Negative
Adequate food for the family	Applying certain techniques can be both time consuming and labour intensive
Vegetable growing is profitable as it brings in extra income	Lack of right equipment to be used for farming
Attending meetings helps farmers to be better organised	Inadequate water for growing vegetables

When farmers were asked about the impact of various practices introduced by the RWH project to the farming community, they responded as shown in Table 6.5.

*Table 6.5 **Perceptions on the impact of technologies introduced by the rainwater harvesting project team on the farming community***

Practice	Impact
Organisational developments	Transforming our farming community in the areas of managing community garden affairs, taking important decisions and accessing resources for the agricultural activities
Marketing	It improves our economic well-being
Land preparation	It is a costly exercise
Cropping plan	We have gained a lot of knowledge by implementing the plans in the garden
Water harvesting	It requires more labour

6.3.4 Impact of the rainwater harvesting project on surrounding communities

The majority of the respondents (95%) confirmed that the community gardens at Ntembeni and KwaMncane were positively affecting the surrounding communities. The community benefited by obtaining food (vegetables) from the gardens. When the farmers were asked whether they had employed some community members to help in their gardens, only 25% said they had done so. For those who had employed some members of the community to help in the community gardens they on average employed one person per week on a temporary basis.

Findings indicated that the community had adopted use of harvested water for domestic purposes (cooking, drinking and washing). In addition, 25% of the respondents had adopted use of harvested water to irrigate their gardens. Sixty percent of the non-farming community members cited that they were benefiting from community gardens' infrastructures. Examples were roads that facilitated access to gardens and equipment like tractors used for ploughing. With regard to community members' participation in RWH project activities such as meetings, farmers' days and demonstrations, 40% of the non-farming community members said they did participate while 60% did not participate.

The other way the community gardens influenced positively on the surrounding communities was by convincing them to see the need to attend farmers' events so that they could benefit from these agricultural activities and be motivated to start their own gardens. This could lead to agricultural progression in the area. Fifty-five percent of the farmers stated that there were some members of the non-farming community who had adopted some practices introduced by the RWH project team. Among the water-harvesting and conservation practices mentioned were planting vegetables on raised beds and mulching the vegetables to smother weeds. Some of the benefits of the RWH project on the surrounding communities included:

- Reasonable prices for vegetable buyers.
- Good quality vegetables and sharing of ideas regarding farming.
- Reduced prices to hawkers.

6.3.5 Impact of rainwater harvesting project on economic status of farming households

In order to ascertain the economic impact of the RWH project on the farming communities, the respondents were asked to rate their current economic well-being. Economic well-being in this context refers to the state of households being healthy, happy or prosperous. All these states depend on various factors, such as family characteristics, the resources of these farm households, production and employment levels, and the ability of income to meet consumption, savings, and other household needs. The responses obtained from the majority of respondents (80%) indicated that there was an improvement in economic well-being.

When asked whether their agricultural skills had improved during the past three years, 90% concurred that they had while the other 10% did not think that they had.

Evidence for improved skills was given as follows:

- Sold produce and bought seeds.
- Earned more money.
- Had access to more land.
- Gained better knowledge in water harvesting techniques.

The respondents who cited that they had access to more land attributed this to the expansion of the community garden following their request for more land from the Induna. Others started cultivating land to which they had user-rights but had not cultivated it before. Some people negotiated the use of fallow plots which were not used by people with user-rights. It was evident that land ownership was a critical factor affecting the uptake of RWH techniques. The need for communal farmers to obtain more secure land tenure for cultivation (e.g. formal land exchanges, lease agreements, user-rights) was also found by Van Averbeke (2008) in the Limpopo province.

The respondents who cited that they had not gained any skills since the introduction of the RWH project attributed this to lack of adequate resources. For instance, they cited that they could not adopt correct times to irrigate due to lack of adequate water for irrigation.

When asked what they used the money earned from the gardens for, it emerged that half of their income was used to buy food. The remainder was divided equally between payment of school fees and buying agricultural inputs.

6.3.5.1 Production and land use intensity

The cultivation of land emerged as another important factor. The majority (65%) of the farmers stated that they cultivated all the land they had access to in winter (Table 6.6).

Table 6.6 Proportion of land cultivated in winter

Proportion of land cultivated	Proportion of farmers (%)
All the land	65
Three quarters of land	15
Half the land	15
One quarter of the land	5

Farmers' access to more land would enable them to participate more actively in agriculture. This view is supported by Schmidt (2006) who points out that the level of farming relies on access to land, water, seeds and agricultural instruments. Schmidt (2006) also mentions that because more than 80% of the population were restricted to less than 13% of the land under apartheid, most black farmland (so-called homelands) were severely overused, thus leading to soil erosion and reduced productivity.

6.3.5.2 Record keeping

The survey revealed that 85% of farmers had adopted financial record keeping in order to ascertain whether they were making a profit or loss. For this reason, the project saw the need to encourage the farmers to maintain their financial records considering that the farmers had been exposed to basic bookkeeping at Zakhe Agricultural College.

6.3.5.3 Changes in farm input expenditure

Discussing the expenditure on farming inputs, 65% of the farmers indicated that their farm input expenditure had increased since 2005. The increase in expenditure was mainly in the purchase of farming inputs such as fertiliser, chemicals and seed. All respondents indicated that there was not much change regarding labour. Reasons given were that they did not have enough resources to pay the workers. Instead, the farmers worked with assistance from families and occasionally from neighbours. Regarding the number of people employed on the farms, only 25% hired part-time labour for peak operations such as planting, weeding and harvesting. The other 75% of the farmers were not able to hire labour due to financial constraints.

6.3.6 Effects of the rainwater harvesting project on household food security

The majority of farmers (75%) cited that they had become more food secure at household level since the introduction of the RWH project. Most farmers (70%) confirmed that none of their household members went hungry at any time of the year or month. However, the remaining 30% cited that their household members sometimes experienced hunger during winter and towards the month ends due to inadequate resources. Regarding meals consumed per day by the farmers' household, 75% stated that they consumed three meals per day while the other 35% said they consumed two meals per day. The survey indicated that household spending among the farmers varied (Figure 6.3).

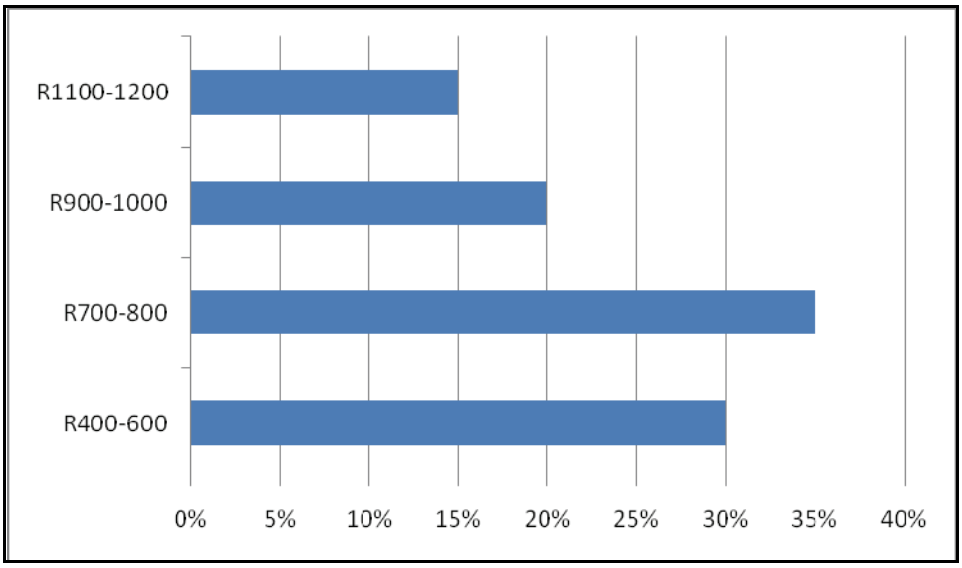


Figure 6.3 Annual household spending by the farmers

With respect to buying or growing most of their household food items, the majority (65%) of farmers indicated that they still bought most of the food but the other 35% maintained that they were growing most of their required food. Discussing the issue of food purchase, 40% of the farmers reported that the food they bought was food that they could not produce. Twenty percent of the respondents mentioned that they would rather buy food because growing vegetables took a lot of time before harvesting and consuming. Twenty five percent of the farmers stated that growing their own vegetables made a huge difference when compared to buying from other sources. Looking at the setbacks for vegetable growing, frost was cited as one of the major constraints for not growing vegetables in winter.

6.3.6.1 Dietary food consumed at household level

The importance of homestead gardens for improved family nutrition has been highlighted by Stimie et al. (2010). However, these authors state that the benefits of these gardens will only be realised if the problem of lack of water on the premises is addressed. This was supported by the current study whereby the respondents mentioned a wide variety of crops (cabbage, kale, potatoes, samp, beans, rice, maize-meal, spinach, butternuts, tomatoes, onions, beetroot) and meat as among the main ingredients in their diets, but only a few of these (cabbage, potatoes, spinach, beetroot, carrots, onions and beans) came from the farmers' produce. The issue of purchasing products in winter accounted for 60% while in summer it was 40%. The reason for the low production in winter was due to inadequate water supply. The higher production in summer was due to frequent rains and, as such, nearly all households planted various vegetables in this season. In addition, 70% of the farmers said they were not able to produce their own products all year round because of their lack of knowledge of pest control.

6.3.6.2 Food acquisition strategies

There was a significant drop in the percentage of farmers buying food from the urban market compared to the baseline in 2005 (Figure 6.4). This was attributed to a significant increase in the number of farmers producing their own food.

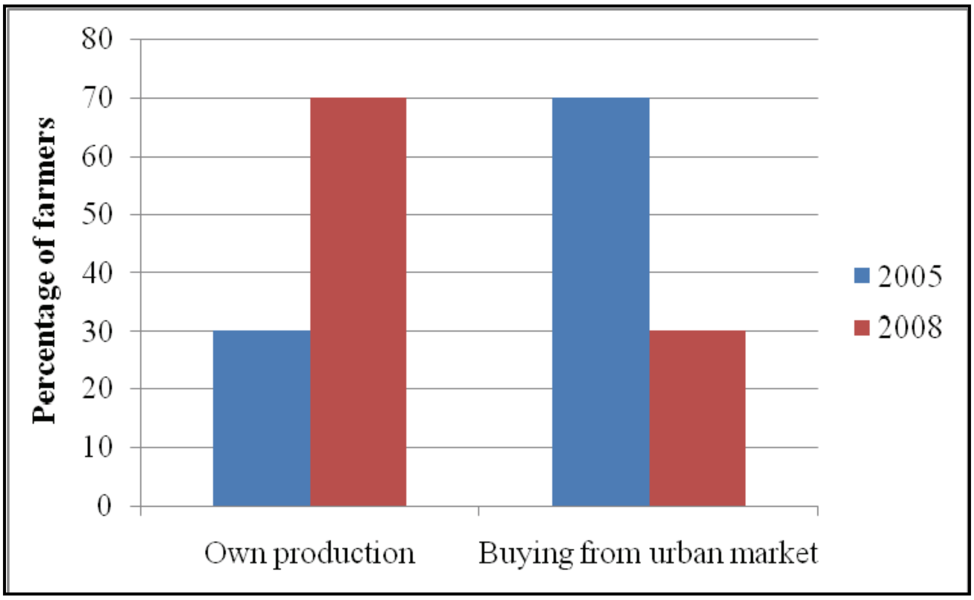


Figure 6.4 Food acquisition strategies by farmers in 2005 and 2008

The above trends demonstrate that there has been a change in the farmers' attitude towards food acquisition strategies; the reason being that most respondents preferred to produce their own food. The contributing factors were that the respondents had acquired skills in water harvesting techniques, which assisted them not only to adopt strategic plans for their livelihoods but also to produce food for their families. This is evident in that 55% of the farmers stated that they were able to produce more food because of knowledge gained from the training courses offered by Zakhe Agricultural College. However, 45% attributed their success in production to the seeds and seedlings provided by Zakhe Agricultural College.

6.3.7 Impact of the rainwater harvesting project on the farmers

6.3.7.1 The role of the rainwater harvesting project team

The farmers described the role of the RWH project team as having positively affected the community. Fifty-five percent of the respondents indicated that there had been evidence of positive changes in terms of using various water harvesting techniques after the training offered to them. Farmers mentioned that Zakhe Agricultural College had played a significant role by providing pipes to facilitate in watering their gardens. This led to a conclusion that rural development can be meaningful when the farmers have the right attitude to learn and implement the concepts they have learned. This was only possible due to the cooperation between the RWH project team and the farmers.

6.3.7.2 Farmers' meetings and network relations

The majority (70%) of the respondents stated that their farmer organisation was registered with the Department of Economic Development. With regard to meetings, 65% of the respondents reported that farmers were having regular meetings. Their constitution provided for certain meetings that needed to be held on a regular basis. The respondents reported that they held monthly and special meetings. The special meetings were called if there were matters that needed urgent attention. The regular meetings were used to deal with outside people and organisations such as the hawkers and other buyers. These meetings were also needed to find markets and to plan for such markets.

6.3.7.3 Collaboration and co-operation between farmers

The situation analysis conducted in 2005 indicated that there was no co-ordination and co-operation between the different sections of the community garden. However, in 2008, the majority (60%) of the respondents acknowledged that there was tremendous change in these aspects. This positive development helped in affirming a collective decision-making strategy. Farmers were able to plan together and to attend to those matters that were of common interest to all of them. However, 40% of the informants thought that although the meetings had taken place, they had not achieved as much as they expected.

6.3.7.4 Systems of resolving conflict among the farmers

Farmers confirmed that there was a system in place to deal with the conflicts that could arise in their farming operations. Farmers convened special meetings to deal with such conflicts. All serious matters, or those matters that could not be handled by farmers (including land disputes), were referred to the tribal authority especially the local *inkosi.*

Vermeulen et al. (2008:101) observe that conflict is inevitable in a multi-stakeholder process and that it is not necessarily a bad thing. Indeed conflict is often the source of motivation for change. The challenge is to manage conflict in a constructive way. Furthermore, Vermeulen et al. (2008:102) recommends that when resolving conflicts and assisting people to negotiate, focus should be on:

- Separating the people from the problem.
- Interests rather than positions.
- Generating a variety of options before settling on an agreement.
- Insisting that agreements are based on objective criteria.

6.3.7.5 Changes in size of land used for farming

The survey carried out in 2008 showed that some farmers had acquired more land for cultivation since 2005. On average, some farmers acquired additional land of up to 75%. Several factors motivated farmers to obtain more land. Among these was the success in farming which was associated with profit making and other gains. The respondents also listed training as an important factor in acquiring more land. Training equipped farmers with new knowledge. Farmers who had undergone training were motivated to get more land in order to increase their land holding, thus increasing production. It should be noted that previously farmers used to cultivate very small garden plots averaging less than 1000 square metres. According to the respondents, farmers had the desire to increase their land holding to push up their production. The increase in production could result in increased profit and better livelihoods. The strategies used by farmers to acquire more land for cultivation included negotiations with the garden committee (25%), working hard and requesting more land from the tribal authority (55%) and acquiring fallow land from people who had user-rights to land but were not utilising it (20%).

6.3.7.6 Extension officer visits to farmer gardens

Seventy percent of the respondents acknowledged extension officers' visits to their gardens, while 30% stated that they were not aware of the visits. The farmers also differed on the frequency of the visits of the extension officers. Generally, the frequency of visits by the extension officers was below expectation (Figure 6.5).

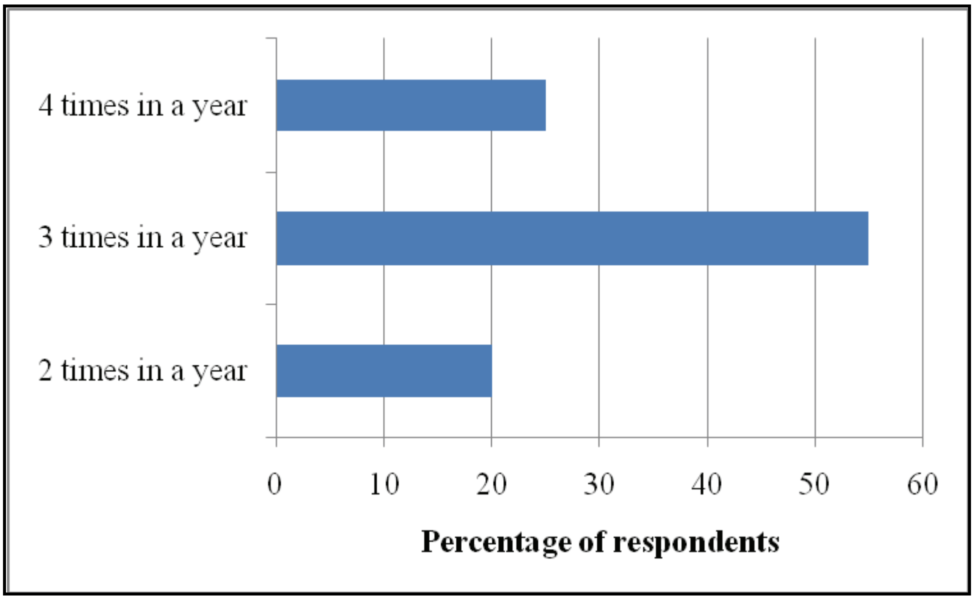


Figure 6.5 Extension officer visits to farmer gardens

6.3.7.7 Marketing of produce

Fifty-five percent of the farmers were of the view that the RWH project team facilitated formal contracts between buyers and producers. Household food security, adequate marketing and distribution of facilities were regarded as vital inputs and outputs. Although rural households often lack these facilities, only 45% of the farmers opted for training on marketing functions.

6.3.8 Impact of the rainwater harvesting project on the surrounding communities

6.3.8.1 Livelihood strategies

When asked about livelihood strategies, 75% of the surrounding community members interviewed said that they were self-employed though they were doing part time jobs at the community gardens. They also did road construction and grew their own vegetables in their homesteads. Some of the surrounding community members observed that, though they had gardens behind their homesteads, they could not produce as much as their counterparts at the community gardens because they lacked skills to produce more vegetables. The group also revealed that, much as they were interested in planting vegetables, most of the households had no fences to prevent cattle from consuming their crops. At least 90% of the respondents acknowledged that the projects at Ntembeni and KwaMncane gardens had actually impacted positively on their lives in that they were able to access vegetables as part of their payment for the work that had been done. They also earned income for their families as payment for the work done.

Ellis (2000) defines livelihood strategies as the complement of activities that generate the means of survival. The author also argues that the primary understanding of livelihood strategies is to shed light on how and when individuals, households and groups negotiate among themselves and with other communities, markets and societies.

Nwonwu (2008) states that a distinct duality marks the agricultural sector in South Africa. There is the well-developed technologically advanced modern farming system on the one hand and a rural subsistence system on the other. The author also argues that in terms of the latter, the level of farm investment capital and technical expertise is often very low.

6.3.8.2 Poverty

Poverty refers to a situation in which income does not meet the important needs. The general perception by 65% of the respondents regarding poverty was that it was rife in their area. One of the reasons stated for this problem was the loss of family members who were the breadwinners. The remaining 35% argued that their survival was because of doing part-time work in the farmers' gardens. Warburton (1998) cited by Corden (1996) stated that traditional community development always has two objectives: to tackle poverty and deprivation and to increase the political participation of excluded groups (particularly those who are poor and disadvantaged). Additionally, Nurnberger (1999) defines absolute poverty as a situation in which income does not meet the level of basic essentials. In this case, there were a number of households whose income could not meet the level of basic essentials.

With respect to the impact of the RWH project within Ntembeni and KwaMncane on alleviating poverty, 90% of the participants responded that, had it not been for the part-time jobs offered to them by the farmers, the situation could have been worse. They were, therefore, grateful that the community garden had made a difference in their lives as mentioned earlier on. The majority of respondents (70%) indicated that the poverty levels had drastically decreased as compared to 2005. This was mainly attributed to part-time or full-time work that some people managed to do in the community gardens. Nevertheless, the same group was quick to state that their major concern was the recent skyrocketing prices of essential commodities that had actually worsened the situation.

It is evident that agricultural development at Ntembeni and KwaMncane contributed to a significant reduction in unemployment levels. More people could be employed in this sector if the government could support the farmers by reintroducing subsidies, thus enable farming to become profitable. In this project, the job opportunities created included land preparation, cutting of grass and fencing of the community garden. According to Berger et al. (2005) small-scale farming provides most of the food produced in Africa, as well as employment for 60% of working people. This was supported by De Klerk et al. (2004) who reported that in South African about 35% of the population is vulnerable to food insecurity. However, on average, monetary income from farming typically contributes less than 10% to total household income (Van Averbeke and Khosa, 2007). In spite of this low contribution, these authors provided evidence of a direct relationship between food production and household nutrition in terms of micronutrient intake in semi-arid regions of South Africa. This highlights the importance of education and knowledge on the value of fresh fruit and vegetables in a balanced diet and could provide an incentive for increased production in homestead and communal gardens (Stimie et al., 2010).

6.3.8.3 Food acquisition

The impact of the community gardens on local diet was overwhelmingly positive as 74% of the respondents indicated. The participants identified the main components of their diet as cabbage, spinach, beetroot, butternuts and tomatoes. All the respondents acknowledged that the vegetables acquired from the community gardens were not only of good quality but also fresh. Conversely, it was interesting to note that the majority (60%) did not agree that it was good to consume vegetables on a daily basis.

6.3.8.4 Access to infrastructure and services at Ntembeni and KwaMncane

Community members mentioned that the community garden has assisted the community to have the road upgraded in order to introduce the bus service in the area. Cypher and Dietz (1997) argued that whatever the cause or causes, agriculture is either neglected or relegated to a subordinate position in development strategies, too often an afterthought to industrialisation. They continued to say that this relative disinterest takes many forms, but of paramount importance to rural cultivators, both large and small, is the inadequate provision of infrastructure and physical capital. Facilities such as schools and health clinics, roads, dams and irrigation, canals, crop storage facilities, farm extension services, agricultural research and farm credit programmes are inadequate, if they exist at all, yet roads and water resources are fundamental to agricultural development and rural development. This view is also supported by Berry (1993) who asserts that rural development programmes in Africa rarely work the way they are supposed to. Since independence, international agencies and African governments have initiated hundreds of programmes designed to accelerate agricultural growth and to raise rural living standards.

6.3.8.5 Participation in farmer information days

Asked about benefits gained during the farmer information day activities, 40% of the respondents said that they had learnt a lot from the events. As a result, they were keen to be involved in growing vegetables and later join the farming community. However, 60% of the respondents indicated that they were not aware of the farmer information days because of not being updated by the farmers regarding the activities taking place in their gardens. According to Cypher and Dietz (1997), smallholders need not only till their land; they also need the services, information and training from agricultural extension services that can help to make them more productive.

The majority (80%) of respondents indicated that it was not easy to join the community garden if one did not know someone who was already participating in the project. Another issue mentioned during the meeting was that ordinary members of the community had to pay a joining fee of R100 which was not affordable to many.

Some members also observed that there was an element of jealousy by a few community members when they discovered that a member was producing good quality vegetables. This view was subject to debate. Inadequate access to farming inputs limited community members who were not farming from leasing farm land (plots).

6.3.9 Impact of the rainwater harvesting project on the key buyers of vegetables

6.3.9.1 Stores

The main buyers of the vegetables were the local Thabethe, Nkabini and Happy stores and two stores in Pietermaritzburg, Evergreen and Southgate Spar. Other buyers were hawkers from the surrounding community. During interviews, these buyers reaffirmed their desire to support the farmers at Ntembeni and KwaMncane by buying their produce. However, they stated the following problems that they had encountered with the farmers:

- The supplies were insignificant to them because they bought from the farmers only on certain days. However, the stores had a formal relationship with the farmers.
- They could not remember the quantities which they had bought from them as it was always occasional.
- Farmers charged very high prices for their vegetables or produce.

6.3.9.2 Product quality and quantity

The main crops produced, i.e. cabbage, potato, butternut and onion have a longer shelf life. All supermarkets indicated that they bought a wide range of vegetables (other than the ones mentioned above) from elsewhere, which they could have bought from these farmers if they had been able to provide them. Concerning quantities, the buyers indicated that they had an unlimited market for the crops that they bought from some of the farmers. As for Southgate Spar, their view was that the produce from Zakhe Agricultural College was of good quality, but the organisation lacked capacity to supply the shop constantly. Vegetables supplied to Spar included cabbage, spinach, beetroot and carrots. The reason for this state of affairs was that learners at Zakhe Agricultural College were not in a position to constantly supply vegetables as per Spar's requirements because they closed for holidays. Thus, supplies to the client were interrupted. The general quality of what is produced was good except for onions, which were only fair.

The price and time delays of delivery were the main issues of concern for the client. Late delivery of vegetables had a negative effect on business. When it came to price fixing, the buyers said the prices asked for by the farmers were very high and that they spent a lot of time trying to convince the farmers to reduce the prices. This may be unfair considering that the community members were the low-income group and that most of them depended on child grants from the government. As a result, the farmers struggled to make a profit since the prices were not market related. The buyers also mentioned that there was a need to meet with the farmers and negotiate the prices of vegetables.

According to the retail stores, the farmers were not able to supply them with produce in time. Time delays in delivery were an important issue that needed improvement, as farmers did not make prior arrangements for delivery of their vegetables. The buyers of produce also mentioned that it was very difficult to make contractual agreements with the farmers as they were unreliable and had no transport to supply their produce in time. The main challenge in addressing these issues was organisational development. Farmers marketed their crops individually and in small quantities.

6.3.9.3 Hawkers

Seventy percent of the hawkers indicated that the project had managed to supply them with a variety of vegetables that were sold to the public. When it came to quality, 55% of the respondents indicated that they were happy with the quality of vegetables while the other 45% said the quality was not good in terms of size and freshness.

On the issue of pricing of the vegetables by farmers, 65% of the respondents were not happy. They said the farmers' pricing was rather high and could not allow them to sell to the public at reasonable prices. By contrast, the remaining 35% of the respondents said that the farmers who sold their vegetables to them fixed the prices reasonably well enough to relate to market prices. When it came to the time of getting the vegetables from the farmers, 60% of the respondents said farmers were unable to supply vegetables throughout the year as anticipated.

6.3.10 Uptake of water harvesting techniques by farmers

The main focus area of the project was to test different techniques of rainwater harvesting and conservation on the trial site and give farmers the opportunity to try these techniques to improve vegetable production in their own plots. They were encouraged to use the techniques which they regarded as most beneficial for increasing the yield of vegetables for their families and the market. The study showed that the ridges and raised beds were the most popular practices and were found in 80% of the plots in the garden. Only 10% of farmers tried the run-off plots and only 15% of plots had mulch. Although the project participants from both Ntembeni and KwaMncane observed the high yields achieved through these techniques, very few implemented them. It became clear from the beginning that the most important criterion for selection was “easy to use”. When asked why they were not using the run-off plots and mulch, the farmers indicated that it was difficult and time consuming to prepare the plots. Sixty five percent of the farmers said they were not using mulch as it was not easy to obtain as one had to cut the grass and dry it before using it. The farmers who were using mulch used different materials such as weeds and crop residues. However, these farmers complained about pests which were affecting their crops in the plots where mulch was used. It should be noted that although water harvesting techniques improved crop yields, the uptake of these techniques by farmers is severely constrained by availability of materials and ease of use.

6.4 Conclusions and Recommendations

6.4.1 Conclusions

The RWH project had a positive impact on the communities of Ntembeni and KwaMncane. The following are the major areas of impact that have been indicated by the communities:

- The project managed to identify the practices that needed improvement and farmers indicated that the project had been beneficial to them as it had enabled them to improve their management skills and practices.
- More crops have been produced in the research sites and many people managed to seek employment opportunities on a part-time basis. By the same token, more land has been used by the farmers to produce food for local and surrounding communities. The project provided new practices and knowledge that made the farmers more productive.
- The project brought an improvement in access to both local and outside markets. The wide scope of crops contributed to a greater variety of goods for the market. This was attributed to the fact that water harvesting enabled vegetables to be produced in winter.
- The economic wellbeing of households improved after the implementation of the RWH project. Farmers sold more produce than they previously did and, therefore, had more income to buy food and other requirements.
- The agricultural income had improved during the past three years and farmers had been able to pay school fees for their children.
- The project managed to promote food security and generate enough income for other needs of households in Ntembeni and KwaMncane.

6.4.2 Recommendations

- The garden committee should manage the marketing function to fix prices and co-ordinate the marketing of their vegetables and access to markets.
- The available market should eventually influence the production plan of the gardens. The water harvesting techniques should enable food to be produced throughout the year so that farmers can make necessary contractual agreements with markets.
- The youth should be encouraged to participate in agricultural activities in these areas so that they can help sustain the gardens in the long term.

CHAPTER 7 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Rainwater harvesting has the potential to improve food production for communities who have a high dependence on agriculture, such as the Umlazi River catchment situated in the eastern region of KwaZulu-Natal near Pietermaritzburg. The aim of this project was to select and implement water harvesting and conservation techniques that would assist the communities in this catchment area (Ntembeni and KwaMncane) to improve their livelihoods by increasing their food production.

The baseline study of the crop production system indicated that the majority of the residents (91.9%) have land-use rights for cultivation and have been allocated less than a hectare of land for agricultural production by the traditional authority. Only 70.3% of the residents use this land for farming. Individual homestead gardens are mainly used for summer production due to water shortages in winter. Thirty two percent of residents had access to additional land (<1 ha) through participation in communal garden schemes. The most important vegetable crops were cabbages and potatoes. The main sources of water supply for agricultural production for the majority of the farmers (70.3%) were pipes followed by streams, which are used by 10.8% of the farmers. Fifty one percent of respondents stated that shortage of water is a result of poor supply systems. The baseline survey therefore indicated that an increase in available water through rainwater harvesting techniques was likely to have a significant impact on vegetable production.

The rainwater harvesting techniques that were implemented to increase water availability included raised seedbeds, ridges and run-off (micro-catchment) plots. In addition, the study demonstrated the effectiveness of the modified in-field RWH technique that was adopted from the Agricultural Research Council. The comparative study between the control (flat), ridged and run-off plots showed that the soil moisture profile for the run-off plots was consistently higher when compared to the control plots. On average, the run-off plots had about 10-20 mm more water (15% of the plant available water content) in the upper 500 mm soil profile. Adding mulch also maintained higher water contents in the soil from a depth of 0.1-0.3 m due to its role in decreasing evaporative losses. The soil moisture in the top 0.2 m of the mulch plots was about 30% compared to the no mulch plots (13%.). This is an important soil conservation strategy as vegetable crops mainly have roots in the top 0.2-0.3 m of the soil layer. Mulching as a technique of soil water conservation is, therefore, a useful strategy in sustaining soil water contents within the root zone.

The study showed that regardless of the crop used, in-field water harvesting using ridges increased biomass. For example, water harvesting techniques increased the yield of cabbage by 50-60% and mulching increased the yield by a further 10-20%. For Chinese cabbage, there was a 40-50% increase in yield due to water harvesting, and mulching increased yield by a further 10%.

The evaluation survey at the end of the project showed that the ridges and raised beds were found in 80% of the plots in the garden. However, only 10% of farmers tried the run-off plots and only 15% of plots had mulch. Although the project participants from both Ntembeni and KwaMncane could see the high yields achieved through these techniques, very few implemented them. The farmers indicated that it was difficult and time consuming to prepare the run-off plots. Sixty five percent of the farmers said they were not using mulch as it was not readily available as one had to cut the grass and dry it before using it. It was concluded that, although water harvesting techniques could improve crop yields, the uptake of these techniques by farmers was severely constrained by availability of materials and ease of use. In retrospect, a cost-benefit analysis of the economic implications of ridging and mulching (where time and land are limiting factors) would have given more insight into the low adoption rate.

The baseline study for livestock production indicated that the rangeland (veld) in the two wards of the study area was in poor condition, ranging from 30.3-54.1% in Ntembeni and from 35.4-63.4% in KwaMncane. Since cattle kept by the communities in the study area are dependent on the rangelands for forage, the low veld condition indicated extremely limited potential for livestock production. This was supported by the questionnaire survey where both fodder shortage and animal diseases were highlighted by the Ntembeni community as major constraints to livestock production. The absence of palatable Decreaser species at the study sites, and the dominance of low quality Increaser II species (14.0-74.5%) when compared to the benchmark value (5%), indicated that livestock owners need to supplement their livestock with additional forage during winter to prevent the animals losing condition, declining in productivity and possibly dying. Supplementation with forage crops which are high in protein (e.g. legumes) have the potential to provide better nutrition for livestock.

This study investigated whether water conservation techniques could be used to grow Dolichos, a fodder legume crop, on the unproductive land adjacent to the boundary fence of the Ntembeni communal garden system. The two factors which were investigated were basin size water harvesting (where the soil across the whole subplot was loosened and shaped to form a large open basin to collect water following rain) and mulching (where entire subplots were mulched with hay to a depth of 150 mm).

Although the dry-matter production of the Dolichos was too low to run a feeding trial, the results indicated that water conservation techniques have the potential to increase fodder production. Fifty seven plants from the 120 seeds (47%) that were planted successfully established on the unproductive land adjacent to the boundary fence. Hole size and mulching did not have a statistically significant effect on the size of plants. This indicates that plants grown in relatively hard soils next to boundary fences can achieve (initial) growth rates similar to that of plants in cultivated soil. In many production systems, the area immediately adjacent to the boundary fence is unproductive, so this provides an opportunity to make better use of resources. Mulching proved an effective way of reducing competition from weeds. The infestation of the allelopathic *Cyperus* weeds in each plot was significantly lower on mulched than on no mulched plots ($P<0.001$). More in-depth studies are required to develop livestock production strategies in degraded communal rangelands that can lead to more productive and sustainable use of land and water resources.

In terms of social benefits of the water harvesting project, the majority of respondents (70%) indicated that poverty levels had drastically decreased in 2008 as compared to 2005. This was mainly attributed to part-time or full-time work in the community gardens. The main buyers of vegetables that benefited from the project were the hawkers from the surrounding communities. Seventy percent of the hawkers indicated that the project had managed to supply them with a variety of vegetables that were sold to the public.

The impact of the community gardens on local diet and food security was rated as positive by 74% of the respondents. All the respondents acknowledged that the vegetables acquired from the community gardens were not only of good quality but were also fresh. This was supported by the commercial buyers who stated that the general quality of what is produced was good except for onions, which were only of fair quality.

The project brought an improvement in access to both local and outside markets. The market survey indicated that buyers had an unlimited market for the crops that they bought from some of the farmers (cabbage, spinach, beetroot, butternuts and tomatoes). However, the farmers produced small quantities and were not able to supply the supermarkets constantly. The buyers of produce stated that it was difficult to make contractual agreements with the farmers as they were unreliable and had no transport to supply their produce in time. This indicates that future projects should focus on organisational development to address market related issues.

The situation analysis conducted in 2005 indicated that there was no co-ordination and co-operation between the different sections of the community garden. However, in 2008 the majority (60%) of the respondents acknowledged that there was tremendous change in these aspects. This positive development helped in affirming a collective decision-making strategy. Farmers were able to plan together and to attend to those matters that were of common interest to all of them.

The survey carried out in 2008 indicated that one of the main constraints to agricultural production was access to land, and in the case of this study, access to plots in the communal garden. The majority (80%) of respondents indicated that it was not easy to join the community garden if one did not know someone who was already participating in the project. The strategies used by farmers to acquire more land for cultivation included negotiations with the garden committee (25%), working hard and requesting more land from the tribal authority (55%) and acquiring fallow land from people who had user-rights to land but were not utilising it (20%). It is recommended that, to address this problem of security of tenure of community garden plots, the proposal by Van Averbeke (2008) be adopted whereby a market for land exchanges in these gardening schemes is established. In this system, plot holders are registered and a rule system is developed and administrated by an external agency such as the Department of Agriculture and Environmental Affairs. In this way, farmers needing more land can apply for land through this open market system. This will increase the productivity of the land and reduce the percentage of fallow land that occurs with the current allocation of land to non-users by the tribal authority.

APPENDIX 1 LITERATURE REVIEW

1 Introduction

Small holder agriculture faces diverse challenges: the challenge of aridity and climatic uncertainty, the challenge of the market-place and economies of scale, the challenge of cost-effective production, the challenge of ecologically diverse systems on small areas of land, the challenge of effective use of labour when demands of diverse activities are often conflicting and the challenge of effectively adding value to products and developing new products/processes. Moreover, in South Africa the discriminatory laws of the past imposed severe constraints on the development of black smallholder agriculture. Since the democratic elections in 1994, the South African Department of Agriculture and Land Affairs has been assisting smallholders to enter the market place. Adequate farmer support requires high numbers of extension officers per farmer. Auerbach (1991) argues that the normal ratios of 1:500 or 1:300 may be adequate for an operating economy, but that capacity building for transformation from subsistence to commercial agriculture will need specialist input and ratios of 1:20 will be required for these specific programmes.

There has been much discussion about small scale, low external input sustainable agriculture, but there are few practical examples in South Africa of what such farms could look like, or how they should be designed (Auerbach, 1999). At farming systems level, efficient use of water in farming systems has been discussed in the watershed context in Asia (Sharma, 1997) and leadership has been found to be more important than technical aspects. D'Souza (1997) commented that gender aspects are also important and that integrated catchment activities often mean extra (unpaid) work for women. Anandajayasekeram & Stilwell (1998) agree that water use is a key aspect of farming systems research in Africa.

At the individual farm level, a key design question is:
"What strategies are available to help improve food security in a way which addresses aridity, poverty and restricted availability of land?"

To answer this question, it is important to address the production, conservation and equity aspects and evaluate the many short-term technologies and extension strategies that have been proposed. Auerbach (1994) showed how these three aspects form the "triple bottom line", each being important for sustainable development (representing economic, environmental and social sustainability respectively). The specific problems of inadequate water for agricultural production are rapidly becoming more serious (Seckler et al., 1998) and conventional irrigation is clearly not the solution for large areas of the world (Penning de Vries et al. 2002). This is illustrated by the fact that when areas of land under irrigation were expanded by about 77% (from 153 million ha in 1966 to 271 million ha by 1998 (World Resources Institute 2000), food production increased during this period but household food security did not improve significantly as the risks associated with small scale production remained as severe as they had been. Penning de Vries et al. (2002) argued that inappropriate agricultural policies play a large part in ecosystem degradation and that, in particular, approaches which help small scale farmers to reduce risks associated with erratic water supply are vitally important. The permaculture design approach is one methodology which systematically addresses efficient water use in agriculture.

Mollison (1988) defined permaculture as the conscious design and maintenance of agriculturally productive ecosystems which have the diversity and resilience of natural ecosystems. It aims for the harmonious integration of landscape and people providing their food, energy, shelter and other material and non-material needs in a sustainable way. It is based on observing the patterns of nature and using these to improve the productivity of systems by placing plants and structures in the system so that they fulfil several functions simultaneously. Rainwater harvesting (RWH) is one of the strategies which permaculture designers take into account from the first approach to analysis of a farm's resources.

Approaches to RWH must look both at reducing water demand and at increasing effective water supply. This literature review will first look at strategies which increase water supply and decrease water demand. It will then look at techniques used throughout Africa and more specifically at the history of RWH in South Africa. Finally, some perspectives on world water supply will be examined in relation to the need to reform irrigation policies so that RWH can play a more useful role in reducing risk in smallholder agriculture. Rather than massive irrigation schemes which help only a few farmers, strategies which help millions of farmers to use rain more effectively by increasing infiltration, reducing evaporation, improving storage capacity of wetlands and artificial storage structures and increasing the water holding capacity of soils should be encouraged.

Auerbach (2005) pointed out that within the context of agricultural production, six priorities present themselves repeatedly:

- Reduce drought vulnerability.
- Improve water quality.
- Improve water use efficiency.
- Increase agricultural productivity.
- Add value to agricultural products.
- Reduce natural resource degradation.

These six priorities are all addressed by RWH in combination with organic farming systems and social systems using local LandCare groups. LandCare is a community based and government supported approach to the sustainable management and use of agricultural natural resources. The overall goal of LandCare is to optimise productivity and sustainability of natural resources to ensure greater productivity, food security, job creation and a better quality of life for all.

2 Rainwater Harvesting Processes and Design

Hatibu and Mahoo (2000) describe the history and effectiveness of rainwater harvesting in Tanzania and summarise some of the most important processes. Since Tanzania is a semi-arid area, this work has relevance to much of Africa – at least those parts where inadequate soil-moisture limits plant growth. High daily and yearly temperatures, low humidity, intense sunlight and high winds contribute to aridity. These factors encourage very high rates of potential evapotranspiration so that rainfall exceeds potential evapotranspiration on only a very few days in the year. In Tanzania, the fact that there is a dry spell in the middle of the growing season makes the impact of this aridity severe and it is compounded by the unpredictable nature of this dry spell – its timing varies from place to place and from year to year. Clearly in such an environment, RWH strategies can make the difference between a viable crop yield and a crop failure.

Responses in the past have often been inappropriate, such as cut off drains which increase run-off and tree planting which decreases the amount of plant available water. Approaches other than drought resistant varieties have now been shown to be effective. In Tanzania, approaches such as "Mashamba ya Mbugani" are traditional. In this case, farmers plant high-water-demand crops lower down the landscape to exploit the concentration of rainwater flowing into the valley bottoms from surrounding high ground. These approaches concentrate on increasing water supply, rather than reducing demand.

If rainwater is not managed, it quickly evaporates or flows away as flash floods often into saline sinks. Micro-catchment systems have catchment areas (CA) which generate run-off and cultivated basins (CB) where run-off is concentrated. The parts are not so clearly distinct in the in-situ systems.

Hatibu and Mahoo (2000) point out that rainwater leaving an area is only wasted if it is not used in the area which it flows into. The quantities of water going through an individual sequence can be evaluated by the general hydrological equation:

$$In - O = \Delta W$$

Where: In is the inflow of water to any given area during any given time period, O is the outflow of water from the area during the selected time period, and ΔW is the changes in volume of storage of water in the area during that time.

In each subcatchment, inflowing water is caught and stored or used as efficiently as possible. Effective rainfall is thus maximised as much as possible through root zone recharge and run-off minimised. Planning RWH can be done once the components of the water balance are understood. Using water balance analysis, reasonable determinations of available water can be made and estimates of infiltration, evaporation and transpiration can help to make this determination more accurate.

Water deficits and surplus can be estimated, once plant water requirements, animal water requirements and groundwater recharge parameters have been determined.

According to Hatibu and Mahoo (2000), planning of both agricultural and urban areas should give more attention to RWH. Factors influencing run-off include land surface (slope, length, vegetation, roughness and erosion risk), soil type, rainfall characteristics (rainstorm amount, intensity, distribution) and catena sequences. Types of run-off include rill flow, gully flow and ephemeral stream flow. Assessing RWH potential requires identification and quantification of naturally occurring run-off and its current use, assessment of effects on downstream users if water is harvested and assessment of alternative water sources.

The essence of RWH is to capture water where it falls in order to meet local needs. Strategies for doing this seek to improve infiltration, minimise root zone water loss and to improve crop water use and productivity. This is done through run-off harvesting (strip catchment tillage, basin systems, semi-circular hoops, conservation bench terraces) and floodwater harvesting (cultivated reservoirs, stream-bed systems, hillside conduits and ephemeral stream diversion).

Over the past thirty years, much research has been carried out to evaluate strategies for using water resources more effectively to help resource poor farmers. Critchley and Siegert (1991) reviewed much of this work. Hatibu and Mahoo (2000) comment that RWH requires the collection of water where it can be useful and also the storage of water at times when there is a surplus for times when water is scarce. In semi-arid areas, if water is not managed it quickly evaporates or runs as flash floods. Thus, the starting point of rainwater harvesting is to capture rainwater where it falls for purposes of meeting the water needs of that area. Micro-catchment systems involve two major components: the catchment area, which generates run-off and the cultivated basin where run-off is concentrated, stored and productively used by plants. Systems with large catchments are called macro-catchment RWH. These include intermediate components such as means for collecting, transferring and storing the run-off.

Macro-catchment systems are appropriate for steep topography such as KwaZulu-Natal and micro-catchment systems are more suitable for drier, flatter areas such as the Free State. In developing strategies for rural development, both systems can be used to reduce the risk of crop failure. Auerbach (1999) also points out that mulches and compost can be used to reduce transpiration and increase soil water and nutrient holding capacity.

Hatibu and Mahoo (2000) point out that shortage of soil water for plant use can be mitigated by approaches other than planting drought resistant varieties. For example, the management and effective use of rainwater is a major factor in stabilising production in semi-arid areas. One of the principles of successful RWH is “slow it, spread it, sink it” (Lancaster, 2010). This process can be helped by the construction of swales, which Mollison (1988) defines as long, level excavations, which can vary greatly in width and treatment from small ridges in gardens, rock-piles across the slope, or deliberately excavated hollows in flatlands and low-slope landscapes. These structures are usually vegetated, with trees or reeds planted on the crest of the swale. Many large swales were constructed in Tennessee to combat “dustbowl” degradation under President Roosevelt’s conservation and job creation programme and are still functioning effectively (Mollison and Slay, 1991).

In many World Bank projects, soil conservation works were constructed and planted with Vetiver grass (*Vetiveria zizanioides*) in order to stabilise soil against erosion by providing a plant which is not palatable to animals, has a dense mass of roots to hold the soil and allows water to pass through while slowing it down so that much of the suspended soil is deposited above the soil conservation structure (National Research Council, 1993). The grass is coarse and does not set seed, so it is unlikely to become invasive. It can also be used for craftwork and aromatic substances in the roots can be used for perfume. The plants grow up to two metres tall, and form a good windbreak. Vetiver, cut and laid on vegetable beds, is reported to be a highly effective mulch which lasts well and is resistant to decomposition (Auerbach, 1999). Vetiver grass is also effective when planted on swales.

The effect of the swale is to catch water which falls on the area above the swale and to slow the water down, maximising infiltration. The vegetation on the crest holds the soil of the swale in the event of intense rainfall causing run-off flow to overtop the swale. The swale also creates a moist micro-climate in the furrow above the swale wall, which often becomes highly productive as plant available moisture is much greater here. Swales are different to contour bunds commonly erected in soil conservation programmes. Soil conservation aims to remove water from the field without damage to the soil; swales promote water infiltration.

Pereira (1973) stated that "The basic tenets of the soil conservation discipline are that the soil surface should be maintained in a receptive condition for the infiltration of rainfall and that surplus water should be led off along gentle gradients without reaching erosive velocities .... the surplus water should be guided along prepared drainage routes ... and be kept free of obstructions". Swales can be used for such drainage routes.

Boers (1994) stated that large catchments can yield less water than small catchments. In extreme cases one ha may yield 20% of annual rainfall as run-off, while 100 ha give 3.5% and 10 000 ha yields only 0.5%! Tauer and Humborg (1992) agree that with larger catchment areas the retention effect increases, resulting in lower run-off rates. They state that suitability of topography, crop water requirements, water storage capacity of soils and water yields from associated catchment areas should be taken into account when designing rainwater harvesting structures.

The optimal size of a catchment for rainwater harvesting can be predicted using various models (Boers, 1994). He warns that shallow-rooted crops will fail in dry years, thus discrediting rainwater harvesting in the eyes of local people. His suggestion is that deep-rooted trees such as Neem (*Adzaderacta indica*) make best use of rainwater harvesting schemes. Such systems have been tested in very arid (Negev Desert) and arid (Niger) areas.

Tauer and Humborg (1992) tested run-off irrigation in the Sahel. They directed run-off from a small (< 1000 ha) catchment after a storm to a nearby field enclosed by ridges and increased soil infiltration and, thus, soil moisture content. Water was subsequently available for uptake by the plants during the dry season as soils were relatively deep and heavy. The principle is that water is collected in a catchment area and used in a field where the water is concentrated. Ratios of collection to concentration areas can range from 1:1-100:1. Although detailed local knowledge is needed, it can be a low-cost strategy. Due to limited planning data, geographic information systems can contribute to planning through accurate satellite mapping, soil degradation estimates and vegetation surveys.

Little attention is given in the literature to strategies which decrease water demand compared with attempts to increase water supply. For example, mulches and shading can reduce the amount of water needed by a crop. Suitably chosen and properly timed mulching has shown considerable promise in reducing direct evaporation loses from soil (Prihar et al., 2010).

3 *Rainwater* Harvesting Techniques in Various African Countries

Critchley et al. (1992) present an overview of rainwater harvesting techniques. They say that imposed solutions to soil erosion (especially penalties) have not worked. More recently, participation has been encouraged by making use of traditional local skills, working through existing institutions and involving intended beneficiaries in the process of programme identification, design and implementation.

The poor do not automatically benefit from soil and water conservation programmes – solutions need to be location-specific if they are to benefit resource poor farmers. Traditional systems are surprisingly widespread and Critchley et al. (1992) call for more attention to be paid to them. This is important, they say, as soil fertility is lost rapidly in the early stages of "topsoil erosion" and can also be lost through exploitative cropping. Infertile soil is, in turn, more vulnerable to erosion and a spiral of degradation becomes established.

They argue that soil and water conservation measures (which include traditional approaches to rainwater harvesting) should be a national priority in all sub-Saharan African countries because it forms the essential foundation for agricultural prosperity. Land degradation results from failure to manage rainfall run-off and also from poor agricultural practices. Long-term approaches are needed, with time frames of at least ten years between evaluations – "Project" time frames of three to five years rarely have much impact either for the success of rainwater harvesting systems or for soil conservation practices in general.

Conservation programmes must seek to introduce durable activities. This implies not only an organisational framework which can be sustained but also techniques which are replicable. A simple design process is desirable though it needs to be given adequate time so that community acceptance is based on informed choices. Appropriate packages are normally characterised by technologies which are relatively cheap, are economical of labour, lead to perceptible yield increases and are grounded in the environmental knowledge and skills of the beneficiaries. They should require a minimum of external support – the principal incentive should be the provision of training to improve the capacity of the local population to conserve their own resources and thereby increase productivity.

Critchley et al. (1992) point to the links between conservation objectives and rainfall zones. High rainfall (above 1000 mm) – objective: to dispose of excess rainfall while conserving soil. Medium rainfall (700-1000 mm) – objective: to hold total rainfall in situ while conserving soil. Low rainfall (300-700 mm) – objective: to concentrate rainfall run-off by water harvesting from a catchment area while conserving soil in the cropped area. According to this classification, the study area is a medium rainfall zone where management interventions should be implemented to hold total rainfall in situ while conserving soil.

One intervention to achieve this is to build engineering structures to promote water infiltration. However, such structures are often poorly maintained and sometimes overtop creating gullies (Critchley et al., 1992). Alternatively, biological techniques can be used such as planting grass strips to slow run-off and filter out sediment. These build up into terrace banks over time. Suitable species for soil and water conservation vary with location. Vetiver has been extensively used by the World Bank, especially in India and Central Africa (Hengchaovanich, 1998, Greenfield, 1999). Vetiver can be cut for mulch, which retains moisture, while other grasses such as Napier grass can be cut for animal feed, often for dairy cows. Agroforestry techniques such as barrier hedges, windbreaks, swales with trees and alley cropping have been used with varied results Grewal et al., 1994). However, although infiltration may be higher, especially with alley cropping, trees often compete with crops for moisture (Wanvestraut et al., 2004). Since rainsplash in heavy rain increases soil erosion and decreases infiltration, ground covers and mulches can act as an anti-erosion measure as they provide a protective layer on the soil surface. Mulch is also effective in forests as an erosion prevention measure. Critchley et al. (1992) reported that there is a positive relationship between degree of ground cover and crop yields and a clear connection between the maintenance of soil fertility and the control of erosion. Conservation planners always need to consider soil fertility maintenance as well as erosion prevention.

Structures, even those based on indigenous soil and water conservation techniques, are often constructed using heavy machinery. Critchley *et al*. (1992) point out that although this is quick, it often fails to involve local people, creates an imbalance between maintenance requirements and the abilities of local land users to carry out maintenance and reduces spontaneous adoption as well as the sense of local ownership. In isolated areas the machinery (if available) often breaks down. An emphasis on local participation usually offers better long-term results, although machinery does have a role.

According to Critchley et al., (1992), if land users are paid by government they tend to assume that government will also take responsibility for maintenance. Their experience indicates that, although incentives or subsidies are important, they need to be carefully thought through. They state that often provision of seed or organic fertiliser is the most appropriate form of incentive as they enhance the first-season benefits. Community infrastructure is also often well received without creating too much dependence.

Critchley et al., (1992) found that availability of labour is often a major constraint to the implementation of large scale soil and water conservation measures used in rainwater harvesting. Women often play a major role in the construction of such works and this can simply add to their burdens. Projects should provide women with adequate access to training and material support and help them to get access to land and trees.

Direct exchange of on-farm experience between land users (more recently called the "farmer-to-farmer" approach) is usually more efficient than getting the message presented by outsiders. The acquisition of new skills has an enormously stimulating effect on land users as it makes them more independent of external support. Key agents in ensuring consistency through the long chain from policy innovation to field execution are supervisory staff in aid agencies and host governments.

Critchley et al. (1992) reviewed indigenous soil and water conservation techniques in different African countries. A summary of the systems found in each country is given below:

The Caag and Gawan systems (Somalia, 150-300 mm)

Caag: In this system a ditch diverts run-off which is impounded by bunds with arms which extend upslope, often about one hectare in size, usually with one longer arm so that excess run-off can flow away (usually only impounds 30 cm of water). Gawan: This system is applied on flat land where run-off is less – small bunds divide plots into grids of basins (usually each about 500 square metres). Although usually closed, sometimes a gap is left to allow water to flow in. In both systems, usually sorghum or cowpeas are grown.

Dogon Plateau (Mali, about 500 mm)

Hillside terraces and earth mounds (along contours, made during weeding) become bunds of decomposing material. Also stone lines and bunds, associated with small earth basins which encourage silt deposition. According to Reij et al. (1996), the Dogon also carry soil in baskets on their heads to bare rocky areas near water, mix the soil with manure and make irrigated gardens which yield 30 t/ha of onions. They also mention stone bunds, micro-basins, mounding, trash lines and grass barriers.

Burkino Faso and Niger

Zai pits (traditionally small pits in the past but now larger with compost added) help improve yields in dry years. This seems to be a very effective rehabilitation system for degraded lands. According to Reij et al. (1996), 12

000 to 25 000 zai pits are used per hectare. One hectare of zai pits takes about 60 x 5 hour workdays to construct. During the dry season, zai trap litter and fine sand deposited by the wind. They also create a micro-climate which protects young plants against wind and run-off. Weeds do not grow on the crusted, barren land between the zai. Mulching has also been widely adopted using 3-6 t/ha of grass. This supplies nutrients, conserves water and also attracts termites which open up the compacted and crusted soil.

Kenya

Fanya Juu terraces are formed by throwing soil up slope from a trench to make bunds on the contour which eventually become bench terraces. They are usually protected by a cutoff drain or diversion ditch.

Reij *et al*. (1996), also summarise practices in various countries:

Northern Sudan (desert)

Low lying crescent embankments (about 100 cm high) are used to harvest run-off on areas up to 100 ha. Lateral structures and cross embankments are also constructed to maximise surface run-off from the wadis. Organic matter is added, and fields are levelled breaking up clods. Vegetation is planted on the embankments to stabilise them; stones and plastic sacks may also be used to reinforce weak points.

Central Sudan (desert)

A catchment two or three times the size of the field is used to catch the water, which is led into the field and kept there by means of low U-shaped bunds called trus (singular: tera). These are similar to Somalian Caags. Large numbers of people are involved in constructing Trus, which raise production potential from two to three sacks of millet to five to seven sacks of sorghum per acre.

Morocco (Atlas Mountains)

Hillside terraces (some of which are over 100 years old interwoven with Juniper trees). Vines, almonds and walnuts are planted along the top of terraces. Riverine and wadi areas are vegetated to prevent floodwaters from submerging new terraces and to filter out gravel. The investment of communal effort in these patches of land is very great and although small, their social value is inestimable.

Northern and eastern Morocco

In these highlands dry stone walls are reinforced with tree lines. In the irrigated areas, these are sturdy structures while in rainfed areas they are low, discontinuous stone structures. Stone walls in the highlands may be 2.5 m high and several hundred metres long. Walls have to be raised regularly when the soil builds up behind them.

Niger (Illela, 448 mm)

Uplands were covered with vegetation 40 years ago – they are now barren due to population pressure causing increasing settlement on the plateau. Run-off from the uplands now causes significant damage to the fertile valley bottom lands. In Illela a major soil and water conservation project was implemented (1972-81) which paid villagers to construct stone bunds and used bulldozers to deep plough barren, crusted soils. Little remains of this project and its activities. An IFAD project supplied 12 people (2 professionals, 10 extensionists) to help build stone bunds on 2300 ha in four years plus 320 ha of demi-lunes. The approach was tools-for-work and community-infrastructure-for-work. Improved planting pits (or Tassa) were used. Yields were more than double those conventionally produced. Fertilisation with manure or chemical fertiliser gave variable results. Farmer managed demonstration plots always outyielded researcher managed plots. Thousands of farmers have adopted these approaches and have improved their food security at family level.

Mali (Djenne Region, 538 mm)

Severe soil erosion – natural regeneration of tree growth helps combat this – farmers protect the young tree shoots against animal damage. They also use leaf mould, manure and some chemical fertiliser. The use of the zai or water pocket allows rainfed farming of millet, sorghum and maize. These small pits (or towalen) are normally about 20 cm in diameter and 10 cm deep. Usually, lines of pits are made across the field in degraded land and a small amount of manure is added to each pit just before the rains. The improved zai are larger (30 x 15 cm) with excavated soil used to make a half-moon bund downslope of the zai pit.

Nigeria (Borno, 250-500 mm)

Bunds and mulching used, usually with Masakwa (drought and cold tolerant short-day sorghum) grown on fertile clay soils around Lake Chad.

Zimbabwe

Although the Alvord System of the 1950s (use of manure, crop rotation) was broadly introduced with some success, it was soon followed by imposition of contour ridges (not exactly on the contour but with a slight fall aimed at draining excess water off the fields). While sometimes appropriate for high rainfall areas, these were inappropriate for arid areas where retention of water is more appropriate. Many farmers rejected the combined package and were often penalised as a result. Often the penalties meant that they constructed contour banks poorly which actually increased erosion.

More recently, intensive production with chemical fertilisers has been promoted and traditional soil conservation methods have been almost totally neglected. However, Training for Transformation approaches have revived some traditional practices, such as stone bunds, infiltration pits, Fanya juu terraces, as well as grass strips, Vetiver grass, conservation tillage, tied ridging, mulching, ripping and organic farming.

Zambia

The study found little evidence of soil and water conservation practices in Zambia. Water stress is a major problem but it has mainly been dealt with by planting cassava (which is drought resistant and grows on poor soils) or by planting finger millet or maize on the edges of the dambos (wetlands).

Ghana (Upper East Region, 800-900 mm)

Slopes are steep and water is conserved using stone bunds conservation tillage (hoeing up ridges, more recently using oxen to plough ridges), birder grasses, strip cropping and terracing.

Tanzania

In the north, rice bunds are constructed for lowland rice and for rice on the sides of valleys using bunds and basins. In order to achieve maximum water harvesting, upslope catchments are deliberately overgrazed. Crusts develop, reducing infiltration and water is led to the rice basins through gaps in bunds. Slow regeneration of the bare grazed areas seems to happen each year and farmers are not concerned about deterioration. If gullies appear, the cross-contour furrows help to rehabilitate them. Now that valley sides are extensively cultivated, valley bottoms are rarely waterlogged. Siltation of dams in the valley bottoms has also decreased and most of the valley bottom soils are now intensively cropped. Mound cultivation is still practised in many areas, where turf is hoed up into mounds and beans or cowpeas are planted on the mounds. The grass is left to decompose, and these compost mounds provide enough fertility for the crop. In valley bottoms, raised beds prevent waterlogging.

In the highlands in the south, grass is cut by the men and laid in a grid on the fields. The women then scoop soil out of the areas between the grass grids, covering all of the grass with soil, forming pits in the area scooped out. The grass strengthens the walls of the pits. Slopes vary around 50%, but fortunately soils have high infiltration rates and landslides do not seem to be a danger. About six years of cropping is often followed by about three years of fallow.

West Cameroon (3600 mm)

Planting on ridges using hedges to keep animals in the upper catchment and agroforestry crops for shade and fruit are strategies used in the wetter areas such as Bamileke (West Cameroon).

4 Rainwater Harvesting in South Africa

Research into rainwater harvesting in South Africa, too, has mainly adopted an engineering-based approach. Pioneer researchers such as Lea, Alcock, Bromberger and Melis at the Departments of Crop Science and of Economics at Natal University started a Subsistence Agriculture Study Group which looked in some detail at domestic rainwater harvesting in the Vulindlela District south-west of Pietermaritzburg in the early 1980's. Using concrete structures, Alcock constructed some rainwater harvesters but the technology-intensive approach was not easy for local resource poor farmers to adopt (Alcock, 1985; Alcock and Lea, 1985; Lea, Alcock and Melis, 1985). Instead, the rapidly urbanising area saw a series of spring protection programmes followed by a major water reticulation scheme. This accords with the experience of many water harvesting programmes which have found that a construction-intensive "engineering approach" which uses large quantities of expensive bought-in materials is not a viable answer for agricultural development.

Conservation-minded farmers through the centuries have recognised the importance of wetlands and of finding ways to slow down rainfall run-off and increase water infiltration.

The tradition of water harvesting in black areas of South Africa is more difficult to trace. South African agricultural production was disrupted not only by white colonisation and Apartheid, but also by the expansion of the Zulu nation in the time of King Shaka. This phenomenon, known as the Mfecane, saw the movement of many tribes to the south, west, northwest and north ahead of Zulu imperial expansion (Guy, 1994). Following this enormous disruption, the white colonists effectively destroyed what was left of black farming systems. The Glen Grey Act of 1897 made it illegal for black farmers to own more than 10 acres (4 ha) of land. In spite of this, some farming traditions have survived. Old Xhosa farmers in the Kokstad area dug furrows below springfed wetlands for irrigation.

The late Robert Mazibuko developed a unique water harvesting process which mimicked the function of wetlands in nature. He worked in the 1950's and 1960's in the Valley of a Thousand Hills, where he applied his "trench-garden" system to water harvesting on the steep hills of the area (Bloch, 1996). He told farmers that they had to create "valleys on the hill". Mazibuko acknowledged what he learned from Father Bernard Huss at the St Francis Teachers' Training College at Marianhill in 1928 (Engel, 1990). He also travelled extensively as a teacher in many countries of Africa. During his early years, he learned much of traditional African methods of production and water harvesting. He also became convinced of the importance of indigenous tree planting as a soil conservation and water harvesting strategy, having met and learned from Richard St Barbe Baker (1944). Some of Mazibuko's ideas have been adopted by gardeners at Nkululeko in the Valley of a Thousand Hills and together with a study of the system on Bachs Fen Farm, these were reported as South African case studies in rainwater harvesting (Jansen, 1997; Auerbach and Jansen, 1997).

Mazibuko's trench system removed soil from the bed, placed organic material at the bottom of the trench and replaced the soil taking care to form a terraced bed which was designed for maximum water retention. His trench gardens retain water dramatically compared to ordinary garden beds, but they do require an investment of labour to develop. The alternative without water harvesting in areas of low rainfall, is that most of the effort which goes into crop production is wasted and regular crop failure has made many communities abandon crops such as maize and beans.

Critchley et al. (1998) review South African RWH needs and Versveld et al. (1996) motivates the importance of introducing policies which support the efficient use of water rather than looking only at irrigation. The South African water Act (DWAF, 1998) attempts to address some of these issues in encouraging community participation in catchment management and in pointing out the costs to society of streamflow reduction activities, but the Act does not go so far as to recommend support for RWH.

Technical aspects of RWH in South Africa are described by Lorentz (1998, 1999) and by Dlamini (1998) in relation to activities in KwaZulu-Natal, and to KwaZulu-Natal and the Free State in Auerbach (2005).

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