Improving Plot Holder Livelihood and Scheme Productivity on Smallholder Canal Irrigation Schemes in the Vhembe District of Limpopo Province

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Water Research Commission

by

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- Growing Green Maize on Canal Schemes in Vhembe: Production Guidelines (WRC Report No. TT 567/13)
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EXECUTIVE SUMMARY

In South Africa, smallholder irrigation scheme development continues to be regarded as an opportunity to trigger rural local economic development, even though historically these projects have not been particularly successful. Smallholder irrigation development in Asia, on the other hand, was an integral part of the 'green revolution', which is widely viewed as having prepared the ground for the subsequent industrial development in that part of the world.

The limited productivity and livelihood impact of South African smallholder irrigation schemes has dominated the literature that assessed this type of rural investments. In this report we explore different opportunities to improve productivity and livelihood impact. The main thrust of the work was aimed at testing a number of farming system innovations but attention was also given to social resource constraints. **Chapter 1** justifies and elaborates the choice of issues that were researched. The research was conducted in the Limpopo Province, which is the heartland of smallholder irrigation schemes in South Africa, more specifically canal schemes, which were the first type of schemes to be constructed. Many of these schemes remain operational indicating that they are durable and resilient.

Chapter 2 sets the scene for the project by reporting on a survey of all registered smallholder irrigation schemes in the Vhembe District. Factors associated with the operational status of schemes were identified. The findings confirm the continued relevance of canal irrigation and show that gravity-fed canal schemes are more likely to be operational and to last longer than pumped schemes. Generally, cropping intensity on smallholder schemes in Vhembe was well below the optimum values of 1.5 to 2.5 that could be achieved in the area. Water restrictions were a significant factor in determining cropping intensity. Degree of commercialisation on smallholder scheme tended to increase as schemes were located closer to local urban centres and the likely reason for this is provided. Remote schemes require external intervention for market access but on most farmer-managed schemes such support was totally absent.

Chapter 3 deals with the reality that being part of an irrigation scheme comes with obligations, which relate to the essence of being a member of a scheme, and that is shared responsibility of the water distribution infrastructure. The case study of Dzindi provides detailed evidence of a rapidly decaying water distribution system, which is at least partially due to neglect on the part

plot holders, who have allowed the collective organisation that was responsible for routine maintenance of the system to collapse. Inadequate routine maintenance and loss of water due to leaks caused by the poor state of the concrete canals, furrows, regulating devices and the night-storage dam that supplies the last irrigation block, are directly responsible for the worsening problem of water shortage at the scheme. As elsewhere on canal schemes, water shortages are felt first by tail-enders. For this reason, establishment of an effective routine maintenance system was identified as a critical condition for the sustainability of canal schemes.

Chapter 4 investigates the Trust tenure system that applied to irrigation schemes located in the Bantu Areas, as elaborated in Proclamation No. R5 of 1963. This system provided the state with the power to cancel the user rights of plot holders who failed to comply with the many terms and conditions for occupation of an irrigation allotment. There were also elements in the system that provided a high degree of security. One of these was the detailed specification of exclusion rights, which served to protect occupants of irrigation schemes from ‘outside’ interference. The empirical work identifies the lack of a comprehensive legal framework that enables plot holder communities to assert their land rights as an important weakness of the current tenure system on smallholder irrigation schemes in Vhembe. The absence of such a framework has left these communities vulnerable to outside interference and has rendered their tenure rights more insecure than before. In the case of Dzindi, land is being taken away to accommodate rising demand for residential land. This precarious situation is identified as a priority issue for government attention. If land rights in irrigation schemes are not protected, the recommendation to develop schemes in proximity to urban centres to provide access to markets, which encourages commercialisation and tends to enhance scheme productivity, has no validity. Inadequacies in tenure security were also identified as one of the reasons why the land exchange market on canal schemes is imperfect.

The work presented in **Chapters 5 and 6** explores the potential of using animal draught as alternative to tractors as a source of draught power in land cultivation. On canal schemes, animal draught enterprises tended to achieve better field efficiency and turning times than tractors but tractor enterprises had higher work rates, field capacity, speed, ploughing width and ploughing depth than animal draught enterprises. Full replacement of tractor enterprises by animal draught enterprises requires the establishment of four to nine animal draught enterprises for every tractor enterprise to compensate for the lower field capacity and work rates of animal draught enterprises. Consequently, besides reducing the carbon footprint of farming, replacement of tractor enterprises by animal draught enterprises would also have a positive effect on rural employment. For this reason, new implements were provided to a selection of animal draught enterprises to enable them to plough, disk and ridge land as required by plot holders. It was postulated that exposure to improved service provision by animal draught enterprises would result in positive perceptions of animal draught among plot holders. Generally, this was not the case. On the contrary, the change in perception tended towards the negative instead of the positive. However, increased scepticism among plot holders about animal draught enterprises presenting a suitable alternative to tractor enterprises was not extreme and there were a minority of plot holders who developed more positive perceptions of animal draught enterprises following exposure. It was concluded that there is a market for the land preparation services provided by animal draught enterprises but this market is limited and considerably smaller than the market for tractor enterprises. Feedback from plot holders indicated that the main advantage of using animal draught was a reduction in the cost of preparing land. This advantage is expected to gain in significance as the cost of diesel rises. Quality concerns raised by plot holders about the service of animal draught enterprises were real, indicating the urgent need to improve the technical capabilities of animal draught enterprises through research and development. Inadequacies in the technical skills of some operators and the lack of suitable nutrition provided to working animals, especially during winter, were also identified as constraints.

Chapters 7, 8 and 9 focused on issues of production, with **Chapter 7** dealing with irrigation scheduling of Chinese cabbage and green maize. In the case of maize, the once-per-week irrigation schedule practised by farmers was found to be best practice. It used less water and gave the highest irrigation water use efficiency of all the methods that were tested. In the case of Chinese cabbage this was not the case. For optimum growth and leaf yield of non-heading Chinese cabbage the soil water content in the upper part of the profile had to be maintained at or close to field capacity. This required the crop to be irrigated at least twice per week, which is more often than farmers have access to irrigation water.

The focus of **Chapter 8** is on improving green maize production. Research results enabled the identification of the best performing cultivar (SC 701) and the optimum planting density for different planting dates but a relatively sparse stand of 2.22 plants m^{-2} was recommended for use by farmers, irrespective of the planting date. Maize streak virus (MSV) was identified as a major constraint to year-round production of green maize in Vhembe and the incidence of maize streak disease (MSD) was shown to depend on date of planting. For the cultivar SC701, incidences in excess of 80% were recorded in the March and April plantings. Use of the MSV-resistant cultivar PAN 67 by farmers at Dzindi is recommended when green maize is planted from January to April, when the risk of MSD is highest and SC701 for all other planting dates, because SC701 produces larger cobs than PAN 67. Intercropping relatively sparse green maize stands (2.22 plants m^{-2}) with pumpkins (0.55 plants m^{-2}) was shown to raise gross enterprise income in green maize production, without affecting water use and cob size of maize. Planting green maize and pumpkin at the same time provided the greatest benefit.

In **Chapter 9** the opportunity of integrating crop and livestock production on canal schemes in Vhembe is explored, using the production of maize and grain legumes as crops and the production of poultry as livestock. For that purpose technology was developed to process grain on-farm for the purpose of formulating poultry diets.

It was found that the biological performance of broilers provided with diets that contained legume grains that were processed on-farm was sub-optimal compared to that of broilers on a commercial multi-phase diet. Use of the on-farm feed also reduced net operating income of broiler enterprises. Indications were that the simple, single-phase on-farm broiler diet that was tested first could be improved. The challenge that remains is to improve the on-farm diet to such an extent that net operating income of broiler enterprises using the on-farm diet is higher than that of enterprises using a commercial diet. Three possible ways of improving the on-farm diet were identified.

Research also showed that cowpeas can be used as the source of protein for inclusion in layer diets. Boiling cowpeas for 30 minutes and germinating cowpeas over a period of four days at room temperature were identified as effective methods to reduce the anti-nutritional factors they contained. However, using cowpeas as the single protein source in a simple layer diet could not be recommended at this stage. Recommendations were made for additional research.

Soya beans, the preferred choice of crop, because of its high protein content, performed poorly compared to elsewhere in South Africa. High temperatures and high humidity appeared to be the reason why the crop that was planted during the expected optimum planting period (September to December) performed poorly. Grain of good quality and reasonable grain yields were obtained only when the crop was planted in February, which caused grain filling to occur during the dry autumn and early winter months. However, the average grain of less than 2 t ha^{-1} did not warrant the production of the crop under irrigated conditions. Cowpeas and pigeon peas were tried out as alternatives to soya beans. Both crops appeared very well adapted to conditions at Dzindi but the grain yields that were obtained (<1 t ha^{-1}) were too low to consider the introduction of either of these two grain legumes as a cash crop for smallholder irrigators. The very low grain yield obtained from pigeon peas was partly due to bird damage.

Various experiments aimed at determining the value of poultry manure for use as a fertiliser in crop production showed that poultry manure contained important plant nutrients, particularly N and P, in concentrations that were higher than in many other types of animal manure. Plant availability of nitrogen and phosphorus immediately or shortly after application tended to be high and increased over time. From a practical perspective, the study indicated that applying poultry manure at rates exceeding 12 t ha^{-1} could not be recommended, because of possible negative effects associated with high application rates of poultry manure in certain crops, such as pumpkins. Other crops, particularly nightshade, were shown to respond positively to application rate of poultry manure up to rates of 20 t ha^{-1} under both greenhouse and field conditions, but these high rates should not be used in practice. Instead, poultry manure could be applied once at rates of 10 to 12 t ha^{-1} to bring the nutrient status of depleted soils to appropriate levels, where after the application rate should be adjusted to the nutrient requirements of the crops being grown. Fertilizer values of poultry manure were determined and these could be used as an initial approximation to calculate the appropriate application rate of poultry manure to meet the nutrient requirements of specific crops.

Chapter 10 summarises the important findings and conclusions emanating from the research work that was done.

Chapter 11 contains the recommendations derived from the findings, with special reference to policy. The policy recommendations are structured in line with the mandates of different departments within the South African government.

The following guidelines, available from the Water Research Commission, complement this report:

- ***Growing Green Maize on Canal Schemes in Vhembe: Production Guidelines*** by W Van Averbeke, K Ralivhesa, S Mbuli, TB Khosa & KW Manyelo

- ***Production Guidelines for Small-Scale Broiler Enterprises*** by K Ralivhesa, W Van Averbeke & FK Siebrits
- ***Guidelines on Management of Working Animals*** by TE Simalenga, S Sibanda & P Jones

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CHAPTER 1

1 Improving smallholder canal irrigation in Vhembe: Setting the research agenda

Wim Van Averbeke

An irrigation scheme can be defined as an agricultural project involving multiple holdings that depend on a shared distribution system for access to irrigation water and, in some cases, on a shared water storage or diversion facility (Van Averbeke *et al*., 2011). The term ‘irrigation scheme’ is also used more broadly to refer to a multitude of entities that correspond to this definition, when these entities share the same bulk conveyance system (Reinders, 2010). The relatively small size of the irrigation plots allocated to Black farmers explains why in South Africa, the term ‘smallholder irrigation scheme’ is commonly used to refer to irrigation schemes on which the land is held by Black people (Machete *et al*., 2004). Accordingly, for the purpose of this report, smallholder irrigation scheme is defined as an irrigation scheme that was constructed specifically for occupation and use by Black farmers (Van Averbeke *et al*., 2011).

The available evidence indicates that in 2010 there were 302 smallholder irrigation schemes with a combined command area of 47 667 ha in South Africa. The plot-holder population on these schemes totalled 34 158. Rivers were the principal source of water. A total of 46 114 ha (96.7%) obtained its water from rivers, either pumped directly, diverted by means of weirs, or through dam storage. Groundwater was used on 1 405.5 ha (3.0%), municipal water on 110 ha (0.2%) and spring water on 37.6 ha (0.1%). Water was pumped on 23 111.8 ha (48.5%), gravitated on 16 497.2 ha (34.6%) and on 8 058.5 ha (16.9%) gravity and pumping occurred in combination (Van Averbeke *et al*., 2011). On all existing schemes, the irrigation system was constructed after 1950. Smallholder irrigation scheme development in South Africa has a much longer history (Van, Averbeke, 2008), but in 2010, schemes that were constructed before 1950 no longer existed in their original form (Van Averbeke *et al*., 2011).

Smallholder irrigation schemes continue to be identified as an important opportunity for local economic development in rural (and urban) areas (Cousins, 2013), but examples of vibrant and successful smallholder irrigation projects in South Africa are relatively few (Van Averbeke *et al*., 2011). A multitude of researchers have identified a range of different constraints that dampen the livelihood outcomes derived by participants from small-scale irrigation farming. Among the primary constraints identified by extension staff on 164 of the 302 smallholder schemes that existed in South Africa in 2010, poor management topped the list (50% of the cases); followed by infrastructural problems (15%); water inadequacies (13%); conflict (12%); and theft (7%) (Van Averbeke *et al*., 2011). This suggested that human (capacity) and social (institutional) resource problems were at the heart of the below-expected performance of smallholder irrigation schemes in South Africa. The prevalence of human and social constraints was also identified by nearly all assessments that were made of smallholder irrigation schemes in South Africa (Bembridge, 1997; Bembridge, 2000; Kamara *et al*., 2002; Shah *et al*., 2002; Machete *et al*., 2004; iSeneke Developments, 2004; Tlou *et al*., 2006; Speelman *et al*., 2008; Yokwe, 2009; Mnkeni *et al*., 2010).

In this report we explore different opportunities to improve these livelihood outcomes. The main thrust of the work was aimed at testing a number of farming system innovations, which we thought could lead to improved use of water, land, labour and other resources on smallholder irrigation schemes. This aspect of the work addressed the human capacity constraint. Attention was also given to social resource constraints but the research that was done was mostly analytical and aimed at understanding the problems and their causes rather than engaging participants in a process that could lead to solving identified problems.

The research was conducted in the Limpopo Province, which is the heartland of smallholder irrigation schemes in South Africa. This is evident from Table 1.1, which shows the operational status of South African smallholder irrigation schemes by Province and irrigation system. In 2010, Limpopo Province counted 170 smallholder irrigation schemes, which represented 56% of the national total of 302 schemes. Table 1.1 also indicates that in 2010, 69 of the 170 schemes (41%) in Limpopo were not operational. The majority of non-operational schemes were pumped schemes (83%) and only 12 (17%) were gravity-fed projects. Among the operational schemes, nearly half (49 of 101) were gravity-fed canal schemes. A similar relationship between irrigation technology and operational status was identified at national level. In 2010, the likelihood of a scheme being operational was 81% for gravity-fed canal schemes, 70% for pumped surface irrigation schemes, 65% for overhead irrigation schemes and 56% for micro-irrigation schemes (Van Averbeke *et al*., 2011). Considering that canal schemes were the first type of schemes to be constructed, making them the oldest, draws attention to their apparent durability and resilience. This was the principal reason why the research work presented in this report focused on canal schemes.

TABLE 1.1: Operational status of South African smallholder irrigation schemes by Province and irrigation system (from Van Averbeke *et al*., 2011)

Province	**Number of operational schemes by irrigation system**				**Number of non-operational schemes by irrigation system**				**Total**
	Gravity-fed surface	Pumped Surface	Overhead	Micro	Gravity-fed surface	Pumped Surface	Overhead	Micro	
Limpopo	49	9	30	13	12	5	41	11	**170**
Mpumalanga	3	0	4	0	1	0	11	0	**9**
Northwest	0	2	0	0	0	0	0	0	**2**
KZN	5	0	30	0	0	0	0	0	**35**
Free State	0	1	0	0	1	0	0	0	**2**
N. Cape	0	2	0	0	0	1	0	0	**3**
E. Cape	4	0	46	1	0	0	16	0	**67**
W. Cape	6	0	1	0	0	0	1	0	**8**
Total	**67**	**14**	**111**	**14**	**14**	**6**	**59**	**11**	**296**[1]

[1] The operational status of six schemes, five in the Eastern Cape and one in KwaZulu-Natal, was not known bringing the total to 302.

WRC report TT344/08 (Van Averbeke, 2008) provided insight into the operation of smallholder canal schemes in the Vhembe District of Limpopo Province from a range of perspectives and identified several elements that could be improved. The research work that was done under the auspices of the current project was based on these insights and sought to contribute information that could be applied to invigorate farming on canal irrigation schemes in the same District. Our premise was that development on canal schemes needed to follow the '*smallholder farmer – diversified farming and reduced risk*' trajectory (Denison & Manona, 2007). Constraints commonly encountered on smallholder canal schemes that were selected for study were:

1. Availability of irrigation water;
2. Access to additional land;
3. Access to markets;
4. Content and structure of the prevailing production systems.

Availability of irrigation water

Many smallholder canal irrigation schemes obtain their irrigation water by means of concrete weirs in small rivers. This makes the availability of water dependent on the seasonal patterns of river flow. In Limpopo Province, which forms part of the summer rainfall area, the availability of irrigation water tends to be most limiting during winter and spring. As is shown in Chapter 2 of this report, plot holder communities on these types of irrigation schemes have little or no control over the amount of water entering their schemes, but jointly they do have control over the way in which the available water is managed. Critical management domains are the routine maintenance of the irrigation infrastructure and the allocation of water to individual plots. Effective management of these domains is dependent on effective collective action (Letsoalo & Van Averbeke, 2005; 2006; Van Averbeke, 2008). Chapter 4 examines the state of the water distribution infrastructure and the effectiveness of routine maintenance being applied at the Dzindi canal scheme. The collective organisation responsible for routine maintenance is also studied.

On the plots, effective scheduling of irrigation is a critical factor in crop production. Scheduling on canal schemes is subject to arrangements that determine when water is available for irrigation. This means that scheduling is subject to restrictions. In Chapter 7, the effect of irrigation scheduling on crop production is investigated for two important crops at the Dzindi canal scheme, namely non-heading Chinese cabbage, a leafy vegetable that is grown during winter, and green maize, which is an important summer crop.

Access to additional land

Livelihoods of plot holder homesteads on small-scale canal irrigation schemes in South Africa are diverse and dynamic and the importance of irrigated farming in the livelihood portfolio of these homesteads also varies (Mohamed, 2006). The farming styles, which are the socio-technical repertoires farmers use to produce, store and transact their produce are also diverse and variability in farming styles, farm objectives and livelihood portfolios are associated. Farm objectives of plot holders on small-scale irrigation schemes range from production of food solely for own consumption to full market-oriented production (Van Averbeke & Mohamed, 2006). Characteristic of market-oriented farmers was that they wanted to expand the scale of their enterprises, whilst those who produced food for home consumption tended to have excess land (Van Averbeke & Mohamed, 2006). These conditions favour the emergence of a vibrant land exchange market. The Trust tenure system that applies on many smallholder canal irrigation schemes has been blamed for the ineffectiveness of the land exchange market on these schemes but there is a lack of information on why exactly this is the case. Chapter 4 contributes to filling this knowledge gap.

Access to markets

Market conditions affect both access to inputs and the ability of farmers to sell their produce. For many of the smallholder canal irrigation schemes remoteness is a critical factor affecting access to both input and output markets. Local resource use and value-adding are ways to reduce the impact of remoteness on market access and it is the hypothesis that integrating crop and animal production can contribute substantially to local resource use, value-adding and market access on smallholder irrigation schemes. Integration of crop and livestock production has the potential to provide economic benefits and improve the financial viability of farm enterprises. In Chapter 9, this potential is explored at the Dzindi canal scheme by introducing a broiler production system that uses on-scheme processing of yellow maize grain and soya beans to manufacture a single-phase diet. The broiler enterprise provides a local market for maize and grain legumes and makes available poultry manure for use as a fertiliser in crop production. Introducing grain legumes in the cropping system of farmers at Dzindi has the important advantage that these crops supply most of their own nitrogen requirements by symbiotic fixation of atmospheric N_2 gas when inoculated with the correct type of rhizobium. Production of maize is well established on smallholder irrigation schemes in Limpopo Province but production of grains legumes is limited. For this reason, research was done to test the production potential of a selection of grain legumes.

Improving prevailing production systems

Technical improvements to the prevailing production systems on smallholder irrigation schemes can enhance the financial viability of plot enterprises and increase the efficiency of water and land use. The technical improvements that were tested were the introduction of animal draught as an alternative to mechanical draught (chapters 5 and 6); the replacement of chemical fertilisers with poultry manure (Chapter 9); and the optimisation of green maize production (Chapter 8).

Overall, the different research projects that were conducted were aimed at achieving the stated project objectives, which were:

- To explore ways of strengthening collective action in the domains of water sharing and infrastructural maintenance on smallholder canal irrigation schemes.
- To develop, implement and assess a community-based institutional system that reduces uncertainty and risk in land exchange contracts.
- To determine the suitability of selected grain legumes as a protein source for use in the on-farm processing and formulation of poultry diets, to introduce grain legumes in the farming system of smallholder irrigators, and to document and assess the adoption process from a social and economic perspective.
- To compare selected options of sourcing draught power for the conduct of farm operations on smallholder irrigation schemes.
- To determine the effectiveness of poultry manure as a fertiliser in smallholder crop production and the effect of replacing chemical fertilisers with poultry manure on the total variable cost of crop production on smallholder irrigation schemes.
- To investigate and improve production and irrigation practices for selected crops with special reference to maize and grain legumes as crops, and to deficit irrigation, cultivar selection, planting date, plant population and intercropping as agronomic practices.
- To develop best-practice guidelines for the production and irrigation of selected crops with special reference to maize and grain legumes as crops, and to deficit irrigation, cultivar selection, planting date, plant population and intercropping as agronomic practices.
- To develop best-practice guidelines for the integration of crop and animal production systems on smallholder irrigation schemes.

The general aim of the research was to make a contribution to rural development. Lack of livelihood opportunities in the rural areas of South Africa, particularly the former homelands, is the root cause for the persistent concentration of poverty in these areas. Urban migration of rural people in response to poverty and lack of livelihood opportunities has resulted in the transfer of poverty from rural to urban areas. This has brought about undesirable social, infrastructural and economic circumstances in the cities. It is our belief that rural development can provide an alternative. It is our hope that our work will make a contribution to the development of smallholder irrigation as a rural development option.

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CHAPTER 2

2 Smallholder irrigation schemes in the Vhembe District

Wim Van Averbeke

2.1 Introduction

South Africa needs to raise employment and reduce poverty, particularly among rural African people. The New Growth Path released by the government in November 2010 was a response to the persistent unemployment problem. It aims to create five million new jobs by 2020. The New Growth Path intends to create 300 000 of these new jobs through the establishment of smallholder farmer schemes (Economic Development Department, 2010). The National Development Plan – Vision 2030, which builds on the New Growth Path, proposes to create 11 million new jobs by 2030, of which about 1 million are expected to arise as a result of agricultural development (National Planning Commission, 2011). Irrigation is 'the driving force' in the agricultural development strategy proposed by the National Planning Commission (2011). It is argued that 0.5 million ha of new irrigation land can be added to the 1.5 million ha of irrigated land that already exists, by using existing water resources more efficiently and by developing new water schemes. This suggests that South African policy advisers and policymakers believe that smallholder scheme development can create a substantial number of new employment opportunities in South Africa. However, the performance of the smallholder schemes that have been set up as part of the post-democratisation land reform programme has been dismal (Umhlaba, 2010). Similarly, assessments of South African smallholder irrigation schemes that were established prior to 1994 indicated that many of these have also performed poorly (Bembridge, 2000; Machete *et al*., 2004; Tlou *et al.*, 2006; Mnkeni *et al.*, 2010). Yet, in water-stressed South Africa, expanding smallholder irrigation is one of the obvious options to trigger rural economic development. Elsewhere in the world, particularly in Asia, investment in irrigation was a key ingredient of the green revolution, which lifted large numbers of rural Asians out of poverty and created conditions that were conducive for the industrial and economic development that has occurred (Turral *et al*., 2010). A similar development trajectory has been recommended for South Africa and other parts of Sub-Saharan Africa (Lipton, 1996). So far, the developmental impact of smallholder irrigation in Sub-Saharan Africa has been limited (Inocencio *et al*., 2007).

Knowledge of factors that have a significant effect on smallholder irrigation scheme performance could assist effective location and design of new schemes. To identify these factors is the main objective of this chapter. The chapter starts with a description of the smallholder irrigation schemes located in the Vhembe District of Limpopo Province. This is followed by an assessment of their performance and an examination of the associations between selected performance indicators and attributes of smallholder irrigation schemes. Smallholder irrigation scheme was defined as an agricultural project that was constructed specifically for occupation by African farmers and that involved multiple holdings, which depended on a shared distribution system for access to irrigation water and in some cases also on a shared water storage or diversion facility. Using this definition, Van Averbeke *et al*. (2011) identified 302 smallholder irrigation schemes in South Africa with a combined command area of 47 667 ha. Among them, 206 were operational, 90 were not, and of six schemes the operational status was unknown (Van Averbeke *et al.*, 2011). The content of this chapter, with minor modifications, was published as a book chapter (Van Averbeke, 2012).

2.2 Review of literature

The use of irrigation by African farmers in South Africa appears to have two centres of origin. One of these centres was the Ciskei region of the Eastern Cape, where technology transfer from colonialists to the local people, resulted in the adoption of irrigated agriculture by African peasants (Bundy, 1988). These early smallholder irrigation developments were mostly private or mission station initiatives and involved river diversion. Most of these early African irrigation initiatives in the Eastern Cape did not last long (Houghton, 1955, Bundy, 1988). The other centre of origin was located in what is now the Vhembe District. Evidence of African irrigation in this area was provided by Stayt (1968), who conducted anthropological research among the Venda during the late nineteen-twenties and published the first account of his work in 1931. Box 2.1 cites Stayt's reference to African irrigation in Vhembe.

The reference to early African irrigation in Vhembe contained in Box 2.1 is significant for two reasons, namely the apparent use of irrigated agriculture by local African people before exposure to European colonists and their continued use, or at least re-adoption, of irrigated agriculture using stream diversion during the nineteen-thirties. This suggests local interest, knowledge and affinity for the use of irrigation as a way of intensifying crop production.

In the northwest of Vendaland there are traces of some very ancient occupation. Colonel Piet Moller, who was an early settler in the Zoutpansberg, has found what he considers indisputable evidence of ancient irrigation works. Most of the old furrows are near Chepisse and it appears that the water was diverted from a small stream there in a series of furrows to a distance of about four and a half miles south. Traces of furrows are also discernible at Sulphur Springs, and at several places by the Nzhelele river, where some of them have been reopened and are utilised by the BaVenda to-day. Colonel Moller says that when he first came across these some forty years ago (around 1880), there was no doubt about their antiquity; to-day they are very difficult to trace, as roads, modern agriculture, and furrows have altered the face of the country considerably and have particularly hidden the ancient workings.

BOX 2.1: Reference to pre-colonial irrigation in Vhembe (Stayt, 1968)

The Tomlinson Commission (1955) also identified the northern parts of South Africa as the area where smallholder irrigation schemes were functioning best, as is evident from its statement reproduced in Box 2.2.

Among the various systems and types of settlement in the Bantu Areas, irrigation farming is undoubtedly the only form of undertaking in which, under European leadership and control, the Bantu have shown themselves capable of making a full-time living from farming, and of making advantageous use of the soil for food production.

The interest shown by Bantu in irrigation farming varies from one locality to another. In some parts of the Transvaal (here reference is made to areas that are now part of Limpopo Province), the Bantu are so enthusiastic that they offer their labour free to construct canals to lead water from streams for the irrigation of their land, while in the Transkei and Ciskei (now part of the Eastern Cape), on the contrary, interest has waned to such a degree, that existing schemes have fallen into disuse.

BOX 2.2: Reference to the performance of African smallholders on irrigation schemes during the period 1950-52 by the Tomlinson Commission (1955)

In 1952, when the Tomlinson Commission completed its data collection, it identified 122 smallholder irrigation schemes covering a total of 11 406 ha. This irrigated area was held by 7 538 plot holders, each holding a plot with an average size of 1.513 ha. All of these were river diversion schemes but it is not clear whether the water conveyance and distribution systems were lined or not. The Tomlinson Commission (1955) did distinguish between what appeared to be indigenous and state controlled irrigation projects, identifying state controlled schemes as performing considerably better than those controlled by African farmers themselves (Box 2.3).

> The Commission collected details of the production achieved on the controlled Olifants River irrigation scheme and the uncontrolled Nzhelele River scheme (Vhembe District). The average size holding were 1.53 morgen (1.3 ha) and 1.71 morgen (1.5 ha), respectively, and other physical factors were approximately equal. It was found that the average income per settler on the Olifants scheme was £110.69 as compared with £28.79 on the Nzhelele scheme. The average yield of grain of all sorts was 47.07 bags (fil in) per settler on the Olifants, as against 9.2 bags on the Nzhelele scheme. This is a clear indication that irrigation schemes for Bantu are successful when under efficient control and guidance and that average Bantu family on 1.5 morgen (1.28 ha) under such schemes, can make a gross income of £110.7 per annum, which renders it unnecessary for members of the family to seek employment elsewhere to supplement the family income.

BOX 2.3: Comparison of the performance of African smallholders on indigenous irrigation schemes with those on irrigation schemes under state control (Tomlinson Commission, 1955)

The 'European control' mentioned in Box 2.3 referred to a set of institutional arrangements imposed by the state, which regulated allocation of water to farmers and land use, including choice of crops, and the provision of technical advice and marketing assistance for the crops that were prescribed to farmers. In line with this observation, the Tomlinson Commission (1955) recommended the construction of new smallholder irrigation schemes and the upgrading of existing schemes as a smallholder development strategy. The Tomlinson Commission (1955) identified a total area of 54 051 ha that had the potential for irrigation development in Bantu Areas and estimated that exploitation of this potential could enable the settlement of 36 000 farmer families, representing approximately 216 000 people. The Tomlinson Commission (1955) recommended that irrigation scheme development should occur in the form of simple canal schemes using river diversion by means of a weir and that uniform regulations should be applied to the running of these schemes. One of these regulations was that ownership and control over tribal land identified for irrigation scheme development needed to be transferred to the state before construction of the scheme. Another was that homesteads would be allocated plots that were 1.28 ha to 1.71 ha in size, as these were deemed adequate to provide for a livelihood based on full-time farming. A third was the enforcement of specified production systems on smallholder irrigation schemes. These production systems were to be designed, enforced and supported by state-appointed superintendents. Farmers who settled on these schemes held their plots under Trust tenure. This form of tenure provided the state with the necessary powers to prescribe land use and to expel and replace farmers whose practices did not comply with these prescriptions. In selected cases the state effectively used these powers to enforce the overall objectives of the schemes by evicting poorly performing families (Van Averbeke, 2008). This authoritarian and paternalistic approach by the state was not limited to irrigation schemes settled by Africans. The same approach had been used on state schemes established for settlement by white farmers during the Great Depression and WWII period (Backeberg & Groenewald, 1995).

Construction of smallholder canal schemes in South Africa was continued until the nineteen-seventies. The 2011 update of the smallholder irrigation scheme data base created by Denison and Manona (2007) indicated that there were 74 smallholder canal schemes left in South Africa. Sixty-seven of these were operational, six were not operational and of one scheme the operational status was not known. The combined command area of existing gravity-fed canal schemes was 11 966.2 ha, which represented 25.1% of the total smallholder irrigation scheme command area in South Africa. Surface irrigation was also practised on 20 schemes that used pumping, sometimes in combination with gravity. Among these 20 schemes, 14 of were operational and six were not. Combined they had a command area of 4 113.7 ha, 8.6% of the total.

From the nineteen-seventies onwards, the design of smallholder irrigation schemes in South Africa was influenced by the modernisation paradigm. This paradigm was based on the belief that modern, capital-intensive infrastructure, to be paid for by the intensive production of high-value crops, could lift smallholders out of poverty (Faurès *et al*., 2007). Pumping and overhead irrigation became the norm in smallholder irrigation scheme development in South Africa. In 2011, there were 175 smallholder irrigation schemes that used overhead irrigation. Combined they had a command area of 27 757.6 ha, 58.2% of the total. Among these 175 schemes, 111 were operational, 59 were not and of five the operational status was not known. Pumped overhead schemes covered a total command area of 16 497.1 ha, gravity-fed overhead schemes 4 451 ha and schemes where gravity and pumping occurred in combination had a total command area of 6 903.5 ha (Van Averbeke *et al*., 2011).

Distinctive of the modernisation paradigm in smallholder irrigation scheme development was the establishment of large projects. In many of the large smallholder schemes that were constructed in South Africa, the design was characterised by functional diversification and centralisation of scheme management. Typically, these large schemes were designed to perform three functions, namely a commercial function, a commercial smallholder development function and a subsistence function. The commercial function was performed by allocating a substantial part of the scheme area to a central unit that was farmed as an estate. Farming on this estate used management and labour (Van Averbeke *et al*., 1998). The commercial smallholder development function was implemented by allocating a limited number of 'mini-farms' to selected African homesteads, who were judged to have the aptitude to make a success of small-scale commercial agriculture. These mini-farms ranged between 5 ha and 12 ha in size. (Van Averbeke *et al*., 1998), The subsistence function was put into practice by providing large numbers of African homesteads with access to food plots, ranging from 0.1 ha to 0.3 ha in size (Van Averbeke *et al*., 1998). In some instances complex arrangements had to be made to implement this multi-functional design, because land holders had to be compensated for handing over their dryland allotments to create room for the central unit estate. A good example was the 2 830 ha Ncora Irrigation Scheme, established in 1976 in the Transkei region of the Eastern Cape (see also Denison & Van Averbeke, 2013). In return for availing their allotments to the scheme, the 1 200 existing land holders at Ncora were offered the right to 0.9 ha of irrigation land. They were given the choice of farming the entire allocation themselves or handing over two-thirds of their allotment to the central unit and remain with a 0.3 ha plot for own use. The latter option provided land holders with production inputs free of charge and an annual dividend derived from the profits made by the central unit. Management of these large schemes was centralised and in the hands of specialised parastatals established by homeland governments (Van Rooyen & Nene, 1996; Van Averbeke *et al*., 1998; Lahiff, 2000). The financial viability of this type of smallholder schemes was dependent on the performance of the central unit. Records show that the financial performance of these central units never met the predictions (Van Averbeke *et al*., 1998). State subsidies were persistently required to keep these schemes afloat. Taking an extreme example, in 1995, the central unit of Ncora Irrigation Scheme required a budget of R21.3 million. It had 650 employees at a cost R16.6 million and operational costs amounting to R4.8 million. The income of the central unit in 1995 was R2.8 million, way short of even meeting its operational costs.

Following the democratisation of South Africa in 1994, the provincial governments decided to dismantle the agricultural homeland parastatals and transfer the management of smallholder irrigation schemes to the farmer communities who benefitted from them. Elsewhere in the world, a similar process, referred to as 'Irrigation Management Transfer' (IMT) had been occurring. Reducing public expenditure on irrigation, improving productivity of irrigation and stabilising of deteriorating irrigation systems were the three main reasons why IMT was implemented by governments (Vermillion, 1997). In South Africa, the dismantling of homeland parastatals and IMT proceeded very swiftly. It started in 1996 in the Eastern Cape and ended in 1998 in Limpopo Province. IMT affected all projects where parastatals were offering services to smallholders. Its effects were most strongly felt on the large, modern smallholder irrigation schemes, because these projects were the most complex to manage. Having been centrally managed from inception, levels of dependency on external management among farmers on these schemes were exceptionally high (Van Averbeke *et al*., 1998). Farming collapsed as soon as IMT had been implemented on these schemes (Bembridge, 2000; Laker, 2004). Small irrigation schemes, particularly the canal schemes, were more resilient and continued to operate, albeit at reduced levels (Kamara *et al*., 2002; Machete *et al.*, 2004).

Besides IMT, the nineteen-nineties also saw the establishment of several new smallholder irrigation schemes. Conceptually, these new schemes were aligned with the Reconstruction and Development Programme (RDP). This Programme was the overall political framework that applied at that time. It was aimed at eradicating poverty and improving the quality of life among poor African people in rural areas and informal urban settlements. Irrigation development focused on improving food security at community or group level and favoured the establishment of small schemes. In 2006, Denison and Manona (2007) identified 62 smallholder irrigation schemes that were established during this era, but combined they only covered 2 383 ha, clearly indicating their limited size (38.4 ha on average). Typically, these projects used mechanical pump and sprinkler technology to extract and apply irrigation water.

When GEAR (Growth, Employment and Redistribution) superseded the RDP as the overall development policy of South Africa, the strategy to eradicate poverty shifted from funding community-based projects to pursuing economic growth through private sector development. Existing irrigation schemes were identified as important resources for the economic development of the rural areas, but they required revitalisation first. The Revitalisation of Smallholder Irrigation Schemes (RESIS) of the Limpopo Province stood out for its comprehensiveness. The RESIS programme evolved from the WaterCare programme, which was launched in 1998 and ran for five years (Denison and Manona, 2007). The WaterCare programme was aimed at revitalizing selected smallholder irrigation schemes in the Province, not only infrastructurally, but also in terms of leadership, management and productivity. Using a participatory approach, WaterCare involved smallholder communities in planning and decision making and provided training to enable these communities to take full management responsibility over their schemes (Denison & Manona, 2007). In February 2000, Mozambique and the Limpopo Province were ravaged by cyclone Conny

(Christie & Hanlon, 2001). Heavy rains caused widespread floods and damage to roads, bridges and also to the weirs that provided water to many of the smallholder canal schemes (Khandlhela & May, 2006). Declared a disaster area, the Limpopo Province was allocated special funding to repair the damage to its infrastructure, providing impetus to the WaterCare programme. In 2002, the Limpopo Province broadened the scope of its irrigation scheme rehabilitation intervention by launching a comprehensive revitalisation programme, called RESIS (REvitalisation of Smallholder Irrigation Schemes). RESIS adopted the participatory approach of the WaterCare programme, but planned to revitalise all smallholder schemes in the Province (Denison & Manona, 2007). As was the case in the WaterCare programme, RESIS combined the reconstruction of smallholder irrigation infrastructure with the provision of support to enable effective IMT. In support of IMT, the programme dedicated one-third of the revitalisation budget to capacity building among farmers. Guidelines for the sustainable revitalisation of smallholder irrigation schemes, which covered the building of capacity among irrigator communities, were developed by De Lange *et al*., 2000. RESIS also sought to enhance commercialisation of the smallholder farming systems on the schemes, in order to improve the livelihood of plot holder homesteads (Van Averbeke, 2008).

During the WaterCare programme and the first phase of RESIS (1998-2005), the emphasis was primarily on the rehabilitation of the existing scheme infrastructure and on sustainable IMT, and less on commercialisation. Canal schemes that were revitalised during this phase remained canal schemes. However, in 2005, commercialisation became the principal development objective of RESIS. The shift in emphasis was probably influenced by the Black Economic Empowerment (BEE) strategy that was introduced in South Africa, first in the mining sector and later on also in other sectors of the economy, including agriculture (Van Averbeke, 2008). Nationally, the BEE strategy was aimed at increasing the share of black people in the economy and it emphasized entrepreneurship. In 2005, the Limpopo Department of Agriculture launched the second phase of RESIS, named RESIS-RECHARGE. The Department equated canal irrigation with subsistence farming and inefficient water use. Consequently, it discouraged and later on rejected revitalisation of canal infrastructure. Instead it funded the transformation of canal schemes into schemes that used modern irrigation technology, such as micro-irrigation, centre pivot and floppy sprinkler systems. Implementation of these new irrigation systems obliterated existing plot boundaries. To get production on these revitalised modern schemes on a commercial footing, the Department engaged the services of a strategic partner in the form of a commercial farmer, who was tasked with running the entire operation. Plot holders were compensated for availing their land holdings by means of dividends, which amounted to half of the net operating income. They no longer had an active part in farming. In the Vhembe District, two smallholder irrigation schemes were revitalised in this way, namely Makuleke and Block 1A of the Tshiombo scheme. The others remained unaffected. With reference to the use of micro-irrigation on smallholder irrigation schemes in South Africa, in 2011 there were 20 such schemes, 11 operational and nine non-operational. Combined they had a command area of 3 830 ha, 8.0% of the total.

Globally, assessment of the performance of irrigated agriculture has received considerable attention, not in the least because of growing competition for water from other sectors (Faurès *et al*., 2007). Molden *et al*. (1998) developed a set of nine indicators to enable comparison of irrigation performance across irrigation systems. These covered irrigated agricultural output, water supply and financial returns. However, for smallholder irrigation schemes in South Africa the data required to calculate the nine indicators are rarely available. Most investigations into the performance of South African smallholder irrigation schemes used operational status, condition of the irrigation system, observations of cropping intensity and farm income in selected instances for assessment purposes. Generally, the conclusion of these studies has been that the contribution of smallholder irrigation schemes to social and economic development of irrigation communities has been far below expectations. (Bembridge & Sebotja, 1992; Bembridge, 1997; Bembridge, 2000; Machete *et al*., 2004; Tlou *et al*., 2006; Fanadzo *et al*., 2010). However, against a background of poor performance of smallholder irrigation schemes, few if any of the studies attempted to identify factors that appeared to contribute to differences in performance among these schemes. Such information could assist effective location and design of new schemes and also suggest priorities when planning revitalisation of existing schemes.

2.3 Materials and methods

The Vhembe District is located in the Limpopo Province of South Africa (Fig. 2.1), and is the most northern district (Fig. 2.2).

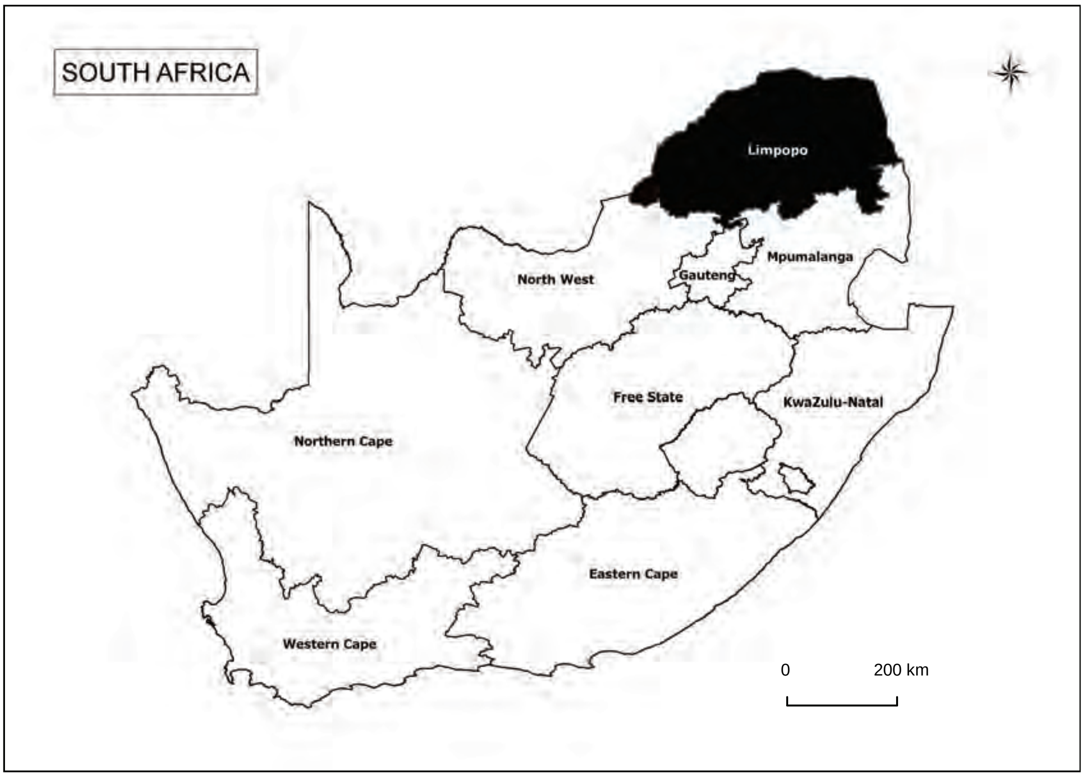

FIGURE 2.1: The Limpopo Province in the north of South Africa

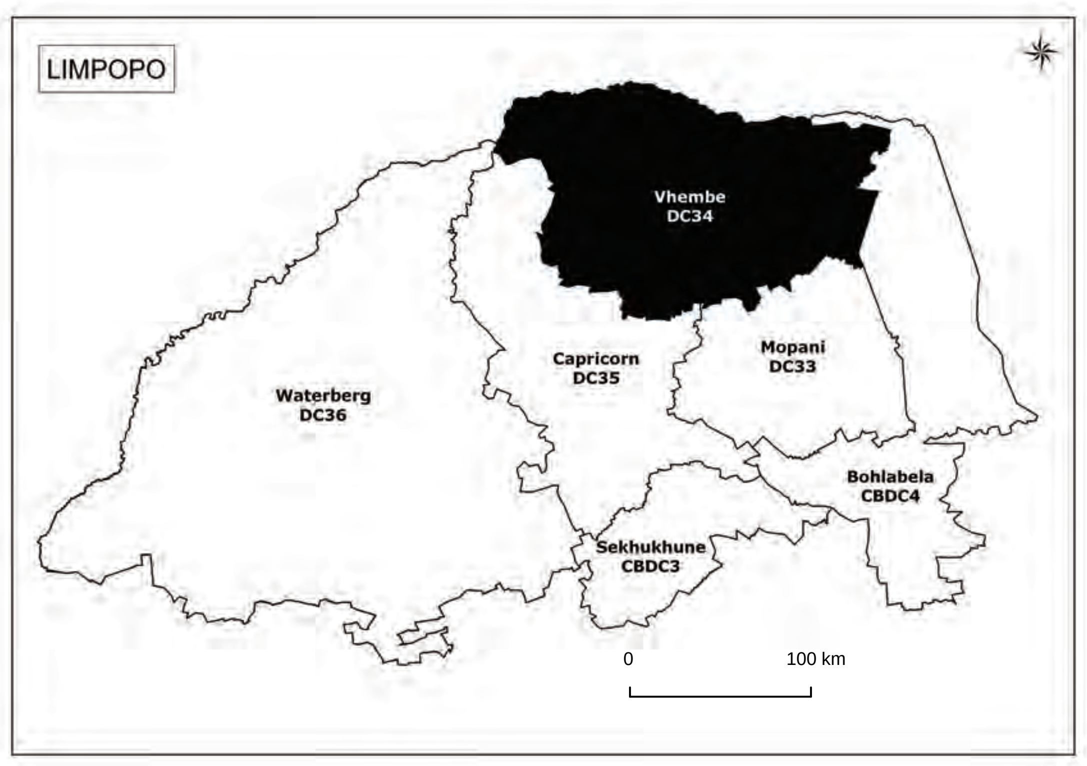

FIGURE 2.2: Location of the Vhembe District in the Limpopo Province

Vhembe borders Zimbabwe in the north and Mozambique in the east. It incorporates the territories of two former homelands of Venda and Gazankulu. The Venda homeland was created for the Venda-speaking people. Gazankulu was the territory allocated to the Tsonga-speaking people, also known as the Shangaan. Culturally, the BaVenda are closely associated with the Shona people of Zimbabwe, whilst the cultural roots of the Shangaan are in Mozambique.

Smallholder irrigation schemes in the Vhembe District were studied by means of a census. The census covered all smallholder irrigation schemes contained in the Vhembe register of the Limpopo Department of Agriculture, which was used as the sampling frame. A structured interview schedule was compiled for use as the survey instrument. The survey was conducted over a period of 10 months and involved four visits to the study area, each lasting between five and ten days. Work started in November 2008 and the last schemes on the list were visited during August 2009. Subsequently, the field data were scrutinised to identify data that were missing or needed verification. All the data queries that were identified were resolved during a follow-up visit to the study area in November 2009. Care was taken to achieve the greatest possible degree of reliability. Where possible, a small panel consisting of farmers, preferably members of the scheme management, and the extension officer were interviewed. At a few schemes only the extension officer or only farmers participated in the interview. Following the completion of the interview, a transect walk of the scheme was done and pictures were taken of selected features. A total of 42 schemes were identified but data collection at the Tshiombo Irrigation Scheme was done for each of the seven sub-units because of important differences amongst them. All other schemes were not subdivided, even when they consisted of multiple hydraulic units, referred to as irrigation blocks.

The first level of analysis was aimed at describing the population of smallholder irrigation schemes in the study area. For this analysis, the population was described one variable at a time, using descriptive statistics to generate summaries. The results provided a useful indication of the issues that affected smallholder irrigation in the study area and the diversity that surrounded these issues. The second level of analysis involved the testing of associations between four variables that were selected as performance indicators and a selection of independent variables that described the schemes.

The four performance indicators were operational status, number of years the scheme had been in operation, cropping intensity and degree of commercialisation. Operational status was selected because it is the primary indicator of performance. Once a scheme has stopped to operate, land use reverts to dryland agriculture. The number of years a scheme had been in operation was selected as an indicator of the durability of the system, which, in turn affects the rate of return on investment. Cropping intensity is a widely used indicator of the intensity with which water and land is being used in irrigated agriculture (Molden *et al*., 2007). Degree of commercialisation was selected because commercialisation has been shown to increase production and accelerate linkages in smallholder agriculture (Makhura *et al*., 1998). The scheme characteristics that were considered in the analysis are shown in Table 2.1.

TABLE 2.1: Selected characteristics of smallholder irrigation schemes in Vhembe, their ranking and the association of the performance indicators they were tested for

Scheme characteristic	**Ranking criteria**	**Performance indicator**			
		Operational status (n=48)	No of years in operation (n=48)	Cropping intensity (n=35)	Degree of commercialisation (n=35)
Hydraulic head	1 = gravity; 2 = pumped	Yes	Yes	Yes	Yes
Irrigation method	1 = surface; 2 = overhead; 3 = micro	Yes	Yes	Yes	Yes
Scheme area	Command area (ha)	Yes	Yes	No	No
No of plot holders	Population count	No	Yes	No	No
Plot size	Plot size (ha)	No	Yes	Yes	Yes
Organisation of production	1= individual; 2 = group	No	Yes	No	No
Water restrictions at scheme level	1 = no restrictions; 2 = seasonal restrictions; 3 = perpetual restrictions	No	No	Yes	No
Cash based land exchanges	0 = not practised; 1 = practised	No	No	Yes	Yes
Water theft	0 = not practised; 1 = practised	No	No	Yes	No
Effectiveness of scheme fence	1= effective; 2 = partially effective; 3 = not effective	No	No	Yes	No
Distance to urban centre	Distance by road (km)	No	No	Yes	Yes

Inclusion of the scheme characteristics shown in Table 1 was justified as follows: hydraulic head for its direct effect on operational costs; irrigation method as an indicator of modernisation; scheme area and number of plot holders as indicators of management complexity; plot size for its association with degree of commercialisation identified in other studies (Van Averbeke *et al*., 1998; Bembridge, 2000; Machete *et al*., 2004); organisation of production because group-based land reform projects have been shown to be prone to failure (Umhlaba, 2010); water restrictions because water is a production factor (Perry & Narayanamurthy, 1998); cash based land exchanges as an indicator of social and institutional responsiveness to demand for land (Shah *et al*., 2002); water theft as an indicator of social order (Letsoalo & van Averbeke, 2006); effectiveness of the scheme fence as a recurrent constraint in smallholder agriculture; and distance to urban centre as a measure of access to sizeable produce markets. Associations between scheme performance and scheme characteristics were assessed using Spearman's rank correlation. Scheme characteristics, their ranking and the association of the performance indicators they were tested for, are shown in Table 2.1. All 48 schemes were included in the analysis of operational status and number of years the scheme had been in operation. Schemes that were not operational (11), as well as two schemes that were no longer managed by plot holders following their revitalisation were excluded from the analysis of cropping intensity and degree of commercialisation.

2.4 Results

2.4.1 Summary description of smallholder irrigation schemes in Vhembe

Selected characteristics of the smallholder irrigation schemes in Vhembe District are presented in Table 2.2. Keeping in mind that the seven hydraulic units of Tshiombo were treated as separate schemes, 37 (77%) of the 48 smallholder schemes were operational and 11 were not. The smallest among the 48 schemes, Klein Tshipise, had a command area of only 8.5 ha, whilst the largest, Tshiombo, had a command area of 847 ha when its seven sub-units were combined. Together, the 48 schemes covered a total command area of 3760.1 ha, of which 3012.4 ha (80%) was located on schemes that were operational. The actual irrigated area on the schemes that were operational was 2693.1 ha. Two reasons were identified for the difference of 319.3 ha between command area and actual irrigated area on operational schemes. The first was infrastructural malfunctioning, which resulted in parts of the command area being withdrawn from irrigation. Schemes affected and areas involved were Khumbe (59 ha), Dopeni (17 ha) and Xigalo (30 ha). The second was that during revitalisation, parts of the command area were excluded, as in the case of Tshiombo Block 1A (8 ha) and Makuleke (204 ha).

TABLE 2.2: Selected characteristics of smallholder irrigation schemes in Vhembe District

Scheme name	Operational	Number of years operational	Command area (ha)	Number of plot holders	Average plot size (ha)	Hydraulic head	Irrigation method
Nesengani	Yes	42	13.7	28	0.415	Pumped	Surface
Nesengani B1	No	17	20.6	116	0.178	Pumped	Overhead
Nesengani B2	No	17	40.9	116	0.352	Pumped	Overhead
Nesengani C	No	17	31.2	131	0.238	Pumped	Overhead
Dzindi	Yes	56	136.2	102	1.285	Gravity	Surface
Khumbe	Yes	56	145.0	138	0.623	Gravity	Surface
Dzwerani	No	20	124.0	248	0.500	Pumped	Overhead
Palmaryville	Yes	59	92.0	70	1.296	Gravity	Surface
Lwamondo	No	6	15.0	75	0.200	Pumped	Micro
Mauluma	Yes	45	38.0	30	1.267	Gravity	Surface
Mavhunga	Yes	45	47.5	32	1.532	Gravity	Surface
Raliphaswa	Yes	46	15.0	13	1.154	Gravity	Surface
Mandiwana	Yes	46	67.0	40	1.675	Gravity	Surface
Mamuhohi	Yes	46	77.0	61	1.262	Gravity	Surface
Mphaila	Yes	21	70.6	59	1.197	Pumped	Overhead
Luvhada	Yes	58	28.8	79	0.365	Gravity	Surface
Rabali	Yes	59	87.0	68	1.279	Gravity	Surface
Mphepu	Yes	49	132.8	133	0.998	Gravity	Surface
Tshiombo Block 1	Yes	48	60.5	47	1.287	Gravity	Surface
Tshiombo Block 1a	Yes	1	128.6	100	1.286	Pumped	Overhead
Tshiombo Block 1b	Yes	45	122.0	115	1.061	Gravity	Surface
Tshiombo Block 2	Yes	46	126.0	98	1.286	Gravity	Surface
Tshiombo Block 2a	Yes	48	173.5	114	1.522	Gravity	Surface
Tshiombo Block 3	Yes	45	128.4	100	1.286	Gravity	Surface
Tshiombo Block 4	Yes	46	56.0	112	0.500	Gravity	Surface
Lambani	No	4	260.0	16	16.250	Pumped	Surface
Phaswana	No	8	16.7	16	1.044	Pumped	Surface
Cordon A	Yes	45	43.7	38	1.150	Gravity	Surface
Cordon B	Yes	45	82.3	65	1.266	Gravity	Surface
Phadzima	Yes	45	102.3	103	0.993	Gravity	Surface
Makuleke	Yes	2	37.3	29	1.286	Pumped	Overhead
Rambuda	Yes	58	170.0	132	1.288	Gravity	Surface
Murara	Yes	42	70.0	7	10.000	Gravity	Surface
Dopeni	Yes	46	30.0	6	5.000	Gravity	Surface
Makhonde	No	10	83.0	58	1.431	Pumped	Micro
Sanari	No	17	17.0	11	1.870	Pumped	Micro
Tshikonelo	No	14	10.0	15	0.670	Pumped	Overhead
Chivirikani	Yes	28	68.3	112	0.609	Pumped	Overhead
Gonani	Yes	13	8.5	30	0.295	Pumped	Overhead
Folovhodwe	Yes	54	70.0	24	2.197	Gravity	Surface
Klein Tshipise	Yes	36	60.0	60	1.000	Gravity	Surface

Scheme name	Operational	Number of years operational	Command area (ha)	Number of plot holders	Average plot size (ha)	Hydraulic head	Irrigation method
Morgan	Yes	40	56.7	35	1.620	Gravity	Surface
Makumeke	Yes	5	17.0	63	0.269	Pumped	Micro
Dovheni	Yes	11	60.0	14	2.143	Pumped	Overhead
Mangondi	No	15	48.0	38	1.260	Pumped	Micro
Xigalo	Yes	5	22.0	24	1.080	Pumped	Micro
Garside	Yes	45	13.7	28	0.415	Gravity	Surface
Malavuwe	Yes	19	20.6	116	0.178	Pumped	Overhead

At Tshiombo Block 1A (Plate 2.1), which was converted from canal to floppy irrigation, various small parts of the command area were not used because they did not fit the layout of the new irrigation system. At Makuleke, centre pivots limited use of the command area to selected parts of the scheme that were sufficiently large and homogeneous to accommodate a centre pivot. The food plot section of the scheme was never revitalised and remained non-operational at the time of the survey. Palmaryville lost 1.3 ha, when the demonstration plot was privatised.

PLATE 2.1: Revitalisation of Tshiombo Block 1A replaced the secondary canals and concrete furrows that conveyed water to the edge of individual farmers' fields with a centrally operated floppy sprinkler system that covers the entire hydraulic unit

2.4.2 Irrigation scheme development in Vhembe

The post-WWII period up to 1969 was very important for smallholder irrigation scheme development in Vhembe. Seven schemes with a total command area of 659.6 ha were established between 1951 and 1959. An additional 21 schemes with a total command area of 1978 ha were constructed during the decade that followed. This means that 2637.6 ha (70% of the existing smallholder irrigation scheme command area in Vhembe) were established between 1951 and 1969. All of the schemes that were constructed during this period were canal schemes. Nesengani, established in 1968, was the only canal scheme that made use of a pump to extract water to small concrete reservoirs from where it was gravitated to the plots. All other canal schemes extracted water by means of a weir or by means of spring diversion and relied entirely on gravity to convey water to the plots. All but one of the schemes that were constructed as canal schemes remained operational as canal scheme in 2009 but several had been fully or partially refurbished. The only exception was Block 1A of Tshiombo, which was recently (2008-09) transformed into a floppy irrigation scheme.

The period 1970 to 1979, which saw the construction of the last two canal schemes in Vhembe, namely Morgan and Klein Tshipise (Plate 2.2) in 1974, was a quiet period for smallholder irrigation development.

PLATE 2.2: The 8.5 ha Klein Tshipise Scheme constructed in 1974 sources its water from a spring and was the last canal scheme to be built in Vhembe

Renewed activity occurred from 1980 onwards and was associated with the commencement of homeland self-government (Beinart, 2001). All smallholder irrigation schemes that were established from 1980 onwards used pumps and pressurised irrigation systems. Dzwerani, established in 1980, was the first pressurised smallholder irrigation scheme in Vhembe. Non-operational at present, the 128 ha scheme at Dzwerani involved the pumping of water from the Dzondo River close to the confluence with the Dzindi River and the application of water by means of dragline sprinklers. Dzwerani was unique in that the 0.5 ha irrigation plots were also used for residential purposes. The idea for this development followed a visit by President Mphephu of the Venda homeland to Israel, where he observed similar arrangements. Dzwerani became a presidential pet project that received full financial support towards the cost of pumping and also towards other inputs, resulting in the development of a high degree of dependency on the state among the plot holder community. The project stopped operating when the pump was washed away during the 2000 flood. During the period 1980 to 1989, 10 of the existing schemes came into being with a combined command area of 495.8 ha. An additional 8 schemes were created between 1990 and 1999, with a combined command area of 506.7 ha. Most of the schemes developed before 1998, when the homeland agricultural parastatals were still operational.

During the first decade of the 21st century, the emphasis of state intervention was on revitalisation of existing schemes rather than on the creation of new schemes. Only two new schemes were established during this period, covering a modest command area of 120 ha. By the end of 2009, 10 of the 48 schemes covering a command area of 902.3 ha (24.0%) had been completely revitalised. Another 12 schemes covering a command area of 1083.3 ha (28.8%) had been partly revitalised and an additional two schemes with a combined command area of 61.5 ha (1.6%) were being revitalised. This brought the total number of schemes that had benefited from revitalisation, or would so soon, to 24, which was exactly half of the total. Combined the schemes that benefitted from revitalisation support covered 54.4% of the total smallholder scheme command area of 3760.1 ha, which left 1713 ha (45.6%) untouched.

2.4.3 Plot holder population and plot size

Smallholder scheme land in Vhembe was held by a total of 3250 plot holders. Makhonde, with 7 plot holders was the scheme with the smallest plot holder population, whilst Tshiombo, when its seven sub-units were combined, had the largest with 660 plot holders. Dividing the total command area of the smallholder schemes by the total number of plot holders showed that on average, a Vhembe plot holder held 1.1570 ha of land, of which 0.8286 was operational irrigation land. However, plot size varied among the schemes. The smallest average plot size (0.178 ha) was found at Nesengani B1. Phaswana had the largest average plot size. The most common average plot size ranged between 1.01 ha and 1.5 ha and was found on 22 schemes. Plots in this size range were also dominant among the population of plot holders. A total of 1431 plot holders (44%) held plots that fitted in this size class.

2.4.4 Sources of water and its extraction and adequacy

Extraction of water directly from rivers using pumps or by means of weir diversion were the two most common ways in which smallholder schemes sourced their irrigation water. Spring water was used at two of the smaller schemes, namely Klein Tshipise (8.5 ha) and Luvhada (28.8 ha) and at Garside, spring water was used as a supplementary source. Makuleke was the only scheme that obtained its water from a dam. Surface irrigation, which invariably involved the use of short furrow irrigation (Plate 2.3), was dominant and occurred on 28 of the 48 schemes. All other methods of applying water were of secondary importance, perhaps with the exception of micro-irrigation (micro jet and drip), which was found on eight schemes but only two of these were operational in 2009.

PLATE 2.3: Short furrow irrigation at the Dzindi canal scheme

Generally, irrigation water availability was reasonably adequate, because only 5 of the 48 schemes reported year-round limitations, whilst on 21 schemes availability was said to be unlimited. Seasonal limitations in availability were mostly encountered on canal schemes. Four of the five schemes that reported availability to be always limited consisted of the last four irrigation blocks of Tshiombo, where lack of water was caused, at least in part, by the front-end blocks extracting more than their share, leaving too little for the tail-end blocks. Front-end tail-end differences in access to water among farmers were commonly reported on canal schemes. Mangondi, a drip irrigation scheme that was not operational in 2009, was the other scheme where water was always limited. Here the problem appeared not to be the source (Levhubu River) but rather the way the extraction system had been set up. Farmers used various ways of dealing with lack of irrigation water. In order of frequency of occurrence these included reducing the area planted to crops (53%), exchanging water among themselves (49%), stealing water from others (44%), reducing the frequency of irrigation (42%), irrigating at night (33%), planting crops that required less water (27%) and extracting water privately from the source using portable pumps (7%).

Only 27 schemes had a water license issued by the Depart of Water Affairs. Payment for water occurred at 17 schemes but water was paid for by the Limpopo Department of Agriculture, not the farmers. Water user association had been established on 28 schemes, but with few exceptions these were not functional. Participation of scheme communities in catchment management activities was limited to a single case. On all but five schemes, management of water extraction and distribution was in the hands of an elected plot holder committee. At Tshiombo Block 1A and Makuleke, the commercial partner was in control and at Sanari (micro irrigation) and Dovheni (designed as a sprinkler line scheme), there was no management organisation and farmers were allowed to draw water whenever they wanted. At Phaswana, water management was the responsibility of the farmer cooperative, but the scheme was no longer operational.

Formal water management rules (captured in writing) had been drawn up at 37 schemes. At one scheme rules existed but had not been written up. The remaining schemes had no rule system in place to manage water. These included Lwamondo (collapsed micro irrigation scheme), Phaswana (non-operational micro irrigation scheme), Tshiombo Block 1A and Makuleke (revitalised schemes that had a commercial partner, who operated the scheme) and the pressurised schemes of Gonani and Dovheni, where water availability was said not to be limiting.

2.4.5 Land tenure and exchange

The Trust tenure system, here defined by the administrative use of the Permission to Occupy application form (see Chapter 4), was by far the most prevalent tenure system on smallholder irrigation schemes in Vhembe. The implication was that land identified for the development of irrigation schemes had either been detribalised and transferred to the state before the scheme was constructed, or continued to be tribal land but was being administered in the same way as the former. Trust tenure is regarded as the least secure of all systems that applied to African land holding and has been identified as a possible reason for the lack of land exchanges on smallholder irrigation schemes (Van Averbeke, 2008). Schemes with traditional tenure (absence of the use of Permission to Occupy application forms) were usually established quite recently but there was one exception. Luvhada, a project developed in 1952 by the community of Mphaila without state assistance also continued to have traditional tenure. Despite the prevailing Trust system of tenure, land exchanges occurred on 72% of the schemes, which was more common than expected. On schemes where land exchanges occurred, the basis for the exchange in order of importance was cash (82%), free land preparation of own parcel (52%), a share of the crop (27%) and just as a favour (9%). The maximum duration of land exchange arrangements on schemes where such arrangements occurred was more than two years in 67% of the cases, up to two years in 12% of the cases and limited to a single season in 21% of the cases.

2.4.6 Farming systems, cropping intensity and degree of commercialisation

The most common farming system involved the production of grain (mostly maize) and vegetables. This farming system was found on 73% of the schemes. The crops that were incorporated in this farming system served both as food crops for own consumption and as crops than could be sold locally (Plate 2.4). All other farming systems (primarily tropical fruit) were less important. In most cases they were established through the intervention of a homeland parastatal or through the implementation of the Joint Venture model. This model transferred control of the scheme to a commercial partner. In return for the release of their land for use by the Joint Venture, plot holders received dividends, which amounted to half of the net operating income.

PLATE 2.4: The main farming system on smallholder irrigation schemes involves the production of maize and vegetables, both of which could be used for own consumption or sales

Cropping intensity varied considerably among the schemes. The majority of schemes had cropping intensities that ranged between 0.8 and 1.6. Schemes with cropping intensities higher than 1.2 were considered to be really active. The highest cropping intensity of 2.0 was found at Tshiombo Block 1A and Makuleke. Both were Joint Venture schemes where the commercial partner did all the farming. Across operational schemes, the proportion of produce that was sold was 50.6%, which was about 5% higher than the 45% recorded in the 1952 survey of smallholder irrigation schemes by the Tomlinson Commission (1955). The difference was partially due to the exceptionally high proportion of produce sold (99%) at the Makuleke and Tshiombo Block 1A Joint Venture schemes.

2.4.7 Performance assessment

The results of the statistical analysis of the association of the four performance indicators and selected characteristics of smallholder irrigation schemes in Vhembe are summarised in Table 2.3. All 48 schemes were included in the analysis of operational status and durability (number of years in operation). For the analysis of cropping intensity and degree of commercialisation, all non-operating schemes and the two schemes where a strategic partner was doing all the farming were excluded from the analysis.

TABLE 2.3: Spearman's rank correlation coefficients and exact probabilities (bracketed) of the associations between four performance indicators and selected characteristics of smallholder irrigation schemes in Vhembe

Scheme characteristic	Performance indicator			
	Operational status (n=48)	**No of years in operation** (n=48)	**Cropping intensity** (n=35)	**Degree of commercialisation** (n=35)
Hydraulic head	-0.618 (0.000)	-0.848 (0.000)	0.057 (0.187)	0.270 (0.029)
Irrigation method	-0.707 (0.000)	-0.847 (0.000)	0.189 (0.071)	0.373 (0.007)
Scheme area	0.154 (0.074)	0.394 (0.002)	-	-
No of plot holders	-	0.348 (0.004)	-	-
Plot size	-	0.019 (0.225)	0.104 (0.104)	0.212 (0.055)
Organisation of production	-	-0.266 (0.018)	-	-
Water restrictions at scheme level	-	-	-0.438 (0.002)	-0.031 (0.215)
Cash based land exchanges	-	-	-0.014 (0.235)	0.019 (0.229)-
Water theft	-	-	-0.244 (0.041)	-
Effectiveness of scheme fence		-	-0.070 (0.174)	-
Distance to urban centre	-	-	0.067 (0.171)	-0.436 (0.002)

Operational status

The correlation between the operational status of smallholder irrigation schemes in Vhembe and hydraulic head was fairly strong (-0.618) and statistically highly significant. The negative correlation coefficient indicated that gravity-fed schemes were more likely to be (and remain) operational than pumped schemes. The correlation between operational status and irrigation method was even stronger (-0.707). This suggested that schemes employing micro irrigation were less likely to be operational than schemes using overhead irrigation. Schemes using surface irrigation were most likely to be operational but this was to be expected because on all gravity-fed schemes plot holders made use of the short furrow method to apply irrigation water.

Durability

The number of years schemes had operated, or had been in operation, before they collapsed, was very strongly correlated with hydraulic head (-0.848) and irrigation method (0.847). The negative sign of both correlations indicated that canal schemes were considerably more durable than pumped schemes. The positive, statistically significant ($p<0.01$) correlation between scheme area and number of years in operation and between number of plot holders and number of years in operation were probably the result of the co-variation of these two factors with hydraulic head. On average, the plot holder population on gravity-fed schemes (71) was slightly larger than on pumped schemes (63) and the average scheme area of gravity-fed schemes (83.4 ha) was also larger than that of pumped schemes (55.7 ha). The statistically significant ($p<0.05$) negative correlation between organisation of production and number of years in operation indicated that group projects were less likely to last than projects where plot holders farmed individually. Plot size did not appear to affect durability of irrigation schemes.

Cropping intensity

Associations between cropping intensity and scheme characteristics were not very strong. Of all the scheme characteristics that were tested, cropping intensity was most strongly correlated with water restrictions at scheme level ($r=-0.438$). This negative correlation, which was statistically highly significant ($p<0.01$), indicated that water restrictions, mostly due to seasonal differences in the supply of the source, inhibited farmers from using their plots as intensively as possible. The weak but statistically significant ($p<0.05$) negative correlation between the occurrence of water theft and cropping intensity was probably the result of water restrictions causing water theft and not due to differences in the degree of social order at the schemes. Hydraulic head, effectiveness of the scheme fence and distance to the nearest urban centre appeared not to affect cropping intensity. Cropping intensity tended to be positively correlated with irrigation method (micro irrigation > Overhead irrigation > surface irrigation) but the correlation was not statistically significant ($p>0.05$). Surprisingly, cropping intensity was not associated with the presence or absence of cash based land exchanges among plot holders.

Degree of commercialisation

Associations between degree of commercialisation and scheme characteristics were also not strong. Of all the scheme characteristics that were tested, degree of commercialisation was most strongly correlated with distance to the nearest urban centre ($r=-0.436$). The relative strength of this correlation indicated that access to local urban markets was a significant factor in determining the orientation of production of plot holders on smallholder irrigation schemes. Remoteness, which reduced access to markets, resulted in farmers focussing more on producing for own consumption. Hydraulic head ($r=0.270$) and method of irrigation (0.373) were positively correlated with degree of commercialisation. This indicated that plot holders on pumped schemes tended to orient their farming more towards markets than those on gravity-fed schemes and that commercialisation was stimulated by the use of overhead and micro irrigation. Degree of commercialisation tended to be correlated positively with plot size, but this correlation was not statistically significant ($p>0.05$). It needs pointing out that among the schemes that featured in the analysis of degree of commercialisation, the range in average plot size among schemes was limited, with the smallest plots being 0.295 ha and the largest 2.197 ha. Water restrictions and the prevalence of cash-based land exchanges did not appear to affect degree of commercialisation.

2.5 Discussion and conclusion

The results of this study show that gravity-fed canal schemes, on which farmers practised short furrow irrigation, were more likely to be operational and to last longer than pumped schemes. This was in line with the observations of Crosby *et al.* (2000) and Shah *et al.* (2002) for South Africa at large. They pointed out that pumped schemes tended to offer better quality irrigation than gravity-fed schemes and that pumping costs helped to impose financial discipline. However, they also stated that pumped schemes were more vulnerable to breakdown and that the cost of pumping tended to squeeze the net operating income of farm enterprises. An analysis of smallholder irrigation projects in Kenya concluded that pumped schemes operated and maintained by groups of smallholders were not sustainable (Scheltema, 2002). All of these projects had collapsed even before it was time to replace the pump, because of their higher financial and organisation requirement relative to gravity-fed schemes. The current study also indicated that pumped schemes were more vulnerable to flood damage that gravity schemes, mainly because during heavy flooding, pumps were washed away.

Generally, the cropping intensity on the smallholder schemes in the study area was well below the optimum values of 1.5 to 2.5 suggested by Faurès *et al.* (2007) but higher than the cropping intensity of 0.45 recorded by Mnkeni *et al.* (2010) at the Zanyokwe smallholder irrigation scheme in the Eastern Cape. Under conditions of adequate water supply, the subtropical climate of Vhembe puts the achievement of cropping intensities of 2 and more within reach. The study showed that water restrictions were a significant factor in determining cropping intensity. The water restrictions encountered on schemes in Vhembe were mostly seasonal and were caused by fluctuations in supply at source, in line with the prevailing summer rainfall pattern. Reductions in cropping intensity in response to water restrictions were also observed by Perry & Narayanamurthy (1998) in Asia. The absence of any evidence of an association between cropping intensity and cash-based land exchanges (rentals) among plot holders contradicted the assertion of Tlou *et al.* (2006) that land tenure was the most important system-on-system factor in irrigated agriculture. Other researchers have also suggested that the development of land rentals would increase cropping intensity on smallholder irrigation schemes in South Africa (Shah *et al.*, 2002; Van Averbeke, 2008) but the results obtained in this study did not support this anticipated effect.

Degree of commercialisation on smallholder irrigation schemes in Vhembe was found to be associated with the location of schemes in relation to local urban centres. As distance between scheme and urban centre increased, farmers were less likely to produce for marketing purposes. Van Averbeke (2008) reported that marketing of farmer's produce at the Dzindi Canal Scheme, which also formed part of the current study, was mainly in the hands of street traders. Subsequent work by Manyelo (2011) showed that street traders purchased fresh produce from farmers in small quantities on a daily basis and most of them (66 of 84) were sedentary traders, who retailed this produce to the public in areas characterised by heavy pedestrian flows, such as the main streets in towns and townships and at the entrance of hospitals. The other 18 street traders were mobile. They retailed produce in villages and townships that surrounded Dzindi, carrying a bag of produce on their heads as they moved from door to door. Bakkie traders, who purchased produce in larger quantities and transported this produce in their vans to the same type of trading places as those of street traders, also purchased produce at Dzindi, but relative to street traders, they were less important. Nearly all 66 sedentary traders who purchased fresh produce at Dzindi used combi-taxis to transport their produce to their retail places and 54 of the 66 used taxis to get to the urban centre of Thohoyandou where they sold the produce. Taxi fares between Dzindi and Thohoyandou were relatively cheap, because of the short distance. Therefore, the negative correlation between degree of commercialisation and distance between scheme and nearest urban centre suggests that the cost of taxi fares could well be the factor that determines whether or not it is financially viable for sedentary street traders to purchase from scheme farmers and travel to urban centres to sell. During the field work it was noted that when schemes were located far away from an urban centre, farmers mainly sold produce to residents around the scheme, to mobile street traders, who retailed door to door and to bakkie traders. The absence of sedentary street traders purchasing fresh produce in these remote schemes, contrary to Dzindi, is a plausible explanation for the negative correlation between degree of commercialisation and distance to urban centres, which was also reported by Magingxa *et al.* (2009) for a sample of smallholder schemes in various other parts of South Africa.

The study of factors affecting the performance of smallholder irrigation schemes in Vhembe District yielded several interesting results, which have implications for smallholder irrigation scheme policy. Smallholder canal schemes were more likely to be operational and to last longer than pumped schemes. This finding questions the desirability of converting canal schemes into pumped schemes, which has been the practice of the RESIS Recharge Programme of the Limpopo Department of Agriculture. The study results suggest that rehabilitating existing canal systems would most probably more sustainable. The study also indicated that in the absence of external interventions, commercialisation among farmers on smallholder schemes was more likely to occur when schemes were located close to urban centres, because proximity made it financially viable for street traders to travel between scheme, as the place of purchase, and town, as the place of retail, using public transport. This is important when the development of new schemes is being considered. For remote schemes, external intervention aimed at supporting market access appeared to be necessary to enhance commercialisation. At this stage, few of the farmer-managed schemes received marketing support from external agencies. Efforts to that effect are recommended and should be facilitated by public extension services in collaboration with the private sector.

Finally, the study results indicated that the two smallholder irrigation schemes that were consolidated and farmed as single entities by a strategic partner (commercial farmer) were characterised by high cropping intensities and high degrees of commercialisation. However, the sustainability of this revitalisation trajectory is highly questionable. The introduction of centre pivot or floppy systems largely prevent plot holders from repossessing their schemes and farm as individuals once the joint venture arrangement comes to an end. As was already pointed out by Crosby *et al.* (2000), 'the worst scenario (for smallholder irrigation scheme development) is where central management not only takes all decisions unilaterally on a top-down basis but also conducts all on-farm operations'.

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CHAPTER 3

3 Water distribution infrastructure and collective organisation on canal schemes: The case of Dzindi

Pim W.M. de Beer & Wim Van Averbeke

3.1 Introduction

The water distribution infrastructure on irrigation schemes conveys water from the source to the sites where it is required. On canal schemes, the water distribution infrastructure consists of a system of primary, secondary and sometimes tertiary canals and devices for regulation and distribution of the water stream to the different parts of the scheme. In some cases reservoirs for overnight storage (balancing dams) also form part of the system (Sagardoy *et al*., 1986).

As was explained in Chapter 2, in all registered canal schemes in Vhembe the canals have concrete linings and the furrows that convey the water from the main canal to the different irrigation plots and strips are also constructed in concrete. Water distribution to farmers on canal schemes in Vhembe follows a rotational system. The schemes were designed to distribute the water to the plots by turns of equal duration throughout the year. Each plot is meant to receive water on a fixed day for a specified period of time that is always constant, regardless of crops planted, growth stage of the crops and cropping intensity (Letsoalo & Van Averbeke, 2006a). In Vhembe, seasonal fluctuations in the flow of water in the canal are commonly experienced on schemes that abstract their water from a river by means of a weir (see Chapter 2). Inadequate supply typically occurs at the end of winter, when farmers start planting of maize (Letsoalo & van Averbeke, 2006a).

The discharge in a canal system is affected by the state of the canal (presence or absence of leaks) and the cleanliness of the canal (presence or absence of objects that interfere with the flow of water). Leaks and obstructions both reduce the discharge. Reductions in discharge typically affect tail-enders (users towards the end of the canal) more than front-enders (users close to the source), resulting in unequal distribution of water among users. In extreme cases, such as Tshiombo, users located at the end of the canal may become completely deprived of water (see Chapter 2). Where equality is the principle on which the distribution of water among users is based, unequal distribution is a cause of conflict (Letsoalo & van Averbeke, 2006a). It is, therefore, important to maintain the discharge of canals as close to optimal levels as possible. This can be achieved by maintaining the system. Sagardoy *et al*. (1986) argued that concrete-lined canal systems require relatively little maintenance and listed the following as the most important maintenance activities:

- replacement of joints and damaged concrete slabs (to limit leakage);
- weed control in the joints and on the surface of concrete slabs;
- control and removal of silt (to avoid obstruction of water flow).

On all canal schemes in Vhembe the '*Regulations for the Control of Irrigation Schemes in the Bantu Areas*' (Proclamation No. R. 5, 1963) applied (and continues to do so). This particular type of Trust tenure system is discussed in detail in Chapter 4. Of importance for the maintenance of the water distribution infrastructure on these schemes was that occupation of an irrigation plot was subject to a multitude of conditions. One of these was that occupants had to perform labour to maintain irrigation works, roadways, drains and other permanent structures located on the irrigation scheme when called upon to do so by the superintendent of irrigation schemes in the District or his representative, the agricultural officer. In practice, it was the resident agricultural officer who was in charge of routine maintenance processes. Assisted by water bailiffs he monitored the state of the main canal and made the decision when it needed cleaning. In consultation with the Scheme Management Committee (SMC), an elected body of farmer representatives, he would also set the date for cleaning to occur (Letsoalo & Van Averbeke, 2006b). The night before cleaning day, the water was closed off at source, and the next morning the canal was subdivided into segments of more or less equal length and each plot holder was allocated one segment to clean. On that day, the inside of the canal was cleaned to limit the period during which irrigation water was unavailable. Clearing the vegetation along both sides of the canal was done next. Plot holders were given a period of two weeks to complete this task. Plot holders were allowed to send substitutes to the cleaning sessions, but absenteeism was punishable. Fines were imposed, which accrued to the plot holder collective for use in scheme projects. Individual plot holders were responsible for keeping the concrete furrows clean. Their condition was monitored by the bailiffs. Greasing of the gates and valves was done by the extension officer or the bailiffs (Letsoalo & van Averbeke, 2006b).

During the first two decades of their existence, the canal schemes were still new and filling of cracks and repairing of joints was seldom necessary. Any major repairs to the canals or to the control gates or valves were carried out by the Department of Public Works upon request by the agricultural officer (Letsoalo & van Averbeke, 2006b).

From about 1975 onwards, state control over the maintenance of the water distribution infrastructure on canal schemes in Vhembe was gradually withdrawn. This withdrawal coincided with the process of transferring governance of the Venda region from the South African Department of Bantu Administration and Development to the Venda homeland government (Letsoalo & Van Averbeke, 2006b). By 1990, plot holders had become *de facto* responsible for their schemes, and this was formalised when a policy of Irrigation Management Transfer was adopted by the Limpopo Department of Agriculture (Van Averbeke *et al*., 2011). In 2006, Letsoalo & Van Averbeke (2006b) reported that maintenance of water distribution infrastructure on canal schemes was no longer of the standard required to keep the system in optimum working condition. They reported that functioning of the main canals was compromised by faulty gates, seepage of water through cracks, a leaking aqueduct and subsidence of sections of the main canal. Cleaning of the main canal was affected by increasing numbers of absconders. At Dzindi, where absconding had become the norm, the Scheme Management Committee replaced the labour system with a system of payment, and used the fees collected from plot holders to pay a contractor to do the cleaning. Cleaning of the concrete furrows, which had remained the responsibility of individual farmers, was no longer strictly implemented. Control gates and valves were no longer greased and several regulating devices were either destroyed, faulty or in a state of disuse (Letsoalo & Van Averbeke, 2006b).

Six years have passed since Letsoalo & Van Averbeke (2006b) reported on the maintenance of the water distribution infrastructure on a selection of canal schemes in Vhembe, including Dzindi, where the labour system used for cleaning the canal was replaced by a system of payment. Casual observations suggested that the system of collecting money from plot holders to hire a contractor to do the cleaning was not effective but no systematically collected information was available to substantiate these observations. For this reason a study of the water distribution system at Dzindi was done. The objectives of the study were:

- To describe and assess the state of the main canal, the flow-regulating devices, division boxes, off-take outlets, over-night storage dam and concrete furrows that convey the water to the plots;
- To describe and assess the cleanliness of the main canal and the concrete furrows that convey the water to the plots with particular emphasis on restrictions to the flow of water; and

- To document and assess the existing processes which make up the maintenance of the water distribution infrastructure at Dzindi.

3.2 Review of literature

3.2.1 Discharge in canals

Discharge in a canal is function of the longitudinal slope, the cross sectional area and hydraulic radius of the water stream and the 'roughness' of the canal lining (Farrington, 1980; Park, 1983; Dringman & Sharma, 1997; Gippel & Stewardson, 1998; Pappenberger *et al*., 2005). The Manning equation (equation 3.1) mathematically expresses the relationship between discharge and the factors that affect it.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$ **equation 3.1**

where:

Q = discharge ($m^3 s^{-1}$);
n = Manning's roughness coefficient;
A = cross-sectional area of the water stream (m^{-2});
R = hydraulic radius (m); and
S = water surface slope (-)

Equation 3.1 shows that discharge is positively related to the inverse of the Manning's roughness coefficient (n). In concrete canal systems the Manning's coefficient value typically ranges between 0.01 and 0.1. The effect of increasing roughness is an increasingly reduced discharge as shown in Figure 3.1. Roughness of the surface of the lining of canals is function of the presence of vegetation, silting and obstructions and of canal irregularities and the extent of canal alignment, (James & Makoa, 2006; Akkuzu *et al*., 2008). According to Israelsen and Hansen (1962) a new concrete lined canal has a Manning's roughness coefficient that ranges between 0.012 (best) and 0.018 (worst). Values ranging between 0.014 and 0.016 are commonly used during the design of canal systems (Israelsen & Hansen, 1962).

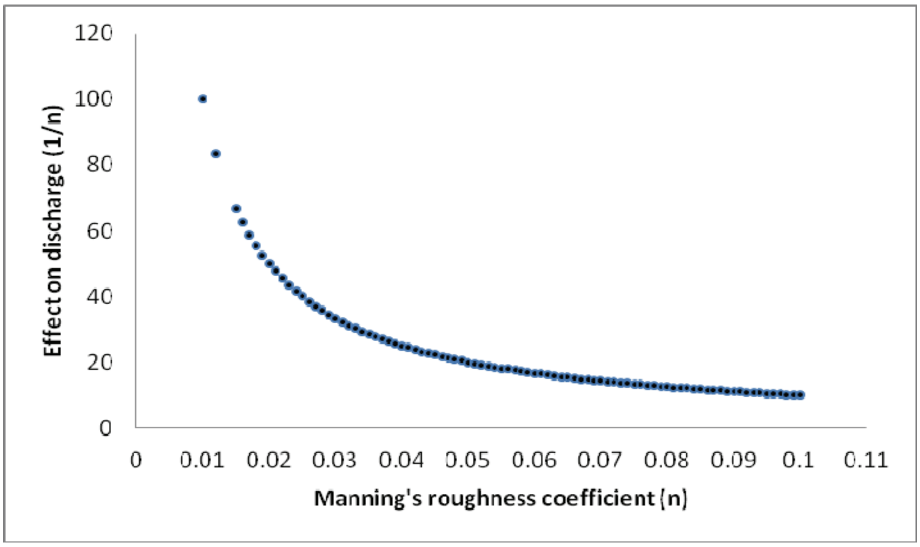


FIGURE 3.1: Relationship between Manning roughness coefficient (n) and its effect (1/n) on discharge in canals

When the factors responsible for increasing roughness are severe, the Manning's roughness coefficient in a concrete canal can attain values as high as 0.1. The discharge in a concrete canal where factors caused the Manning's roughness coefficient to attain a value of 0.1 (1/n =10) would only be 15% of the discharge that would occur when that same canal was in a good state and had a Manning's roughness coefficient of 0.015 (1/n = 66.7). It is, therefore, of great importance that canal roughness is minimised. This is achieved by cleaning the canal of sediments and plants, by filling up cracks and holes, and by repairing joints to prevent plants from finding foothold (Akkuzu *et al*., 2008). Also important is that plants and algae do not only increase roughness by obstructing flow. The organic acids they secrete are also responsible for the dissolution of cement, which roughens the lining of the concrete by exposing the aggregate fragments (Guillitte & Dreesen, 1995).

3.2.2 Organisation and maintenance

Plot holders on irrigation schemes share one source of water and are all dependent on the water distribution infrastructure that conveys the water to their plots, farms or farm dams. Management of the operation and maintenance of the water distribution infrastructure is widely regarded as complex and difficult because of the multiple layers of decision making (Marbry, 1996:11). According to Langworthy and Finan (1996), important decisions that need to be taken on irrigation schemes are:

- Quantity and timing of water deliveries to each member;
- Procedures for paying for the operation and maintenance of the network;
- Mechanisms to adjust schedules in the face of unforeseen interruptions of operation; and
- Procedures to monitor and punish infractions against the operating rules.

Decisions on these issues can be made by farmers themselves or by outsiders with authority over the irrigation scheme (Langworthy & Finan, 1996). Most irrigation schemes are managed by a combination of farmers and outsiders (Langworthy & Finan, 1996). In such cases, problems often arise in a vertical way amongst the different layers. When authorities wield more power than farmers, decisions can be made against the wishes of farmers. Such top-down decisions can have positive or negative effects on farmers (Langworthy & Finan, 1996). Referring to Ostrom (1993), who compared 108 irrigation systems, Marbry and Cleveland (1996) indicated that farmers who managed their own schemes recorded higher yields than farmers on agency-managed irrigation schemes. This would suggest that farmer-managed schemes tend to perform better than agency-managed schemes.

Maintenance activities on canal schemes can be subdivided in three categories, namely routine, special and deferred (Sagardoy *et al*., 1986). Special and deferred maintenance needs special expertise, because it involves rebuilding or repairing parts of the canal, and usually falls outside the responsibilities and capabilities of plot holders. Routine maintenance, on the other hand, is well within the capabilities of plot holders and often it is also their responsibility. As indicated in the introduction to this chapter, concrete-lined canal systems require much less maintenance than unlined canal. Important maintenance activities include replacement of joints and damaged concrete slabs (to limit leakage), weed control in the joints and on the surface of concrete slabs, and control and removal of silt to avoid obstruction of water flow (Sagardoy *et al*., 1986).

3.3 Materials and methods

3.3.1 Study area

The study was done at the Dzindi canal scheme (23°1'45"S and 30° 26' 30" E) located in Itsani village, Thulamela Local Municipality, Vhembe District, Limpopo Province, South Africa. Itsani village is situated about 10 km southwest of Thohoyandou, which is the administrative centre of the Thulamela Municipality and the Vhembe District. The Dzindi canal scheme was decommissioned in 1954 and has been in operation for 58 years. It has a command area of 135.6 ha, which are subdivided into 106 plots of 1.28 ha each. Dzindi obtains its water from a weir on the Dzindi River and is subdivided into 4 blocks, with Block 4 closest to the weir and Block 1 and 2 furthest from this source. An overnight storage or balancing dam stabilises the supply of irrigation water to plots located in Block 1. The predominant cropping system used by farmers on the scheme is summer production of maize and winter production of vegetables (Van Averbeke, 2008). The climate at Dzindi can be described as subtropical with a dry and a wet season (Van Averbeke and Mohamed, 2006). Most of the rain falls during the summer, from October to March, with an average rainfall of about 700 mm. Cropping intensity at Dzindi is higher during summer than in winter but since most of the rain falls during summer, the irrigation requirement usually does not peak during this period. Instead the peak demand tends to be at the end of winter (August and September), when the summer crops are planted but the rainy season has not yet started.

3.3.2 Assessment of the state of the water distribution infrastructure

3.3.2.1 State of the main canal

The state of the main canal was assessed by subdividing the canal in segments with a length of about 25 m. A total of 388 canal segments, which made up the full length of the main canal, were assessed. The assessment of the main canal and the furrows was conducted during the period 3 December to 21 December 2012.

Assessment of each segment was done using six indicators, namely,

- the degree of roughness of the concrete lining inside the canal,

- the presence and size of cracks;
- the depth of soil removal from the canal banks;
- the extent to which canal banks were affected by soil removal;
- the extent of leakage from the canal;
- the alignment of the canal sections.

For all six indicators a key was developed. The keys, presented in Tables 3.1 to 3.6, consisted of a description enabling categorisation, a category score accompanied by a descriptor, and a factor for use in the global assessment of the state of the canal considering all seven indicators. The category score consists of an ordinal scale with the value 1 (lowest value) indicating the perfect state and the highest value representing the worst state that was encountered. The descriptor is a descriptive code, which links the category score to the indicator under consideration. The description explains how value scores were assigned based on field observations and measurements. The factor assigned to each score value reflects the effect or impact of the state of the indicator on the overall state of the canal. The overall state of a particular section of the canal was then obtained by calculating the product of different factors for the six indicators.

Table 3.1 shows the key for the assessment of the concrete lining inside the main canal. Exposure of the canal surface to the scouring effect of running water, sometimes loaded with sediment, and to algae, which hasten the dissolution of cement, can roughen the surface of the concrete compared to when it was new. The rougher the surface the more resistance it offers to water flow, thus affecting the flow rate of the water in the canal and the volume of water delivered to the plots per unit time.

TABLE 3.1: Key for the assessment of the roughness of the concrete lining inside the main canal

Score	Descriptor	Description	Factor
1	Smooth	The concrete lining is 'as new'. It can be compared to the cement joints of a brick wall or the concrete kerbs along a road	1.00
2	Slightly roughened	The concrete lining is somewhat scoured as a result of dissolution of the cement	0.95
3	Roughened	The concrete lining is visibly uneven as a result of substantial dissolution of the cement	0.9
4	Severely roughened	The concrete lining is very rough because of high degree of cement matrix removal leaving aggregate exposed	0.85

An example of a 'severely roughened' canal lining surface showing exposed aggregate appears in Plate 3.1.

PLATE 3.1: Example of a 'severely roughened' canal lining surface

Table 3.2 shows the key for the assessment of crack size. Cracks occurred in both the section joints and in the concrete sections themselves, where they appeared as wide fissures or as holes. The size of the crack was used to allocate a score. Cracks allow for water to leak or seep from the canal making it unavailable for irrigation purposes. This type of water loss has an important effect on discharge, which was taken into account when assigning the factors.

TABLE 3.2: Key for the assessment of crack size

Score	Descriptor	Description	Factor
1	None	Cracks are absent	1.00
2	Small	Cracks < 3 cm wide	0.95
3	Moderate	Cracks 3-10 cm wide	0.80
4	Large	Cracks > 10 cm wide	0.70

An example of a crack in the main canal is shown in Plate 3.2. The crack was between 3 cm and 10 cm wide and was categorised as 'moderate crack', resulting in a score of 3, which carried a factor of 0.80. The number of cracks per unit length of concrete canal was not considered directly. Instead the effect of this feature was taken into account when the degree of leakage was assessed.

PLATE 3.2: A 'moderate' crack

Table 3.3 shows the key for the assessment of the depth of soil removal adjacent to the canal. Holes or gullies created by water eroding the soil adjacent to the concrete canal reduce the support provided to the canal structure. This makes the canal vulnerable to cracking and even collapse. Scoring of this indicator was done in function of the depth of soil removal that had occurred.

TABLE 3.3: Key for the assessment of the depth of soil removal adjacent to the canal

Score	Descriptor	Description	Factor
1	No soil removal	Soil adjacent to the canal is intact	1.00
2	Shallow	In places, soil adjacent to the canal has been removed to a depth <20 cm	0.90
3	Moderately deep	In places, soil adjacent to the canal has been removed to a depth of 20-30 cm	0.85
4	Deep	In places, soil adjacent to the canal has been removed to a depth of >30 cm	0.75

Table 3.4 shows the key for the assessment of the extent of soil removal adjacent to the canal. The longer the gullies or the more frequent the holes in the soil, the higher the vulnerability of the canal to cracks or collapse, and the greater the threat of the canal developing serious leaks.

TABLE 3.4: Key for the assessment of the extent of soil removal adjacent to the canal

Score	Descriptor	Description	Factor
1	None	No soil removal on either side of the canal	1.00
2	Low	< 50% of the soil on either side of the canal is affected by soil removal	0.95
3	High	> 50% on either side of the canal is affected by soil removal	0.85

Plate 3.3 shows a canal section where more than 50% of the right-hand side of the canal is affected by soil removal (high extent) and where in places the depth of soil removal exceeds 30 cm. This section was scored 4 = ‘deep removal’ and 3 = ‘high extent’.

PLATE 3.3: Canal section in which more than 50% of right-hand side of the canal is affected by soil removal (high extent) and where in places the depth of soil removal exceeds 30 cm ('deep removal')

Table 3.5 shows the key for the assessment of the degree of leakage from the canal. Wherever leakage could be observed, it was either categorised as minor or as major. Minor leakage referred to the occurrence of seepage indicated by the saturation of the soil adjacent to the canal without any evidence of visible flow of water out of the canal. Major leakage was indicated by water visibly flowing out of the canal. An example of a 'major leakage' is given in Plate 3.4.

TABLE 3.5: Key for the assessment of the degree of leakage from the canal

Score	Descriptor	Description	Factor
1	None	No leakage	1.00
2	Minor	Occurrence of seepage indicated by saturation of the soil adjacent to the canal without any evidence of visible flow of water out of the canal	0.90
3	Major	Water visibly flows out of the canal	0.80

PLATE 3.4: An example of a 'major leakage' in the main canal of Dzindi

Table 3.6 shows the key for the assessment of the state of alignment of neighbouring concrete canal sections. Movement of two neighbouring segments relative to each other results in misalignment. Substantial misalignment can cause seepage or even leakage of water from the canal.

TABLE 3.6: Key for the assessment of the state of alignment of adjacent canal segments

Score	Descriptor	Description	Factor
1	Aligned	Canal is aligned	1.00
2	Poorly aligned	Difference in alignment 0-2 cm	0.98
3	Very poor aligned	Difference in alignment 3-10 cm	0.95
4	Not aligned	Difference in alignment > 10 cm	0.90

An example of a canal section that was allocated a score value of 4 ('not aligned') is shown in Plate 3.5. The difference in alignment between adjacent canal segments is greater than 10 cm and the concrete sections are no longer connected. Leaking of water is clearly visible.

PLATE 3.5: Two canal segments that are no longer aligned

The value scores and associated factors for the six indicators that were used to assess the state of the main canal at Dzindi are summarised in Table 3.7. The final assessment of each canal segment was obtained by multiplying the six factors that were assigned for each of the six indicators. The product of these six factors provided a global assessment score, which could range between 0 and 1, and which reflected the overall state of the canal section.

TABLE 3.7: Key for the calculation of the overall state of sections of the main canal

Key	**Score**			
	1	**2**	**3**	**4**
Roughness of the concrete lining	1.00	0.95	0.90	0.85
Crack size	1.00	0.95	0.80	0.70
Depth of soil removal	1.00	0.90	0.85	0.75
Extent of soil removal	1.00	0.95	0.85	-
Degree of leakage	1.00	0.90	0.80	-
State of alignment	1.00	0.98	0.95	0.90

Five main global assessment categories were then defined by specifying global assessment score limits, as shown in Table 3.8, and a colour code was assigned to each of these five categories.

TABLE 3.8: Global assessment score categories and associated colours used in the assessment of the overall state of sections of the main canal at Dzindi

Global assessment score category	Descriptor	Class	Colour on map
1.00	Perfect	1	Blue
0.95-0.99	Very good	2	Green
0.66-0.94	Good	3	Yellow
0.42-0.65	Poor	4	Orange
<0.42	Very poor	5	Red

The colour codes signifying the five main global assessment score categories were then used to map the state of the main canal. An example of such a map is shown in Figure 3.2. On the map, three canal sections with different colour codes are indicated by means of white arrows. Plate 3.6 illustrates the state of the canal section coloured green in Figure 3.2, Plate 3.7 shows the section coloured yellow and Plate 3.8 is a picture of a red-coloured canal section in Figure 3.2. Table 3.9 presents the global assessment scores allocated to each of these segments and illustrates how this score was derived using the different factors assigned for each of the six indicators that were used in the assessment.

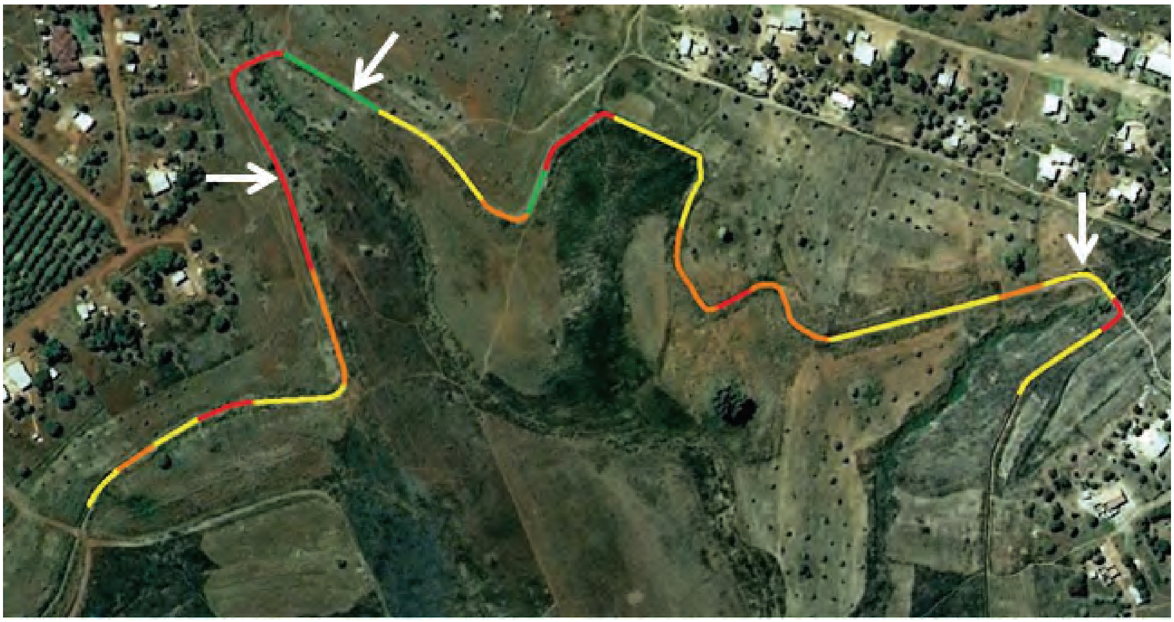


FIGURE 3.2: Map of the global state of part of the main canal at Dzindi

TABLE 3.9: Practical elaboration of the procedure used to assess the global state of segments of the main canal at Dzindi using three examples

Key	Green canal segment		Yellow canal segment		Red canal segment	
	Descriptor	**Factor**	**Descriptor**	**Factor**	**Descriptor**	**Factor**
Roughness of the concrete lining	Slightly roughened	0.95	Slightly roughened	0.95	Severely roughened	0.85
Crack size	None	1.00	Small	0.95	Large	0.70
Depth of soil removal	None	1.00	None	1.00	Moderately deep	0.85
Extent of soil removal	None	1.00	None	1.00-	High	0.85
Degree of leakage	None	1.00	Minor	0.90	Major	0.80
State of alignment	Aligned	1.00	Aligned	1.00	Not aligned	0.90
Product		**0.95**		**0.81**		**0.31**
Global assessment category	**2**		**3**		**5**	

PLATE 3.6: Example of a canal section that was categorised as being in a ‘very good’ state

The lining of the canal segment shown in Plate 3.6 had a slightly roughened surface (0.95); no cracks (1.00), leaks were absent (1.00), no evidence of soil removal adjacent to either side of the concrete (1.00 and 1.00); and no misalignment of the concrete segments (1.00). The resulting product of the six factors (see also Table 3.9), which constituted the global assessment score, was 0.95 x 1.00 x 1.00 x 1.00 x 1.00 x1.00 = **0.95** (see bottom Table 3.9). Referring to the categories in Table 3.8, the global assessment score for state of 0.95 placed this particular canal segment in the ‘very good’ category and was coloured green in Figure 3.2.

The yellow canal segment indicated with a white arrow in Figure 3.2 is shown in Plate 3.7. The lining of the canal segment had a slightly roughened surface (0.95); cracks were present but all were narrower than 2 cm (0.95); there was no evidence of soil removal adjacent to either side of the concrete (1.00 and 1.00); there was evidence of seepage but no visible evidence of water flowing out of the canal (0.90 for leakage) and there was no misalignment of the concrete segments (1.00). The resulting product of the six factors was 0.95 x 0.95 x 1.00 x 1.00 x 0.90 x1.00 = **0.81** (see bottom Table 3.9). Referring to the categories in Table 3.8, the global assessment score for state of 0.81 placed this particular canal segment in the 'good' category and was coloured yellow in Figure 3.2.

PLATE 3.7: Example of a canal section that was categorised as being in a 'good' state

The red canal segment indicated with a white arrow in Figure 3.2 is shown in Plate 3.8. The lining of the canal segment shown in Plate 3.8 was severely roughened (0.85); cracks were present and large (0.70); moderately deep soil removal occurred adjacent to either side of the canal (0.85) to a high extent (0.85); water could be seen flowing out of the canal indicating major leakage (0.80) and concrete sections had moved relative to each other to the extent that they were no longer aligned (0.90).

PLATE 3.8: Example of a canal section that was categorised as being in a 'very poor' state

The resulting product of the six factors was 0.85 x 0.70 x 0.85 x 0.85 x 0.80 x 0.90 = **0.31** (see bottom Table 3.9). Referring to the categories in Table 3.8, the global assessment score for state of 0.31 placed this particular canal segment in the 'very poor' category and was coloured red in Figure 3.2.

The procedure elaborated for the three examples (Table 3.9) was applied to all 388 segments of the main canal of Dzindi that were assessed, and these assessments were captured on a total of 20 maps. For purposes of this report, a further reduction was made by subdividing the length of the main canal into 16 large segments using natural borders, such as a fence or a furrow outlet, to separate the segments. For each large segment, the 'average' global assessment score was obtained by calculating the arithmetic mean of the scores assigned to the different elementary segments that made up the large segment. These 'average' values were then used to construct an overview map that depicted the state of the entire main canal at Dzindi.

3.3.2.2 State of the concrete furrows

The concrete furrows were assessed using two indicators, namely the proportion of the concrete segments, used to construct the furrow, that were damaged, and the severity of the damage to the segments. The concrete segments were each about 3 m long, but variability was observed.

In cases where the entire concrete furrow consisted of one straight line of segments, a single assessment was done for the furrow as a whole. Only where the furrow had bends was it subdivided into sections and each section was assessed separately. The procedure of allocating weighing factors to the different scores and multiplying these factors to obtain the global assessment score was again applied. This procedure was explained in detail in section 3.3.2.1 for the assessment of the state of the main canal.

Table 3.10 shows the key used for the assessment of the proportion of damaged segments in concrete furrows and Table 3.11 the key for assessment of the severity of damage to affected concrete segments. The global assessment score, which could range between 0 and 1, reflected the overall state of the concrete furrow or furrow section. Four main global assessment categories were then defined by specifying global assessment score limits. These are shown in Table 3.12. Colour codes were again assigned to each of the four categories for mapping purposes.

TABLE 3.10: Key for the assessment of the proportion of damaged segments in concrete furrows

Score	**Descriptor**	**Description**	**Factor**
1	Perfect	100% of the concrete sections are intact	1.00
2	Good	80-99% of the concrete sections are intact	0.95
3	Poor	50-79% of the concrete sections are intact	0.85
4	Very poor	0-49% of the concrete sections are intact	0.70

TABLE 3.11: Key for the assessment of the severity of damage to affected concrete segments

Score	**Descriptor**	**Description**	**Factor**
1	None	Cracks are absent or <0.5 cm wide	1.00
2	Small	Cracks 0.5-3 cm wide	0.98
3	Moderate	Cracks 3-10 cm wide	0.95
4	Large	Cracks >10 cm wide	0.90

TABLE 3.12: Global assessment score categories and associated colours used in the assessment of the overall state of concrete furrows at Dzindi

Final factor	Descriptor	Class	Colour on map
1.00	Perfect	1	Blue
0.90-0.99	Good	2	Green
0.77-0.89	Poor	3	Yellow
<0.77	Very poor	4	Red

3.3.2.3 Other parts of the water distribution system

All flow-regulating devices, division boxes and off-take outlets were assessed in terms of their functioning. Complete or partial malfunctions were recorded and pictures were taken. The condition of the over-night storage dam at Block 1 was described in terms of sedimentation, the occurrence of vegetation growing inside the dam and the functionality of the inlet and outlet valves. Pictures were taken to illustrate the condition.

3.3.3 Cleanliness of the canal

3.3.3.1 Cleanliness of the main canal

Three indicators were used to assess the state of cleanliness of the main canal, namely interference by vegetation, presence of sediment, and the presence of large loose stones obstructing water flow in the canal. For each of the three indicators a key was developed, which are presented in Table 3.13 to 3.15. The assessment procedure was the same as explained in section 3.3.2.1 and observation were again done for canal sections that were about 25 m in length.

Table 3.13 shows the key for the assessment of the degree of interference of water flow by vegetation in the canal. An example of ‘very high’ interference of water flow by vegetation in the canal is shown in Plate 3.9. Large clumps of grass and weeds growing inside the canal and grass and weeds growing on the banks hanging inside the canal all affect the flow of water. The interference is such that dead plants and garbage are caught by the plants, reducing flow even further.

TABLE 3.13: Key for the assessment of water flow interference by vegetation in the canal

Score	**Descriptor**	**Description**	**Factor**
1	None	No vegetation grows or hangs in the canal	1.00
2	Low	Vegetation occupies 0-2% of the canal cross section	0.98
3	Moderate	Vegetation occupies 3-5% of the canal cross section	0.95
4	High	Vegetation occupies 6-20% of the canal cross section	0.85
5	Very high	Vegetation occupies >20% of the canal cross section	0.60

PLATE 3.9: An example of 'very high' water flow interference by vegetation

Table 3.14 shows the key for the assessment of the depth of sediment in the canal. The thickness of the layer of sediment was measured in the bottom of the canal. First, the height of the water surface was measured from the top of the sediment layer with a ruler. Then the ruler was pushed through the sediment layer to the concrete surface and the height of the water surface was again measured. The difference in height between these two measurements was taken as the depth of the sediment layer in the canal. The main effect of sediment is a reduction in the cross section of the canal, which affects discharge (see equation 3.1). Sediment might also increase roughness. It was also observed that when water flowing in the canal reached a section where a thick sediment layer was present, overflowing occurred (see Plate 3.10).

TABLE 3.14: Key for the assessment of the depth of sediment in the canal

Score	Descriptor	Description	Factor
1	None	No sediment	1.00
2	Shallow	Sediment layer 0-2 cm	0.98
3	Moderately deep	Sediment layer 3-5 cm	0.95
4	Deep	Sediment layer 6-10 cm	0.85
5	Very deep	Sediment layer >10 cm	0.60

PLATE 3.10: This part of the canal was characterised by a thick layer of sediment, which appeared to be the cause of the overflowing that occurred

Table 3.15 shows the key for the assessment of size of large loose stones obstructing water flow in the canal. Stones severely increase the roughness of the canal surface (see Plate 3.11)

TABLE 3.15: Key for the assessment of the size of large loose stones obstructing water flow in the canal

Score	Descriptor	Description	Factor
1	None	No stones	1.00
2	Small	Stones with a size of 0-2 cm (gravel)	0.95
3	Moderate	Stones with a size of 3-10 cm	0.85
4	Large	Stones with a size of >10 cm	0.60

PLATE 3.11: A 'large' stone placed in the main canal increases the water level ahead of it and creates turbulence in the water flow behind it

The key for the assessment of the overall state of cleanliness of the main canal is shown in Table 3.16. The procedure of allocating weighing factors to the different indicator scores and multiplying these factors to obtain the global assessment score was again applied. This procedure was explained in detail in section 3.3.2.1 for the assessment of the state of the main canal. The global assessment score, which could range between 0 and 1, reflected the overall state of cleanliness. Four main global assessment categories were then defined by specifying global assessment score limits. These are shown in Table 3.17. Colour codes were again assigned for mapping purposes.

TABLE 3.16: Key for the calculation of the overall state of cleanliness of the main canal

Key	**Score**				
	1	**2**	**3**	**4**	**5**
Water flow interference by vegetation	1.00	0.98	0.95	0.85	0.6
Depth of sediments	1.00	0.98	0.85	0.85	0.6
Large loose stones obstructing water flow	1.00	0.95	0.85	0.6	

TABLE 3.17: Global assessment score categories and associated colours used in the assessment of the overall state of cleanliness of the main canal at Dzindi

Final score	**Descriptor**	**Class**	**Colour on map**
1.00	Perfect	1	Blue
0.96-0.99	Very good	2	Green
0.86-0.95	Good	3	Yellow
0.61-0.85	Poor	4	Orange
<0.61	Very poor	5	Red

3.3.3.2 Cleanliness of the concrete furrows

Cleanliness of the concrete furrows was done in the same way as for the assessment of their state. In cases where the entire concrete furrow consisted of one straight line of segments, a single assessment was done for the furrow as a whole. Only where the furrow had bends was it subdivided into sections and each section was assessed separately. Two indicators were used, namely degree to which the water flow was interfered with and the extent of the furrow length that was affected. Table 3.18 shows the key for the assessment of the degree of water flow interference by vegetation, sediment and stones (obstructions), and Table 3.19 the key for the assessment of extent. The global assessment score, which could range between 0 and 1, reflected the overall state of cleanliness of the concrete furrows. Four main global assessment categories were then defined by specifying global assessment score limits. These are shown in Table 3.20. Colour codes were allocated to each category for mapping purposes.

TABLE 3.18: Key for assessment of the degree of water flow interference by obstructions in the concrete furrows at Dzindi

Score	Descriptor	Description	Factor
1	None	Furrow is clean	1.00
2	Low	Obstructions occupying 1-20% of the furrow cross section interfere with the water flow	0.95
3	Moderate	Obstructions occupying 21-50% of the furrow cross section interfere with the water flow	0.85
4	High	Obstructions occupying >50% of the furrow cross section interfere with the water flow	0.70

TABLE 3.19: Key for the assessment of the extent of water flow interference by obstructions in the concrete furrows at Dzindi

Score	Descriptor	Description	Factor
1	Perfect	100% of the concrete sections is clean	1.00
2	Good	Obstructions occur along 1-20% of the furrow	0.98
3	Poor	Obstructions occur along 21-50% of the furrow	0.95
4	Very poor	Obstructions occur along 51-100% of the furrow	0.90

TABLE 3.20: Global assessment score categories and associated colours used in the assessment of the overall state of cleanliness of the concrete furrows at Dzindi

Final factor	Descriptor	Class	Colour on map
1.00	Perfect	1	Blue
0.90-0.99	Good	2	Green
0.77-0.89	Poor	3	Yellow
<0.77	Very poor	4	Red

3.3.4 Perceptions of water adequacy and canal maintenance among plot holders at Dzindi

To obtain the perceptions on water adequacy and canal maintenance among plot holders at Dzindi, interviews were conducted during the month of January 2013. Face-to-face interviews, involving the asking of both open and closed questions, were done with a sample of 28 plot holders obtained using a judgmental sampling strategy (Kumar, 2011). In each of the four irrigation blocks, one or more concrete furrows were randomly selected, and on each of the furrows that were selected, one plot holder located near the top of the furrow, one near the middle and one near the end were sampled for data collection. Data collection was aimed at obtaining information on availability of irrigation water and maintenance of the water distribution system. After the preliminary results of the water distribution infrastructure assessment and the plot holder survey were available, feedback was provided to the Scheme Committee in a meeting held on the 29th of January 2013. Subsequent to this feedback, the members of the Scheme Committee were asked to express their views, particularly on routine maintenance activities and the state of cleanliness of the water distribution system.

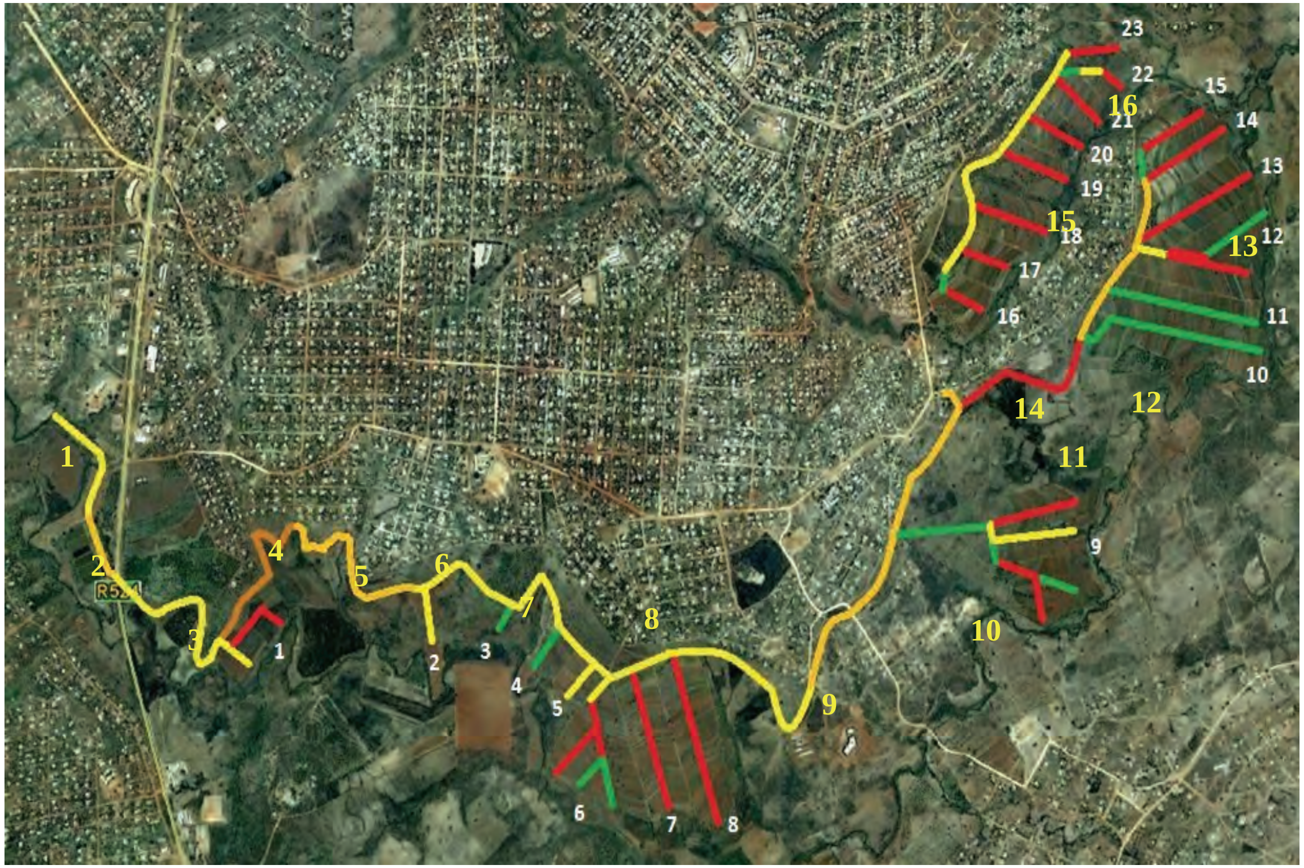
3.4 Results

3.4.1 State of the water distribution infrastructure at Dzindi

Table 3.21 shows the global average assessment scores indicating the state of the main canal for each of 16 subdivisions, as well as the boundaries that defined each of these subdivisions. Figure 3.3 shows the state of the main canal and concrete furrows at Dzindi. The meaning of the colours depicting the state of the main canal and the concrete furrows is explained in Table 3.22.

TABLE 3.21: Boundary specifications of the 16 subdivisions of the main canal and the average global assessment score indicating the state of the main canal

Section	Description	Number of segments	Global assessment score
1	Weir – Dzindi Nature Reserve	27	0.75
2	Dzindi Nature Reserve – Road R524	11	0.61
3	Road R524 – End orchard	13	0.76
4	End orchard – Furrow 1	20	0.70
5	Furrow 1 – Half way furrow 2	33	0.52
6	Half way furrow 2 – Furrow 2	38	0.63
7	Furrow 2 – Furrow 3	20	0.66
8	Furrow 3 – Furrow 8	45	0.68
9	Furrow 8 – Gravel road bridge	34	0.66
10	Gravel road bridge – Division box Block 3	30	0.59
11	Division box Block 3 – Division box agric. office	22	0.59
12	Division box agricultural office – Furrow 10	27	0.39
13	Furrow 10 – Furrow 15	26	0.59
14	Division box agricultural office – Siphon grid	3	0.54
15	Night dam – Furrow 19	25	0.68
16	Furrow 19 – Furrow 23	14	0.76



Main canal	
(blue)	Perfect
(dark green)	Very good
(light green)	Very good
(pale yellow)	Good
(yellow)	Good
(orange)	Poor
(brown)	Poor
(red)	Very poor
(purple)	Very poor
Concrete furrows	
(blue)	Perfect
(green)	Good
(yellow)	Poor
(red)	Very poor

FIGURE 3.3: The state of the canal (sections numbered in yellow) and concrete furrows (numbered in white) at Dzindi

TABLE 3.22: Global assessment score categories and associated colours used in the assessment of the overall state of the main canal and concrete furrows at Dzindi

Class limits	Descriptor	Class	Colour
Main canal			
1.00	Perfect	1	
0.98-0.99	Very good	2	
0.95-0.97	Very good	2	
0.81-0.94	Good	3	
0.66-0.80	Good	3	
0.54-0.65	Poor	4	
0.42-0.53	Poor	4	
0.32-0.41	Very poor	5	
<0.32	Very poor	5	
Furrows			
1.00	Perfect	1	
0.90-0.99	Good	2	
0.77-0.89	Poor	3	
<0.77	Very poor	4	

Figure 3.3 depicts the average state of the 16 different sections of the main canal of Dzindi. From Figure 3.3 it can be seen that the average state of these 16 sections ranged between very poor (section 12) and good. Table 3.21 indicates that eight of the 16 sections had an average global assessment score of 0.66 or higher. However, it needs pointing out that very poor parts could occur within a section that was rated as good. To provide information that could be of use in the planning of special or deferred maintenance, sites where considerable water loss was observed are highlighted.

Following the stream entering the main canal at the weir, the first important cause of water loss from the canal is found at the Nature Reserve of Dzindi (section 2 in Table 3.22). At the Reserve there are six ponds of about 80 m by 30 m in size and three smaller ponds. These ponds, which are used for fish farming, are meant to receive water from the canal, but plot holders at Dzindi explained that filling of the ponds should occur at night. This is no longer the case. Instead, the height of the water in the ponds appears to be in perpetual equilibrium with the water level in the canal (Plate 3.12).

PLATE 3.12: The height of the water in the fish farming ponds at the Dzindi nature reserve are in perpetual equilibrium with the water level in the canal

At the time of the assessment, only two off-takes used for the filling of the ponds were open, but the gates on the other off-takes appeared to be ineffective in preventing water from flowing from the canal into the ponds.

Along the length of the canal, all the aqueducts that crossed natural drainage ways were in a poor state and were leaking badly.

In nearly all of the 16 sections referred to in Table 3.21, there were parts where the concrete canal was badly damaged or had completely collapsed (see Plate 3.13). The part of the canal that was most severely damaged was found between the division box near the Agricultural office and the off-take of furrow 10 in Block 2 (Figure 3.3 and Table 3.21). Removal of soil adjacent to the concrete canal was both deep and extensive along that part of the canal.

PLATE 3.13: Complete collapse of the concrete canal

Other sites of concern were the bridges over the canal. The weight of the bridges had caused the canal to subside. In some cases, subsidence exceeded 10 cm. At several sites along the canal drains were installed to divert excess water from the canal and safely dispose of it. Draining excess water from the canal is of importance during times of heavy rain and river flow. However, only the drain located just ahead of the division box at the agricultural office was working properly. This meant that excess water could only be disposed off for the first time after 7 km of flow.

The state of the concrete furrows also left a lot to be desired. This is evident in Figure 3.3. Only a few furrows appear green in colour on the map, indicating that that they were more than 80% intact. The state of the concrete furrows was worst in Block 1 (Figure 3.3). In some cases, sections had been completely removed, whilst in others the concrete was broken, as is shown Plate 3.14. There was very little evidence of repair work or replacement. Only in Block 3 had some parts of the concrete furrows been renovated. The main causes for furrows to crack and crumble were soil removal adjacent to the furrow and tractors and vehicles driving over the furrow.

PLATE 3.14: A broken furrow

About 50 m downstream of the inlet to the canal at the weir is a Chipoletti weir that is meant to regulate the water level in the canal, but this device is no longer functional. As a result, overflowing occurs during times of high rainfall and river flow (Plate 3.15). This causes erosion of the soil next to the canal, which, in turn, can cause structural damage to the concrete structure.

PLATE 3.15: The dysfunctional Chipoletti weir located about 50 m below the river diversion causes the water level in the canal to be too high during periods of high rainfall and strong river flow

Dzindi has two division boxes, one at Block 3 and one near the Agricultural Office. The division box at Block 3 is meant to regulate the proportion of the stream in the main canal that enters Block 3. The gate that enables flow regulation is missing and plot holders now regulate the water flow by putting stones in the box (Plate 3.16). The concrete at the off-take has been damaged, probably to increase the size of the stream that enters Block 3 (Plate 3.16). The second division box near the agricultural office regulates the water flow to Block 1 (over-night storage dam) and Block 2. The gate at the division box to adjust the stream of water that is diverted to Block 2 is still functional and in reasonably good state. The gate of the division box to adjust the amount of water flowing to Block 1 is buckled and is no longer working.

PLATE 3.16: The dysfunctional division box at Block 3

The water distribution system at Dzindi has 22 concrete furrows that are fed directly from the main canal. When the scheme was built, each off-take was equipped with an iron gate that allowed regulation of the stream entering the furrow, as well as for completely closing off the off-take. At the time of the assessment, only a few of these gates were still in place, and all of them were only partially effective in closing off the water stream (Plate 3.17). At off takes where the gates were missing, plot holders used pieces of cloth, stones, grass and leaves to regulate the flow or close it off, but this was ineffective. As a result, water continuously flowed into the furrows reducing discharge in the main canal.

PLATE 3.17: Iron gates, which regulate the flow into the concrete furrows and close off the flow when the furrow is not in use, are either missing or in poor condition

Before canal water reaches Block 1, it is stored in an over-night balancing dam (Plate 3.18). The design of the water distribution system requires that the dam is filled during the night, and then emptied during the day when irrigation occurs, because the discharge from the main canal to Block 1 is inadequate.

PLATE 3.18: The over-night storage dam at Block 1 is dysfunctional due to a missing outlet valve and urgently needs removal of sediments and plants

For several years now, the outlet valve at the dam has been inoperative. As a result, water flows into the dam and then immediately out. The attempts by plot holders attempt to stop the outflow from the dam by blocking the grid that filters out dirt in the water flowing out of the dam with old blankets was ineffective. Not much water is stored during the night and this has a negative effect on the discharge in the concrete furrow system during the day. According to the extension officer the valve was repaired more than a year ago and has been sitting in the store room of the extension office, waiting to be installed. The dam itself has not been cleaned for a long time and vegetation is progressively colonising the dam, as is evident Plate 3.18.

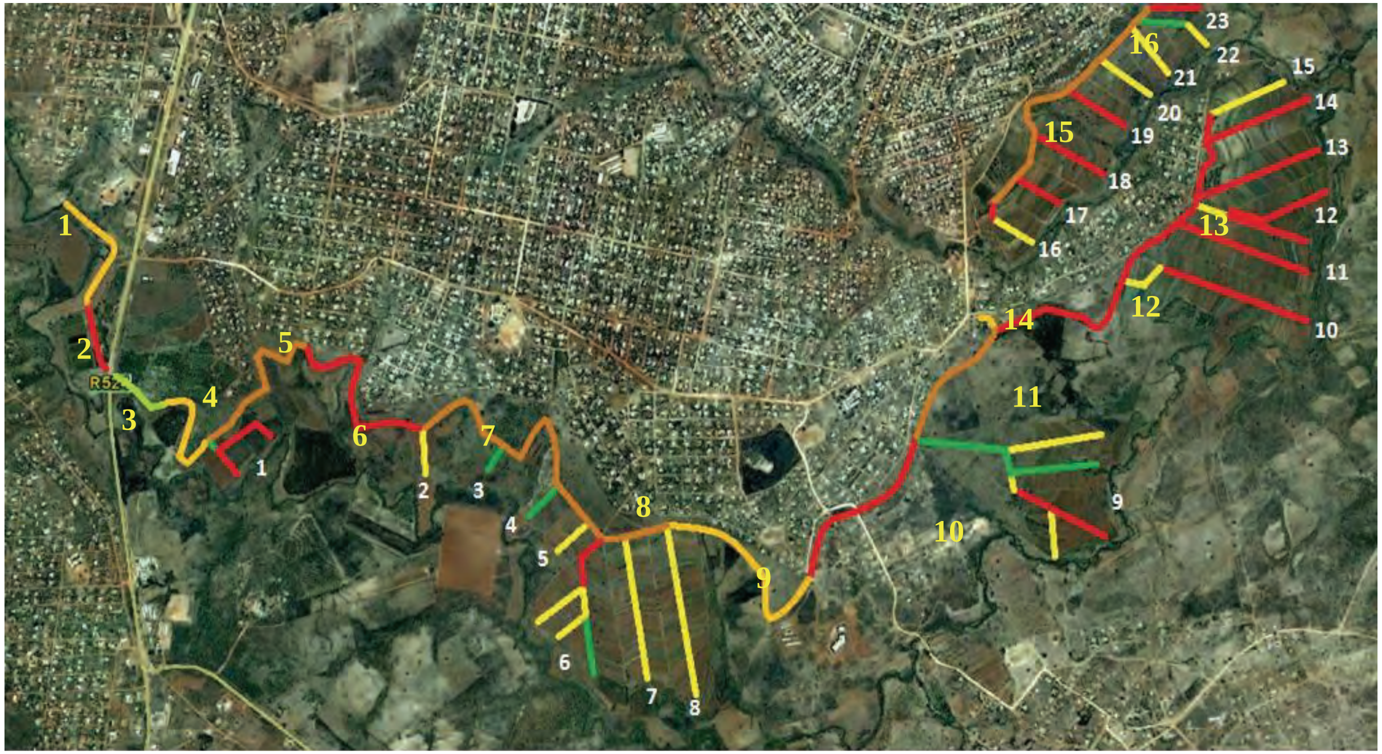
3.4.2 The state of cleanliness of the main canal and concrete furrows

Table 3.23 shows the global average assessment scores indicating the state of cleanliness of the main canal for each of 16 subdivisions as well as the boundaries that defined each of these subdivisions.

TABLE 3.23: Boundary specifications of the 16 subdivisions of the main canal and the average global assessment score indicating the state of the main canal

Section	Description	Number of assessment sections	Average factor
1	Weir – Dzindi Nature Reserve	27	0.74
2	Dzindi Nature Reserve – Road R524	11	0.56
3	Road R524 – End orchard	13	0.96
4	End orchard – Furrow 1	20	0.82
5	Furrow 1 – Half way furrow 2	33	0.66
6	Half way furrow 2 – Furrow 2	38	0.52
7	Furrow 2 – Furrow 3	20	0.67
8	Furrow 3 – Furrow 8	45	0.71
9	Furrow 8 – Gravel road bridge	34	0.75
10	Gravel road bridge – Division box Block 3	30	0.52
11	Division box Block 3 – Division box agric. office	22	0.64
12	Division box agricultural office – Furrow 10	27	0.53
13	Furrow 10 – Furrow 15	26	0.54
14	Division box agricultural office – Siphon grid	3	0.74
15	Night dam – Furrow 19	25	0.67
16	Furrow 19 – Furrow 23	14	0.69

Figure 3.4 shows the state of cleanliness of the main canal and concrete furrows at Dzindi. The meaning of the colours depicting the state of cleanliness of the main canal and the concrete furrows is explained in full in Table 3.24.



Main canal
Perfect
Very good
Very good
Good
Good
Poor
Poor
Very poor
Very poor

Concrete furrows
Perfect
Good
Poor
Very poor

FIGURE 3.4: The state cleanliness of the canal (numbered in yellow) and concrete furrows (numbered in white) at Dzindi

TABLE 3.24: Global assessment score categories and associated colours used in the assessment of the state of cleanliness of the main canal and concrete furrows at Dzindi

Output key factors	Descriptor	Class	Colour
Main canal			
1.00	Perfect	1	
0.98-0.99	Very good	2	
0.96-0.97	Very good	2	
0.91-0.95	Good	3	
0.86-0.90	Good	3	
0.73-0.85	Poor	4	
0.61-0.72	Poor	4	
0.41-0.60	Very poor	5	
<0.41	Very poor	5	
Furrows			
1.00	Perfect	1	
0.90-0.99	Good	2	
0.77-0.89	Poor	3	
<0.77	Very poor	4	

Figure 3.4 shows that the cleanliness in the main canal of Dzindi irrigation scheme leaves a lot to be desired. In five of the 16 subdivisions of the main canal cleanliness was very poor (scores all lower than 0.60) and poor in all the others (scores between 0.61 and 0.85), except for section 2 (score of 0.92). This particular section is largely located within a private, fenced-off orchard. Indications were that this particular section was last cleaned in 2005, suggesting that the other parts of the canal have not been cleaned for more than seven years.

In most subdivisions sediment covered the bottom of the canal. In some instances the thickness of the layer of sediment exceeded 15 cm and covered more than a quarter of the total depth of the canal. It was observed that wherever the layer of sediment in the canal was especially thick, the water level in the canal was too high, causing overflowing (see Plate 3.10), which, in turn, eroded the soil adjacent to the concrete, thus weakening the base and threatening its integrity.

Between Block 4 and Block 3 houses have been built close to the canal (Figure 3.4). Already in 1980 Headman Makumbane warned Headman Tshikororo that building houses close to the canal would result in pollution of the irrigation water and deterioration of the canal due to human activities such as the washing of clothes (Van Averbeke, 2008). This warning was valid, because people are using the canal for washing and other purposes. During the assessment people were observed washing clothes, washing their bodies, dishes and vegetables, extracting water and using the canal as a toilet and waste disposal site. Meanwhile, children were playing in the canal. Before houses were built, a soil ridge of about 1,5 m high was constructed to prevent rainwater carrying sediment and dirt from entering the canal. During the process of building houses, the ridge was removed and rain water now flows into the canal. Entry of water carrying particles is especially worrying along gravel roads, which turn into rivers during heavy rain storms and convey a lot of water into the canal (Plate 3.19). In was not surprising that the deepest sediment layers and the greatest amount of garbage was found where the canal was in close proximity of a residential area.

PLATE 3.19: Rain water carrying sediment enters the canal

The reduction in the discharge in the canal has farmers worried, in the sense that they receive less water at their plots than they used to. To increase the water level in the canal and thereby augment the stream entering the furrow that supplies their plots, farmers put large stones in the canal just after the furrow outlet. These stones are often left in the canal after irrigation has been completed. Since none of the off-takes can be closed properly, this practice increases the amount of water that is lost along the canal.

On occasion, assessment was barely possible due to the dense vegetation that was growing along the canal. This suggested that the contractor who has been hired to keep both sides of the canal free of weeds, grass and bushes did not clear the vegetation over the entire length of the canal. In parts where the vegetation had not been cleared, plants hanging in the water obstructed flow, increasing roughness and reducing discharge. This kind of obstruction of flow was particularly serious after the division box at Block 3, with more than 20% of the canal cross section being affected.

Cleaning of the concrete furrows was also being ignored as is evident from Figure 3.4. Green-coloured furrows were in a minority. The green colour signified that more than 80% of the length of the furrow was clean (flow of water obstructed over less than 20% of the cross section). The state of cleanliness of the furrows was especially poor in Block 2, where several furrows were filled with sediment and had a lot of vegetation growing in them (Plate 3.20). Some farmers kept the vegetation that was growing along the furrow at bay but left the inside of the furrow full of dirt.

PLATE 3.20: Vegetation has overgrown a concrete furrow causing severe obstructions

Typically, concrete furrows were not cleaned at all after they had past the last plot along the line. From there onwards, soil and vegetation were covering the concrete completely, causing unused water to flow into the veld instead of being returned to the Dzindi River. On occasion, new fields had been cleared below the irrigation plots at the bottom of furrows. The users of these fields employed a network of unlined furrows to divert excess water running out of the concrete furrows onto their land.

One of the consequences of the relatively poor state of the canals and concrete furrows and the generally poor state of cleanliness of these structures was that the discharge in the canal reaching Block 1 and 2 were very low, and inadequate to practise short furrow irrigation effectively. For all practical purposes, the plots along furrows 22 and 23 in Block 1 (Figure 3.4) no longer formed part of the scheme and had been returned to dryland cultivation. Furrow 15 in Block 2 had also not received water for a long time, but this furrow had not yet been closed off at the time of the assessment.

3.4.3 Plot holder perceptions of water adequacy and canal maintenance

The results of the plot holder survey indicated that plot holders were aware of the benefits of cleaning the canal. Eight out of ten stated that cleaning the canal increased discharge, whilst nearly two out of ten were aware of the negative effect plant roots have on the lifespan of concrete structures. This suggests that lack of awareness of why canal cleaning is necessary was not the reason why the canal and the furrows were in such poor state of cleanliness. Almost all plot holders who were interviewed pointed to the Scheme Committee. They were adamant that the Committee was responsible for the cleanliness of the main canal, because the Committee collected money to have it cleaned. Every year plot holders pay 150 Rand to enable the Committee to hire a contractor to clear the vegetation along the canal. In total about R13 000 was being collected annually in this way. Several sources confirmed that the value of this contract was R5000. When asked what the remainder of the fees were used for, the Committee explained that some of the money was saved to provide for the purchase of materials, such as cement and aggregate, for use in emergencies when a break in the canal occurred.

During the assessment of the cleanliness of the water distribution system it was evident that the contractor did not clear the vegetation along the entire length of the canal and this was confirmed by several participants. Of greater importance however, was that the contractor was not being hired to clean inside the canal, where most of the roughness originated. During the feedback meeting with the Committee it became clear that the last time the inside of a section of the canal was cleaned was in 2005. This happened when a canal section collapsed in the orchard between Road R524 and Furrow 1, and water entry into the canal was blocked to allow for repairs (see Letsoalo & van Averbeke, 2006b). As was indicated earlier, this particular section of the canal was also the cleanest of all.

All plot holders admitted that they were responsible for the cleanliness of the concrete furrow that supplied their plots but offered no real reasons for the poor state of cleanliness of these parts of the system.

The apparent neglect of routine maintenance at Dzindi does not mean that collective action is dead at the Scheme. During the interviews with plot holders, more than 70% indicated willingness to participate actively in cleaning activities but they all insisted that the initiative needed to come from the Committee, to make it official. They indicated that many plot holders would not participate without involvement of the Committee. These statements suggest that the plot holder community at Dzindi is divided into a group still keen on participation in collective activities and another that is not interested. Even in the absence of a call to action from the Committee, a few plot holders sacrificed their time in service of the community. One plot holder in Block 4 regularly checked the inlet of the canal at the weir removing dirt from the grid and other participants recounted that he crawled into the pipe under Road R524 when the water was severely obstructed and removed the obstacles that blocked the flow. Another example was provided by two women found cleaning a part of the canal in Block 1 (Plate 3.21).

PLATE 3.21: Two women cleaning the inside of the canal at Block 1

The findings suggest that the water distribution system at Dzindi is performing well below its design parameters. Typical for canal schemes is that reductions in discharge affect tail-enders more than front-enders. This was also evident at Dzindi when the perceptions of plot holders of water adequacy were recorded. The results are shown for the scheme at large in Figure 3.5, which shows that the majority of plot holders perceived irrigation water to be insufficient all of the time. When perceptions of the adequacy of irrigation water were related to position of the plot along the canal it was evident that tail-enders experienced water shortages more intensely than front-enders (Table 3.25). Statistical analysis showed that this relationship was significant ($p \leq 0.05$).

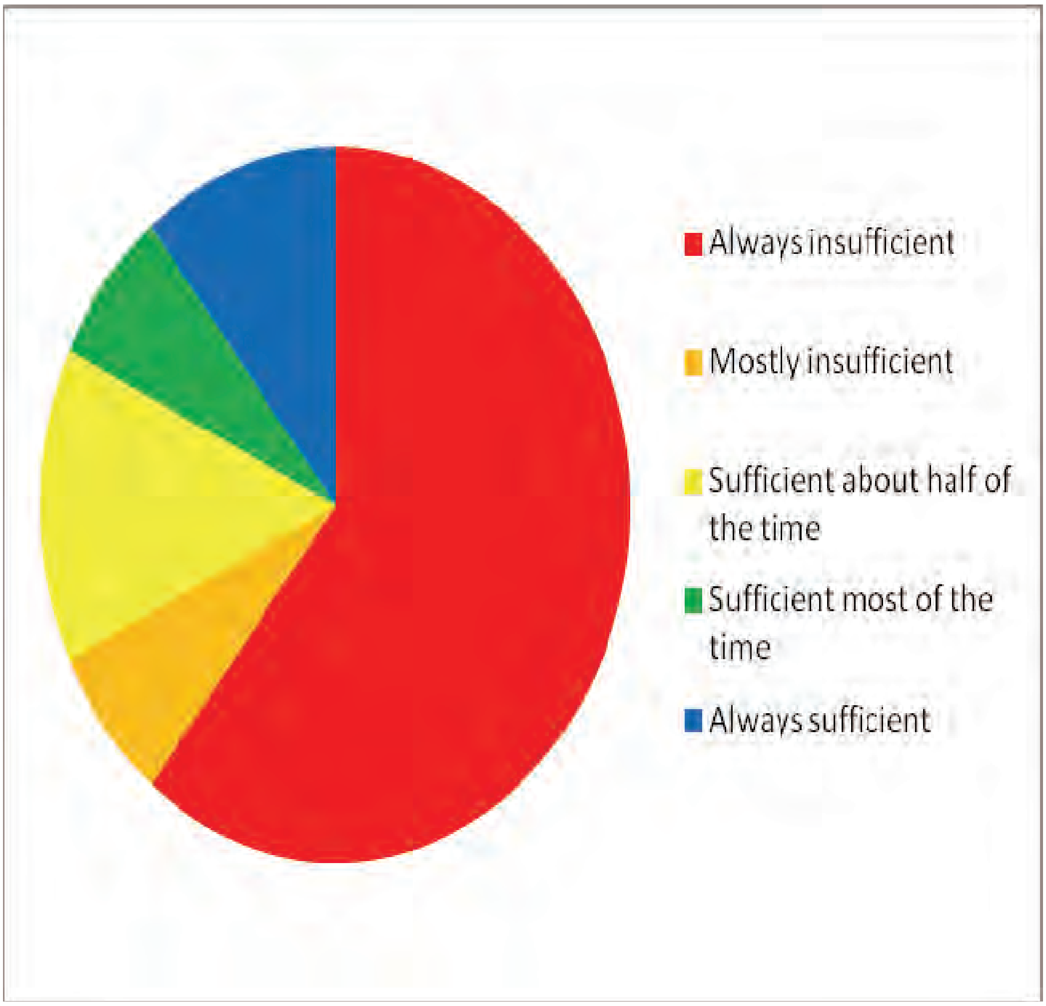


FIGURE 3.5: Plot holder perception of water adequacy at Dzindi n=27; 2013)

TABLE 3.25: Relationship between location along the canal (block number) and plot holder perception of water adequacy level (n=27; 2013)

Block number	**Adequacy**[#]					**Mean**
	5	**4**	**3**	**2**	**1**	
1 (n=7)	0	0	0	1	6	1.14[b]
2 (n=9)	0	1	0	1	7	1.44[ab]
3 (n= 4)	0	0	2	0	2	2.00[ab]
4 (n=8)	3	0	3	0	2	3.25[a]

[#] 1 = always insufficient; 2 = mostly insufficient; 3 = sufficient about half the time; 4 = mostly sufficient; and 5 = always sufficient

The statistical test did not identify a significant relationship between position of plot along concrete furrow and plot holder perception of water adequacy level (Table 3.26), indicating that position along the canal was more important than position along the furrow.

TABLE 3.26: Relationship between position of plot along concrete furrow and plot holder perception of water adequacy level

Block number	**Adequacy**[#]					**Mean**
	5	**4**	**3**	**2**	**1**	
Front (n=11)	1	1	2	0	7	2.00
Middle (n=9)	1	0	3	1	4	2.22
Tail (n= 8)	1	0	0	1	6	1.63

[#] 1 = always insufficient; 2 = mostly insufficient; 3 = sufficient about half the time; 4 = mostly sufficient; and 5 = always sufficient

During the feedback meeting with the Committee, at which the main findings of this study were presented, the issue of how to improve the water distribution system was raised. It was generally accepted that plot holders would have to rely on government for funding to improve the state of the system. Routine maintenance, on the other hand, remained the domain of the plot holders themselves. It was pointed out that cleaning inside the canal could only be done effectively if the entry of water was blocked off. Closing the entry of water into the canal could only last for a few days, because keeping the canal dry for longer could cause crop water stress on the plots. One of the ideas to clean the entire canal in a short period of time was to hire a large contingent of about 100 unemployed people for two days, assign each of them 100 m of canal to clean, and get the plot holders to monitor the quality of the work. It was estimated that this could be achieved with a budget of about R15 000. The Committee expressed its concerns about the erosion of know-how and skills to construct concrete canal sections to replace parts that are beyond repair.

3.5 Discussion and conclusion

In 2005, Van der Stoep and Nthai (2005) estimated that the distribution efficiency of the water distribution system at Dzindi was about 70%. They concluded that only Block 1 faced water shortages, mainly due to poor management of the system in terms of diverting water into the dam. Eight years later, the state of the infrastructure appears to have deteriorated considerably and routine maintenance has come to a halt. As a result, both Block 1 and 2, which are located at the tail-end of the canal, receive too little water to enable effective short-furrow irrigation and there is evidence that parts of Block 3 are also affected.

The shortage of water experienced by most farmers at Dzindi must be attributed to both poor management (lack of routine maintenance) and the deteriorated state of the water distribution infrastructure. Large holes, cracks, misalignment and missing sections were observed along the main canal. As a result, leaking of water from the concrete canal was a major problem. Aqueducts and section of the canal that passed under bridges were of particular concern. Canal water was also lost due to the absence or poor working order of the gates regulating the flow of water into the concrete furrows and those regulating flow into the fish ponds located in the Dzindi nature Reserve. The broken outlet valve of the over-night storage dam prevented water from accumulating during the night, and this affected discharge in the whole of Block 1. The valve is repaired but no plan has been made for its instalment.

Throughout the scheme, the state of cleanliness of the canals and concrete furrows was well below standard. Obstructions in the form of stones, rubbish, sediments, algae and higher plants increase the roughness and reduce discharge, in addition to reducing the cross sectional area of the canal. Using data provided by Boman *et al*. (2012), it was estimated that the average Manning's roughness coefficient of the main canal was at least 0.05, and perhaps as high as 0.09. Using the lower value and the value of 0.015 for concrete canals in perfect state, the discharge near the division box at the agricultural office was probably only about one-third of what was when the scheme was established. It is, therefore, not surprising that all plots along the last furrow in Block 2 (furrow 15) have ceased to receive irrigation water, whilst others experience serious shortages. Restoring an effective routine maintenance system is, therefore, critical for the performance of the Scheme.

The key question is whether re-invigourating the collective organisation, which was responsible for routine maintenance of the water distribution system in the past, is possible? The response to this question has to be affirmative for two main reasons.

Firstly, the human and/or financial resource requirements for effective routine maintenance of the water distribution system at Dzindi are not excessive and do not exceed the capacity of this irrigator community. According to Sagardoy *et al*. (1986) earthen canal systems with a canal width less than 2 m and a canal depth less than 1 m, need to be cleaned inside (removing the sediment) every two years when the water has a high sediment load and every three years when it has a low sediment load. The canal at Dzindi is lined with concrete, which should extend the time interval even more, perhaps to every five years. Evidence for the validity of this postulation was the difference in the state of cleanliness between the main canal section located in the private orchard (Section 3 in Figure 3.4) and the rest of the canal. Considering that the main canal section located in the private orchard was last been cleaned in 2005 (seven years ago), indicates that cleaning the canal once every five years would probably be adequate. The use of a five-year cycle for the removal of sediment from the balancing dam would probably be adequate as well. Removing weeds and bush along both sides of the canal and alongside the edges of the balancing dam should be done annually (Sagardoy *et al*., 1986), but this is already being done at Dzindi as far as the main canal is concerned, through the hiring of a contractor, who gets paid from plot holder contributions. Sagardoy *et al*. (1986) recommend a two-year maintenance cycle for gates and other flow-control devices to maintain these components of the system in optimum working order. If and when these devices have been repaired or replaced at Dzindi, this aspect of routine maintenance will need to receive attention.

The second reason why re-invigourating the collective organisation responsible for routine maintenance of the water distribution system at Dzindi is possible is the continued interest of at least part of the community of plot holders in the state and operation of the scheme. This is evident from their voluntary engagement in scheme-related activities, which are done on behalf of the group. Such voluntary activities include serving on the Scheme Committee, participation in cleaning work, and participation in repair works. The findings contained in this chapter will be presented to the Dzindi community with a view of assisting the process of re-invigourating the collective organisation.

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CHAPTER 4

4 Land tenure on canal schemes in Vhembe: The case of Dzindi[1]

Thapelo C Masiya & Wim Van Averbeke

4.1 Introduction

Land tenure refers to a set of relationships among individuals with respect to land and its products, as well as the rights and obligations of individuals to use the land (FAO, 2002; Mosaka & Mullins, 2006; Manona & Baiphethi, 2008). Rights associated with land tenure include user rights, exclusion rights, transfer rights and enforcement rights. The degree of security offered by a tenure system arises from the rights allocated by that system to land holders (FAO, 2002).

Different tenure systems apply on South African smallholder irrigation schemes. These include traditional tenure, freehold tenure, leasehold, quitrent tenure and Trust tenure (Lahiff, 1999; Mosaka & Mullins, 2006; Van Averbeke, 2012). The survey reported on in Chapter 2 indicates that Trust tenure, as laid down in the '*Regulations for the Control of Irrigation Schemes in the Bantu Areas*' applied on all canal schemes in Vhembe. These 'Regulations' were contained in Proclamation No. R. 5, 1963, which appeared in Government Gazette Extraordinaire (Regulation Gazette No. 159), which was published on the 11th of January 1963.

Using a system-on-system effects analysis, Tlou *et al*. (2006) identified tenure as the system that had the greatest overall impact on all other systems relevant to irrigation farming. However, other than the link between tenure and access to finance[2], Tlou *et al*. (2006) did not provide clear evidence of the ways in which the land tenure system affected the other systems. At this stage, the specific factors that contribute to tenure security on South African smallholder

[1] The authors have purposefully omitted names of participants and stakeholders that feature in this chapter to avoid influencing processes that might occur in future and might involve the use of the content of this chapter as a source of information.
[2] This refers specifically to the use of land as collateral when accessing loans.

irrigation schemes, or the absence of tenure security, are not well understood (Van Averbeke *et al*., 2011). This knowledge gap justified the study reported on in this chapter.

The objectives of the study were:

- To analyse the content of the Trust tenure system as regulated by Proclamation No. R. 5, 1963;
- To describe the historical application of this particular type of Trust tenure system at Dzindi Irrigation Scheme and its implications on tenure security and scheme operation;
- To document the current tenure system that applies at Dzindi; and
- To investigate the implications of the current tenure system on tenure security and scheme operation.

4.2 Review of literature

4.2.1 The meaning of land tenure

Land tenure has been defined in different ways but broadly the various definitions of land tenure can be divided into two groups. In the first group of definitions, the focus is on the terms and conditions under which land is held, used and transacted (Bruce, 1986; De Villiers, 1996; Adams, Sibanda & Turner, 1999). The conditions or set of rules which regulate access to or utilization of land or the method in which access to land is granted and the way in which land should be looked after, all form part of land tenure. The process of applying these conditions or rules and operating them is called land administration. In the second group of definitions, the focus is on social relationships, but with due attention to terms and conditions. One example is the definition of land tenure proposed by the Economic Commission for Africa (2004), who defined land tenure as a "social construct that defines the relationships between individuals and groups of individuals by which rights and obligations are defined with respect to control and use of land". The social aspect in this definition indicates that land tenure has communal meaning and that members of settlements can share certain rights attached to the settlement, which could include right to arable land, residential land, grazing of stock on commonage land and natural resources. A similar view was expressed by the FAO (2002), which defined land tenure as “the relationship, whether legally or customarily defined, among people, as individuals or group, with respect to land”.

Land tenure can be viewed as a bundle of rights to land, which are subject to terms and conditions. Generally, four types of rights are identified, namely, user rights, exclusion rights, transfer rights and enforcement rights. User rights stipulate the privileges a holder has to utilize the land for production or other purposes, make permanent improvements, harvest products from the land and derive income from the land (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999; FAO, 2002; FAO, 2005). Exclusion rights specify the privileges a holder has to exclude others from claiming use or transfer rights in relation to a piece of land (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999; FAO, 2002). Transfer rights stipulate the privileges a holder has to transmit the rights of the land to his or her successor, as well as those to alienate rights to the land through sales, donations, mortgaging, leasing, renting or bequeath (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999:9; FAO, 2002; FAO, 2005). Enforcement rights refer to the legal, institutional and administrative provisions that are available to guarantee the rights related to the land (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999). Information on these four types of rights are summarised in Table 4.1.

TABLE: 4.1 Bundle of rights that make up a tenure system

Type of rights	**Definition**
User rights	The right of a holder to occupy a homestead, to utilize the land for annual and perennial crops or to make permanent improvements, to derive income from the land, and to graze animals, to have access for gathering fuel, fruits, thatching grass and minerals (Feder & Feeny, 1991; Adams Cousins & Manona, 1999; Adams, Sibanda & Turner, 1999; FAO, 2002; FAO, 2005).
Transfer rights	The rights of a holder to transmit the rights of the land to his or her successor, or the rights to alienate rights to the land through sales, donations, mortgaging, leasing, renting or bequeath (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999:9; FAO, 2002; FAO, 2005)
Exclusion rights	The right of a holder to exclude others from claiming the user rights or transfer rights in relation to a piece of land (Feder & Feeny 1991; Adams, Cousins & Manona, Adams, Sibanda & Turner, 1999; FAO, 2002).

Type of rights	Definition
Enforcement rights	The rights to enforcement of legal and administrative provisions which are available to protect the right holder (Feder & Feeny, 1991; Adams, Cousins & Manona, 1999:9; Adams, Sibanda & Turner, 1999).

As indicated, each of the four rights that make up the bundle can be subject to specific terms and conditions. Accordingly, a land tenure system can be defined as the combination of the different rights pertaining to land holding that are held by individuals or groups and the terms and conditions that apply to each of these rights. It is this definition of land tenure system that will be used throughout this chapter.

4.2.2 Trust tenure on canal schemes in Vhembe

Trust tenure was first applied on land that had been bought by the South African Native Trust, later called the South African Development Trust (SADT) in terms of the Development Trust and Land Act, No 18 of 1936 (De Wet, 1987). Following the promulgation of the Act, the specifics of Trust tenure were gradually developed, refined and amended. so as to suit particular circumstances. Relevant Trust tenure legislation pertaining to irrigation schemes located in the 'Native Areas' or 'Bantu Areas', included the Regulations: Grobler Irrigation Scheme, District of Thaba 'Nchu (Proclamation No. 173 of 1938); Taungs Irrigation Scheme Regulations (Proclamation No. 4 of 1943); Linokana Irrigation Scheme Regulations (Proclamation No 106 of 1948); Seodin Irrigation Scheme Regulations (Proclamation No 195 of 1948); Olifants River Irrigation Scheme Regulations (Proclamation No. 371 of 1948); and the Control of Irrigation Plots on South African Native Trust Land (Proclamation No 29 of 1951). All of these proclamations were repealed by Proclamation No. R. 5, 1963, called the '*Regulations for the Control of Irrigation Schemes in the Bantu Areas*'.

The Regulations for the Control of Irrigation Schemes in the Bantu Areas' applied to land located in the Bantu Areas that had been declared 'an irrigation scheme' by the Minster of Bantu Administration and Development. This was done by notice in the *Government Gazette*. The Regulations provided for the Minister to appropriate the identified land and it also stipulated the terms of awarding compensation for existing owners or occupants of that land. In cases where the identified land was tribal, transfer from tribe to the Bantu Development Trust usually followed negotiations between state and tribal leadership. Typically, the chief of the tribe and the homesteads that held land within the boundaries of the proposed scheme were offered compensation for making way to the development by being offered plots on the scheme (Van Averbeke, 2008).

Lahiff (1999) reported that land tenure of certain smallholder irrigation schemes in Limpopo Province were regulated by the '*Bantu Areas Land Regulations*' which were contained in Proclamation R188 of 1969. The *Bantu Areas Land Regulations* provided comprehensive regulations for all types of land located in the Bantu Areas but made no mention of irrigation schemes. One important difference between the two tenure systems was the exclusion of traditional leadership from the land allocation and administration processes on land where the *Regulations for the Control of Irrigation Schemes in the Bantu Areas* applied, whilst on land where tenure was regulated by the *Bantu Areas Land Regulations*, traditional leadership had to be consulted when decisions were made.

In all situations where Trust tenure applied, allocations were made by means of 'Permission To Occupy' (PTO) certificates and land rights were granted conditionally. Land rights could be forfeited when the right holder broke any of the stated conditions, and this was the principal reason why Trust tenure was considered the least secure tenure system available to Black people in South Africa (Cokwana, 1988; Kille & Lyne, 1993; Roth & Haase, 1998).

Since 1994, legislation aimed at improving tenure security and land rights of Black people in South Africa has been promulgated. This included the Upgrading of Land Tenure Rights Act 112 of 1991, the Development Facilitation Act 67 of 1995, the Communal Property Association Act, No 28 of 1996, and the Interim Protection of informal Land Rights Act 31 of 1996 but several tenure-related questions remain unanswered, particularly those pertaining to tenure in the former homelands (De Villiers, 2003; Mosaka & Mullins, 2006). The Communal Land Rights Act (Act No 11 of 2004) was to provide answers to some of these questions, but this Act was declared invalid and unconstitutional by the Gauteng High Court (LRC, 2010). As a result, tenure in the former homelands remains unresolved. Affected smallholder irrigation schemes are mainly located in the North West, Limpopo, Mpumalanga, KwaZulu-Natal and Eastern Cape Provinces (Denison & Manona, 2007; Walker, 2008).

4.2.3 Land exchanges on smallholder irrigation schemes

In water-stressed countries, such as South Africa, irrigation land is a valuable asset, because irrigation can reduce or eliminate water deficits in crop production (Van Averbeke, 2008; Annandale *et al*., 2011). Yet, land on smallholder irrigation schemes in South Africa is not used as intensively as possible. For example, Perret (2002) reported that about one-third of plot holders at the irrigation schemes of Dingleydale and New Forest, formerly located in Limpopo Province and now in Mpumalanga Province, had abandoned farming and were leaving their land lying idle. Substantial numbers of pot holders not using their irrigation allotments were also recorded at Zanyokwe Irrigation Scheme in the Eastern Cape (Mnkeni *et al*., 2010, Fanadzo *et al*., 2010). Medium- to long-term fallowing of plots by a significant proportion of plot holders is one of the reasons for the relatively low cropping intensities that characterise contemporary South African smallholder irrigation schemes (see also Chapter 2).
The relatively low use of land on many operational smallholder irrigation schemes in South Africa contrasts sharply with the apparent demand for additional land by some farmers on these schemes (Van Averbeke & Mohamed, 2006) and also by people residing in the surrounds of these schemes (Van Averbeke, 2008). Poorly functioning land exchange markets, particularly for land rentals, appear to be one of the reasons why both dry land and irrigation land in African smallholder settings is not cropped more intensively (Roth & Haase, 1998; Shah *et al*., 2002; Tshuma, 2009).

Inadequacies in tenure security, or at least the perceptions of such inadequacies, among land holders and people seeking to lease land have been identified as being among the reasons why land exchange markets in smallholder environments do not function well (Thomson & Lyne, 1991; Perret, 2002; Machethe *et al*., 2004; Blanc, 2005; Mosaka & Mullins, 2006; Dengu & Lyne, 2007; Van Averbeke & Bennett, 2007; Manona & Baiphethi, 2008).

4.3 Materials and methods

To develop a clear understanding of the bundle of rights related to land awarded by the Trust tenure system as regulated by the Proclamation No. R. 5, 1963, this Proclamation was scrutinised for statements related to the four different types of rights that make up a tenure system. All relevant statements were marked on a copy of the Proclamation text using a highlighter. Then the various statements were subdivided into four categories, each representing one of the types of land rights. Then all statements in each of the four categories were coded and important codes were identified. These codes were then used to construct a summary of the tenure system using a table format. Finally the different entries in the table were elaborated to further advance understanding.

To describe the historical application of Trust tenure system as regulated by the Proclamation No. R. 5, 1963 at Dzindi Irrigation Scheme and its implications on scheme operation and maintenance and the livelihoods of plot holders, use was made of information on the history of Dzindi contained in Van Averbeke (2008) and Manyelo (2011). Some new information was also gleaned from interviews with plot holders.

To document the current tenure system that applies at Dzindi, field data were collected by means of interviews, observations and the collection of artefacts (documents). This included data on:

- The various actors that were playing a part in the land administration system;
- The procedures being used in the land administration system;
- The forms, receipts and other documents that were being handed out to plot holders by the authorities as part of the land administration processes;
- The experiences of people with the entire tenure system.

Participants in this part of the study included plot holders; people who had accessed and used land belonging to others, members of the scheme leadership, the local extension technician, civil servants working for the Department of Agriculture; the Department of Rural Development and Land Reform; and the Department of Local Government and Housing, which has since changed its name to the Department of Cooperative Governance, Human Settlement and Tribal Affairs); as well as civil servants working for the Thulamela Municipality in which Dzindi is located. Documents were obtained from the National Library of South Africa, local extension workers, members of the scheme leadership, local municipalities and plot holders. Wherever possible, photos were taken and documents photocopied to generate records for future reference. Information on the processes and procedures that applied in cases of land transfers was obtained from plot holders who had recently transferred their plots and also from those whose applications were still pending, as well as officials involved in the process of land transfers, such as the members of the scheme leadership, local extension workers, traditional leadership and municipal staff. Sampling of primary stakeholders (plot holders and people who had obtained experience with land exchanges, be it as lessors or lessees, was done in accordance with the redundancy principle (Strydom & Delport, 2005). This meant that sampling was continued until no new information was obtained by further enlargement of the sample size (additional units sampled were redundant), indicating that saturation had been reached. On the whole, 114 participants were interviewed but some of the participants provided information on more than one aspect of tenure. When categorised thematically, a total of 230 interviews were conducted. Among these, 25 interviews were conducted with participants who had obtained first-hand experience with land exchanges at Dzindi. Thirteen of these were lessors and 12 lessees. A further 45 interviews on the issue of renting in or renting out land were done with plot holders of Dzindi who did not have first-hand experience with this form of land exchange. A total 88 interviews contained information on the current land tenure and administration system at the Scheme, and 43 interviews provided information on how this system worked in the past. Twenty interviews dealt with the land conflict with the Municipality, and nine with the land conflict involving the chief and the tribal authority. Key questions that were asked during this part of the study were how both plot holders and people accessing land from plot holders exercised their different tenure rights; what the perceptions were among these participants of their different tenure rights, with specific reference to the security of these rights; and what changes they proposed to the existing land administration system.

Fieldwork was done by the senior author. Semi-structured interviews were the main method of data collection. These interviews were done with the help of a Venda-speaking field assistant who, where necessary, translated the questions asked by the researcher from English to Tshivenda and the responses by the participants from Tshivenda into English. Interviews were recorded using a digital voice recorder, which the participant was aware of, and had given permission to. Interviews took place at the work places or at homes of participants. Voice recording were complemented with field notes, which captured key issues and observations not captured on voice recording. After every day, the audio recordings were transferred to a storage device and stored in digital form. The recordings were then transcribed verbatim in the language that was spoken using a word processor (MS Office Word®). These texts were then translated in English with help of the field assistant. The accuracy of the translations was verified by a third person fluent in both English and Tshivenda. Data collection was continued until no new information was obtained when additional participants were sampled. This indicated that data saturation had been reached (Strydom & Delport, 2005).

The data (English texts) were analysed by means of line-by-line initial coding, followed by pattern coding (Saldaña, 2010). Themes used in the analysis included the four types of tenure rights; regulations, conditions and security of these different rights; and issues associated with land exchanges, such as land renting, duration of rental contracts, compensations, the form in which agreements were captured and sharing of water on plots where parts were rented out.

4.4 Results

4.4.1 The Trust tenure system as regulated by Proclamation No. R. 5, 1963

Proclamation No. R.5 of 1963, entitled 'Regulations for the control of irrigation schemes in Bantu Areas', and known as the 'Irrigation schemes control regulations', hereafter referred to as the Regulations, applied to land located within the Bantu Areas, as defined by the Native Administration Act of 1927 and the Native Trust and Land Act of 1936, which had been declared an 'irrigation scheme'. For land in the Bantu Areas to be declared an irrigation scheme, the Regulations required the Minister of Bantu Administration and Development to declare by notice in the Gazette that such land was needed for this purpose. After that the state would appropriate such land and transfer it to the South African Native Trust, as constituted by the Native Land and Trust Act of 1936, effectively transferring ownership of the land to the state. The Regulations explain how existing occupants or owners of land in areas that had been declared irrigation schemes were to be compensated for the loss of their land. At the time of promulgation of the Regulations on the 11th of January 1963, the Regulations were deemed to apply to any future irrigation schemes as well as all irrigation schemes that already been established in the Bantu Areas. The Regulations specified the rights, obligations and conditions for occupying land on these irrigation schemes. The smallholder canal schemes in Vhembe, which were the focus of this study, form part of the population of irrigation schemes on which the Regulations applied.

To obtain the right to occupy land on an irrigation scheme, the person had to be a Bantu as defined by the Native Trust and Land Act of 1936. Although the Regulations do not refer specifically to gender, in at least one instance the text implies that only males qualified for the right to occupy land[3]. Applications to occupy land on an irrigation scheme were made on a

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[3] On page 4 of the Regulations it is stated that 'No person, other than a probationer or occupier or the wives and unmarried children of such probationer lessee or occupier shall…' Use of the word wife instead of spouse indicates that probationer lessees and occupiers were expected to be male.

specially designed form, which was filled out in duplicate. When application to occupy land on an irrigation scheme was granted, the applicant was issued with a written temporary permission to occupy and was referred to as a ‘probationer lessee’. At a later stage, the temporary permit could be upgraded to ‘permission to occupy’ in which case the applicant would attain the status of ‘occupier’. Granting of both these permissions was done by the Native Commissioner. Here on after both probationer lessees and occupiers will be referred to as plot holders.

Table 4.2 summarises the results of the analysis of tenure rights in accordance with Proclamation R5 of 1963. Three types of land were covered by the Regulations, namely the irrigation allotment, the residential allotment and the commonage. Narrative explanations accompany the codes contained in Table 4.2. This narrative is structured in accordance with the four types of rights that make up a tenure system.

4.4.1.1 User rights

User rights were awarded and regulated by the state, represented by the Native Commissioner appointed for the District in which the irrigation scheme was located. The right of plot holders to use land on irrigation schemes was subject to a wide range of conditions and prescriptions. These were elaborated in the Regulations under the heading of ‘Control of schemes’. Monitoring and enforcement of the control measures was the responsibility of the Superintendent of irrigation schemes, who was an official appointed specifically for this purpose. In the absence of a Superintendent, monitoring and enforcement of control measures were the mandate of the Agricultural Officer. Plot holders were obliged to allow entry by any person authorised to inspect the irrigation allotment and residential sites at any time.

The rights to the use of the irrigation allotment, the residential plot and the commonage were tied together, but specific conditions and prescriptions applied to each of these three types of land. Specific conditions and prescriptions that applied to the right to use the irrigation allotment included:

- Plot holders had to conduct their farming in accordance with a prescribed system that specified the rotation of crops, planting dates and the fertiliser and irrigation practices that had to be applied;

- Upon request by the superintendent, plot holders had to perform labour to eradicate noxious weeds on scheme land and to maintain irrigation works, roadways, drains and other permanent structures located on the irrigation scheme;
- Plot holders had to be present on the scheme at all times and required permission to be absent from the scheme for a period exceeding 14 days;
- Plot holders were liable to pay rent for the right to use the irrigation allotment.

Specific conditions and prescriptions that applied to the right to use the residential allotment included:

- Use of the residential allotment by plot holders was restricted to the erection of a residence and other buildings for domestic purposes;
- Occupation of the residential plot was restricted to the plot holder, or the wife or wives and unmarried children of the plot holder;
- Plot holders were liable to pay rent for the right to use the residential allotment; and
- Plot holders could be called upon to demarcate (fence) their residential allotment.

Specific conditions and prescriptions that applied to the right to use of the commonage included:

- The commonage could only be used for the rearing of livestock;
- Plot holders were not allowed to plough or erect any structure on the commonage;
- The state had the authority to regulate the number and class of animals that were permitted to make use of scheme commonage land; and
- The keeping of pigs and poultry was specifically prohibited.

Offences against the regulations were punishable. Penalties included fines up to R200; jail sentences up to six months when fines were not paid; and expulsion from the irrigation scheme. Expulsion meant that the plot holder lost all land rights granted by the permission to occupy and was obliged to leave the scheme within a period of three months.

TABLE 4.2: Analysis of tenure rights in accordance with Proclamation No. R.5 of 1963

Description of right	Allocating authority	Right holder	Terms and conditions	Regulating authority	Penalties for non-adherence
Right to use • irrigation plot for crop production	State	Plot holder	Prescribed farming system must be adhered to	State	Fine or expulsion
			Unremunerated labour must be performed to maintain the scheme infrastructure		Fine
			Full-time presence on scheme-plot is compulsory and temporary absence is subject to state approval		Fine or expulsion
			Annual rent is payable		Expulsion
• commonage to keep livestock	State	Plot holder	Number and class of animals are restricted and small stock (goats) are not permitted	State	Fine or confiscation of animals
• residential plot for residential purposes	State	Plot holder	Annual rent is payable	State	Expulsion
			Full-time presence on plot is compulsory and temporary absence is subject to state approval		
Right to exclude	State	State and plot holder	Only plot holder, spouse and unmarried minor children are allowed to enter the scheme and use the plot	State	Fine
Right to transfer land	State	State	State transfers land following the death of a plot holder or cancellation of the PTO	State	
Right to enforce	State	State		State	

4.4.1.2 Exclusion rights

Excluion rights were the domain of the state, but the regulations protected plot holders against interference from other people. Presence on the irrigation scheme was restricted to plot holders and their family and even access to the commonage was limited to them. However, whilst the Regulations provide a degree of protection to plot holders, the thrust of the Regulations was concerned with the rights of the state to exclude (expel) plot holders who did not abide by the terms and conditions of the Regulations. It is primarily for this reason that Trust tenure was regarded as highly insecure.

4.4.1.3 Transfer rights

The Regulations granted transfer rights to the state. Legally, plot holders had no transfer rights at all. User rights to land returned to the state upon the death of the plot holder. Renting out land to others was specifically prohibited.

4.4.1.4 Enforcement rights

The Regulations granted enforcement rights to the state only, but plot holders could obviously appeal to the state to have their user rights enforced, as long as they abided by the terms and conditions of the Regulations.

4.4.2 Application of the Trust tenure system as regulated by Proclamation No. R. 5, 1963 at Dzindi

Historical evidence indicates that the Regulations were implemented strictly at Dzindi. Plot holders were instructed what to grow and in which rotation. The farming system that was imposed involved a rotation of cereals and pigeon peas but plot holders were allowed to grow crops of their choice on a small portion of their irrigation allotment (Manyelo, 2011). Participation in cleaning of the canal and the storage dam at Block 1 of the scheme was enforced, as was full-time farming. Non-compliance with the latter prescription was the primary reason why certain plot holders were expelled from Dzindi during the first two decades of its existence (Van Averbeke, 2008). There was also the removal of all Tsonga-speaking plot holders and their deportation to Gazankulu at the time of the creation of the Venda and Gazankulu homelands.

These forced removals occurred between 1969 and 1974 (Van Averbeke, 2008). Whilst the expulsion of Tsonga-speaking farmers was clearly politically motivated, the Regulations made provision for such action, through a clause that provided for the transfer of the powers of the Native Commissioner to a Regional Authority, and a clause that granted the authorities the power to expel plot holders on irrigation schemes for ‘administrative reasons’.

Application of the Regulations also brought about certain benefits for plot holders at Dzindi. These included:

- The state protected the irrigation scheme community against land invaders;
- The state took responsibility for the marketing of the produce arising from imposing a particular crop rotation;
- Scheme land was conserved;
- The scheme infrastructure was kept clean and in good working order; and
- Plot holders had equal access to irrigation water.

From the analysis of the tenure system described in the Regulations, several underlying policy objectives are discernible. These are briefly discussed.

- **Realising return on public investment**: The state was intent on bringing about social and economic returns on the investment that were made to establish the irrigation scheme through productive use of this asset. For this reason, the state insisted on full-time farming by occupants using a farming system which the state considered to be productive. The Regulations made provision for the pursuit of this objective by making full-time use of irrigation allotments a condition for occupation of an irrigation allotment, and by awarding power to representatives of the state to prescribe the farming system to be used by plot holders. The Regulations also gave these officials the power to withdraw permission to occupy from occupants who failed to meet the terms and conditions of the right to use land on irrigation schemes.

- **Create opportunities for agrarian livelihoods in the Bantu Areas**: Poverty, hunger, low life expectancy, urban migration, male absenteeism, natural resource degradation and declining contributions of agriculture to the livelihoods of rural Africans characterised the ‘Bantu Areas’ after WWII (see for example Houghton, 1955). The separatist homeland policy of the Government made it imperative that these territories developed their own economies. Considering that these territories were predominantly rural, the South African Government was keen to identify opportunities for rural homesteads in the Bantu Areas to make a living off the land, which was one of the main reasons for setting up the Tomlinson Commission. The report by the Tomlinson Commission (1955) specifically identified irrigation allotments of about 1.5 to 2 morgen (1.3 to 1.7 ha) on schemes controlled by state officials, as being adequate to provide Black rural homesteads with a decent living. The Regulations provided the legal means for state officials to implement this model on all smallholder irrigation schemes that had been established in the Bantu Areas, as well as any new schemes that were to be constructed.

- **Conserve land**: In government circles, the Bantu Areas were considered land degradation hot spots (Beinart, 2003). One of the central objectives of Trust tenure, as contained in the Land and Trust Act of 1936, was to provide the state with the authority and powers to prevent users of Trust land from employing practices thought to degrade land and force users to employ farming practices that were thought to conserve or improve the land. Accordingly, the Regulations made provision for the state to enforce conservation practices to protect the natural resource base.

- **Maintain the water distribution infrastructure**: In 1963 it was known that the functioning and life span of a (concrete) canal scheme was dependent on effective routine maintenance. To keep irrigation schemes functioning adequately and to extend their lifespan as much as possible, the provision of labour toward infrastructural maintenance was incorporated as a condition of occupation of an irrigation allotment.

- **Transfer responsibility of irrigation schemes to a regional authority**: In 1951, The Bantu Authorities Act (Act No 68 of 1951) was promulgated. This Act provided for the establishment of regional authorities in the different Bantu Areas and paved the way for the re-emergence of the system of traditional rule under chiefs and traditional leadership, which by that time was in an advanced stage of decay (Giliomee & Mbenga, 2007). The Regulations provided for the transfer of authority of all land in the Bantu Areas to regional authorities, including irrigation schemes. Upon transfer, the regional authority would perform the functions of the Native Commissioner, a committee appointed by the regional authority would assume the functions of the superintendent of irrigation schemes with due regard to the terms and conditions contained in the Regulations. The judicial capacity of the Native Commissioner to rule on offences against the Regulations would be transferred to the court of the Chief or headman that had jurisdiction. This clause opened the door for the re-entry of tribal leadership in the affairs of irrigation schemes.

4.4.3 Analysis of the current tenure system at Dzindi

Table 4.3 summarises the results of the analysis of the current tenure system at Dzindi. The narrative explanations of the codes in Table 4.3 are again structured in accordance with the four types of land rights.

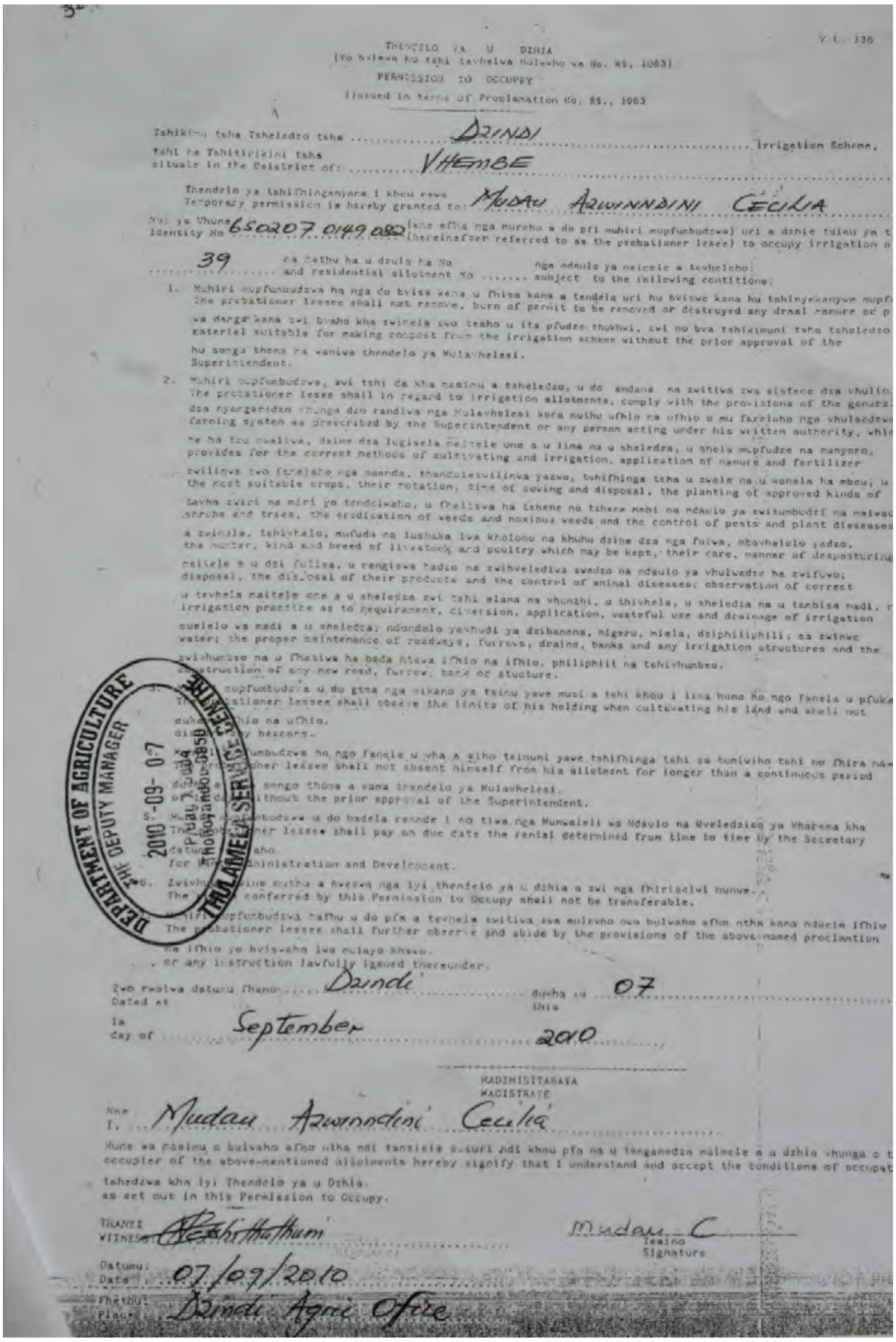
4.4.3.1 User rights

Administratively, application for permission to occupy an irrigation allotment at Dzindi is still done using the same form as was introduced following the gazetting of Proclamation No. R5., 1963. As is evident from Plate 4.1, which shows the first page of an application form that was filled out and filed in 2010, on top of the form the Proclamation is specifically referred to. The application form (Plate 4.1), states the exact same terms and conditions for occupation of an irrigation scheme allotment as those contained in the Regulations and at the top of the page even makes specific reference to Proclamation No. R5., 1963. The form refers to adherence to prescribed farming system, the performance of unremunerated labour to maintain scheme infrastructure, the full-time presence requirement, and the annual payment of rent.

TABLE 4.3: Analysis of current land rights, terms and conditions at Dzindi Irrigation Scheme

Description of right	Allocating authority	Right holder	Terms and conditions	Regulating authority	Penalties for non-adherence
Right to use • Irrigation land for crop production	Multiple competing authorities	Plot holder	Administratively, the same conditions as specified in Proclamation R5 of 1963, but in practice these conditions are no longer enforced	Scheme Management Committee	Fines
• Commonage land to keep livestock	None	Anyone	None, and current use exceeds the rearing of livestock	Disputed	None
• Residential plot for residential purposes	Municipality; DGHSTA[1]; traditional leaders	Residential plot holder	Residential land is no longer linked to the irrigation allotment	Multiple authorities	None
Right to exclude	Multiple agencies make claims	Scheme Committee and plot holder	Plot holders must be registered and Scheme Committee membership is governed by a constitution	Disputed	Not clear
Right to transfer land	Multiple agencies	Family of plot holder and multiple agencies	Some transfer rights rest with the registered plot holder, others with his or her family (bequest)	Multiple stakeholders	Not clear
Right to enforce	Multiple agencies make claims	Unclear		No clarity	No clarity

[1] Department of Cooperative Governance, Human Settlement and Traditional Affairs



V.L. 136

THENDELO YA U DZHIA
(Yo bviswa hu tshi tevhelwa Mulayo wa No. R5, 1963)
PERMISSION TO OCCUPY
(Issued in terms of Proclamation No. R5., 1963)

Tshikimu tsha Tsheledzo tsha ...... DZINDI ...... Irrigation Scheme,
tshi re Tshitirikini tsha
situate in the District of: ...... VHEMBE

Thendelo ya tshifhinganyana i khou iwa
Temporary permission is hereby granted to: MUDAU AZWINNDINI CECILIA

No: ya Vhune
Identity No 650207 0149 082 (hereinafter referred to as the probationer lessee) to occupy irrigation ...

39 ... and residential allotment No ...... subject to the following conditions:

1. The probationer lessee shall not remove, burn or permit to be removed or destroyed any draal manure or ... material suitable for making compost from the irrigation scheme without the prior approval of the Superintendent.

2. The probationer lesee shall in regard to irrigation allotments, comply with the provisions of the general ... farming system as prescribed by the Superintendent or any person acting under his written authority, which provides for the correct methods of cultivating and irrigation, application of manure and fertilizer ...

...

6. The rights conferred by this Permission to Occupy shall not be transferable.

The probationer lessee shall further observe and abide by the provisions of the above named proclamation or any instruction lawfully issued thereunder.

Dated at ...... Dzindi ...... this 07
day of ...... September 2010

MADZHISITARATA
MAGISTRATE

I, ... Mudau Azwinndini Cecilia
occupier of the above-mentioned allotments hereby signify that I understand and accept the conditions of occupat...
as set out in this Permission to Occupy.

WITNESS: [signature]
Mudau C
Signature

Date: 07/09/2010
Place: Dzindi Agric Office

Plate 4.1: Application for permission to occupy an irrigation allotment at Dzindi which was filled out and stamped by the Department of Agriculture on the 7th of September 2010

Fieldwork showed that none of the terms and conditions for occupation of an irrigation scheme allotment was still adhered to by the plot holders at Dzindi, nor were there any authorities that insisted on adherence. Whereas relaxation on the enforcement of tenure conditions and prescriptions has removed many of the anxieties plot holders had in the past about losing the user rights over their irrigation plots, it inadvertently also contributed to the deterioration of conditions on the Scheme.

In Chapter 3, a detailed account of the rapid deterioration of the water distribution infrastructure was provided. Of particular concern was the decay and ultimate abandonment of the collective organisations for routine maintenance of this infrastructure through the provision of labour by plot holders for this purpose. This collective organisation was based on the condition contained in the Regulations that right holders had to provide unpaid labour services towards maintaining the infrastructure of the scheme by all occupants as a condition for occupation. All accounts by plot holders indicated that the water distribution infrastructure was kept in good state as long as this condition was enforced, but this is no longer the case.

The condition of full-time presence on the allotment is no longer enforced and long-term fallowing is on the increase. A few plots have been lying fallow for several years. A survey of all plots conducted in 2012 showed that eight of the 106 plots had not been used for at least one year. Subsequent enquiries revealed that several of these fallowed plots belonged to people who had left Dzindi and Itsani to go and live elsewhere. The following are a selection of plot holder statements, which clearly indicate that full-time presence (farming) on the irrigation allotment as a condition for user rights is no longer adhered to.

> *The plot next to mine has not been cultivated for several years and even the concrete furrow that feeds it is covered in bushes, whereas we know that it is our task as registered plot holders to clean it regularly, but nothing is happening.*
>
> *Some plot holders cultivate their land whenever they like. There is a large area of land that has developed bushes, because of not being used and no one is saying a word about that situation, whereas we have leaders.*
>
> *Many plots are not being used, because the holders of these plots have just decided not to use them. No one is saying a word about the problem of unused land and this problem requires serious attention. Some plot holders do not*

cultivate their land because of water problems and that is understandable, but some have just decided not to cultivate at all, and that presents a problem.

Plot holders just leave their land idle and there is no action taken against them. In the past, the land was taken away from plot holders who did not use it for a period longer than one year.

There is a large amount of land which is covered in bush, because it has not been cultivated for a long time. Leaving plots fallow and letting bush grow along the concrete furrow disturbs the flow of water and makes the irrigation furrow to crack. Cracking of the irrigation furrow causes a great loss of water and now we are crying for water because of canal cracking.

Presently the extension officer no longer monitors us and this gives the impression that the rules that apply are no longer effective. Even people appointed by the government to ensure that water is monitored (bailiffs) are ineffective. They spend time having fun during working hours but month end they get paid.

There are people who have left the plots vacant for no reason, just like the plot which is located above mine. That plot is no longer farmed, because the old woman, who was the holder of that plot, has passed away. The children are all working in Gauteng. There is no one left to farm. There are many abandoned plots in Block 1. Some plots have no owners. For example, Plot number 11. It is unoccupied because the plot holder has passed away and the children of the deceased are not interested in farming.

Rental collection, which continues to be done by the Limpopo Department of Agriculture, appeared to be ineffective, as is evident from the following narratives:

It has been years since I paid the annual rental fee of R12. I last paid rent when it was still payable at the extension office. I heard rumours that there is someone from the Department of Agriculture in Thohoyandou, who comes to Dzindi once a year to collect the rent but this visit is not well organised. As a result, some of *us fail to pay, simply because we do not know when that person is coming and our leaders do not tell us.*

I used to pay R12 every year but it has been at least three years since I last paid. I am not sure whether it has been increased or not. I heard rumours that there is a man from the Department of Agriculture in Thohoyandou, who comes to Dzindi once a year to collect the rent but that man comes without making arrangements with us.

I don't know whether the annual rental fee is still paid or not, because I have not paid for more than three years. In the past I used to pay the rental fee in return for my user rights.

In the past, the annual rental fee of R12 was paid at the extension office on the due date in return for user rights. There was a fine, which was imposed for not paying the rental fee on the due date. Now I use my plot without paying the annual rental fee. I can't even remember when I last paid rent. What I know is that it is no longer paid at the extension office. There is someone from the Department of Agriculture who comes to Dzindi to collect the rent. Many of us are unable to pay, because the event is not well arranged and the strategy used is poor.

When Trust tenure was still fully applied, annual rental fees were paid in return for user rights. If I failed to pay, this was recorded at the extension office, but this is no longer happening. I have not paid for years. I don't know what is going on.

During the period when the authority over irrigation schemes resided with the Native Commissioner, the Superintendent of irrigation schemes, and the agricultural officer, there was no ambiguity about who allocated the right to use an irrigation allotment, and for that matter, the right to use a residential allotment and the commonage belonging to the Scheme. Since then, the right to use residential land and the commonage has been delinked from the right to use the irrigation allotment. The authority over the allocation and regulation of residential sites is now held by the Thulamela Municipality, the Department of Cooperative Governance, Human Settlement and Traditional Affairs, and the tribal authority. A spokesperson of the Department of

Cooperative Governance, Human Settlement and Traditional Affairs explained that this Department issued Permission to Occupy (PTO) certificates for 'all (residential) land that was under the control of tribal authorities'[4]. The official pointed out that the Department collaborated with the Thulamela Municipality, particularly in cases of land transfer or change of ownership, with the Municipality making the recommendation but the Department making the decision.

Right to use the commonage of Dzindi Irrigation Scheme had been extended to all residents of settlements surrounding the Scheme. Consequently, 'open access' best describes the tenure that applies to the commonage at present. This has caused much dismay among the plot holder community at Dzindi, because livestock left unattended on the commonage also wanders onto the irrigation lands causing damage. In the absence of a clearly defined authority allocating right to use the commonage, nothing is done about plot holder complaints.

Of even greater concern has been the excising of commonage land for residential purposes, which has brought residential developments onto the commonage of the Scheme. Plate 4.2 is an aerial photograph of Dzindi that was taken in 2004. On the photo it can be seen that in the north-east of Dzindi, where Block 1 is located, growth of the township of Shayandima had extended to the edge of the irrigation allotments. Most of the commonage in that part of the Scheme had already been incorporated in the township of Shayandima and land use has changed from agricultural to residential. In the central north of the Scheme is the settlement of Itsani, which is located on tribal land. Plate 4.2 shows that in some parts, Itsani has extended to the edge of the canal. It also shows that an RDP housing development was constructed on the commonage land between Block 4 and Block 3.

In the south and south east, the northern edge of the settlement of Manamani is visible, also a tribal settlement. Since the aerial photograph in Plate 4.2 was taken, part of the arable land between the residential section and Dzindi River has since changed its use from arable to residential. Recently, parts of the commonage across the Dzindi River, along the road that links Itsani and Manamani, have been subdivided into residential plots and houses are being built on these plots. Clearly, the practice of excising commonage land from Dzindi is rapidly reducing the size of this land resource.

[4] The official elaborated the meaning of 'land under the control of tribal authorities' as 'all land that requires the authority of the chief before it can pass from one person to the other'.

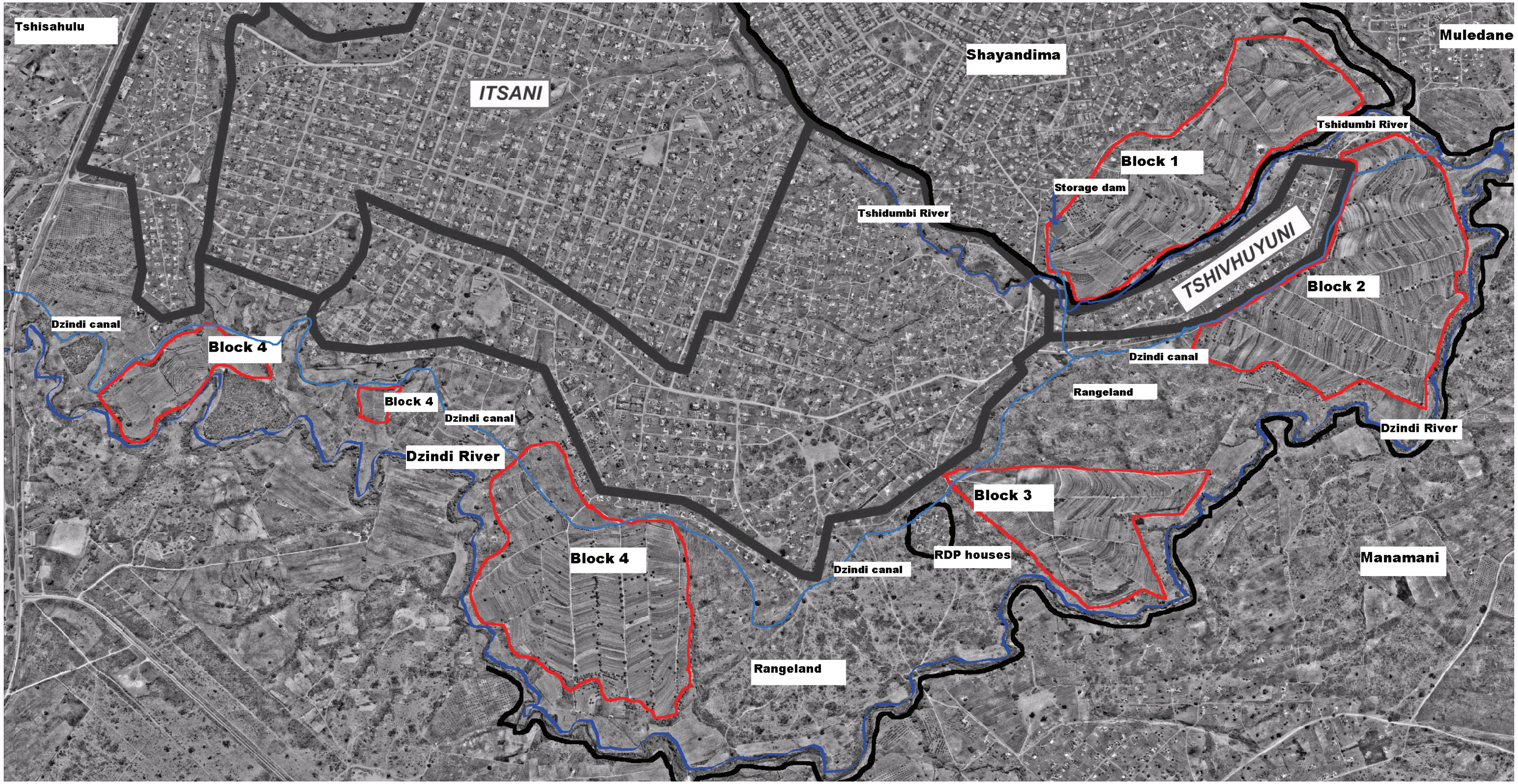


PLATE 4.2: Dzindi, Itsani and surrounding settlements in 2004 (from Van Averbeke, 2008)

Whilst developments on the commonage have been most disturbing to the registered plot holders of Dzindi, irrigation allotments remained unaffected. This changed in 2012, when the Thulamela Municipality demarcated and allocated residential sites on an irrigation plot in Block 1 of Dzindi and on one of these sites a house was being erected (Plate 4.3).

PLATE 4.3: Demarcation of residential sites on an irrigation allotment in Block 1 of Dzindi Irrigation Scheme by the Thulamela Municipality was soon followed by the construction of houses (Picture October 2012)

Plot holders were up in arms and demanded immediate demolition of the house that was under construction. The Department of Agriculture, the Department of Rural Development and Land Reform and the Department Cooperative Governance, Human Settlement and Traditional Affairs became involved in an attempt to resolve the crisis but seemingly to no avail.

According to Dzindi plot holders, it was not the first time the Municipality had demarcated residential stands on land belonging to the Scheme. A few years ago, sites had also been demarcated but when plot holders approached the Municipality and explained that Scheme land could not be used for residential purposes, the Municipality agreed and the planned residential development was abandoned. However, in 2012, the Municipality again demarcated 32 stands on Scheme land and allocated these to applicants. Plot holders raised the matter with the Department of Agriculture and with the Department of Rural Development and Land Reform, but these Departments failed to convince the Municipality that their action was illegal. The following account elaborates the origins and nature of the land conflict

> *This land conflict started when the Municipality turned one of the irrigation plots in Block 1 into a residential area. A house that was being built inside this plot was about to be roofed* (See Plate 4.3)*. After unsuccessful attempts to convince the owner that building a house on an irrigation allotment was not allowed, we requested a meeting with the Thulamela Municipality. We went there with representatives of the Department of Agriculture and the Department of Rural Development and Land Reform, expecting these Departments to support our case and explain to the Municipality that its actions were illegal. Land is the area of specialization of these two Departments, but they appeared to be afraid to defend us. They behaved like people who were lost.*
>
> *A person from another organisation spoke on our behalf about our rights to land. He said that in the past, the terms and conditions that applied to holding irrigation land on smallholder irrigation schemes were oppressive and that we should not be oppressed again. Our extension officer, who was the programme director at that meeting, spoke on our behalf about Proclamation R5 of 1963, but the Municipality spoke of some newer Proclamation, dating back to 1982, which gave the Municipality the authority over land in the township. The Municipality stated that Dzindi Irrigation Scheme was part of the township. The Municipality also claimed that township land could only be used for residential purposes and not for farming. When the Municipality was making these claims, representatives from the Department of Agriculture just kept quiet. By the looks of it, the Municipality had authority over the Department of Agriculture and the Department of Rural Development and Land Reform.*
>
> *I think if this problem does not get resolved we (Dzindi plot holders) will proceed to the National Department of Agriculture or to a court of law to open a case against the Municipality. Before I came here in Itsani I was staying in Shayandima (the formal township located north of Dzindi). This was around 1960. During that time, residential plots were located far away from the Scheme. The Irrigation Scheme was clearly separated from the residential areas but now*

residential areas have moved onto Scheme land. Some of the stands have big houses built on them. To me it is quite clear, the Municipality wants to take control of our Scheme.

The lady, whose plot was turned into a residential area, lamented that her PTO certificate was worthless, because it had failed to assert and protect her exclusive user rights to the irrigation allotment referred to in the PTO. Even the Department of Agriculture and the Department of Rural Development and Land Reform had been unable to restore her user rights for which the Native Commissioner had granted her husband's family the permission to occupy[5]. She gave the following account of her experiences:

One day, the person who has now built a house on my plot came to me and complained that I had planted maize on his residential stand. I said to him that the stand that he was referring to was my irrigation plot, which has been in this family since the start of the Scheme in 1954. He said that he did not have time to listen to my stories and that he would cut down my maize plants and start building his house. He added that there was nothing I could do about that. He then cut all my plants and started digging the foundations for his house. I ran to the extension officer and the Scheme Management Committee to report the matter. The Scheme Management Committee went to him and advised him to stop building on my plot. He responded that he would not stop building, because he had obtained a 'deed of grant' for his site, for which he had paid money, He said that Thulamela Municipality had sold him the residential site and he continued building.

When he had completed the foundations, the Scheme Management Committee visited him for the second time and told him that he was not allowed to build a house on an irrigation allotment. He was not interested in what the Committee had to say and carried on building. I did not know what to do anymore. I just went home. After the Scheme Management Committee failed to resolve the matter, there was nothing I could do.

[5] The plot had been held by her husband's family since inception of the Dzindi Irrigation Scheme.

Sometime later I got very angry when he started digging in an area where I had planted tomatoes. That is when I decided to go to the chief to report the matter. The chief called the Scheme Management Committee to appear before him but they explained to the chief that they had tried their best to resolve the matter. The explained that the Municipality was allocating Scheme land to the people for residential purposes. The chief then wrote a letter to the Municipality and invited them to a meeting. In that meeting, a staff member representing the Municipality, his name was Maluleke, asserted that the person who had built his house on my plot was in possession of a legal document that entitled him to his stand, and that even if the matter would go to court, I would never win the case. That is when I lost all hope of ever getting my plot back. As times goes on, the Municipality will take my entire plot from me until there is no land left for me to farm. Now that the house is almost ready, I have problems getting a tractor to enter what remains of my plot, because the house has closed off access. I now have to ask my neighbour for permission to have the tractor drive over his plot every time I want to plough some land.

I cannot understand what is happening. The first time these problems started, the Municipality demarcated sites in the orchard I had established on commonage land. When the Scheme Committee confronted them, they asked for forgiveness and promised that they would never interfere with farming land again, and we understood that. But now they are entering our irrigation allotments and we do not know what they are aiming at. I was very surprised when they started using sticks to demarcate stands inside my irrigation plot. I have a PTO certificate for my plot. Is it possible that a 'deed of grant' can top my PTO certificate? If this is indeed the case then our PTO certificates are worthless. It also means that we are paying rent for nothing.

Whilst the Chief supported the Dzindi plot holders when they challenged the Municipality, he, in turn, appeared to be behind a land grab on the commonage land located between Block 3 and Block 2. The area concerned is located between the canal and the road. One of the plot holders, who was intimately involved in the matter, provided the following account:

“As residents of this place (Itsani), we were very surprised when we were informed that there were residential stands being demarcated on Scheme land between Block 3 and Block 2. As a mother of three young boys, I decided to stake a claim on three stands, so that my boys would have a place to build their own homes when they get older. I was afraid that outsiders would get all the land, whereas this is my area. I went to the place where demarcation was apparently occurring and was given the name of the man who was acting on behalf of the Chief and the Tribal Council, and who was doing the allocations. When I arrived at his home, I told him that I had come to apply for three residential stands. He asked me to return the following day, which I did, and he informed me that he would visit me at my home and take me to the area to show me the three stands that would be allocated to me. I must admit that I had my reservation about all of this. I wondered how I was going to be given the stands, because we were never informed by the Chief that there would be an allocation of the stands.

When he did not turn up, I gave him a call on his cell phone and he said that he was still busy giving other people residential stands. Later that day, I heard voices on the other side of the bushes. I followed the noise and saw a large number of people following the man who was allocating sites. I heard that many of them had paid him in advance for a residential stand. I was told that a stand cost R1200.00. Two ladies I know were also there and their stands were demarcated, near the playground next to Block 2. He said to me and the other plot holders who were there that we should not be worried, because our stands would be allocated in a better place. He told us to come back the following morning.

The next day there was an even larger crowd next to the playground, because the news of the allocation of residential plots had spread like wildfire. Three of the Chief’s men were there dishing out sites. I saw people paying cash on the spot. We, the plot holders, approached those men and told them that we also wanted stands, even when we had no money to pay, because this was our land. We told them that they had no authority to give outsiders stands inside our Scheme, whilst leaving us and our children without a place to stay. They again *told us not to worry and continued giving other people residential stands and it was a very busy day for them. We failed to be given stands and were told to come on Saturday to get our residential allotments.*

On Saturday, there were even more people looking for stands but also the plot holders were there in large numbers. The Chief's people were again allocating stands. People who had money were given beautiful stands, whilst those without money were given stands in a bad place. Some of the residential stands were very expensive. Some were sold for R3000, others R2000. All were paid for in cash. This money was paid to the chief.

Plot holders became angry. They ascertained that such a thing would not happen at Dzindi. They told the Chief's men that their way of allocating stands was wrong and that they would fight for their land. They questioned the powers of the Chief's men to allocate residential stands in the Scheme without the consent of plot holders. As this was going on, plot holders became increasingly excited and they started throwing insults at the Chief's men. Seeing that the situation was heating up, the Chief's men decided to flee the scene. One of them raced away at high speed in his car, because he was afraid of being killed by the community. This whole incident happened on the 16th of July 2012."

After the events of that Saturday, the Scheme Management Committee called on the Tribal Council to come and explain why it was allocating residential stands inside the Scheme without the consent of the plot holders. A large meeting attended by plot holders, the Scheme Committee and members of the Tribal Council was held late in the afternoon at the extension office of Dzindi. The members of the tribal council read a letter, which they claimed was written by the Chief. In the letter it was asked why the extension officer (representing the Department of Agriculture) was trying to control land that belonged to the Chief. It was also stated that the Chief had the authority to do whatever he wanted with the land, because it was his. The plot holders refused to believe that the Chief had written the letter and told the members of the Tribal Council that they wanted to hear the words from the Chief's mouth.

A meeting was arranged with the Thulamela Municipality, the Department of Agriculture, the Department of Rural Development and Land Reform, the Department of Cooperative

Governance Human Settlement and Traditional Affairs, Disaster Management, the Dzindi plot holders and the Chief with the allocation of residential sites by the Chief on the agenda. The Chief ignored the invitation and did not attend the meeting.

Plot holders then mobilised and together they went to the Chief's place to find out why he was allocating residential stands inside the Scheme. The following is a participant's account of the meeting that occurred at the Chief's place.

> *The day we went to the Chief we mobilized. We organised as many bakkies as we could get hold of so that all of us could be there. When we arrived the Chief looked at us and he realized that we were many, even though only plot holders were present. This convinced him that we were very serious. As a result he proclaimed that he had wronged us. He also told us that we had made him angry by reporting the matter to the Department of Agriculture, which suggested that he had done something illegal. He said that we should have spoken to him only about the problem and then maybe he could have done something to resolve it. We responded that we could not wait for him to attend to the problem, because it had been created in his presence. We explained that when we observed that the problem was getting bigger despite our objections, we had to consult other stakeholders to find a solution.*
>
> *At the meeting the Chief changed his mind. He was afraid, because we were many. He even turned against his own council, as if he was not the one who sent them to go and demarcate the residential stands. He announced that he would no longer allocate sites in the Scheme. He also said that he wanted to see the committee again. He said that he wanted to know their plans and that he wanted regular meetings to discuss the irrigation scheme.*

4.4.3.2 Exclusion right

In Limpopo Province, registered smallholder irrigation schemes fall under the Department of Agriculture (Tapela, 2012). This Department represents the state, which is the owner of the land. It is, therefore, the mandate and duty of that Department to protect the community of registered occupants of the schemes against land grabs and other forms of interference by outsiders that infringe on the user rights of the legitimate occupants of the scheme. Without this protection, the land rights of the plot holder communities are very vulnerable, as was shown in the previous section.

4.4.3.3 Transfer rights

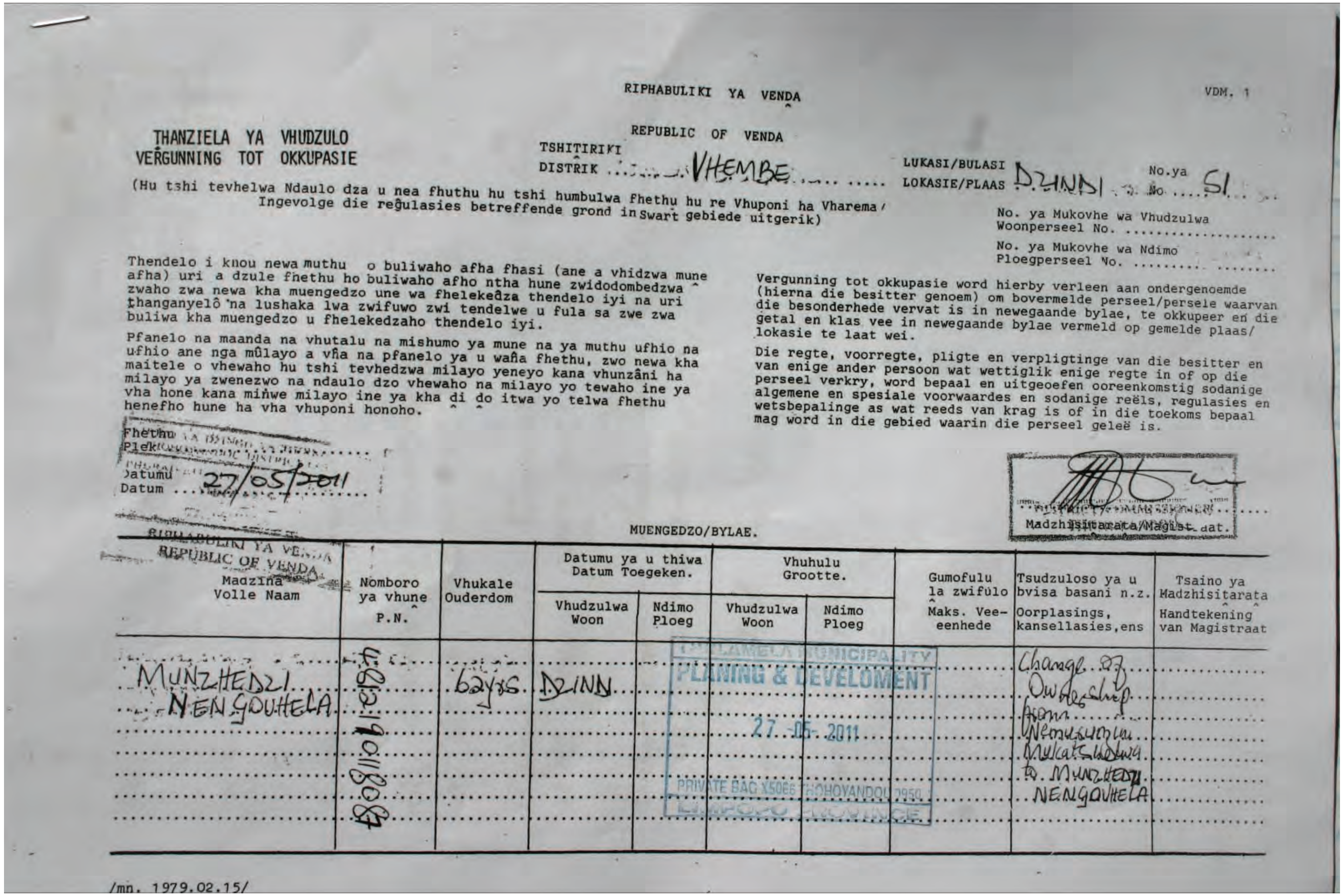
Legally, transfer rights rest with the Department of Agriculture but at present a multitude of agencies are involved in the process of transferring land. These agencies appear to operate outside their mandate. Also, transfer rights have become blurred. Even though the Department of Agriculture continues to use the same application for permission to occupy as was used in the past, since Proclamation No. R5 of 1963 was gazetted, the transfer rights of plot holders appear to have been enhanced somewhat, at least in practice. Two types of transfer rights are of particular importance to farming, investments and productivity on irrigation schemes, namely the right to bequest land, and the right to rent out land to others. These two types of transfer rights will be discussed separately.

Right to bequest land

In the past, when the native Commissioner was in control of irrigation schemes located in the Bantu Areas, the right to use the irrigation allotment returned to the state upon the death of the registered plot holder or when the plot holder left the scheme. It was then the prerogative of the Commissioner to transfer the plot to a new applicant. In case of death, the new plot holder could be one of the children of the plot holder but the Regulations did not make any statement on such preference. In practice, however, children of the deceased occupant received preferential consideration from the authorities. This is evident from the many plots at Dzindi that have remained in the hands of the same families since inception of the Scheme in 1954.

At present, the process of transferring a plot starts in the family of the deceased plot holder. For all practical purposes it is the family who decides on who the new registered plot holder will be. Once negotiations on this matter have been concluded, the family meets with the Scheme Committee, which sits every Tuesday morning. The Committee will verify the identity document of the deceased and that of the proposed new plot holder and will insist on the presence of at least three family members of the deceased to confirm that the family has indeed agreed that the plot should be transferred to the proposed new plot holder. When these conditions are met, the Committee records the name of the proposed new plot holder. Then the Committee writes a letter in which it recommends that the applicant becomes the new plot holder. Once the Committee has made its recommendation, the applicant fills out the application form issued in terms of the Proclamation No. R.5 of 1963 (see Plate 4.1) in the presence of the extension officer, who also writes a letter of recommendation. The applicant then proceeds to the Tribal Authority, which also issues a letter of recommendation. From there the applicant proceeds to the Thulamela Municipality, where the full dossier is handed over to an official, who then issues the Permission to Occupy certificate (Plate 4.4), but not before checking whether the applicant owes the Municipality any money. If the applicant is in good standing, the certificate is handed over. If not, all debt to the Municipality must first be settled before the certificate is issued. One of the plot holders who recently went through the transfer process recalls her experiences as follows:

> *I started at the extension office, where I met with the Scheme committee and the Committee wrote an approval letter, to which a letter from the extension officer and the land transfer form were attached. No witnesses were required in my case, because I am the wife of the deceased holder of the plot and the Committee knows about that. From the extension office I went to headman, where I paid R300 for a recommendation letter. From there I went to Thulamela Municipality to get the PTO certificate. At Thulamela both the residential stand and the plot were changed in my name but first I had to pay R2000, which was owed by the residential stand. They advised me to fill an indigent form since I am not working. I filled out that form and my debt was reduced to R1300. I paid off that debt in three monthly instalments. The first month I paid R500, then R400, and then a final amount of R400, in that sequence. When I had paid the debt in full, I received the two PTO certificates.*



RIPHABULIKI YA VENDA

VDM. 1

REPUBLIC OF VENDA

THANZIELA YA VHUDZULO
VERGUNNING TOT OKKUPASIE

TSHITIRIKI
DISTRIK ....VHEMBE.......... LUKASI/BULASI
LOKASIE/PLAAS DZINDI No.ya
No 51

(Hu tshi tevhelwa Ndaulo dza u nea fhuthu hu tshi humbulwa fhethu hu re Vhuponi ha Vharema / Ingevolge die regulasies betreffende grond in Swart gebiede uitgerik)

No. ya Mukovhe wa Vhudzulwa
Woonperseel No. ....

No. ya Mukovhe wa Ndimo
Ploegperseel No. ....

Thendelo i knou newa muthu o buliwaho afha fhasi (ane a vhidzwa mune afha) uri a dzule fhethu ho buliwaho afho ntha hune zwidodombedzwa zwaho zwa newa kha muengedzo une wa fhelekedza thendelo iyi na uri thanganyelô 'na lushaka lwa zwifuwo zwi tendelwe u fula sa zwe zwa buliwa kha muengedzo u fhelekedzaho thendelo iyi.

Pfanelo na maanda na vhutalu na mishumo ya mune na ya muthu ufhio na ufhio ane nga mûlayo a vña na pfanelo ya u waña fhethu, zwo newa kha maitele o vhewaho hu tshi tevhedzwa milayo yeneyo kana vhunzâni ha milayo ya zwenezwo na ndaulo dzo vhewaho na milayo yo tewaho ine ya vha hone kana miñwe milayo ine ya kha di do itwa yo telwa fhethu henefho hune ha vha vhuponi honoho.

Vergunning tot okkupasie word hierby verleen aan ondergenoemde (hierna die besitter genoem) om bovermelde perseel/persele waarvan die besonderhede vervat is in newegaande bylae, te okkupeer en die getal en klas vee in newegaande bylae vermeld op gemelde plaas/lokasie te laat wei.

Die regte, voorregte, pligte en verpligtinge van die besitter en van enige ander persoon wat wettiglik enige regte in of op die perseel verkry, word bepaal en uitgeoefen ooreenkomstig sodanige algemene en spesiale voorwaardes en sodanige reëls, regulasies en wetsbepalinge as wat reeds van krag is of in die toekoms bepaal mag word in die gebied waarin die perseel geleë is.

Fhethu
Plek ....
Datumu
Datum ....27/05/2011.........

....
Madzhisitarata/Magistraat.

MUENGEDZO/BYLAE.

Madzina Volle Naam	Nomboro ya vhune P.N.	Vhukale Ouderdom	Datumu ya u thiwa Datum Toegeken.		Vhuhulu Grootte.		Gumofulu la zwifulo Maks. Vee-eenhede	Tsudzuloso ya u bvisa basani n.z. Oorplasings, kansellasies, ens	Tsaino ya Madzhisitarata Handtekening van Magistraat
			Vhudzulwa Woon	Ndimo Ploeg	Vhudzulwa Woon	Ndimo Ploeg			
MUNZHEDZI NENGOVHELA	4812190118084	62yrs	DZINDI					Change of Ownership from Nemushungwa Mulatedzi to MUNZHEDZI NENGOVHELA	

THULAMELA MUNICIPALITY
PLANNING & DEVELOPMENT
27 -05- 2011
PRIVATE BAG X5066 THOHOYANDOU 0950
LIMPOPO PROVINCE

/mn. 1979.02.15/

PLATE 4.4: This 'Permission to occupy' certificate for Plot 51 at Dzindi Irrigation Scheme was issued by the Thulamela Local Municipality on the 27th of May 2011

The inclusion of the traditional leader and the Municipality in the transfer process is a development that is not in line with the Regulations. When the headman was asked about his role in the process, he had the following to say.

> *What is happening here is that after the family itself has agreed because in some families you will find that there are many children, so after they have agreed what we do is to follow what has been written on the letter provided to us by the applicant. At Makumbane we write a letter of support in accordance with the letter from the extension officer provided to us by the nominee. If the holder has passed away the extension officer will send the nominee to us. What we do as I have said earlier is that we write a confirmation letter and then we send the Person to Thulamela Municipality to be issued with the PTO certificate.*

Officials at Thulamela Municipality explained their role as follows:

> *At Thulamela Municipality we want a letter from the Department of Agriculture and a letter from the Tribal Authority. That is all we need but we also recover debt for services rendered. If the stand of the previous holder of the plot or the nominee owes us money, we will recover this debt before we issue the PTO certificate. The services that we are talking about include roads, water, dustbins and street lights. Some people do not pay the Municipality and they accumulate debt. When they come here they find out that their debt has grown. If the son succeeds his father on the plot we first check if his father did not owe us any services before the transfer of the land can be processed. If the applicant applying for land transfer is not working we tell him or her to fill an indigent form to show that indeed he is not working. After we have approved the land transfer we send people back to the Department of Agriculture that so they put them in the land register. The final land transfer is done by us. To make sure that information of land transfers stays safe both us and the Department of Agriculture keep records. If the PTO certificate is lost the applicants are always welcome to approach us to obtain a new PTO certificate.*

When asked about the legislation that provided the Municipality with the authority to issue PTO certificates for irrigation allotments, there was some hesitation and uncertainty, and in the end, the Municipality admitted that such legislation did not exist.

> *Actually for agricultural land we do not have the exact legislation that gives us the right to issue out PTO certificates. We were just guided by the Department of Agriculture to assist them in with the issuing of PTO certificates for irrigation land, but to issue out PTO certificates for residential plots we are guided by Proclamation R188 of 1969 and Proclamation 45 of 1990. We submit PTO application forms for residential plot to the Provincial Department of Cooperative Governance, Human Settlement and Traditional Affairs in Polokwane for approval before we issue them to the residents.*

Plot holders at Dzindi were not very complementary about the new land transfer administrative system. This is what they had to say:

> *This whole process of involving the tribal authority and Thulamela Municipality in land transfers is delaying the process. If your residential stand owes the Municipality money, you have to pay first. The tribal leader also wants money for his recommendation. Including these new parties in the process of land transfer has given these parties more power to rule us. The Municipality is new. It was only created in 1996, but it has so much power over us. We do not know how this came to be and it is not permissible.*

Right to rent out land to others

When research at Dzindi started in 2003, land exchange in the form of renting was said to be non-existent at the scheme, and field observations showed that renting land was definitely not common and if it occurred it was done clandestinely, because scheme leadership forbade it (Van Averbeke, 2008). The idea to allow plot holders to rent out land was introduced and talked about in several general meetings with plot holders and implemented by renting land from one of the plot holders in Block 2, when water in Block 1 was not available due to a faulty valve and the research plot (Plot 1) could not be used. Since then, land exchange has become quite common at Dzindi. Different arrangements that applied to the exchange of land with others were encountered. Some made some land available in lieu of payment for land preparation services.

Other rented out parts of their plots for cash. There were also arrangements that were based purely on friendship and trust.

The information on the perceptions, opinions and experiences among plot holders and outsiders who had rented in land at Dzindi, or had considered to do so, provided evidence of differences pertaining to the desirability, benefits and functioning of land exchanges at the scheme. Most accounts indicated that the prevailing procedures governing land exchanges were subject to improvement. In what follows a selection of statements are presented. The selection was done to provide full cover of the issues raised by both opponents and proponents of renting irrigation land, and both lessors and lessees.

Opponents among lessors

> *Renting out a plot in return for payment is against the law.*
>
> *Problems with leasing arise when the rental contract comes to an end, because it the leaseholder may not want to let go of the land, claiming that they have spent a lot of money on fertilisers.*
>
> *At Dzindi, all land-leasing contracts are verbal agreements and they do not have the consent of the extension officer. This makes it difficult for the extension officer to intervene when there is a fight or disagreement on the issue of leasing.*
>
> *One person who was renting land from a plot holder went to the extension officer and asked for the land he was renting to be transferred to his name. Luckily, the extension officer rejected his request. Plot holders now fear that they could lose their plots if they leased them out to other people.*
>
> *At Dzindi we irrigate according to the time table. If I rent out part of my plot I will end up fighting for water with my lessee, because water is very scarce.*
>
> *Lessees do not want to weed the plot, especially along the irrigation furrow. Here at Dzindi we control weeds along the furrow to keep away snakes.*

When the money, which the lessee has paid for using the plot, has been consumed, the lessee still has a contract and is using your land. Now you regret leasing out your land, because there is hunger at home and you want to make use of your plot to grow food.

If I would ever rent my plot to other people I would become jealous at some stage or steal produce from the lessee. To prevent that from happening to me, it is better that I do not rent out.

Negative experiences among lessees

My plot is very small. A couple of years ago I rented a portion of a plot from another plot holder in return for cash. I was paying R300 per strip for a year but as soon as the plot holder noticed that I was making money he became angry and evicted me, long before the lease had expired. The situation was very unpleasant, because he arrived at the leased land with a slasher and cut all my maize plants down. All of this was caused by jealousy, because after evicting me he never farmed that particular parcel of land. In fact, as we speak, his entire plot is covered in bushes.

Leasing of land against payment increases the risk in farming, because it adds to the cost.

From the statements by lessors who opposed the renting out of land, the most common objection by far was that lessees refused to move out of their plots after the rental contracts had expired. This created conflict, which was difficult to resolve, because there was no authority to adjudicate in the matter, as contracts were made verbally. Fear of losing one's plot was also raised several times. Also important was the issue of sharing water with a lessee, which was another source of potential conflict.

All participants who had experience with renting land from Dzindi plot holders lamented the untrustworthiness of plot holders. They argued that plot holders reneged on rental agreements and chased them out before the end of the contract had been reached. They blamed jealousy as the reason for this behaviour of plot holders. One participant pointed out that leasing land added to the cost of production and increased the risk in farming.

There were also lessors who had positive experiences renting out their land. They indicated that if it were not for leasing, their plot would be lying fallow. Some elderly plot holders openly explained that leasing was helping them financially, because they depended on a social pension for income, and this income was insufficient to plough their plots. Most of them were renting out part of their plots in return for land preparation services. Several stated that they had never encountered problems with lessees.

> *I lease six strips of my plot to another farmer during summer and the entire plot during winter. In return, he prepares the rest of my plot for the planting of maize in summer. I only use my plot for maize production, because winter production of vegetable is too expensive for me.*

> *I have been renting out part of my plot for some time now and I have not experienced any difficulties with the lessee. Leasing out part of my plot helps me to pay for land preparation and keeps my entire plot cultivated. Without renting out part of my land it would be very difficult to keep my whole plot cultivated. To those unable to farm their land for financial or other reasons, I recommend that they look at me as an example.*

> *I have a good relationship with the person who rents from me. It is impossible that a plot can be taken away from a registered plot holder. Those who claim that are lying.*

> *I have given someone else the use of my plot free of charge. He has been using it for a while now and he can continue to do so for as long as he wants. I am too old to farm and that is why I gave him permission to use my plot.*

> *If I did not rent out part of my plot I would not be able to farm at all, because I am not working. Land preparation services are very expensive. How much would you spend to prepare a large plot like this? Can I prepare the whole of it? No I cannot.*

Even among plot holders who had never rented out land there were some who viewed the renting in and out of the land at Dzindi as a positive development. Some of them encouraged other plot owners, who for one or other reason were incapable of farming their plots, to rent them out or relinquish them for reallocation. The following recorded statements illustrate this:

> *I think that plot holders who are unable to make use of their plots must rent them out to others or transfer them to people who can make use of the land, or return the plot to the Scheme Committee for reallocation. I think that if this could be done, land use at this scheme would increase.*
>
> *There is no problem with renting out of land. If I see that I am no longer capable of farming it is better that I rent my plot to someone who can make use of it.*
>
> *"Renting out of land is a good thing and the only way in which to bring the plots that are no longer cultivated back in production. If the option of renting land would be promoted by the leadership of the scheme, the entire scheme would become fully utilised.*
>
> *"I think that if the problems surrounding the leasing of land could be resolved, land at Dzindi will be more productive. In the past, we used to come together as plot holders whenever we had problems but nowadays everyone is doing their own thing.*
>
> *I do not think that there is a fundamental problem with leasing of land. Plot holders just do not like leasing out their land to others, who are better farmers, because they are jealous.*

Plot holders identified greater certainty and better enforcement of the rules as the two conditions necessary to make land leasing at Dzindi an accepted practice, as is evident from the following statements:

> *The Scheme Committee must adopt a clear and unambiguous stance on the matter of land leasing. Sometimes they say that plot holders are allowed to rent*

out their plots and sometimes they say that plot holders should not rent out their land.

Some plot holders still believe that the extension officer will come and evict them if they rent out their plots to other people.

Lessors verbally negotiate land-leases and do not seek consent from the extension officer. This makes it difficult for the extension officer to intervene when there are problems. The extension officer becomes aware of a leasing agreement only when there is a fight.

Currently the conditions for land occupation are no longer enforced and plot holders do as they wish. In the past breaking the conditions of occupation was an offence and serious fines were imposed. Now plot holders are reported for misconduct but nothing happens. The only thing that is still active is the maintenance of the main canal, for which we each pay R150 per year.

From the empirical work done on transfer rights at Dzindi Irrigation Scheme it can be concluded that plot holder homesteads have more say over the bequest of irrigation allotments than was the case in the past, when in accordance with the terms and conditions of Proclamation No. R.5 of 1963, plot holder homesteads had no formal rights in this decision. The data also show that new agencies, in the form of tribal leadership and the Municipality, have entered the process of transferring allotments, without any legal provisions for their participation. These agencies extracted benefits from applicants. Tribal leadership required payment for its endorsement, whilst the Municipality used the process to recover debt incurred on services provided to the deceased and the applicant in relation to their residential stands. The right to lease out part or all of the irrigation allotment, which was specifically prohibited by Proclamation No. R.5 of 1963, was being exercised by a substantial number of plot holders at Dzindi. Lack of certainty provided by scheme leadership, the absence of formal contracts specifying the terms and conditions of the leases and a general inability of scheme leadership to enforce rules, were the principal factors impeding this form of land exchange at the Scheme.

4.4.3.4 Right to enforce

The right to enforce the terms and condition for occupation of allotments on an irrigation scheme in what were the Bantu Areas has always been with the state. Proclamation No. R.5 of 1963 made provision for the transfer of the powers of the native Commissioner to a Regional Authority. When this would happen, the Regulations indicated that the judiciary powers of the Commissioner pertaining to ruling over offences against the terms and conditions in the Regulations would be transferred to the court of the tribal leader of the area in which the irrigation scheme was located. In the case of Dzindi, this transfer probably occurred as Venda was ushered towards independence and persisted during the brief period of independence. This explains why the Chief was called upon when the Scheme Committee was faced with a plot holder who had committed an offence but refused to accept the ruling by the Committee (Letsoalo & Van Averbeke, 2006). Accordingly, it would appear that during the period 1970 to 1990, tribal leadership re-entered the irrigation schemes and was given enforcement rights (not transfer rights) but, as stated in the Regulations, these enforcement rights were restricted to the application of the terms and conditions contained in the Regulations, nothing else. All other enforcement rights remained with the state, at present represented by the Limpopo Department of Agriculture.

4.5 Discussion and conclusion

Trust tenure has long been regarded as the most insecure of tenure systems that applied to land held by black people in South Africa. The particular Trust tenure system that applied to irrigation schemes located in the Bantu Areas, as elaborated in Proclamation No. R.5 of 1963, was no exception, mainly because the state had the power to cancel the user rights of plot holders who failed to comply with the many terms and conditions for occupation of an irrigation allotment. Evidence from Dzindi shows that up until about 1970 the state effectively used its power to evict plot holders for reasons of non-compliance. There were also elements in the system that provided a high degree of security. One of these was the detailed specification of exclusion rights, which served to protect occupants of irrigation schemes from ‘outside’ interference.

Political developments leading to the Bantu Areas becoming self-governing regions (and later on independent states as in the case of Venda) relaxed enforcement of the terms and conditions of occupation. This relaxation reduced the threat of eviction for non-compliance among plot holders and increased their tenure security, at least in practice. Shortly before the 1994 elections, these homeland regions were reincorporated in South Africa. In the Limpopo Province, the provincial Department of Agriculture was mandated to represent the state on the smallholder irrigation schemes located within its boundaries. Soon after, this Department adopted a policy of Irrigation Management Transfer (IMT), which provided for the plot holder communities on smallholder irrigation schemes to assume responsibility for the management of their schemes. Elsewhere in the world IMT had been implemented as a strategy to improve scheme management performance, to increase the profitability of irrigated agriculture and to reduce recurrent public spending on operation and maintenance of the schemes (Vermillion, 1997; Shah *et al*., 2002). In South Africa, adoption of the policy of IMT promised to improve the lives of poor people by means of a process that empowered them to take control over their own resources and destiny (Van Averbeke, 2008).

The empirical work presented in this chapter shows up the weaknesses and shortcomings of the way in which IMT has been implemented on smallholder irrigation schemes in Limpopo Province. Whilst it is widely accepted that irrigator communities can benefit from managing their own affairs (Ostrom, 1993; Marbry and Cleveland, 1996), it is still necessary for the state to provide these communities with a legal framework that enables them to assert their rights. The evidence from Dzindi suggests that this framework is not in place. This has left these irrigator communities highly vulnerable to outside interference and has rendered some of their tenure rights more insecure than before. In Vhembe, new agencies, including the Municipality and Traditional leadership have claimed authority over matters pertaining land on irrigation schemes and have acted on these claims by grabbing land that belonged to the irrigator community. Elsewhere, similar developments have been reported when the state withdrew its direct control. For example, Manzungu (1999) reported on traditional leadership usurping power from the popular-elected scheme committee at the Mutambari Irrigation Scheme in Zimbabwe, following government withdrawal. At Dzindi, the actions of both the Municipality and the tribal leadership involved land grabs. Clearly, a crisis is developing, and the tenure status of 'registered irrigation schemes' in Limpopo Province needs urgent government attention.

At Dzindi, the absence of a well-functioning land exchange market has long prevented plot holders from adjusting the size of their farm enterprise to their capacity to produce. This explains the coexistence of demand for land and idle land that could satisfy part or all of the demand for irrigation land. The fieldwork demonstrated the existence of inadequacies in the security offered by the prevailing land exchange system, or at least the perception of such inadequacies, among both land holders and people seeking to lease land. The lack of (perceived) tenure security was identified as an important reason for the poorly functioning land exchange market. The development of improved scheme-based land administration institutions and systems could enable plot holders to use their land more flexibly. Here specific reference is made the option to rent out land to others. The role of improved scheme-based land administration institutions and systems should be to protect the land rights of both the plot holders and the people who obtain permission to make use of land and this can be achieved by removing the uncertainties surrounding land rights and lease contracts.

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CHAPTER 5

5 Field performances of tractor and animal draught systems for land preparation on canal schemes in Vhembe

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5.1 Introduction

In South Africa, primary cultivation on land belonging to Black people evolved from hoeing to ploughing with draught animal power from about 1850 onwards. This technological change increased the land area under crops (Bundy, 1988). From about the middle of the twentieth century, the ability to cultivate became increasingly constrained as many rural African homesteads lacked the cattle numbers required to form a ploughing span (Starkey, Jaiyesimi-Njobe & Hanekom, 1995). In response to the draught-power crisis, the state introduced public tractor services in the South African Bantu Areas, later called homelands, where the large majority of African farmers were found (Joubert & Kotsokoane, 2000). Tractor numbers in these areas peaked during the 1970s, when a total of 12 000 tractors were in operation. This number gradually declined and only 2000 to 3000 state-owned tractors were still in active use when the public tractor services in the homeland areas were discontinued completely in 1995 (Starkey, Jaiyesimi-Njobe & Hanekom, 1995:26).

When the public tractor services were introduced in the former homelands (elsewhere also referred to as Bantu areas), they targeted smallholder irrigation schemes in particular, because these schemes were projects of modernisation. As a result, when public tractor services were withdrawn, cultivation on these schemes had become almost entirely dependent on tractor power (Van Averbeke, 2008). In the dryland farming areas, on the other hand, animals were only partially replaced by tractors as the source of power in primary cultivation, resulting in the preservation of knowledge and equipment needed to cultivate land using draught animal power in these areas (Joubert & Kotsokoane, 2000).

Following the withdrawal of the public tractor services, hiring the services of privately owned tractor enterprises became the principal way in which farmers on smallholder irrigation schemes in Limpopo Province cultivated their plots (Van Averbeke, 2008). The change from public to private service providers brought about efficient gains in terms of timeliness and quality of the service but also raised the cost of cultivation per unit area (Lahiff, 2000).

The high and rising cost of tractor cultivation, primarily propelled by the rising cost of fossil fuel, has generated interest among smallholder irrigators for an alternative that is more affordable. Draught animal power presents a potentially attractive alternative to tractor power. Conversion from tractor power to draught animal power would uncouple cultivation services from the price of diesel. Converting to animal draught power is also expected to contribute to local economic growth by increasing local employment, because animal-draught enterprises have much lower work speeds than tractor enterprises (Starkey, Jaiyesimi-Njobe & Hanekom, 1995). For this reason a greater number of animal-draught enterprises would be required to satisfy the cultivation needs of farmers than in the case of tractor enterprises. However, whereas the prevailing economic circumstances on smallholder irrigation schemes favour the adoption of cultivation systems that are cheaper than those offered by private tractor enterprises, it is not known whether socially, technically and economically animal draught land preparation enterprises are an appropriate and sustainable alternative to the existing tractor enterprises. Two critical factors need to be considered when asking questions about the mode of cultivation on canal schemes, namely,

- the extent to which farmers are prepared to hire the land preparation services provided by animal-draught enterprises instead of tractor enterprises; and
- the financial sustainability of the animal-draught land preparation enterprises.

Other issues to be considered are concerns about the welfare of animals used for draught in terms of health, harnessing, nutrition, handling and care; disease and parasitic problems; and injuries caused by poor harnessing (James & Krecek, 2000), as well as malnourishment, as it is claimed that most draught animals are under-nourished (Israel & Pearson 2000). As a result supplementary feeding is required. Hoof care is one of the critical animal care concerns, particularly in equines. James and Krecek (2000) reported that overgrown hooves and poor shoeing were problematic in equines used for draught purposes.

Considering that draught animal power enterprises provide a service that is locally available and of no real risk to farmers, and that smallholder scheme communities are small, which means that news travels fast, the decision of farmers to use the land preparation services provided by draught animal power enterprises or not, is expected to be determined mainly by differences in price and quality of the services between animal and tractor enterprises. Elements known to contribute to quality of the service are the depth and width of ploughing and the length, height, width, size, shape, spacing and straightness of the ridges (Li, Su & Yuan, 2007). The financial sustainability of draught animal power enterprises is of paramount importance. Of particular concern is whether the enterprise provides operators with a reasonable income. The financial sustainability of draught animal power enterprises is determined by costs and earnings. Among the costs are capital costs, operational costs, repair and maintenance costs and labour. Income is determined by the field performance of an enterprise when preparing land, which will determine how much land can be prepared per unit time and, therefore, how much income can be generated per unit time (Sikhwari, 2008).

The aim of the research contained in this chapter was to assess draught animal power as an alternative power option for agricultural production. The specific objectives were to determine and compare the field performance of tractor-draught and animal-draught systems of land preparation on canal schemes in Vhembe.

5.2 Materials and methods

5.2.1 Animal draught equipment

In order to compare the operation of tractor and animal draught enterprises, new animal-drawn equipment was supplied to participants. The following implements were purchased from AFRITRAC in North mead in Vereeniging:

- 2 x VS8 single furrow plough
- 4 x zig zag harrow
- 4 x high wing ridger
- 2 x donkey ploughs
- 2 x oxen yoke
- 2 x donkeys harness sets

Plate 5.1 shows the VS8 single furrow plough and the high wing ridger and Plate 5.2 the zig zag harrow.

PLATE 5.1: The VS8 single furrow plough and the high wing ridger supplied to participants at Dzindi and Rabali

PLATE 5.2: The zig zag harrow supplied to participants at Dzindi and Rabali

One set of implements, comprising a single furrow plough, zig zag harrow and high wing ridger, were donated to each of two participants who used cattle for draught power at Dzindi. Similar set of implements comprising one donkey plough, zig zag harrow and high wing ridger were given to each of two participants at Rabali who were running donkey enterprises. The project also purchased two yokes.

5.2.2 Field performance

One animal traction enterprise and one tractor power enterprise each participated in the field performance studies at the Dzindi and the Rabali smallholder irrigation schemes. Information on Dzindi appears throughout this report and more detail can be obtained in Van Averbeke (2008). The Rabali Irrigation Scheme (22^{o} 52' 20"S and 30^{o} 06' 02"E) is also described in Van Averbeke (2008) but in less detail. Rabali forms part of the Nzhelele cluster of smallholder irrigation schemes.

At each of the two irrigation schemes, four farmers were identified for collaboration in the research activities. Measurements were done on their plots. Each farmer had paired irrigation strips adjacent to each other. In one of the strips, land preparation (ploughing, disking/harrowing and ridging) was done using animal draught and in the other using tractor power. Measurements carried out during the operations were draught power requirements, penetration resistance and percentage soil moisture content at the time of operation, work rate and field efficiency. The cost of each operation was also recorded.

A 102 kW Landini tractor from the Agricultural Research Council's Institute for Agricultural Engineering (ARC-IAE) was used to measure draw bar power required to pull the tractor drawn implements i.e. disk plough, disk harrow and ridger. The tractors of the tractor enterprises at the schemes could not be used for measurements of draw bar power because the instruments are fixed to the Landini tractor. However, local tractors were used to measure drawbar pull, draught force and work rate. For that purpose, a dynamometer was attached between the tractor and implement on the linkages to measure draught and power output as shown in Plates 5.3 and 5.4.

PLATE 5.3: Telemetry was used to collect data on measure draw bar power required to pull the tractor drawn implements

PLATE 5.4: A dynamometer was attached between the tractor and implement on the linkages to measure draught and power output

For both tractor and animal draught, a load cell and a data logger were placed between the implements and source of draught to measure speed, force and power during ploughing, harrowing and ridging as shown in Plate 5.5.

PLATE 5.5: A load cell and a data logger were placed between the implements and source of draught to measure speed, force and power during ploughing, harrowing and ridging

Indicators of field performance include speed of operation, force, power, field efficiency, field capacity, work rate and ploughing depth and width. They were determined using the methods described by Mohammed *et al*. (2007:21). For tractors, speed was determined by measuring time spent to cover a distance of 20 m whilst preparing land.

Draught power was measured during ploughing, harrowing and ridging operations. The time taken to perform each operation was also measured including the turning time at headlands. For tractor operations, speed was determined by measuring time taken to cover 20 m. For each operation the time taking to complete the plot was measured as well as the time spent turning at headlands. The ratio of the actual time taken to perform each operation and the time taken from start of operation to completion including down time and turning time was used to determine the field efficiency. Field capacity was determined by capturing the time spent by source of draught to prepare a given area. Work rate was determined by measuring the area that a source of draught (enterprise) can prepare per day or 24 hours (Simalenga & Joubert, 1997:17). Ploughing depth was measured using a steel rod which was pushed vertically into the ploughed layer until a hard pan was reached and a tape measure was then used to determine the depth to which the rod penetrated the soil. Ploughing width was determined by measuring the implements width. A soil auger was used to take soil samples which were put into a container that was immediately sealed. The soil in the container was then weighed using a scale, dried for 48 hours and then weighed again to determine percentage soil moisture.

The field performance experiments for animal-draught land preparation and tractor enterprises' were conducted under similar conditions in terms of soil type, soil water content and vegetation. All measurements were replicated four times. Field performance indicator data obtained for the two types of draught power (animal-draught and tractor enterprise) were analysed and compared using analysis of variance (ANOVA).

The field performance experiment at Dzindi was conducted on a deep Hutton soil form with clay content of 25-35% (Van Averbeke, 2008). Four plots were randomly selected with an average size of 0.05 ha to conduct the field performance experiment for tractor and animal-draught land preparation enterprises with average moisture content of 42.8%. Paired plots were selected where one strip was ploughed, disked and ridged by a tractor enterprise (MF 188) and the other one was ploughed, harrowed and ridged by implements drawn by animals here referred to as animal-draught enterprise which consisted of four cattle with average mass of 249 kg.

The field performance experiment at Rabali was conducted on a sandy soil. The experiment was conducted in April and May 2010 during the period when farmers prepare their land for winter crops. Four plots averaging 0.08 ha were selected randomly for the field performance experiments for tractor and animal-draught land preparation enterprises. The average moisture content of the plots at the time was 35.8%. Paired plots were set up with one strip ploughed, disked and ridged by a tractor enterprise (Ford 5000) and the other was ploughed, harrowed and ridged by implements drawn by draught animals comprising of four donkeys with average weight of 135 kg.

5.3 Results

5.3.1 Field performance measurements at Dzindi

Table 5.1 shows the field performance data measured during ploughing by the animal (cattle) draught and tractor enterprises at Dzindi.

TABLE 5.1: Field performance of animal-draught (cattle) and tractor enterprises when ploughing at Dzindi

Performance test	Mean ± Standard error		Significance level
	Animal draught enterprise	Animal draught enterprise	
Depth (cm)	15 ± 0.48	20 ± 0.29	p < 0.002
Width (cm)	35± 0	60 ± 0	p < 0.001
Draught (KN)	0.79 ± 0.13	5.76 ± 0.57	p < 0.001
Speed (km hr^{-1})	3.0 ± 0.3	8.0 ± 1.94	p < 0.04
Turning time (sec)	17.1 ± 0.71	48.5 ± 11.76	p < 0.03
Power output (kW)	1.95 ± 0.71	7.81 ± 1.89	p < 0.02
Field capacity (ha hr^{-1})	0.06 ± 0.01	0.25 ± 0.03	p < 0.003
Work rate (ha day^{-1})	0.35 ± 0.05	2.5 ± 0.25	p < 0.001
Field efficiency (%)	72.4 ± 4.95	57.7 ± 1.82	p < 0.03

The results in Table 5.1 indicate that when ploughing, the tractor enterprise performed better than the cattle draught enterprise in terms of depth, width, speed, field capacity and work rate. The differences in depth, width, draught, field capacity and work rate between the animal draught and the tractor enterprise were highly significant ($p<0.01$). The animal draught enterprise performed better than the tractor enterprise in terms of turning time and field efficiency. The animal draught enterprise spent less time when turning than the tractor enterprise. The more time a tractor enterprise spends on reversing instead of turning, the lower its field efficiency. This explains why the field efficiency of animal draught enterprises was higher than that of tractor enterprises.

Table 5.2 shows the field performance data measured during the harrowing operation by the animal draught enterprise and the disking operation by the tractor enterprise at Dzindi and Table 5.3 contains field performance data measured during the ridging operation.

TABLE 5.2: Field performance of the animal-draught (cattle) enterprise when harrowing and the tractor enterprise when disking at Dzindi

Performance test	**Mean ± Standard error**		**Significance level**
	Animal draught enterprise	**Tractor enterprise**	
Depth (cm)	15 ± 0.41	22 ± 0.29	$p < 0.001$
Width (cm)	140 ± 0	190 ± 0	$p < 0.001$
Draught (KN)	0.62 ± 0.07	1.15 ± 0.30	$p = 0.06$
Speed (km hr^{-1})	3.0 ± 0.25	8.5 ± 1.27	$p < 0.005$
Turning time (sec)	16.4 ± 1.28	38.1 ± 4.32	$p < 0.002$
Power output (kW)	1.92 ± 0.34	5.50 ± 0.06	$p < 0.002$
Field capacity (ha hr^{-1})	0.33 ± 0.07	0.60 ± 0.05	$p < 0.01$
Work rate (ha day^{-1})	1.99 ± 0.4	5.95 ± 0.51	$p < 0.008$
Field efficiency (%)	72.6 ± 13.31	61.7 ± 2.26	$p = 0.44$

TABLE 5.3 Field performance of the animal-draught (cattle) and the tractor enterprise when ridging at Dzindi

Performance test	**Mean ± Standard error**		**Significance level**
	Animal draught enterprise	**Animal draught enterprise**	
Depth (cm)	27 ± 0	27 ± 0.63	$p = 0.70$
Width (cm)	40 ± 0	40 ± 0	$p = 1.00$
Draught (KN)	0.92 ± 0.13	1.02 ± 0.62	$p = 0.84$
Speed (km hr^{-1})	2.5 ± 0.23	5.2 ± 0.15	$p < 0.006$
Turning time (sec)	16.5 ± 1.05	35.4 ± 3.74	$p < 0.002$
Power output (kW)	2.33 ± 0.45	7.71 ± 2.89	$p = 0.08$
Field capacity (ha hr^{-1})	0.16 ± 0.01	0.65 ± 0.05	$p < 0.007$
Work rate (ha day^{-1})	0.93 ± 0.07	6.45 ± 0.51	$p < 0.003$
Field efficiency (%)	73.5 ± 7.73	66.3 ± 1.26	$p = 0.39$

When disking or harrowing (Table 5.2) the tractor enterprise performed significantly better than the cattle draught enterprise in terms of depth, width, speed, field capacity and work rate ($p<0.05$). The animal draught enterprise tended to have the highest field efficiency but the observed difference between the two types of enterprises was not significant ($p=0.44$).

Table 5.3 indicates that there was no significant difference in the depth and width of the ridges made by the animal draught and tractor enterprises. The tractor enterprise travelled at significantly higher speed but spent significantly more time turning and used significantly more power output when ridging than the animal draught enterprise. The tractor enterprise worked faster than the animal draught enterprise, and for that reason the tractor enterprise achieved significantly better field capacity, speed and work rates. The tractor can also work more hours per day (± 10 hours) than cattle.

5.3.2 Field performance measurements at Rabali

Field performance data measured during the ploughing operation by the animal draught and the tractor enterprise at Rabali are presented in Table 5.4.

TABLE 5.4: Field performance of the animal-draught (donkey) and tractor enterprises when ploughing at Rabali

Performance test	Animal draught enterprise		Tractor enterprise		Significance level
	Mean	SE*	Mean	SE	
Depth (cm)	25.7	± 0.28	35.9	± 0.28	p < 0.0001
Width (cm)	35	± 0.00	120	± 0.00	p < 0.0001
Speed (km hr^{-1})	2.8	± 0.19	4.3	± 0.19	p < 0.0001
Turning time (sec)	8.2	± 0.34	14.9	± 0.34	p < 0.0001
Field capacity (ha hr^{-1})	0.1	± 0.01	0.3	± 0.01	p < 0.0001
Work rate (ha day^{-1})	0.3	± 0.05	2.7	± 0.05	p < 0.0001
Field efficiency (%)	77.1	± 1.13	53.4	± 1.13	p < 0.0001

* *SE* is standard error

Table 5.4 indicates that there were highly significant differences ($p<0.001$) between the animal draught and tractor enterprises for all the variables that were measured. The tractor ploughed wider and deeper than when donkeys were used and the tractor also had the highest speed, field capacity and work rate but the longest turning time and lowest field efficiency. Field performance data measured during the harrowing operation by the animal draught enterprise and the disking operation by the tractor enterprise at Rabali are presented in Table 5.5. Table 5.5 shows that the tractor performance (disking) was better than the performance of the donkeys (harrowing) for all indicators that were measured.

TABLE 5.5: Field performance of the animal-draught (donkey) enterprise when harrowing and tractor enterprise when disking at Rabali

Performance test	**Animal draught enterprise**		**Tractor enterprise**		**Significance level**
	Mean	SE	Mean	SE	
Depth (cm)	25.8	± 0.25	36.5	± 0.24	$p < 0.0001$
Width (cm)	140	± 0.00	190	± 0.00	$p < 0.0001$
Speed (km hr^{-1})	3.7	± 0.10	4.9	± 0.10	$p < 0.0001$
Turning time (sec)	16.0	± 0.23	10.0	± 0.23	$p < 0.0001$
Field capacity (ha hr^{-1})	0.3	± 0.01	0.6	± 0.01	$p < 0.0001$
Work rate (ha day^{-1})	1.4	± 0.05	5.5	± 0.05	$p < 0.0001$
Field efficiency (%)	55.3	± 0.51	59.4	± 0.51	$p < 0.0001$

[*] *SE* is standard error

Field performance data measured during the ridging operation by the animal draught and the tractor enterprise at Rabali are presented in Table 5.6.

TABLE 5.6: Field performance of the animal-draught (donkey) tractor enterprises when ridging at Rabali

Performance test	Animal draught enterprise		Tractor enterprise		Significance level
	Mean	SE	Mean	SE	
Depth (cm)	30.3	± 0.37	36.1	± 0.37	$p < 0.0001$
Width (cm)	38.9	± 1.23	41.0	± 1.23	$p < 0.2447$
Speed (km hr^{-1})	3.0	± 0.22	5.4	± 0.21	$p < 0.0001$
Turning time (sec)	9.4	± 0.65	11.1	± 0.65	$p < 0.0803$
Field capacity (ha hr^{-1})	0.2	± 0.01	0.3	± 0.01	$p < 0.0001$
Work rate (ha day^{-1})	0.8	± 0.05	2.9	± 0.05	$p < 0.0001$
Field efficiency (%)	71.9	± 1.36	56.1	± 1.36	$p < 0.0001$

* *SE* is standard error

The field performance of the tractor was significantly better than that of the donkey span in terms of depth of the furrows, speed, field capacity and work rate. The donkey span tended to have a shorter turning time and demonstrated significantly greater field efficiency than the tractor.

5.4 Discussion and conclusion

The overall results indicate that on canal schemes, animal draught enterprises tended to achieve better field efficiency and turning times than tractors. Generally, the herringbone layout of the irrigation strips on canal schemes, with most concrete furrows serving plots on both sides, makes it difficult for tractor enterprises to turn. This is especially the case when the land has a fairly steep slope, resulting in narrow terraces. To avoid driving over the concrete furrows, tractors have to reverse to the starting point, and this affects their field efficiency and fuel use. Draught animals do not experience this constraint. Tractor enterprises showed higher work rate, field capacity, speed, ploughing width and ploughing depth than animal draught enterprises.

If animal draught enterprises were to replace tractor enterprises, a greater number of animal draught enterprises would be needed than in the case of tractor enterprises to satisfy the demand for cultivation services. This is the direct result of the lower field capacity and work rates of animal draught enterprises compared to tractor enterprises. Roughly, for ploughing, disking (harrowing) and ridging, nine (9), four (4) and four (4) animal draught enterprises would be needed, respectively to do the same amount of work as a tractor enterprise. This is of major importance for the local employment opportunities that can be created through backward economic activity linked to smallholder irrigation.

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CHAPTER 6

6 Plot holder perceptions of alternative sources of draught power with particular reference to the use of animals on canal schemes

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6.1 Introduction

When smallholder canal schemes were established, they were regarded by the state as projects of modernisation. Consequently, they were the preferred targets for availing public tractor services. The availability of public tractors contributed to the rapid abandonment of the use of animal draught among farmers on smallholder irrigation schemes (Starkey, Jaiyesimi-Njobe & Hanekom, 1995). Public tractor services were dismantled towards the end of the 20th century but by that time cultivation on smallholder schemes had become almost entirely dependent on tractor draught (Van Averbeke, 2008). When public tractor services were withdrawn from these schemes, farmers resorted to hiring the services of privately owned tractor enterprises to get their land prepared (Van Averbeke, 2008).

Rising crude oil prices and other factors, such as increases in fuel levies, have caused the diesel price in South Africa to increase considerably during the past decade, as is shown in Figure 6.1. The rise in the fuel price has had an effect on the prices charged by privately owned tractor enterprises for their services. At Dzindi the price to plough, disk and ridge a single strip, on average 0.08 ha in size, increased from R75.00 in 2005 to R105.00 in 2007, R140.00 in 2009, R160.00 in 2011 and R195.00 in January 2012. The rising cost of land preparation has placed financial strain on the cropping enterprises of smallholder irrigators, generating interest in an alternative that is more affordable. As was pointed out in Chapter 5, animal draught is the most obvious alternative to tractor draught.

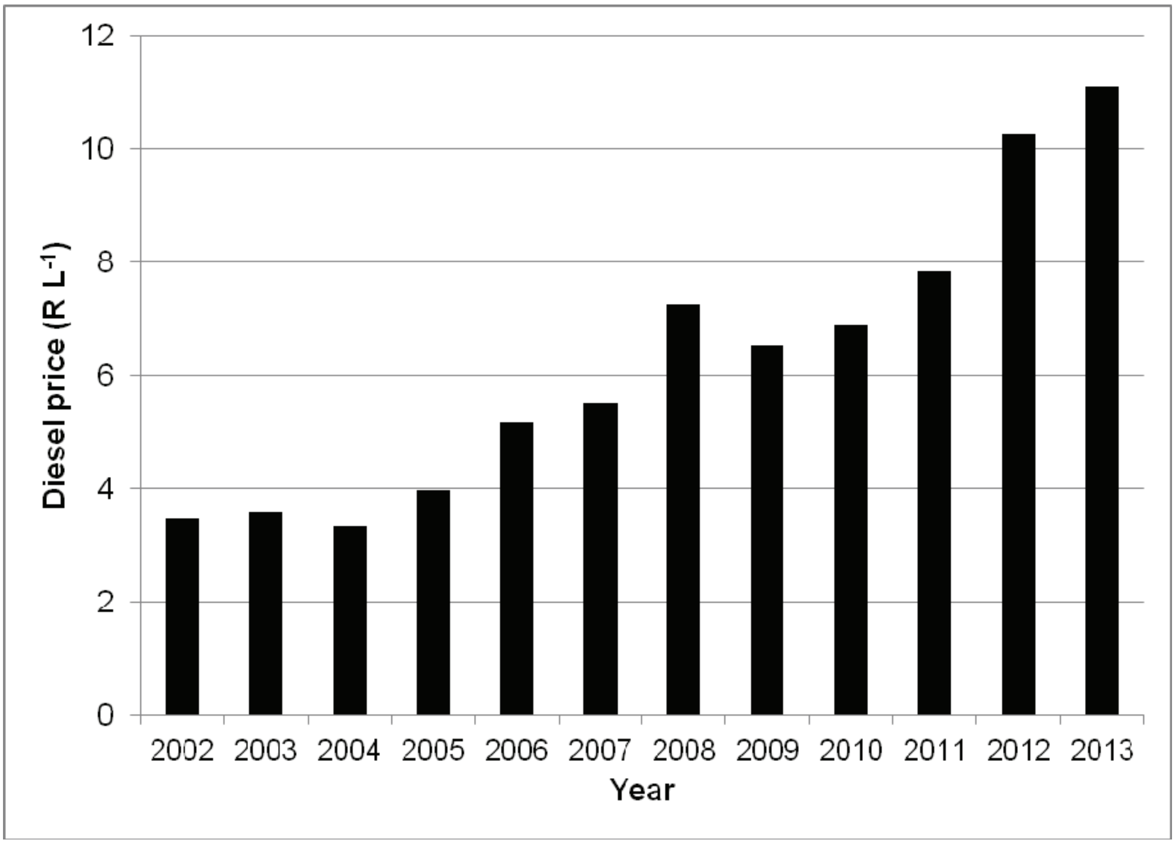

FIGURE 6.1: January wholesale price of 500 ppm diesel in Gauteng

From a broad societal perspective, animal draught represents a potentially attractive alternative to tractor draught. As was pointed out in Chapter 5, conversion from tractor to animal-draught cultivation is expected to contribute to local economic growth by increasing local employment. Since animal draught results in much lower work speeds than tractors (Starkey, Jaiyesimi-Njobe & Hanekom, 1995), a greater number of animal-draught enterprises would be required to satisfy the cultivation needs of farmers than in the case of tractor enterprises. Conversion from tractor to animal-draught cultivation would also have a positive environmental effect, because the carbon footprint of animal draught enterprises is negligible compared to that of tractor enterprises (Wilson, 2003).

Broad societal benefits are unlikely to be paramount in determining whether or not the conversion from tractor to animal-draught cultivation would occur on smallholder irrigation schemes. Instead, it could be expected that the extent to which farmers are prepared to hire the land preparation services provided by animal-draught enterprises instead of tractor enterprises would be the primary factor. Interest in the services of animal-draught enterprises among farmers is expected to be influenced by issues of price and quality of the service relative to that provided by tractor enterprises.

Despite the prevailing economic circumstances that appear to favour animal draught, it is not known at this stage whether smallholders on irrigation schemes would consider hiring enterprises that use animal draught instead of tractors to cultivate land. To find out to what extent farmers on smallholder canal irrigation schemes in Vhembe District perceived animal-draught enterprises to be an appropriate alternative to tractor enterprises for the provision of land preparation services was the objective of the study reported on in this chapter. In the first part, the meaning of perception and the factors affecting perception are briefly discussed. This is followed by a short review of perceptions of animal draught and tractors that prevail in South African society. Next, the materials and methods used in the collection and analysis of empirical data on plot holder perceptions are elaborated, followed by the results of the analysis of the data. In the final part the findings are discussed and conclusions are drawn.

6.2 Review of literature

6.2.1 Perception: definition and factors

Perception is a complex and dynamic process that is used by individuals to choose, interpret and translate information from the environment. Perception provides meaning, which results in a pattern of behaviour or thought (Mullins, 2010; Schermerhorn *et al*., 2011). Therefore, perception is important because it determines people's behavioural responses to situations, and these responses present themselves in the form of decisions and actions. According to Mullins (2010), perception is influenced by internal factors related to the state of an individual, the environment and factors external to the individual. Internal factors influencing perception include the sensory systems and psychological factors. The latter include learning, intelligence, ability, training, interests, expectations, goals, past experiences, motivation and personality (Mullins, 2010).

Robbins *et al.* (2008) and Schermerhorn *et al.* (2011) grouped the factors that influence perceptions in three categories, namely the perceiver, the target and the situation. Personal characteristics of the perceiver, such as attitudes, motives, interests, expectation and experiences, influence perception (Robbins *et al.*, 2008; Schermerhorn *et al*., 2011). The perceiver's concept of reality is determined by his or her subjective experience (Sekuler & Blake, 1994). As a result, interpretation and use of information differ amongst individuals (De Bruin & Van Lange, 1999). According to Branje *et al*. (2003) the characteristics of the perceiver influence his or her judgement and this can result in a particular response set. Characteristics of the target, such as novelty, motion, sound, size, background, proximity and similarity, can also influence perception, as well as situational factors, such as time, work settings and social settings, in which an object is perceived (Robbins *et al.* 2008). Van den Ban and Hawkins (1996) considered perception to be relative (comparative) rather than absolute and Troy and Kerry (2010) pointed out that perception can change over time.

The senses of people receive a flood of stimuli from the surrounding environment. The brain cannot make sense of all the stimuli, although it is has the capacity to process vast amounts of information (Van den Ban & Hawkins, 1996; Mather, 2009). As a result, an individual's sensory system only pays attention to a selection of stimuli (Van den Ben & Hawkins, 1996). What is selected for attention is influenced by factors such as interest, background, experience and attitudes (Robbins *et al.* 2008) but typically people tend to select that what relates to their needs and values (De Mooij, 2011).

Perception is affected by 'mental set' (Van den Ben & Hawkins, 1996). Mental set is an important perceptual concept which communication designers can use to decrease alternative interpretations given to a stimulus. For example a presenter will use bold writing in a slide presentation in order to 'set' the audience to pay attention to the issues the presenter considers to be of importance. The general tendency among people is to give more attention to large, bright, moving, intense, loud, novel, and repeated objects (Mullins, 2010)

Cognitive styles influence perception. Cognitive styles are defined as attributes, self-consistent styles of functioning shown by people in their perceptual and intellectual activities (De Mooij, 2011). Under the same conditions perceptions can vary among different individual because of their different cognitive styles. Mental processes of individuals work in different ways depending on personality factors, such as tolerance for ambiguity, degree of open and closed mindedness and authoritarianism. (Van den Ben & Hawkins, 1996).

6.2.2 Perceptions of animal draught in South African society

Research indicates that South African smallholders differ in their opinions on animal draught. Negative perceptions of animal draught reported by Musa and Bello (1993) included that animal draught was holding back scientific and technological development, that it failed to reduce human effort, and that it presented a risk to animal health. Starkey and Koorts (1995) and Joubert and Kotsokoane (2000) reported that substantial numbers of South African smallholders considered animal draught to be an old fashioned and impractical technology that had no place in modern farming. On the other hand, there were also smallholders who held a more positive view of animal draught and who considered animals to be a viable source of draught in smallholder farming (Lawrence & Pearson, 2002). Advantages of using animals instead of tractors for draught included lower cost, greater ease of maintenance and stable resale value (Musa & Bello, 1993).

6.3 Materials and methods

The study used a pre-test and post-test design (Leedy & Omrod, 2005) to measure the effect of the 'intervention' on the perceptions of farmers, which were measured using survey research at the Dzindi and Rabali canal schemes described in Chapter 5. The intervention that separated the pre-test from the post-test survey consisted of providing selected animal draught enterprises at both schemes with the necessary implements to plough, disk and ridge land, train the operators of the enterprises in the use of these implements, and allow for sufficient time (about two years) for farmers to observe the different operations executed by these animal draught enterprises. Additional details on the implements that were made available at the two schemes are provided in Chapter 5.

The study population consisted of all plot holders at the Dzindi and Rabali Irrigation Schemes. A sampling fraction of 50% was used when selecting the sample. For each scheme the list of registered plot holders was used as the sampling frame. Simple random sampling was used to draw the samples. A sample of 51 plot holders was drawn from the population of 102 plot holders at Dzindi and a sample of 34 plot holders from the population of 68 plot holders at Rabali.

Dzindi is a canal scheme with a command area of 135.6 ha that is subdivided into 106 plots of 1.28 ha each. Nearly all the land at Dzindi is prepared by the four tractor enterprises that operate in the scheme but there is also one service provider who uses cattle to provide draught power. The predominant soils (about 75%) at Dzindi consist of Hutton form soils (Van Averbeke, 2008:48).

Rabali is a canal scheme with a command area of 87 ha that is subdivided into 68 plots of 1.28 ha each. Most of the land at Rabali is prepared by tractor enterprises that operate in the scheme but about 10 farmers hire the services of the four animal draught enterprises that operate in the scheme, all of which use donkeys for draught. The soils in Rabali are predominately sandy.
The survey made use of face-to-face interviews and a survey instrument that contained 17 questions, which were formulated to measure the perceptions of plot holders towards the use of animal draught in land preparation. The same instrument was used during both the pre-test and the post-test survey. Each question consisted of a statement and participants were asked to indicate the extent to which they agreed (or disagreed) with the statement. Participants were provided with explicit alternatives from which they were to select their responses. These responses were formulated using a Likert-type scale with *1 = strongly agree; 2 = agree; 3 = not sure; 4 = disagree; and 5 = strongly disagree* as the alternatives. The questionnaire was translated into *Tshivenda*, the vernacular language of plot holders at the two study sites. The interviews with plot holders were done at theirs plots or homes, in accordance with the preference of individual participants. The pre-test survey was conducted during August and September 2009 at Dzindi and Rabali respectively; post-test survey two years later, during December 2011 at both schemes. At both schemes the same participants were interviewed during both surveys.

The data (scores for each of the variables) obtained in both the pre-test and post-test surveys were coded and captured on spread sheets using MS Office Excel. Using the Statistical Analysis Software (SAS) package (Statistical Analysis Software Institute Inc, 2000), three different statistical tests were performed to measure change in the perceptions of animal draught among participants. For each of the different variables and study site these three tests were:

- Comparison of the pre-test mean score with the post-test mean score for each variable and at each study site using the General Linear Model (GLM) procedure to conduct an analysis of variance. The validity of this particular procedure is subject to debate, because when applying this procedure to calculate the mean score, the intervals between adjacent scores are assumed equal in extent. Strictly speaking, this assumption is without base when using an ordinal scale, as was the case in this study, but the analysis does serve the purpose of providing an idea of the significance of the changes in perception that occurred;

- Assessment whether paired observations on two variables, expressed in a contingency table, are independent of each other using the Pearson's Chi-square test of independence; and
- Assessment of change among individual participants across occasions using the two-sided Wilcoxon matched-pairs test, which was developed to analyze data from studies with repeated-measures. In the repeated-measure design employed in the current study, each individual was assessed on the different measures (variable scores) on two occasions (before and after the intervention).

6.4 Results

6.4.1 Dzindi irrigation scheme

The perceptions of plot holders at Dzindi towards using animal draught enterprises for the various operations that comprise the cultivation of their land for short furrow irrigation are captured in Figures 6.2 to 6.10. All nine figures show plot holder perceptions before the introduction of the project intervention (pre-test) and 27 months after the intervention (post-test) was implemented. It should be kept in mind that the higher the score value, the greater the extent of disagreement of participants with the statements put to them.

Figure 6.2 shows the extent of agreement among plot holders with the statement, '*I would be prepared to hire an animal draught enterprise to plough my land if it were available'.* Figure 6.2 shows that before the intervention occurred, the majority of plot holders (82%) held positive perceptions towards the hiring of animal draught enterprises for the ploughing of their plots. Following exposure to the work done by such an enterprise through the project intervention, their perceptions were less positive, because only 62% of plot holders indicated that they would be prepared to hire an animal draught enterprise for ploughing purposes. The negative change in perception was also evident from the change in the mean score, which increased from a pre-test value of 2.00 to a post-test value of 2.53, an increase that was significant (p=0.004), and from the results of the Wilcoxon matched pairs test (p<0.001), and to a lesser extent from the Chi-square test (p=0.07).

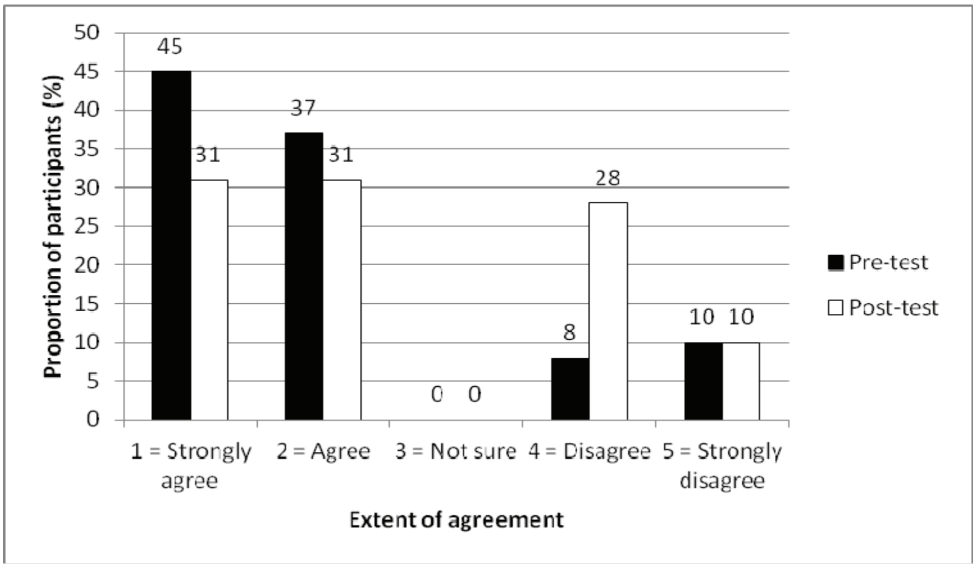

FIGURE 6.2: Extent of agreement among plot holders at Dzindi with the statement, '*I would be prepared to hire an animal draught enterprise to plough my land if it were available'*

Figure 6.3 shows the extent of agreement among plot holders with the statement, '*I am prepared to hire an animal draught enterprise to disk my land if it were available'.* The results in Figure 6.3 show that 53% of plot holders were prepared to hire an animal draught enterprise to disk their plots prior to the intervention (pre-test). This dropped to 49% in the post-test survey. The mean score increased from a value of 2.51 in the pre-test survey to 2.88 in post-test survey, but this change was not significant (p = 0.068). The results of the Wilcoxon matched pairs test (p = 0.679) and Chi-square test (p = 0.051) also indicated that the change in perception was not significant.

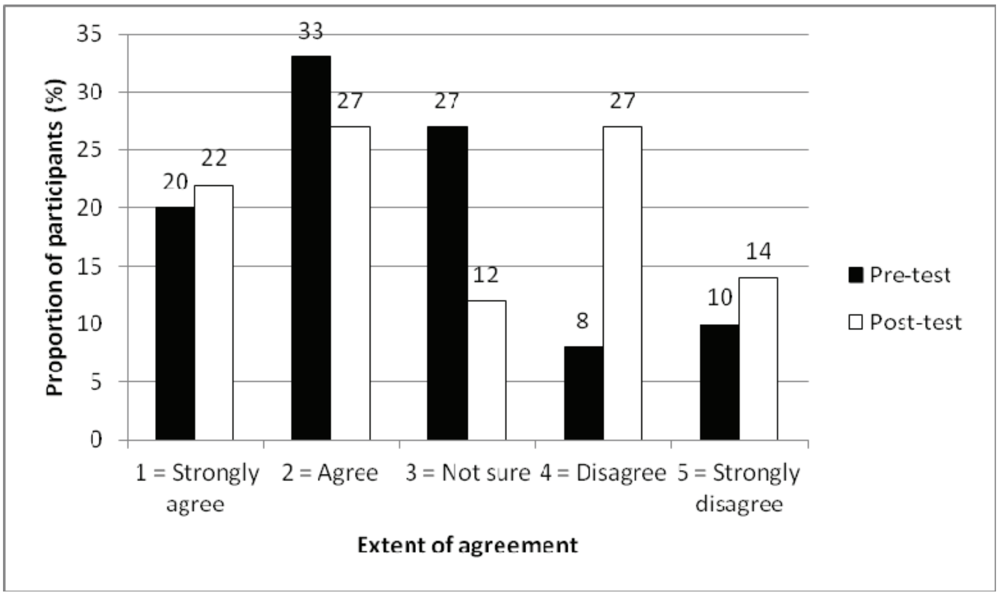

FIGURE 6.3: Extent of agreement among plot holders at Dzindi with the statement, '*I would be prepared to hire an animal draught enterprise to disk my land if it were available'*

Figure 6.4 shows the extent of agreement among plot holders with the statement, '*I would be prepared to hire an animal draught enterprise to ridge my land if it were available'.*

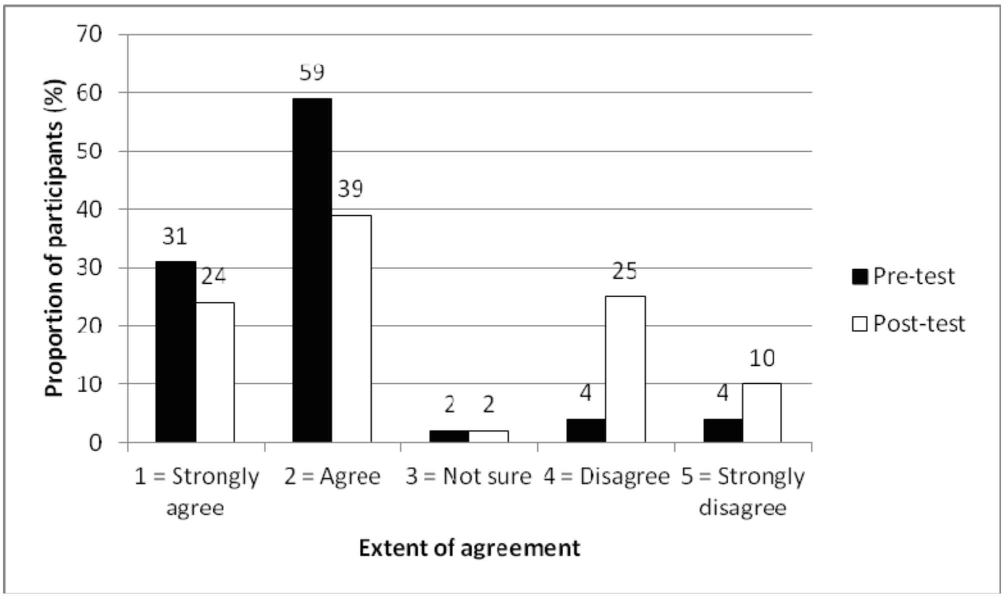

FIGURE 6.4: Extent of agreement among plot holders at Dzindi with the statement, '*I would be prepared to hire an animal draught enterprise to ridge my land if it were available'*

The results depicted in Figure 6.4 show that the large majority (90%) of plot holders held positive perceptions towards hiring animal draught enterprises to ridge their land before the intervention (pre-test). Perceptions changed after being exposed to the ridges constructed by animal draught enterprises, and only 63% still held positive perceptions at the time of the post-test survey. The mean score value increased from 1.90 (pre-test) to 2.59, (post-test), a change that was significant ($p < 0.001$). The significance of the deterioration in the perceptions of farmers was also evident from the results of the Chi-square test ($p = 0.018$) and the Wilcoxon matched pairs test ($p < 0.001$).

Figure 6.5 shows the extent of agreement among plot holders with the statement, '*I would hire an animal draught enterprise to prepare my land if it cost less than a tractor enterprise'.*

Figure 6.5 shows that the number of plot holders who would hire the services of an animal draught enterprises to cultivate their plots if these were cheaper was very high in the pre-test survey (88%) and remained high in the post-test survey (76%). The change in the mean score, which increased from a pre-test value of 1.76 to a post-test value of 2.12, was, however, significant ($p = 0.035$). The Wilcoxon matched pairs test also indicated that the change in view among farmers was significant ($p = 0.03$) but this was not supported by the results of the Chi-square ($p = 0.520$).

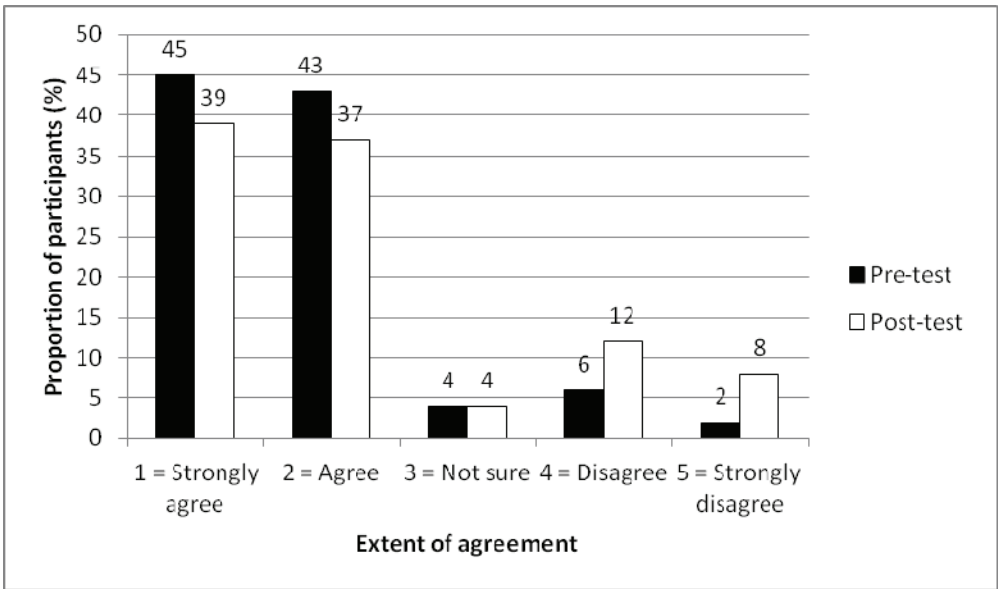

FIGURE 6.5: Extent of agreement among plot holders at Dzindi with the statement, '*I would hire animal draught enterprise to prepare my land if it cost less than a tractor enterprise''*

Figure 6.6 shows the extent of agreement among plot holders with the statement, '*I would hire an animal draught enterprise to prepare my land if it prepared land in the same way as a tractor enterprise'.*

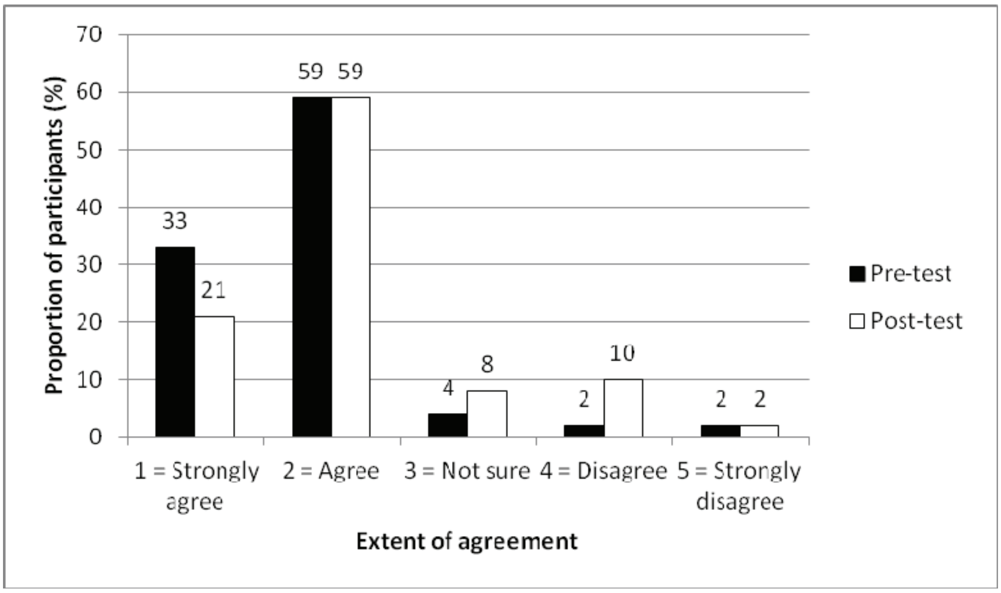

FIGURE 6.6: Extent of agreement among plot holders at Dzindi with the statement, '*I would hire an animal draught enterprise to prepare my land if it prepared land in the same way as a tractor enterprise'*

The results depicted in Figure 6.6 indicate that before the intervention, the majority of plot holders (82%) would consider hiring an animal draught enterprise to cultivate their land if the quality of the service (condition of the land after the operation has been completed) was the same as that of a tractor enterprise This number dropped to 70% in the post-test survey. The mean score value increased from 1.80 in the pre-test survey to 2.12 in the post-test survey, which was significant ($p = 0.038$). The results of the Wilcoxon matched pairs test also indicated that the change was significant ($p < 0.001$), but the results of the Chi-did not ($p = 0.329$).

Figure 6.7 shows the extent of agreement among plot holders with the statement, '*Animal draught enterprises plough as deep as tractors''.* Figure 6.7 shows that before the intervention the majority of plot holders (62%) did not believe that animal draught enterprises ploughed as deep as tractors. After exposure, the degree of disbelief was even more prevalent (84%). The mean score value increased from 3.55 (pre-test) to 4.08 (post-test), which was significant (p =

0.013). The results of the Wilcoxon matched pairs test also indicated that the change was significant (p = 0.013), but the results of Chi-square test (p = 0.095) did not.

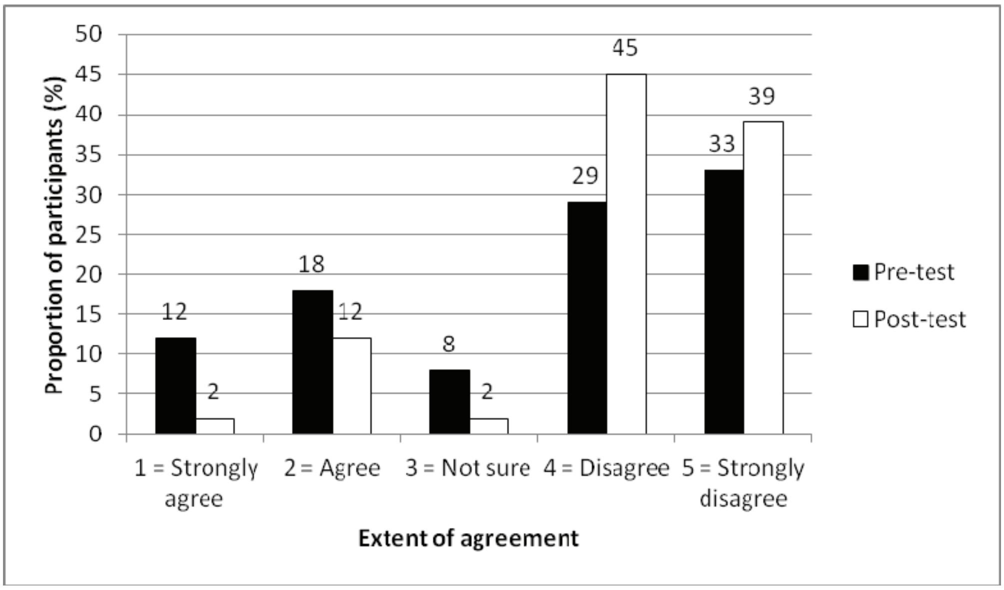

FIGURE 6.7: Extent of agreement among plot holders at Dzindi with the statement, '*Animal draught enterprises plough as deep as tractors'*

Figure 6.8 shows the extent of agreement among plot holders with the statement, *'I prefer to have my land prepared by a tractor enterprise'.* Figure 6.8 shows that before the intervention (pre-test), the majority of plot holders (74%) indicated that they preferred to have their land prepared by a tractor enterprise. The proportion of plotholders who preferred tractor enterprises increased to 86% after the intervention (post-test). This change decreased the mean score value from 2.22 recorded in the pre-test survey to 1.86 in the post-test survey but this change was not significant (p = 0.080). The lack of significance of the change in perception was supported by the results of the Chi-square test (p = 0.238) and the Wilcoxon matched pairs test (p > 0.825).

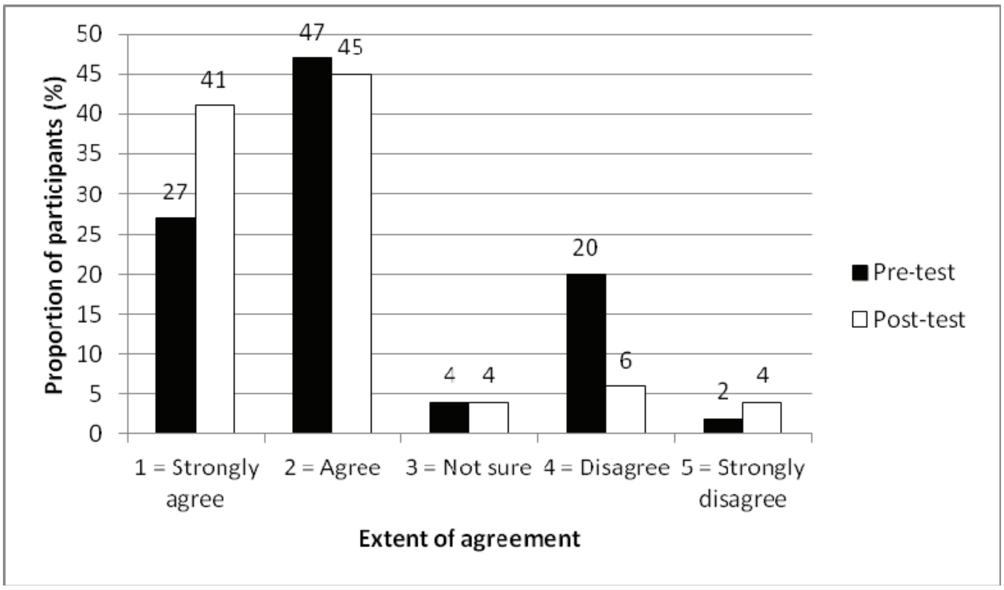

FIGURE 6.8: Extent of agreement among plot holders at Dzindi with the statement, *'I prefer to have my land prepared by a tractor enterprise'*

Figure 6.9 shows the extent of agreement among plot holders with the statement, *'The use of animal draught to prepare land is old fashioned'*

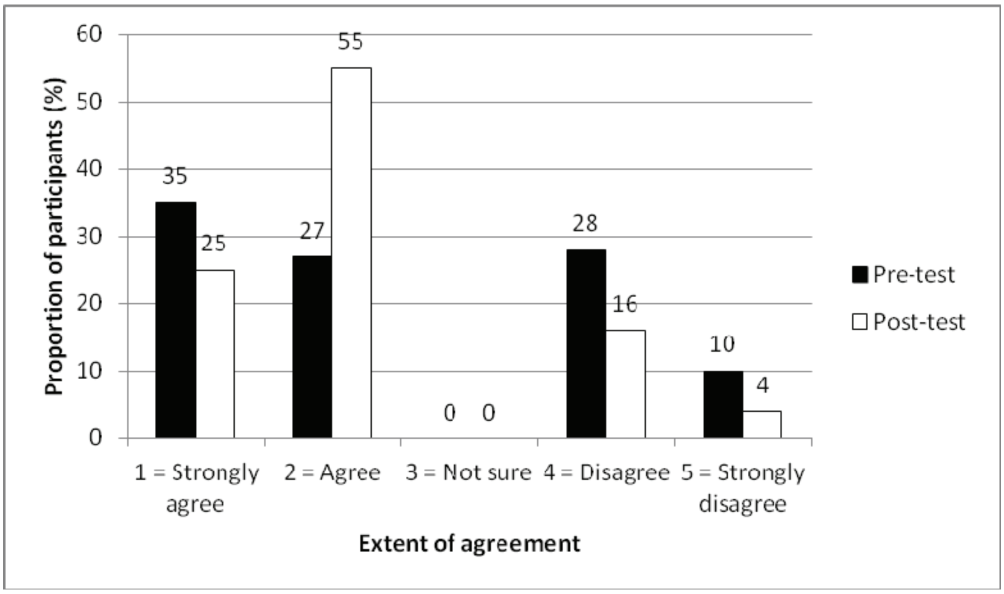

FIGURE 6.9: Extent of agreement among plot holders at Dzindi with the statement, *'The use of animal draught to prepare land is old fashioned'*

Figure 6.9 shows that prior to the intervention (pre-test) 62% of plot holders perceived land preparation using animal draught enterprises as old fashioned. Their number increased to 80% of plot holders in the post-test survey. The mean score value decreased from 2.49 (pre-test) to 2.18(post-test) but the change was not significant (p = 0.135). On the other hand, the results of Chi-square test (p = 0.039) and of the Wilcoxon matched pairs test (p < 0.001) indicated that the change in perception should be considered significant.

Figure 6.10 shows the extent of agreement among plot holders with the statement, *'If it were available I would prefer to have my land prepared by animal draught enterprises'*

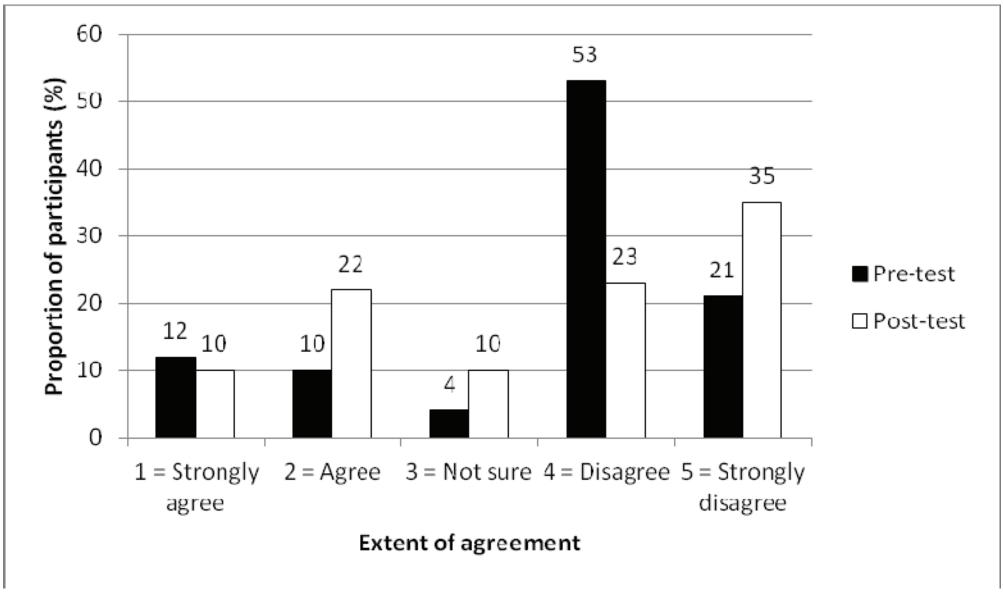

FIGURE 6.10: Extent of agreement among plot holders at Dzindi with the statement, *'If it were available I would prefer to have my land prepared by animal draught enterprises'*

The results shown in Figure 6.10 show that the majority of plot holders (74%) held negative perceptions towards using animal draught enterprises as their preferred land preparation mechanism during the pre-test survey. The number of plot holders who held negative perceptions dropped to 58% after they had been exposed to cultivation by animal draught enterprises using newly introduced equipment. The mean score value dropped from the pre-test value of 3.63 to the post-test value of 3.53, but this reduction was not significant (p > 0.680). However the results of Wilcoxon matched pairs test (p < 0.006) and Chi-square test (p = 0.026) indicated that the change in plot holder perception was significant.

6.4.2 Rabali irrigation scheme

The perceptions of plot holders at Rabali regarding the use of animal draught enterprises to provide cultivation services for short furrow irrigation are presented in Figures 6.11 to 6.19. All nine figures show the plot holder perceptions before (pre-test) and after (post-test) the project intervention, which consisted of the introduction of new animal-drawn single mouldboard plough, ziz-zag harrow and ridger.

Figure 6.11 shows the extent of agreement among plot holders with the statement, '*I would be prepared to hire an animal draught enterprise to plough my land if it were available'.*

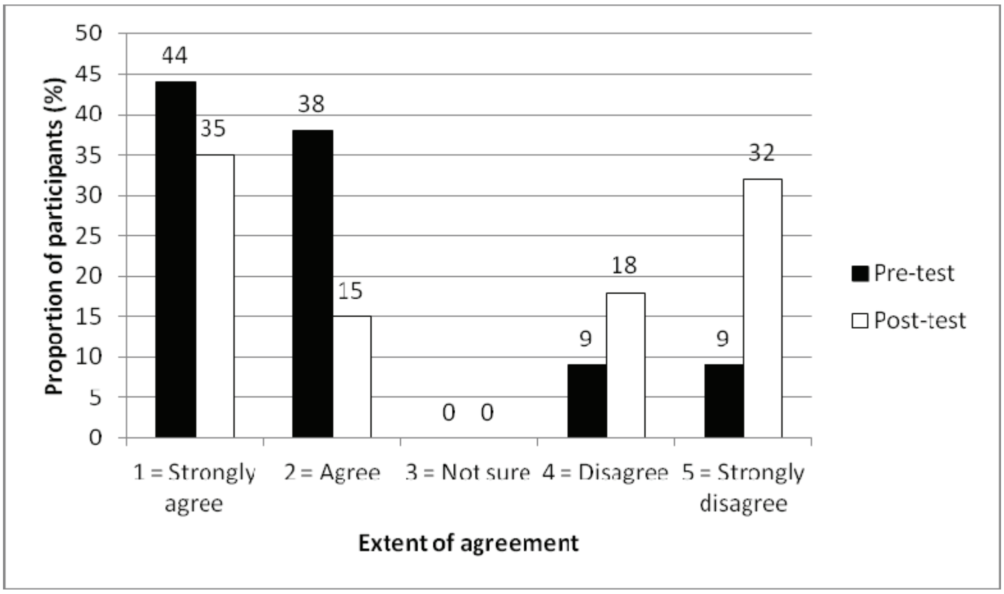

FIGURE 6.11: Extent of agreement among plot holders at Rabali with the statement, '*I would be prepared to hire an animal draught enterprise to plough my land if it were available'*

Figure 6.11 shows that before the intervention, 82% of plot holders held positive perceptions towards the hiring of animal draught enterprises for the ploughing of their plots. Following the project intervention, plot holder perceptions were less positive, with only 50% of plot holders indicating that they would be prepared to hire an animal draught enterprise for ploughing purposes. The change mean perception score increased from a pre-test value of 2.00 to a post-test value of 2.97, an increase that was significant (p = 0.015). The significance of the change in perception from more to less positive was also evident from the results of the Wilcoxon matched pairs test (p = 0.026), and the Chi-square test (p = 0.024).

Figure 6.12 shows the extent of agreement among plot holders with the statement, '*I would be prepared to hire an animal draught enterprise to disk my land if it were available'.*

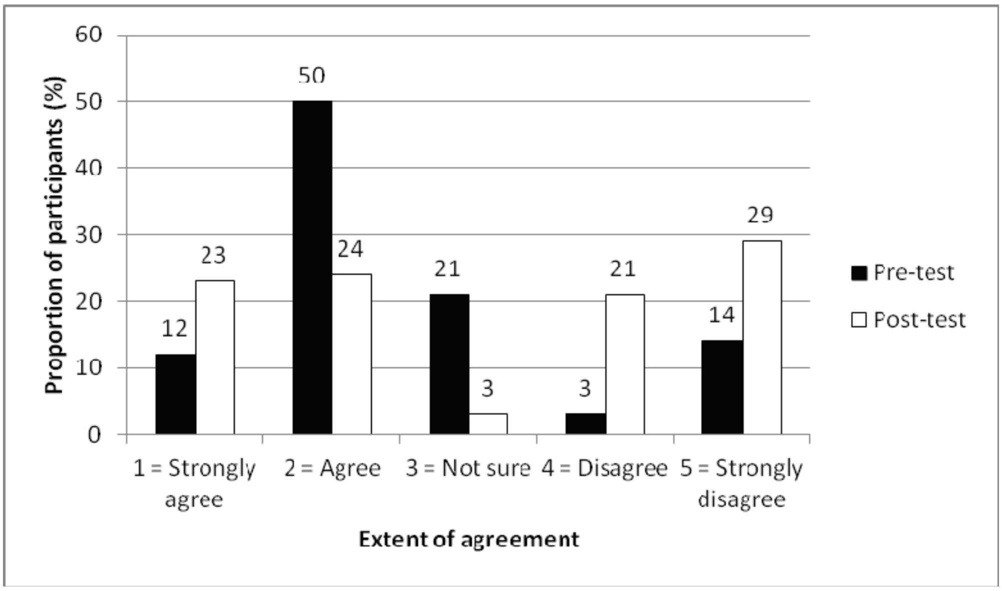

FIGURE 6.12: Extent of agreement among plot holders at Rabali with the statement, '*I would be prepared to hire an animal draught enterprise to disk my land if it were available'*

In Figure 6.12, the results of the pre-test survey show that 62% of plot holders were prepared to hire an animal draught enterprise to disk their plots prior to the intervention but only 49% still held this view 26 months later when the post-test survey was done.. The mean test score increased from a value of 2.59 in the pre-test survey to 3.09 in post-test survey, but this change was not significant (p = 0.078). The lack of significance of the change in perception was also evident from the results of the Wilcoxon matched pairs test (p = 0.139) but the results of the Chi-square test (p < 0.004) indicated that the change was significant.

Figure 6.13 shows the extent of agreement among plot holders with the statement, '*I would be prepared to hire an animal draught enterprise to ridge my land if it were available'.* The results depicted in Figure 6.13 show that the majority (88%) of plot holders held positive perceptions towards hiring animal draught enterprises to ridge their land before the intervention (pre-test). Perceptions changed after plot holders were exposed to the ridges constructed by animal draught enterprises. The number of plot holders who still had positive perceptions of ridging using animal draught had dropped to 47% at the time of the post-test survey As a result of the change in perceptions, the mean score value increased from 2.12 (pre-test) to 3.03, (post-test), which was significant ($p < 0.002$). The significance of the change in the perceptions of farmers was also apparent from the results of the Chi-square test ($p < 0.001$) and the Wilcoxon matched pairs test ($p < 0.003$).

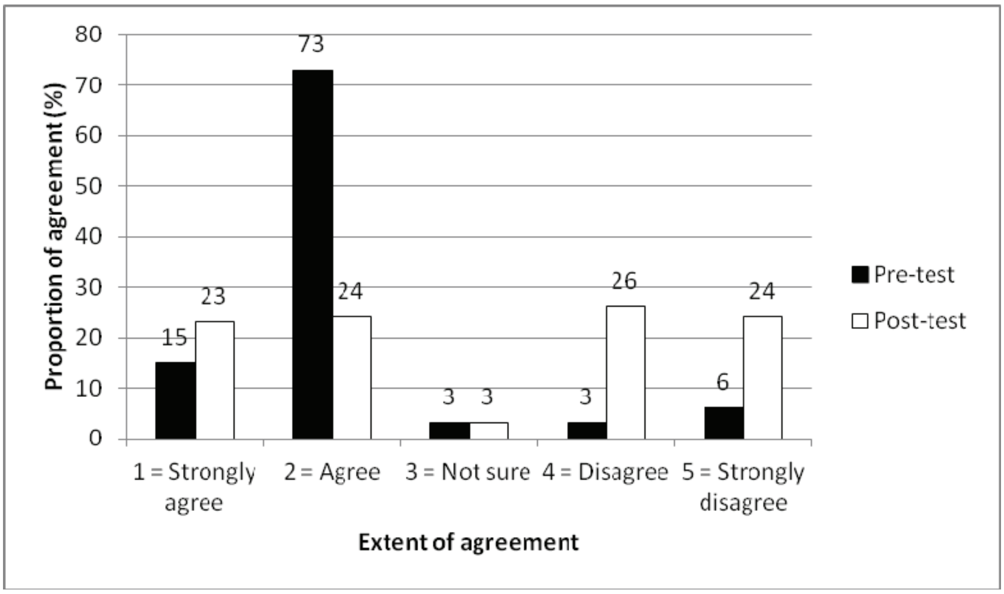

FIGURE 6.13: Extent of agreement among plot holders at Rabali with the statement, '*I would be prepared to hire an animal draught enterprise to ridge my land if it were available'*

Figure 6.14 shows the extent of agreement among plot holders with the statement, '*I would hire an animal draught enterprise to prepare my land if it cost less than a tractor enterprise'.* Figure 6.14 shows that the number of plot holders who would hire the services of an animal draught enterprises to cultivate their plots if these were cheaper was very high in the pre-test survey (83%), but dropped to 52% in the post-test survey. The decrease in the proportion of plot holders altered the mean score from a pre-test value of 1.79 to a post-test value of 2.85, a change that was highly significant ($p < 0.001$). The significance of the change was also evident from the results of the Wilcoxon matched pairs test ($p < 0.001$) and the Chi-square test ($p = 0.014$).

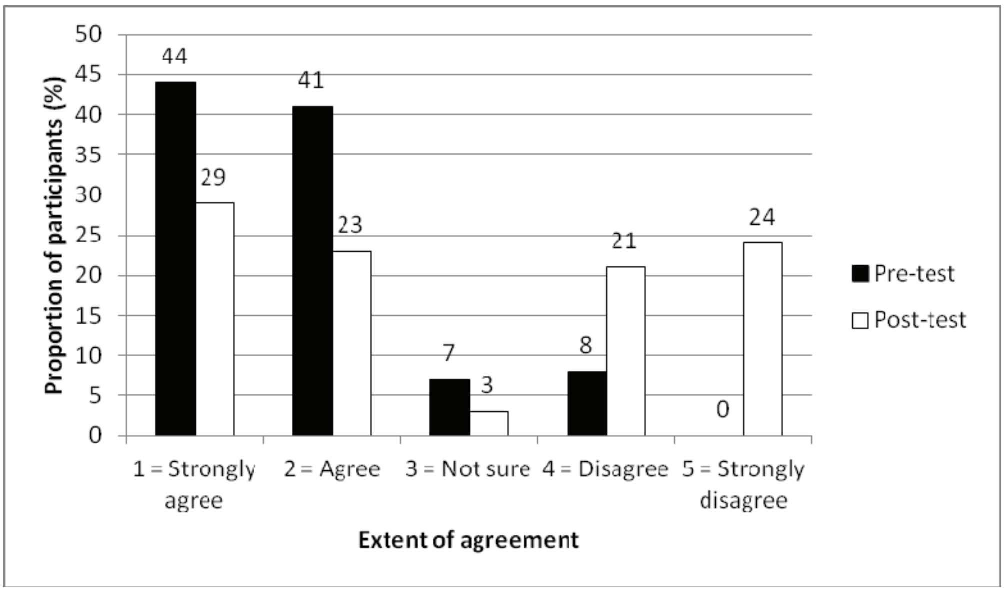

FIGURE 6.14: Extent of agreement among plot holders at Rabali with the statement, '*I would hire animal draught enterprise to prepare my land if it cost less than a tractor enterprise'*

Figure 6.15 shows the extent of agreement among plot holders with the statement, '*I would hire an animal draught enterprise to prepare my land if it prepared land in the same way as a tractor enterprise'.* The results depicted in Figure 6.15 indicate that before the intervention in 2010, the large majority of plot holders (90%) would hire an animal draught enterprise to cultivate their land if the quality of the service (condition of the land after the operation has been completed) was the same as that of a tractor enterprise The number dropped to 59% in 2011 when post-test survey was conducted. This change altered the mean score value from 1.76 in the pre-test survey to 2.65 in the post-test survey, which was highly significant ($p < 0.002$). The notion that the change in perception was highly significant was also supported by the results of the Wilcoxon matched pairs test ($p < 0.003$) and the Chi-square test ($p < 0.003$).

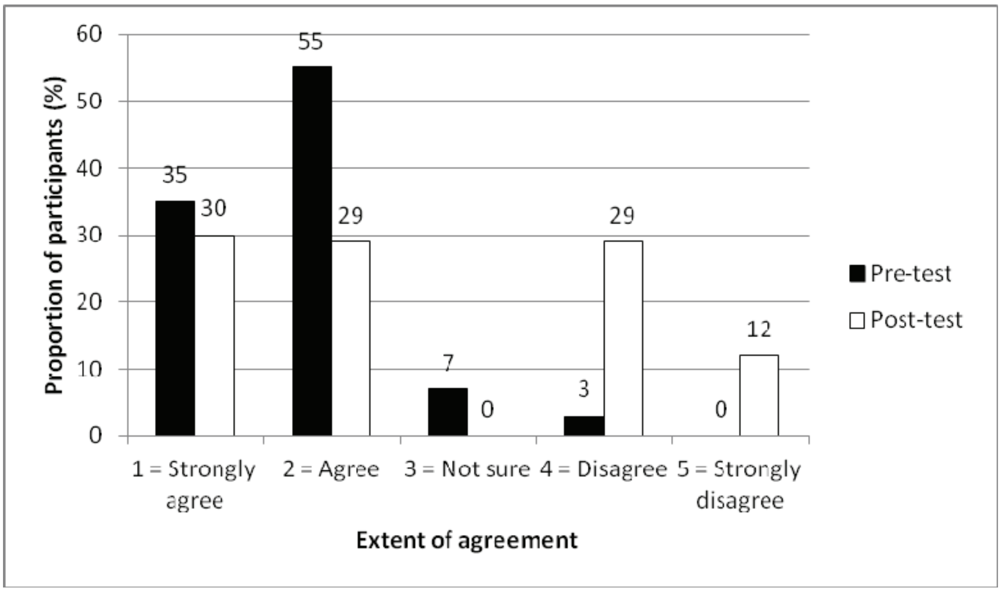

FIGURE 6.15: Extent of agreement among plot holders at Rabali with the statement, '*I would hire an animal draught enterprise to prepare my land if it prepared land in the same way as a tractor enterprise'*

Figure 6.16 shows the extent of agreement among plot holders with the statement, '*Animal draught enterprises plough as deep as tractors'.*

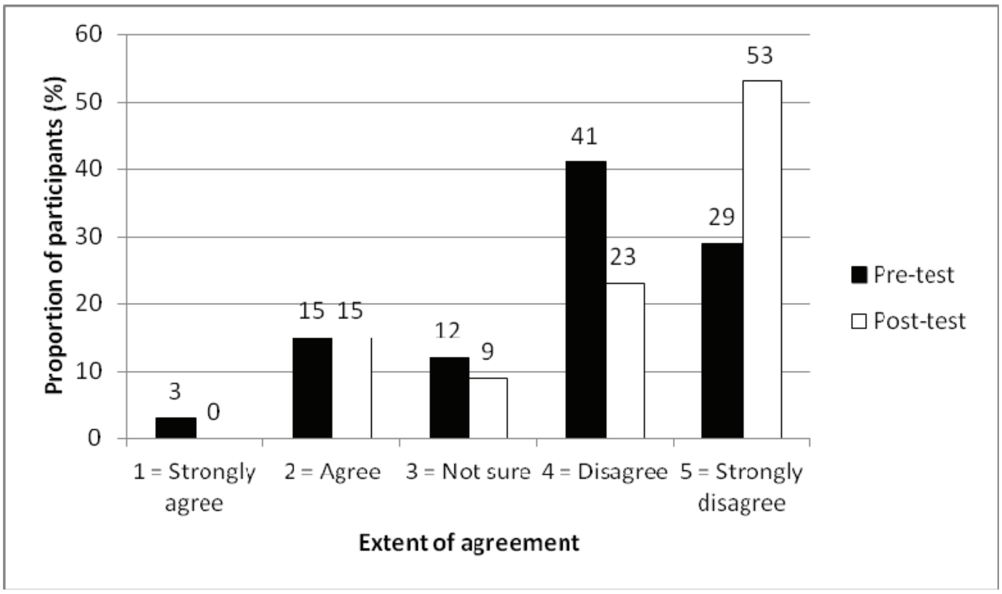

FIGURE 6.16: Extent of agreement among plot holders at Rabali with the statement, '*Animal draught enterprises plough as deep as tractors'*

Figure 6.16 shows that before the intervention the majority of plot holders (70%) did not believe that animal draught enterprises ploughed as deep as tractors. After exposure, the degree of disbelieve increased to 76%. The mean score value increased from 3.79 (pre-test) to 4.15 (post-test), but this increase was not significant ($p = 0.200$). The results of the Chi-square test ($p = 0.281$) and Wilcoxon matched pairs test ($p = 0.204$) also showed that the change was not significant.

Figure 6.17 shows the extent of agreement among plot holders with the statement, *'I prefer to have my land prepared by a tractor enterprise'.* Figure 6.17 shows that before the intervention (pre-test), the majority of plot holders (79%) indicated that they preferred to have their land prepared by a tractor enterprise. The proportion of plotholders who preferred tractor enterprises decreased to 44% after the intervention (post-test). This change increased the mean score value from 2.18 recorded in the pre-test survey to 3.18 in the post-test, the change was significant ($p < 0.006$). The significance change in perception was supported by the results of the Chi-square test ($p < 0.0001$) and the Wilcoxon matched pairs test ($p < 0.008$).

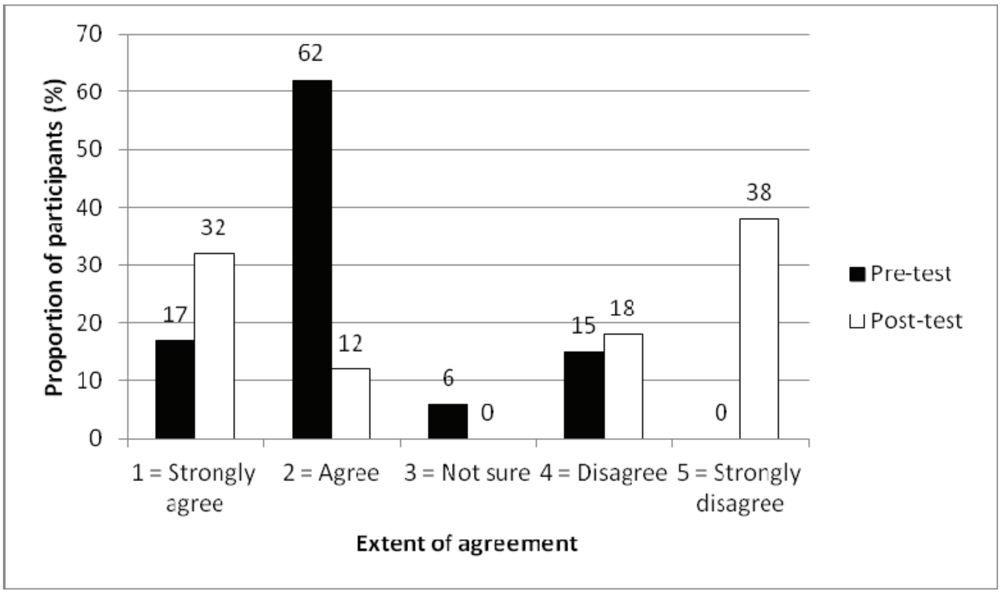

FIGURE 6.17: Extent of agreement among plot holders at Rabali with the statement, *'I prefer to have my land prepared by a tractor enterprise'*

Figure 6.18 shows the extent of agreement among plot holders with the statement, *'The use of animal draught to prepare land is old fashioned'*

Figure 6.18 shows that prior to the intervention (pre-test), 70% of plot holders perceived land preparation using animal draught enterprises as old fashioned. Their number dropped to 52% of plot holders in the post-test survey. The mean score value increased from 2.24 (pre-test) to 2.88 (post-test) but the change was not significant (p = 0.066). The results of the Chi-square test (p = 0.124) and Wilcoxon matched pairs test (p = 0.069) also supported the notion that the change was not significant.

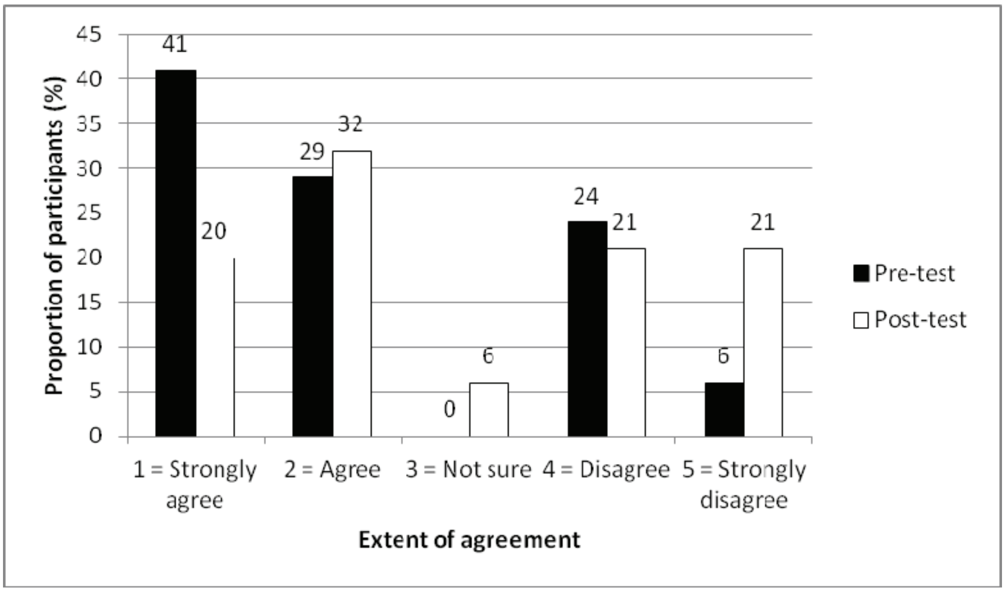

FIGURE 6.18: Extent of agreement among plot holders at Rabali with the statement, *'The use of animal draught to prepare land is old fashioned'*

Figure 6.19 shows the extent of agreement among plot holders with the statement, *'If it were available I would prefer to have my land prepared by animal draught enterprises'*

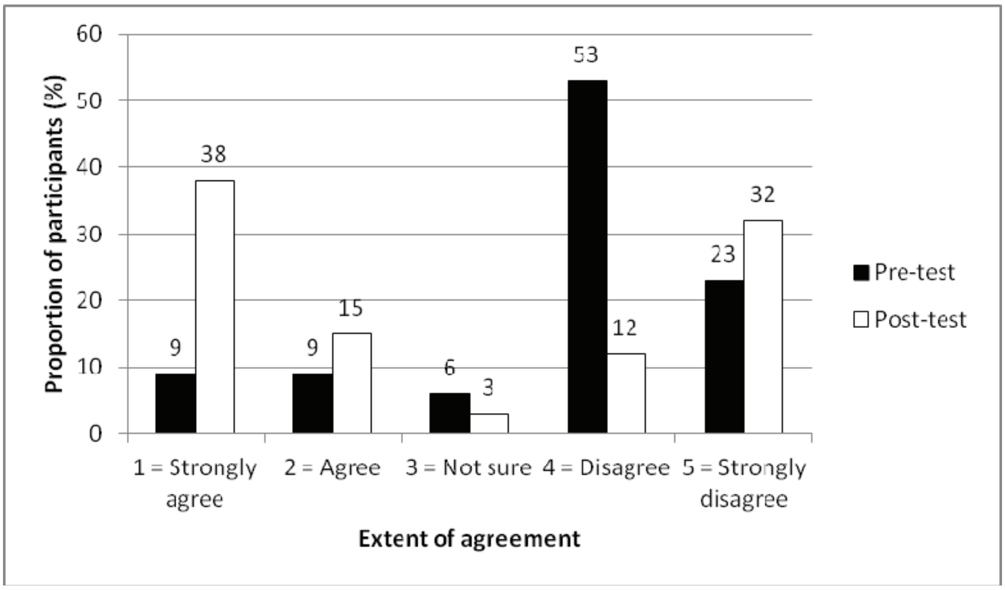

FIGURE 6.19: Extent of agreement among plot holders at Rabali with the statement, *'If it were available I would prefer to have my land prepared by animal draught enterprises'*

The data presented in Figure 6.19 show that only a minority of plot holders (18%) identified animal draught enterprises as their preferred choice of land preparation service during the pre-test survey. In the post-test survey, considerably more plot holders (53%) favoured animal draught enterprises. This is also indicated by the change in the mean score value which decreased from 3.74 in the pre-test survey to 2.85 in the post-test survey, a change that was significant ($p = 0.011$). The significance of the change in perception was supported by the results of the Wilcoxon matched pairs test ($p = 0.019$) and the Chi-square test ($p < 0.003$).

6.5 Discussion and conclusion

In this chapter the change in perceptions of plot holders on canal schemes about the use of land preparation services provided by enterprises using animal draught following the supply of new implements that enabled these enterprises to plough, disk and ridge land, as required by plot holders, was investigated. The working hypothesis of the study was that exposure to improved service provision by animal draught enterprises would result in plot holders developing more positive perceptions of animal draught enterprises. Generally, this was not the case. On the contrary, the change in perception tended towards the negative instead of the positive, with the majority of plot holders at both canal schemes developing a more definitive preference for tractor services. It was encouraging to see that the increased scepticism among plot holders about animal draught enterprises presenting a suitable alternative to tractor enterprises was not extreme. Moreover, at both schemes there were a minority of plot holders who did develop more positive perceptions of animal draught enterprises following exposure. From this it can be concluded that at this stage there is a demand for the land preparation services provided by animal draught enterprises on canal schemes, but this demand is limited and considerably smaller than the demand for tractor enterprises.

Plot holders identified the following advantages of using land preparation services provided by animal draught enterprises:

- Reduced cost per unit land prepared;
- Compared to tractors, which leave the section of the irrigation strip used for turning unprepared, animal draught enterprises cultivate the entire length of the irrigation strip; and
- Do not bury the nutrients contained in the topsoil as deeply as tractors.

The major disadvantages of using land preparation services provided by animal draught enterprises identified by plot holders included:

- Response time of animal draught enterprises is much longer than that of tractor enterprises;
- Some operators lack the required skills;
- Largely unavailable during winter because of the poor condition of the draught animals;
- Operate very slowly;
- Cannot cultivate dry soil;
- Land needs to be cleared of weeds first before animal draught enterprises can cultivate it, which increases labour for plot holders;
- Shallow ploughing depth;
- Bury the thrash and weeds less well than tractors;
- Compared to disking by tractor, zig-zag harrowing gives inferior results and was not worth the expense;
- Ridges constructed using animal draught are uneven in height and width, not straight and partially destroyed, because the animals trample on them.

The feedback obtained from plot holders indicated that the main advantage of using animal draught was a reduction in the cost of preparing land. This advantage is expected to gain in significance as the cost of diesel rises.

The quality concerns raised by plot holders about the service of animal draught enterprises were genuine (see also Chapter 5). This indicates that there is a need for research and development aimed at improving the technical capabilities of animal draught enterprises. Improvements of existing implements to better suit the needs of farmers on canal schemes is one of the avenues to be explored. Another is to have a new look at availing mules or horses, which might be better suited for this kind of work.

Other aspects that need attention are inadequacies in the technical skills of some operators, which have a negative effect on the quality of the different land preparation operations; and inadequacies in the management skills of some owners of animal draught enterprises, which affect the reliability of the service. Skills levels could be improved through training. For training purposes, the training manual developed by Simalenga, Sibanda & Jones (2012), entitled '*Guidelines on management of working animals'*, which was prepared under the auspices of this project, should prove useful.

The unavailability of animal draught enterprises during winter, apparently the result of the poor condition of the animals, suggests that working animals are being treated in the same way as other livestock in the smallholder areas of South Africa, in the sense that the animals are largely left to fend for themselves as far as satisfying their nutritional needs is concerned. Climatic conditions (seasonal rainfall) are responsible for the cyclical pattern in the availability grass and browse for livestock, explaining why the condition of livestock deteriorates during winter and improves during summer. It is critical that working animals receive adequate nutrition to maintain strength and condition so that services can be provided throughout the year. The production of nutritious animal feed on some part of the irrigation land is an obvious option to address this constraint.

The conclusions and recommendations presented above mirror those provided by plot holders, who recommended the following interventions to strengthen the contribution of animal draught enterprises to cultivation on canal schemes:

- The number of animal draught enterprises operating at the different schemes should be increased;
- Operators of animal draught enterprises should be trained;
- The operating speed of animal draught enterprises should be increased;
- The zig-zag harrow should be replaced by an implement that is able to generate a tilth that resembles the one achieved by disking;
- Grazing land should be set aside for draught animals so that these animals can be kept in working condition;

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CHAPTER 7

7 Irrigation scheduling on canal schemes

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7.1 Introduction

In Vhembe, where rainfall is highly seasonal, the availability of irrigation provides smallholders with important advantages over dryland farmers. One obvious advantage is that it enables farmers to produce crops outside the rainy season, creating opportunities to market produce during periods of limited supply when commodity prices tend to be high. Another is that it enables farmers to augment water availability to their crops during the rainy season, when the area experiences a dry spell. However, on most canal schemes in Vhembe access to irrigation water is restricted for various reasons, including:

- Seasonal fluctuations in the flow of the rivers that supply water to the schemes;
- Distribution losses caused by deterioration of the irrigation infrastructure (see Chapter 3);
- The front-ender – tail-ender phenomenon resulting in unequal access to water among farmers along the length of the main canal and along some of the secondary concrete distribution furrows (see Chapter 3); and
- Scheme rules that limit access to water among farmers, usually to one event per week (Van Averbeke, 2012 and Chapter 3).

Scheduling of irrigation plays a critical role in optimising the use of the irrigation water that is available. According to Annandale *et al*. (2011), the principal objective of irrigation scheduling is 'to minimise wasteful losses of water (percolation beyond what is necessary for salt leaching, surface runoff and evaporation) and maximise transpiration, which is the beneficial loss of water due to its direct link with dry matter production.' Irrigation scheduling is concerned with decisions on when to irrigate and how much water to apply. Annandale *et al*. (2011) reported on various methods that have been developed to assist the making of irrigation scheduling decisions. These methods are aimed at objective scheduling of irrigation based on crop water use, which can be estimated using various approaches. Annandale *et al*. (2011) pointed out that interest among farmers in objective scheduling was closely associated with the type of irrigation system they used. Farmers who used mechanised systems, such as centre pivot and micro-irrigation, were more interested in objective scheduling than farmers who practised surface irrigation. Annandale *et al*. (2011) also reported that flat-rate water tariffs militated against the adoption of objective scheduling among farmers. Such tariffs tended to encourage farmers to over-irrigate their crops. Finally, they warned that technology-driven approaches often failed to take the specific goals of the farmers and the constraints under which they operated into account and that this was a serious constraint to adoption of improved scheduling practices by farmers. Annandale *et al*. (2011) argued that adoption of improved scheduling practices depended on the relative advantage of new over current practice and on the compatibility of new practice with the existing farming system.

Most of the constraints to the adoption of objective irrigation scheduling identified by Annandale *et al*. (2011) apply to farmers on canal schemes in Vhembe. In 2010, they virtually all practised surface irrigation and none of them paid for water (Van Averbeke, 2012). In addition, their irrigation practices were governed by water-sharing rules, which restricted their decisions on when to irrigate to dichotomous propositions, i.e. to irrigate or not. They also had limited control over the amount (depth) of water to be applied during any particular irrigation event as a result of the short-furrow irrigation practice they applied. According to Crosby *et al*. (2000), the amount of water (gross application) that is added to the soil when using short-furrow irrigation is primarily function of the following factors:

- The infiltration characteristics of the soil;
- The flow rate of the stream in the lead furrow
- The time at which the flow in the short furrow is cut, i.e. before the water front reaches the cross-ridge to apply little water, or after it has reached the cross-ridge and water has been allowed to dam up against it in order to apply more water. Manipulation of the time when the flow in the short furrow is cut appears to allow farmers to vary the amount of water applied between about 10 mm and 20 mm (Crosby *et al*., 2000).

Considering the context in which irrigation scheduling on canal schemes occurs and the factors that constrain adoption of objective scheduling, particularly objective scheduling methods that require substantial levels of sophistication, it is imperative that research aimed at developing irrigation scheduling advice for canal irrigation scheme farmers would keep things simple. This requirement was at the forefront of our minds when we formulated the irrigation treatments to be tested. The following assumptions were made about the ability of smallholder canal irrigators to adjust their scheduling practices:

- Farmers can irrigate the conventional way; which comprises a single irrigation before planting, followed by not more than one irrigation per week after the crop has been planted, depending on the amount of rainfall received during the period between consecutive irrigation dates;
- Farmers can raise the soil water content of their soils prior to planting, followed by conventional irrigation after planting, as described above;
- Farmers can increase the frequency of irrigation to two irrigations per week by practising night-irrigation, which is an option in some but not all canal schemes;
- Farmers can combine the latter two practices.

Vegetables and maize are important commodities on canal schemes in the Vhembe District (Van Averbeke, 2012), but also on other smallholder schemes in South Africa (Mnkeni *et al*., 2010; Van Averbeke, Denison & Mnkeni, 2011; Cousins, 2013). This is clearly illustrated in Table 7.1, which shows the gross cash income generated by farmers at the Dzindi canal scheme through sales of fresh produce to street traders (Manyelo, 2011).

TABLE 7.1: Estimated gross income in cash obtained by farmers at Dzindi through sales of different commodities to the full population of street traders operating at the Scheme (June 2008 - May 2009) (from Manyelo 2011)

Fresh produce commodity	**Trader category**				**Total** (N=101)
	Bakkie (N=17)	**CBD** (N=54)	**Door-to-door** (N=12)	**Township pavement** (N=18)	
			R Annum^{-1}		
Green maize		97 015.00	5 056.00	15 593.00	117 663.00
Pumpkin leaves		36 190.00	3 384.00	9 026.00	48 599.00
Chinese cabbage		33 796.00	6 454.00	8 380.00	48 630.00
Nightshade		29 206.00	4 149.00	8 726.00	42 081.00
Swiss chard		6 210.00	935.00	3 780.00	10 925.00
Cabbage	138 125.00				138 125.00
TOTAL	**138 125.00**	**202 417.00**	**19 979.00**	**45 503.00**	**406 024.00**

CBD= Central Business District; R Annum^{-1}= Rand per year; N= Population

Besides the commodities listed in Table 7.1, maize grain was the only other commodity of note at Dzindi (Mohamed, 2006). Table 7.1 shows that in 2009, cabbages were top of the list in terms of gross total monetary income to farmers, followed by green maize, non-heading Chinese cabbage, pumpkins and nightshade. From this list two contrasting crops were selected to serve as test crops in the current irrigation scheduling study, which was aimed at developing scheduling advice for canal irrigation scheme farmers in the Vhembe District. These two crops were green maize and non-heading Chinese cabbage.

Green maize was selected because

- Among the fresh produce commodities listed in Table 7.1, (green) maize was the only crop of which the harvested part was a reproductive organ. For all other fresh produce commodities in Table 7.1 it was the leafy parts of the plants that were harvested and sold.
- Among the listed commodities only green maize and pumpkins are summer crops even though green maize can be grown all year round (see Chapter 7). This has implications for irrigation scheduling, because rain in Vhembe falls almost exclusively during summer
- Maize has a deep root system that can extract large quantities of water from deep soils before showing stress (Dardanelli *et al*., 1997). For example, in experiments on a deep fine sandy (8-10% clay) soil of the Mangano series of the Hutton form at Vaalharts irrigation scheme, maize extracted water from as deep as 200 cm, which was the maximum depth to which soil water content was being monitored (Boedt & Laker, 1985). Measuring the profile available water capacity of maize on the same Dzindi soil as was used in the current study Nndwammbi (2009) recorded a value of 81 mm and reported that the crop was extracting water from depths exceeding 1575 mm.

Non-heading Chinese cabbage (*Brassica rapa* subsp. *chinensis*) was selected because

- It is a crop of which the leafy parts are harvested.
- Together with white cabbage it is the main winter crop at Dzindi.
- It has a very shallow root system, which is mainly limited to the upper 35 to 40 cm of the soil profile (Opeña *et al*., 1988; Nndwammbi, 2009).

The specific objective of the study was to evaluate the effect of different irrigation scheduling practices on the yield of these two crops.

7.2 Review of literature

7.2.1 Irrigation scheduling

Irrigation scheduling is deciding when and how much to irrigate (Leib *et al*., 2002). In the past, irrigation scheduling was usually aimed at optimising water supply to the crop to achieve the highest possible production. Global water shortages, which are becoming increasingly serious, have created the need to develop methods of irrigation that minimise water use and maximise water use efficiency. Deficit irrigation, defined as the application of water below the full evapotranspiration (ET) requirements of the crop (Fereres & Soriano, 2007) is increasingly considered as a strategy in irrigated farming under conditions of limited water availability. One of the main ways in which deficit irrigation is applied in order to avoid yield reductions is to provide the crop with a substantial soil water reserve. The idea behind this strategy is that water extraction from the soil reserve can make up for the deficits that result from applying less water than needed to meet the full ET requirements of the crop. In this way transpiration and biomass production can be maintained at maximum rates.

Vanassche and Laker (1989) highlighted the importance of applying water frequently when using deficit irrigation to avoid yield reductions. They referred to this practice as 'deficit high frequency irrigation' and reported greater amounts of water being extracted from the soil profile, especially from the deeper layers, before onset of crop water stress than when long drying cycles were used. South African examples where deficit irrigation reduced water consumption without negatively affecting yield, and thus increasing water use efficiency, include:

- Marais (1985) for wheat;
- Vanassche & Laker (1989) for maize and wheat;
- Fischer (1995) for tomatoes;
- Nel (1995) for grape vines; and
- Beukes *et al*. (2003) for deciduous fruit.

Annandale *et al*. (2011) provided a broad overview of approaches to deficit irrigation other than deficit high frequency irrigation but not all of these have application in canal irrigation.

7.2.2 Irrigation scheduling in maize production

Irrigation scheduling and deficit irrigation in the production of maize have received considerable attention (Vanassche & Laker, 1989; Pandey *et al*., 2000; Farré & Faci, 2009; Mansuri-Far *et al*., 2010; Popova & Pereira, 2010) but in all of these studies grain and total biomass were the focus of attention. Fundamentally, green maize production is also concerned with grain and total biomass but has the additional requirement that the cobs being produced must meet size requirements and must be filled uniformly to be marketable. This has implications for planting density, because intra-specific competition for light reduces cob size when a threshold is exceeded (Van Averbeke, 2008; Chapter 7). As a result, maize is planted less dense when grown for green maize (not more than 4 plants m^{-2}) than when planted for grain (6-8 plants m^{-2}).

There is general agreement that maize is most sensitive to water deficit during the 30 day period that brackets anthesis. Water stress during this period reduces kernel number and kernel mass, and consequently grain yield and harvest index (Otegui *et al*., 1995; Pandey *et al*., 2000; Çakir, 2004; Moser *et al*., 2006; Igbadun *et al*., 2007; Farré & Faci, 2009; Mansuri-Far *et al*., 2010). Maize growth and yield is not much affected, and could even benefit, when exposed to water stress during the seedling stage. Water stress during this early stage of growth makes the maize plants better adapted to water stress later in the season than plants that were well-irrigated during the seedling stage (Kang *et al*., 2000). Water stress during vegetative growth has much less impact on biomass production and grain yield of maize than when water stress occurs during the period around anthesis (Pandey *et al*., 2000). However, water stress during the period of rapid vegetative growth reduces plant height and leaf area (Çakir, 2004) and kernel number could be reduced as well (Eck, 1986). Water stress during grain filling mainly affects kernel mass (Eck, 1986).

In green maize production in Vhembe, the marketability of maize cobs is dependent on cob size and uniformity of grain filling (Van Averbeke, 2008; Manyelo, 2011). Results of studies that investigated the effect of water stress on maize indicate that water stress should be avoided totally during the 30 days bracketing anthesis, because this reduces kernel number, which is associated with cob size (van Averbeke, 2008). Water stress during early vegetative growth appears allowable but water stress during rapid vegetative growth, which starts about 30 days after planting, should also be avoided because of its potential negative effect on kernel number and, therefore, cob size. Water stress during the grain filling stage could cause kernel abortion if severe, but when mild it is expected to mainly affect kernel mass. Whilst kernel mass reduction is not desirable in green maize production, it does not preclude cobs from being marketable as it neither affects cob size nor uniformity of grain filling. This contrasts with maize produced for grain, because reduction in kernel mass causes a decline in grain yield.

Reducing planting density can also be used as a strategy to avoid water stress because increasing the spacing between plants increases the size of the soil water reserve available to each plant (Van Averbeke & Marais, 1995). However, under relatively well-watered conditions reducing planting density tends to reduce water use efficiency (Van Averbeke & Marais, 1992; 1994). One reason for the reduction in water use efficiency resulting from lowering planting density is that it tends to increase evaporation losses (less soil shading) more than it reduces transpiration losses (lower leaf area surface) The second reason is that reducing the planting density below the optimum reduces both biomass and grain yield. However, in green maize production, the use of below-optimum planting densities is quite attractive, because it can protect the plants against the negative effects of minor growth limitations, such as mild water deficits or nutrient deficits, by providing a greater soil volume to each plant from which to tap water and nutrients. When planting green maize at the optimum density (spacing that produces the highest number of marketable cobs per unit area as identified in Chapter 7) the crop is highly sensitive to growth factor limitations, and when these do occur they may cause crop failure, in the sense that the cobs produced do not meet the quality requirements (small size, incomplete filling).

7.2.3 Irrigation scheduling in the production of leafy vegetables

Irrigation scheduling in the production of leafy vegetables has mostly been aimed at meeting the full evapotranspiration requirements of these crops, because the achievement of maximum yield of leafy vegetables appears to be dependent on the full evapotranspiration requirements of these crops being met (Costa, Ortuňo & Chaves, 2007). The principal reason for this is that leaf production is a function of cell expansion, which is among the plant physiological processes most sensitive to water stress (Hsiao, 1973; Costa *et al*., 2007). As indicated earlier, the circumstances prevailing on canal irrigation schemes could prevent farmers from meeting the full evapotranspiration requirements of the various leafy vegetables they produce. This was tested for Chinese cabbage.

7.3 Materials and methods

7.3.1 Green maize experiments

In this study, charging of the soil profile to field capacity prior planting and planting maize at a density below the optimum for green maize production were combined to reduce the risk of water deficit in green maize production. The focus of the study was on the effect of charging the rooting depth of the soil to field capacity before planting. The effect of this practice on green maize was investigated in the context of existing irrigation practice at Dzindi, where farmers irrigate once per week, applying about 20 mm, and do not charge the full rooting depth to field capacity. The hypothesis of the study was that irrigating the soil profile to field capacity before planting increases the leaf area per plant, cob length, ear length and kernel number per ear of early planted green maize relative to when the crop is grown using the existing irrigation scheduling practice of farmers, which does not involve the filling of the soil profile before planting. This hypothesis was tested by means of two field experiments conducted during the 2009-10 and 2010-11 summers at Dzindi Irrigation Scheme.

Variables describing the climate of Thohoyandou are presented in Table 7.2. The data in Table 7.2 are based on a ten-year record that lasted from 1981 to 1990 (Weather Bureau, 1992). During that period, Thohoyandou received an annual rainfall of 697 mm but that period coincided with a dry cycle and the long-term mean annual rainfall of Thohoyandou might be higher than indicated. Table 7.2 shows that most of the rain (79.5%) falls during the six-month period that starts in October and ends in March. The daily mean number of sunshine hours show that cloudy conditions prevail during this period limits evaporative demand. As a result, reference crop evapotranspiration (ETo), which was estimated by De Mey (2002), shows a peak during May and another peak during August and September. The total annual reference crop evapotranspiration (ETo) amounts to 1709 mm, and the resulting aridity index (P/ETo) is 0.41. The climate of areas with an aridity index ranging between 0.25 and 0.50 is categorised as semi-arid (Stewart, 1988).

TABLE 7.2: Climatic variables for Thohoyandou (after Weather Bureau, 1992; De Mey, 2002)

Month	P (mm)	Mean t_{max} (^{0}C)	Mean t_{min} (^{0}C)	R.H (%)	Wind speed (km/d)	Sunshine (hr/d)	Radiation (MJ/m^2.d)	ETo (mm/d)
January	74	30.8	19.9	60.5	207.4	6.0	13.4	4.02
February	108	30.0	19.7	62.0	207.4	5.4	14.4	4.17
March	75	29.6	18.9	60.0	190.1	5.9	16.9	4.56
April	47	27.6	16.4	58.5	190.1	6.5	19.2	4.79
May	15	26.2	12.7	54.0	198.7	8.6	22.9	5.26
June	17	23.6	9.9	53.0	198.7	8.7	23.0	4.95
July	14	23.7	9.8	53.5	198.7	9.1	23.6	4.99
August	11	25.4	11.7	52.0	207.4	9.1	23.2	5.23
September	39	27.2	14.2	50.5	233.3	8.9	21.6	5.41
October	93	27.5	16.3	53.5	224.6	7.1	17.1	4.64
November	76	28.9	17.6	57.5	224.6	6.4	14.2	4.16
December	128	30.0	19.4	58.0	216.0	6.1	13.0	3.97
Total	**697**							**1709**

The experiment was conducted on Plot 1 of the Dzindi Irrigation Scheme (23^o 01'S; 30^{o}26'E), Thulamela Municipality, Vhembe District, Limpopo Province, South Africa. The soil at the experimental site was classified as Hutton Suurbekom (Soil Classification Working Group, 1991) and Rhodic Ferralsol (ISSS-ISRIC-FAO, 1998) and had a depth that exceeded 1500 mm.

The experiment involved three irrigation treatments, namely

- Full irrigation treatment (FIT);
- Farmer treatment (FT); and
- Charged farmer treatment (CFT).

The full irrigation treatment (FIT) consisted of charging the soil profile to field capacity to a depth of 1575 mm before planting, followed by recharging the soil profile to field capacity whenever 20 mm water had been extracted from the profile.

In the farmer treatment (FT), 20 mm was applied before planting and there after the crop received a single irrigation of 20 mm every week. The application of 20 mm corresponded with the average amount of water that entered the Hutton soils at Dzindi when using short furrow irrigation (Van der Stoep & Nthai, 2005). The weekly irrigation interval was in line with the rules governing access to water at Dzindi and most other smallholder canal schemes (Van Averbeke, 2008).

In the charged farmer treatment (CFT), the soil was charged to field capacity before planting to a depth of 1575 mm, and there after the crop received a single irrigation of 20 mm per week.

The treatments were laid out using a randomised complete block design with four replications. The plot size of 9.6 m x 4.5 m was used, resulting in a gross plot size of 43.2 m^{-2}. Plots were separated from each other by a 1.4 m wide strip.

The soil at the experimental site was prepared by ploughing, disking and ridging, followed by the laying out of the plots. The maize cultivar SC701, one of the premier green maize cultivars in South Africa, was used as the test crop. In each plot, maize was planted in 6 rows that were 0.75 m apart, using an intra-row spacing of 0.6 m, resulting in a planting density of 2.22 plants m^{-2}.

The 2009 experiment was planted on the 28th of September 2009 and harvested on the 31st of December 2009. The 2010 experiment was planted on the 5th of August and harvested on the 29th of November 2010. The August planting date used in the 2010 experiment coincided more closely with the planting date used by local green maize growers than the late-September planting date used in 2009.

At planting, furrows were opened using a hand hoe and the fertiliser mixture 2:3:4 (30) at the rate of 450 kg ha^{-1} in 2009 and 350 kg ha^{-1} in 2010 as well as limestone ammonium nitrate (LAN) (28%N) at the rate of 107 kg ha^{-1} in 2009 and 90 kg ha^{-1} in 2010 were applied in the bottom of these furrows. These fertilisers were worked into the soil by dragging a stick along the bottom of the furrow. Then 10 L water was applied uniformly along the length of the furrow, and when the water had infiltrated a marked planting chain was used to locate the planting stations at which three seeds were pressed into the wet soil and covered with about 5 cm of soil, using a rake. At the four-leaf stage (about 4 weeks after planting), the plants were thinned out to one plant per hill. Immediately after thinning, LAN was band placed in a furrow parallel to each row, which was opened by means of hand hoe about 15 cm to the side, at the rate of 107 kg ha^{-1} in 2009 and 90 kg ha^{-1} in 2010. Five additional applications of LAN at the same rates of 107 kg ha^{-1} in 2009 and 90 kg ha^{-1} in 2010 using the same procedure, occurred two weeks later, and then at weekly intervals with the last application taking place at anthesis (about 70 to 75 days after planting). Table 7.3 summarises the nutrients received by the crop.

TABLE 7.3: Summary of nutrient application in the 2009 and 2010 green maize irrigation experiments at Dzindi

Type of fertiliser	Fertiliser application rate (kg ha^{-1})	Total N applied (kg ha^{-1})	Total P applied (kg ha^{-1})	Total K applied (kg ha^{-1})
		2009		
2:3:4 (30)	450	30	45	60
LAN (28% N)	6 x 107	180	0	0
TOTAL	**-**	**210**	**35**	**60**
		2010		
2:3:4 (30)	350	23	35	47
LAN (28% N)	6 x 90	151	0	0
TOTAL	-	**174**	**35**	**47**

The plots were kept free of weeds throughout the growing period and the stands were protected against pests and diseases using practices recommended by The National Department of Agriculture (2007:93-103) for the control of cutworms (*Agrotis* spp.), leaf hoppers (*Cicadulina bila*), aphids (*Rhopalosiphum maidis*) and maize stalk borer (*Busseola fusca*).

Data collected included soil water content at regular intervals during the growing season in all plots, water applied, leaf area of maize plants at regular intervals until anthesis, cob length, ear length, and kernel number per ear of the main ear.

Total consumptive water use by maize in the different treatments was calculated using the procedure reported by Van Averbeke & Marais (1992), and was the sum of rainfall received during the growing season, the total amount of irrigation water applied and the contribution of stored soil water, obtained by deducting the soil water content at planting from the soil water content at harvest. Rainfall data were collected on-site using a plastic rain gauge mounted 1.2 m above the soil surface. Soil water in the different treatments was monitored by means of

Neutron Moisture Probe (Waterman, model FY500, Geotech, Pretoria). For this purpose, two 1.8 m long aluminium access tubes were inserted in the soil at representative positions in the planting row near the middle of the plots after ridging was completed and plots had been laid out. Soil water was monitored every second day in the FI treatment and once per week in the FT and CFT treatments to a depth of 1575 mm. The FI treatment plots were irrigated as soon as soil water monitoring indicated that the profile water had dropped 20 mm below field capacity.

Leaf area development in the different treatments was monitored using the procedures described by Van Averbeke & Marais (1992). To that effect, 10 plants located in the net plot area were randomly selected in each of the 12 plots and their leaf area development was recorded. Measurements were done once per week and involved the determination of length and width of the leaves that had become fully developed during the seven day period that followed the previous leaf measurement. For each leaf, the product of length and width was multiplied by a correction factor to account for the shape of the leaves. The correction factors for the different leaf positions were obtained from Van Averbeke (1991:116-117). At any one stage during the season, total leaf area of a plant was the sum of the areas of all fully developed leaves minus the area of the leaves that had senesced by that time.

The length of the main cob was determined in two ways. The first measurement was the length of the cob as it was being traded, with part of the stem and the inner husk still intact. This measurement is referred to as the cob length. The second measurement followed the removal of the remainder of the husk and stem, leaving only the ear (the rachis to which the kernels are attached) and this measurement is referred to as the ear length. Kernels per ear were counted following measurement of the ear length. Marketability of the cobs was determined using the criteria shown in Table 7.4.

TABLE 7.4: Length limits for the three grades of green maize cobs and ear and prices paid to farmers at Dzindi in 2010

Grade	**Cob length** (cm)	**Approximate ear length**[1] (cm)	**Farm price**
1	>30	>22	R2.00
2	27 to 30	19-23	R1.50
3	<27	<19	Not marketable

[1] Ear differs from cob in that the cob still has part of the stem and the inner husk still intact

Hawkers who purchase cobs use cob length to assess marketability. Statistical analysis of multiple samples of cobs purchased by street traders from farmers at Dzindi showed that to be marketable as Grade 1 cobs, cobs needed to be longer than 30 cm. This confirmed the length limits reported by Van Averbeke (2008). Additional background on the criteria used by street traders when purchasing cobs from farmers at Dzindi is provided in Chapter 8 of this report.

Analysis of variance using the SAS statistical package (Statistical Analysis Software Institute Inc., 2000) was performed to test for treatment effects and the Fisher's protected LSD test (p=0.05) to separate treatment means.

7.3.2 Chinese cabbage experiments[6]

Non-heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*) is an annual, flowering, leafy vegetable, in which the leaves form a rosette (Hill, 1990). Depending on variety and growing conditions, the crop takes six to eleven weeks from sowing to harvest (Rubatzky & Yamaguchi, 1997). The crop is harvested as complete plants or by sequentially removing single leaves (Matsumura, 1981; Peirce, 1987). Fresh leaf yields range between 5 t ha^{-1} and 30 t ha^{-1}, depending on prevailing environmental conditions, variety and planting density (Tindall, 1983).

Non-heading Chinese cabbage is an important indigenised leafy vegetable in the Vhembe District of Limpopo Province, where it is primarily grown during the dry winter months, making it reliant on irrigation for its water requirements. Smallholder canal schemes are the primary locus of production of this crop in the District (Van Averbeke, Tshikalange & Juma, 2007a). Farmers on canal schemes in Vhembe almost invariably practise short-furrow irrigation and share irrigation water through the use of a time table (Van Averbeke, 2012). As indicated in the introduction of this report, short-furrow irrigation leaves limited room to adjust the amount of water applied per irrigation event and irrigation frequency is determined by the prevailing water sharing arrangements, which usually restrict farmers to a single irrigation per week. However, on schemes where water in the main canal flows continuously and is not used to fill storage dams during the night, plot holders can access additional irrigation water after sunset.

[6] Some of the findings on irrigation scheduling in Chinese cabbage presented here have been published in the South African Journal of Plant and Soil (VAN AVERBEKE, W. & NETSHITHUTHUNI, C. 2010. Effect of irrigation scheduling on leaf yield of non-heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*). *South African Journal for Plant & Soil*, 27(4): 322-327.)

Generally, achieving maximum yield of leafy vegetables is dependent on the full evapotranspiration requirements of these crops being met (Costa, Ortuňo & Chaves, 2007), but the circumstances prevailing on canal irrigation schemes could prevent farmers from achieving this requirement. The objective of this study was to determine the effect of different irrigation scheduling practices on the leaf yield of non-heading Chinese cabbage and to assess the implications of the findings for the production of the crop on smallholder canal schemes in the Vhembe District.

The effect of five different irrigation scheduling practices on the leaf yield of non-heading Chinese cabbage was investigated experimentally on the same plot as was used to conduct the green maize scheduling experiments. Five irrigation scheduling treatments were arranged using a complete randomised block design with four replications.

- The full irrigation (FI) treatment was aimed at meeting the crop water requirements in full and consisted of charging the upper 800 mm of the soil profile to field capacity before planting, followed by recharging this part of the profile to field capacity every other day.
- The minimal irrigation (MI) treatment was a deficit irrigation treatment, which involved charging the upper 800 mm of the soil profile to field capacity before planting, followed by the application of 20% of the amount of water applied to the FI treatment on a weekly basis.
- The farmer (F) treatment mimicked the irrigation practice of Chinese cabbage growers at Dzindi and consisted of applying 20 mm of water before planting, followed by weekly applications of 20 mm each.
- The double frequency farmer (DFF) treatment was the same as the F treatment except that the plots received two applications of 20 mm per week instead of one.
- The charged farmer (CF) treatment, consisted of charging the upper 800 mm of the soil profile to field capacity before planting, followed by the application of 20 mm irrigation water per week.

The experiment was conducted twice, first in 2007 and again in 2009. The focus of the 2009 experiment was to determine whether differences in fresh leaf harvests among irrigation scheduling treatments were due to differences in the number of leaves per plant, differences in the size and mass of leaves, or both.

The soil was prepared by ploughing, disking and ridging. The individual plots were 5.1 m long and 4.5 m wide. The planting rows were spaced 0.75 m apart, in line with farmer practice, and the spacing between plants in the row was 0.3 m, resulting in a planting density of 4.44 plants m^{-2}, which was slightly lower than the average planting density of 5.3 plants m^{-2} used by producers in Vhembe (Van Averbeke *et al*., 2007a).

The first experiment was planted on the 27th of May 2007 and the second on 15 June 2009. In both seasons the crop was propagated directly from seed of the *dabadaba* land race, which was sourced from local farmers. At planting, furrows were opened using a hand hoe and a marked planting chain was used to locate the planting stations at which five seeds were pressed into the wet soil and covered with about 10 mm of dry soil. At the four-leaf stage, the plants were thinned out to one plant per hill.

Cattle and chicken manure were each applied at the rate of 3 t ha^{-1} (air-dry) after ploughing and incorporated in the soil during disking. At planting, the fertiliser mixture 2:3:2 (22) was applied in the planting furrow at the rate of 624 kg ha^{-1}. LAN (28% N) was band-placed at the rate of 150 kg ha^{-1} when the plants had reached the eight-leaf stage and again one week later at the rate of 100 kg ha^{-1}. The resulting total application of 213 kg N ha^{-1}, 99 kg P ha^{-1} and 75 kg K ha^{-1} were within the optimum range for *dabadaba* identified by Van Averbeke, Juma & Tshikalange (2007b).

A knapsack sprayer was used to apply Parathion (active ingredient *parathion*) for the control of aphids (*Brevicoryne brassicae*) and bagrada bugs (*Bagrada hilaris*) and Kelthane (active ingredient *dicofol*) for the control of red spider mites (*Tetranychus urticae*) at the rates recommended by the National Department of Agriculture (2007).

All harvesting of leaves occurred between 7 and 9 am when the leaves were at full turgor. Harvesting was done in accordance with the staged harvesting procedure described by Van Averbeke *et al*. (2007b). This involved harvest of the fifth leaf when the plants reached the eight-leaf stage, harvest of the sixth and seventh leaf one week later and harvest of the remaining leaves when peduncle elongation was observed in 50% of the plants. The first four leaves of each plant were removed when the fifth leaf was harvested and their mass was added to total biomass, because their small size does not render them marketable. Biomass measurements were done using a portable electronic scale with a capacity of 23 kg and an accuracy of 100 mg. Dry biomass was obtained by drying representative moisture samples in a forced draught oven at 65 ^{o}C until constant mass

Soil water content in the plots was monitored by means of a neutron hydro probe (Waterman, model FY500, Geotech, Pretoria). For this purpose, two access tubes were inserted in the two central planting rows near the centre of each plot. Soil water was monitored to a depth of 900 mm.

Irrigation water was applied in the furrows by means of calibrated buckets. For any particular period of growth, consumptive water use was the sum of the change in stored soil water content, the rainfall received and the irrigation water applied during that period. Daily rainfall was measured on site.

In the 2009 experiment 10 plants were randomly selected in each plot for detailed monitoring of leaf size, leaf number, leaf mass (fresh and dry) and total biomass at final leaf harvest.

Data collected in the 2007 experiment included soil water content at regular intervals during the growing season and fresh leaf mass. To these were added area and fresh and dry mass of leaves for each leaf position, as well as total biomass (fresh and dry) in the 2009 experiment.

Analysis of variance using the SAS statistical package (Statistical Analysis Software Institute Inc., 2000) was performed to test for treatment effects and the Fisher's protected LSD test (p=0.05) to separate treatment means.

7.4 Results

7.4.1 Green maize

Rainfall received during the growing season of maize in two experiments is presented in Table 7.5. From Table 7.5 it is evident that in the 2009 experiment, which was planted at the end of September, the expected effects of irrigation treatment on leaf area per plant, cob and ear length and kernel number per ear among treatments were unlikely to feature due to the above-average rainfall received during the last two-thirds of the growing season. A total of 418.3 mm rain was recorded, with most of it falling during November.

TABLE 7.5: Rainfall recorded in the 2009 and 2010 green maize irrigation experiments at Dzindi

Period	**Rainfall (mm)**
28-30 September 2009	0.0
01-31 October 2009	8.0
01-30 November 2009	308.8
01-31 December 2009	101.5
Total 2009 growing season	**418.3**
5-31 August 2010	0.0
01-30 September 2010	0.0
01-31 October 2010	16.0
01-29 November 2010	153.3
Total 2010 growing season	**169.3**

The 2010 experiment was planted early in August with the expectation that rainfall would have less impact on soil water availability than was the case in the 2009 experiment. As per expectation, Table 7.5 shows that there was no rain during the first two months of the experiment and in October a mere 16 mm of rain was recorded, but November was quite wet. The total amount of rainfall received during the entire 2010 growing season was 169.3 mm.

Plates 7.1 and 7.2 show maize in the 2010 green maize irrigation scheduling experiment. Selected results obtained in the 2009 and 2010 irrigation scheduling experiments with green maize are presented in Table 7.6.

PLATE 7.1: View of part of the 2010 irrigation scheduling experiment at Dzindi when maize had just entered the stage of rapid vegetative growth

PLATE 7.2: View of part of the 2010 irrigation scheduling experiment at Dzindi when maize was about ready to have the cobs harvested for green maize

TABLE 7.6: Effect of irrigation treatment on leaf area per plant at pollen shed, leaf area per plant at anthesis, cob length, ear length and kernel number per ear of maize in the 2009 and 2010 green maize irrigation experiments at Dzindi

Variable	**Irrigation scheduling treatments**			**Level of significance**	**LSD (p=0.05)**
	Full irrigation	**Charged farmer treatment**	**Farmer treatment**		
		2009 experiment			
Total consumptive water use (mm)	838[a]	653[b]	582[b]	0.002	110.7
Total irrigation water applied (mm)*	473	260	206		
Leaf area per plant at anthesis (cm^2)	837	880	850	0.42	-
Cob length (cm)	33.4	33.9	33.9	0.73	-
Ear length (cm)	26.5	26.1	26.1	0.60	-
Kernel number of main ear	646[a]	629[a]	586[b]	0.03	43
Proportion of cobs that were marketable (%)	100	100	100	-	-
		2010 experiment			
Total consumptive water use (mm)	811[a]	508[b]	466[b]	<0.001	47
Total irrigation water applied (mm)	762	431	350		
Leaf area per plant at anthesis (cm^2)	1167	1165	1142	0.75	-
Cob length (cm)	39.7	39.9	39.0	0.74	-
Ear length (cm)	31.4	29.6	29.2	0.13	-
Kernel number of main ear	682	655	654	0.40	-
Proportion of cobs that were marketable (%)	100	100	100	-	

LSD = Least significant difference; * includes irrigation water applied to raise the water content of the profile to field capacity

In the 2009 experiment, differences in consumptive water use due to treatment were highly significant. Total consumptive water use in the full irrigation treatment (838 mm) was 185 mm (28%) more than in the charged farmer treatment (653 mm) and 256 mm (44%) more than in the farmer treatment (582 mm). Differences in consumptive water use due to treatment were again highly significant in the 2010 experiment. Total consumptive water use in the full irrigation treatment (811 mm) was 303 mm (60%) more than in the charged farmer treatment (508 mm) and 345 mm (74%) more than in the farmer treatment (466 mm). Treatment differences in irrigation water applied, including pre-plant irrigation applied to raise the water content of the soil to field capacity in the full irrigation and charged farmer treatment were identified. The abundance of rainfall received during the second half of the growing season in the 2009 experiment was responsible for the reduced irrigation requirement compared with the 2010 season, during which much less rain was received.

In the 2009 experiment, leaf area per plant at anthesis, cob length and ear length of maize in the three scheduling treatments were very similar. The minor differences among the treatment means were not significant ($p>0.05$). Considering the large differences among treatments in irrigation water applied, it was somewhat surprising that there were no treatment effects on leaf area per plant at anthesis, cob length and ear length in the 2010 experiment. Minor differences in the numerical values among the treatment means were not significant ($p>0.05$). Noteworthy, however, were the substantial differences between the cob length and ear length treatment means obtained in the two seasons. Compared to the 2009 experiment across treatments, maize in the 2010 experiment had 35% more leaf area per plant at anthesis, produced on average cobs that were 17% longer, and had ears that were 15% longer and contained 7% more kernels. Differences in intercepted photosynthetic radiation per plant (IPARP) were probably responsible for the differences in these indicators between the two seasons. Cloudy conditions, which reduce IPARP, prevailed during much of the 2009 season, whilst during most of the 2010 season the sky was not overcast.

In the 2009 experiment, the number of kernels on the main ear was affected significantly ($p<0.05$) by treatment. Ears in both the full irrigation treatment and charged farmer treatment contained significantly more kernels than those of maize plants grown in the farmer treatment. In the 2010 experiment the ears in the full irrigation treatment tended to have more kernels than those in the other two treatments, but differences among treatment means were not significant ($p>0.05$), despite the large differences in applied irrigation water and consumptive water use.

Also of importance to the objectives of the study was the net contribution of stored soil water to consumptive water use of maize. In the 2009 experiment, treatment effect on the net contribution of stored soil water to consumptive water use of maize was significant (p=0.035). In the full irrigation treatment the soil water content at harvest was 4.9 mm more than at planting and in the case of the farmer treatment it was 1.2 mm more. This meant that in these two scheduling treatments, stored soil water made no net contribution to the consumptive water use of maize. The charged farmer treatment was the only scheduling treatment in which the soil reserve made a net contribution to consumptive water use of maize. On average this contribution amounted to 54 mm, which represented 8.3% of total consumptive water use in this treatment. In the 2010 experiment, stored soil water did not make a net contribution to consumptive water use of maize in the full irrigation and the farmer treatments. At harvest the soil in the full irrigation treatment contained 8 mm more than at planting, whilst in the farmer treatment it was 29 mm more. The charged farmer treatment was the only treatment in which stored soil water made a positive net contribution to consumptive water use of maize but this contribution was very small (13 mm), and contributed only 2.6% to the total consumptive water use of maize in this treatment. Differences in the net contribution of stored soil water to consumptive water use of maize in the 2010 experiment were not significant (p=0.109).

7.4.2 Chinese cabbage

Table 7.7 presents the yield of fresh marketable leaves, consumptive water use and net contribution of stored soil water to total consumptive water use of non-heading Chinese cabbage obtained in the five irrigation scheduling treatments of the 2007 and 2009 experiments. Plate 7.3 shows work on one of the experimental plots.

PLATE 7.3: One of the plots in the irrigation scheduling experiment with Chinese cabbage at Dzindi

In both experiments, irrigation scheduling practice significantly ($p<0.001$) affected total consumptive water use, fresh leaf yield and net contribution of stored soil water to total consumptive water use of non-heading Chinese cabbage.

In the 2007 experiment, the highest yields were obtained in the full irrigation (FI) and double frequency farmer (DFF) treatments, which also recorded the highest consumptive water use. Differences in yield and total consumptive water use between these two treatments were not significant ($p>0.05$). The minimal irrigation (MI) and farmer (F) treatments produced the lowest yields but also recorded the lowest total consumptive water use. The differences in yield between these two treatments was significant ($p<0.05$) but the difference in total consumptive water use was not.

TABLE 7.7: Effect of irrigation scheduling practice on the yield of fresh marketable leaves, consumptive water use and net contribution of stored soil water to total consumptive water use of non-heading Chinese cabbage (*Brassica rapa* subsp. *chinensis*) obtained in the 2007 and 2009 experiments at Dzindi

Irrigation scheduling treatment	**Yield of fresh marketable leaves** (kg m^{-2})	**Total consumptive water use** (mm)	**Net contribution of stored soil water to total consumptive water use** (mm)
		2007 experiment	
Full irrigation (FI)	3.907[a]	301[a]	11[b]
Minimal irrigation (MI)	2.310[d]	176[c]	57[a]
Farmer scheduling (FT)	2.644[c]	192[c]	-19[c]
Double frequency farmer scheduling (DFFT)	3.815[a]	302[a]	-29[c]
Charged farmer scheduling (CFT)	3.156[b]	247[b]	36[ab]
Mean	**3.166**	**244**	**11**
LSD (p=0.05)	0.298	32	29
		2009 experiment	
Full irrigation (FI)	2.875[a]	437[a]	8[c]
Minimal irrigation (MI)	1.200[c]	188[d]	73[a]
Farmer scheduling (FT)	1.475[c]	250[c]	49[ab]
Double frequency farmer scheduling (DFFT)	2.600[a]	391[b]	23[bc]
Charged farmer scheduling (CFT)	2.050[b]	272[c]	71[a]
Mean	**2.040**	**308**	**45**
LSD (p=0.05)	0.289	39.6	27.6

The absence of a significant difference in total consumptive water use between these two treatments appeared to be due mainly to the difference in the net contribution of stored soil water to total consumptive water, which amounted to 57 mm in the MI treatment, whilst in the FT treatment there was no net contribution (-19 mm) as the soil water content at harvest was higher than that at planting.

Relative to the F treatment, charging the upper 800 mm to field capacity prior to planting (CF treatment) significantly ($p \leq 0.05$) increased total consumptive water use, net contribution of stored soil water to total consumptive water and yield. Generally, stored soil water made a positive net contribution to total consumptive water use in the CF and MI treatments, both of which were charged to field capacity before planting and involved weekly irrigation intervals. In the F and DFF treatments, in which the soil was not charged to field capacity before planting, the soil water content at harvest was higher than at planting.

Total consumptive water use in the 2009 experiment was higher than that in the 2007 experiment but the yields of fresh leaves were lower. As in the 2007 experiment irrigation scheduling practice affected both total consumptive water use and fresh leaf yield, with treatment effect being highly significant ($p<0.001$) for both variables. The highest yields and highest consumptive water use were again recorded in the full irrigation (FI) and double frequency farmer (DFF) treatments. The minimal irrigation (MI) and farmer (F) treatments produced the lowest yields and recorded the lowest total consumptive water use. It follows that the general trend in the relationships between irrigation scheduling, total consumptive water use and yield observed in the 2007 experiment also applied to the data obtained in the 2009 experiment. Relative to the F treatment, charging the upper 800 mm to field capacity prior to planting (CF treatment) again increased total consumptive water use (8.8%), net contribution of stored soil water to total consumptive water use (45%) and yield (39%), indicating that charging the upper part of the profile to field capacity before planting is beneficial. The significant increase in yield has to be ascribed to differences in the amount of stored soil water at planting between these two treatments, even though the difference in net contribution of stored soil water to total consumptive water use of Chinese cabbage between the CFT (71 mm) and the FT (49 mm) was not significant ($p>0.05$).

Table 7.8 shows the effect of irrigation scheduling on total number of leaves and fresh mass of leaves for each leaf position of non-heading Chinese cabbage in the 2009 experiment.

TABLE 7.8: Effect of irrigation scheduling practice on total number of leaves and fresh mass of leaves for each leaf position of non-heading Chinese cabbage (*Brassica rapa* subsp. *chinensis*) obtained in the 2009 experiment

Variable	**Irrigation scheduling treatments**					**Significance level**	**LSD (p=0.05)**
	Full irrigation (FI)	**Minimal irrigation (MI)**	**Farmer Scheduling (FT)**	**Double frequency farmer scheduling (DFFT)**	**Charged farmer scheduling CFT)**		
Number of leaves per plant	13.5	12.5	14.0	13.8	13.5	0.199	-
Fresh mass leaf 3 (g)	2.7	2.2	2.0	2.6	2.4	0.863	-
Fresh mass leaf 4 (g)	5.8	4.5	4.1	4.6	5.0	0.462	-
Fresh mass leaf 5 (g)	11.5	7.7	7.7	9.9	10.7	0.090	-
Fresh mass leaf 6 (g)	43.0	26.9	23.4	30.1	27.7	0.008	9.7
Fresh mass leaf 7 (g)	51.0	31.5	29.4	38.7	35.3	<0.001	6.9
Fresh mass leaf 8 (g)	52.6	33.2	32.2	43.0	39.3	<0.001	5.6
Fresh mass leaf 9 (g)	59.0	38.9	40.4	50.5	44.9	0.007	10.3
Fresh mass leaf 10 (g)	60.7	37.0	40.9	51.8	45.7	0.012	12.7
Fresh mass leaf 11 (g)	67.9	39.2	46.0	60.0	48.6	0.014	16.0
Fresh mass leaf 12 (g)	58.3	37.8	42.5	52.5	43.3	0.008	10.7
Fresh mass leaf 13 (g)	51.3	30.6	32.6	46.4	33.3	0.016	13.3
Fresh mass leaf 14 (g)	42.0	26.4	26.0	39.6	27.8	0.049	13.2

The results in Table 7.8 clearly show that irrigation scheduling mainly affected the mass of the leaves of Chinese cabbage plants and not the number of leaves per plant. Differences among the five irrigation scheduling treatments in total number of leaves per plant were not significant (p=0.199), but differences in leaf mass were significant from leaf position 6 until leaf position 14. The pattern in the mass of individual leaves was in line with that observed for total yield of fresh leaves.

7.5 Discussion and conclusion

7.5.1 Green maize

Summarising the results obtained in the two green maize irrigation scheduling experiments, the following general statements and conclusions can be made:

- Total consumptive water use by maize was much higher in the full irrigation treatment than in the other two irrigation scheduling treatments but this had no effect on cob size, which is the main quality criterion in green maize production in Vhembe.
- In all treatments of both experiments the mean cob size exceeded the minimum length of 30 cm for marketability by a substantial margin.
- Irrigation scheduling had little effect on the growth and yield of green maize under the conditions that applied, which were characterised by high rainfall during grain filling. Based on these results, the irrigation scheduling practice of local farmers, as represented by the farmer treatment, must, therefore, be considered as adequate. In both experiments consumptive water use, and especially the quantity of irrigation water applied, in the farmer treatment was lower than in the other scheduling treatments that were tested, and in 2010 it was much lower. Thus where water is scarce, the farmer scheduling practice is much better than the others, using less water and giving the highest irrigation water use efficiency. The full irrigation treatment actually wasted a lot of water, including losses due to deep-percolation.
- Charging the upper part of the soil profile to field capacity prior to planting by applying four irrigations, which was estimated to add about 80 mm of water to the soil, and then proceeding with the normal farmer irrigation practice for the rest of the season (referred to as the charged farmer treatment) meant that 80 mm more irrigation water was applied per season compared with the farmer treatment. It increased consumptive water use but did

not result in any material benefit over the farmer treatment. However, charging the soil profile prior to planting could still be advisable when farmers seek to reduce risk associated with events that prevent them from applying water once per week, especially during the most critical part of the growing season. This would be particularly critical during seasons with low rainfall during those critical periods, as occur sometimes. The lower kernel numbers per ear recorded in the farmer treatment compared to the charged farmer treatment in the 2009 experiment could be seen as a warning sign in this regard.

7.5.2 Chinese cabbage

Summarising the results obtained in the two irrigation scheduling experiments with Chinese cabbage, the following generalising statements and conclusions can be made:

- Irrigation scheduling affected both total consumptive water use and yield of fresh marketable leaves of non-heading Chinese cabbage. For optimum growth and leaf yield, non-heading Chinese cabbage required the soil water content in the upper part of the profile to be maintained at or close to field capacity and this required the crop to be irrigated at least twice per week. The principal reason why Chinese cabbage and many other leafy vegetable crops require frequent irrigation to produce optimally is that leaf production is function of cell expansion, which is among the plant physiological processes most sensitive to water stress.
- Use of weekly irrigation intervals without charging the soil profile to field capacity before planting, which is the prevailing farmer practice on canal schemes, was shown to limit the yield of non-heading Chinese cabbage to about two-thirds of the maximum. Charging the upper 800 mm of the soil profile to field capacity before planting and the subsequent use of weekly irrigation intervals was shown to be advantageous but inadequate to achieve maximum leaf yield.
- The water allocation rules at Dzindi and other canal schemes in the north of South Africa limit access to water to a single day per week. Optimising irrigation scheduling for non-heading Chinese cabbage is dependent on institutional arrangements that enable farmers to irrigate more frequently. On canal schemes where the water flows continuously and is not diverted in night storage dams, farmers could increase irrigation frequency from once to twice or thrice per week by irrigating at night.

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CHAPTER 8

8 Green maize production

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8.1 Introduction

In the Thohoyandou area smallholders have been producing green maize as a commodity for at least three decades (BENSO and RAU, 1979), and they continue to do so. Manyelo (2011) reported that the trade of green maize in this area was controlled by street traders, who selected and purchased cobs whilst these were still attached to the plants growing in farmers' plots. She also reported that traders cooked the cobs without removing the light-green inner leaves of the husk, and then sold these cooked cobs still covered by the husk at places characterised by dense human traffic. Manyelo (2011) identified four categories of street traders who purchased fresh produce from the 102 plot holders at the Dzindi Irrigation Scheme, where she conducted her research. These four categories were bakkie traders, central business district (CBD) traders, township-pavement traders and door-to-door traders. The total number of traders in each of these four categories who purchased produce from Dzindi is shown in Table 8.1.

Bakkie traders, who used small trucks (bakkies) to operate their enterprises, did not trade in green maize but all other categories of traders did. The CBD trader category consisted of traders who had their stands in the commercial parts of Thohoyandou. They used taxis to travel between Dzindi and town. The township pavement trader category contained traders who retailed along roadsides in the townships and at the local hospital. The door-to-door trader category contained traders who hawked produce in the surrounding townships and villages, moving on foot from door to door, carrying a polypropylene grain bag filled with produce on their heads. On occasions, they used public transport to travel between their homes and the locality where they practised their trade.

TABLE 8.1: Number of street traders sourcing fresh produce from farms at Dzindi Irrigation Scheme by trader category (June 2009)

Informal trader category	Fresh produce commodities purchased at Dzindi	Total
Bakkie	White cabbage and some Swiss chard	17
Central business district	Leafy vegetables and green maize	54
Door-to-door	Leafy vegetables and green maize	12
Township pavement	Leafy vegetables and green maize	18
Total		**101**

Table 8.1 shows the number of traders who sourced fresh produce from Dzindi in each of the identified trader categories and the principal commodities they purchased from farmers at that Scheme. Manyelo (2011) estimated that sales of green maize cobs to hawkers contributed R117 754 to total gross income of the farmer population at Dzindi during the period July 2008 to June 2009. Manyelo (2011) investigated seasonality of the commodities sold by a sample of 16 street traders who sourced their produce from Dzindi Irrigation Scheme during 2009. She sampled four traders from each category listed in Table 8.1. Among the 12 traders sampled from the three categories known to be involved in the green maize trade, 11 reported that they did indeed trade green maize.

Investigating seasonality of the green maize trade among these 11 traders, she found that green maize was mostly sold during a five-month period that lasted from October to February (Fig. 8.1). The trade in green maize started in September and ended in March. No trading in green maize occurred during the period April to August, inclusive. Manyelo (2011) found that the period during which street traders were involved in the green maize trade was entirely dependent on the availability of cobs on the plots at Dzindi. This meant that no green maize was available at Dzindi during the period April to August and that availability during the months of March and September was limited.

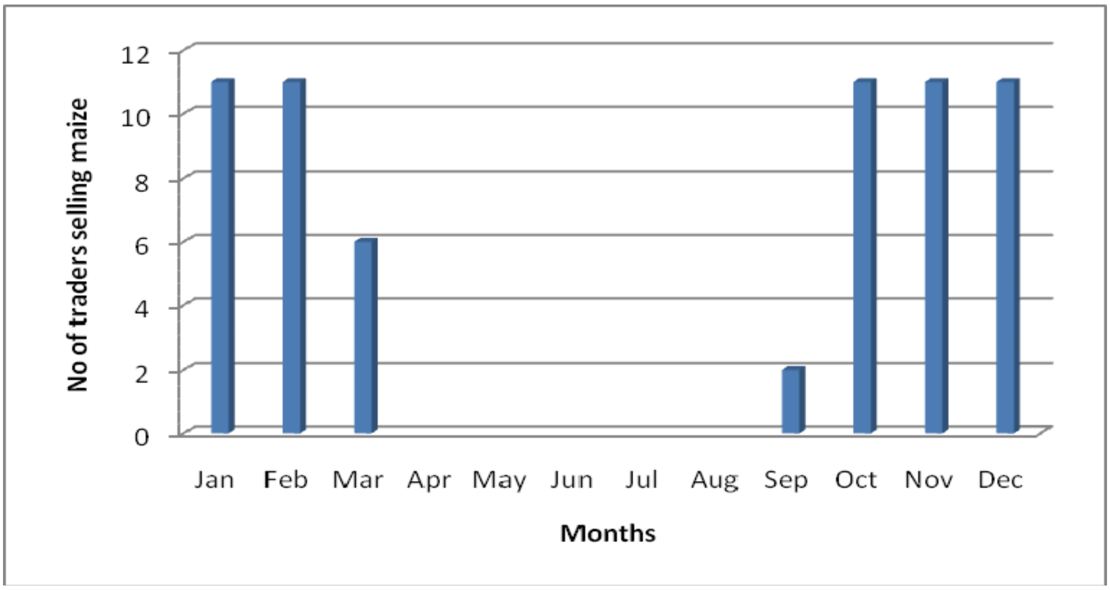


FIGURE 8.1: Frequency of participation in the green maize trade among a sample of 12 street traders who sourced produce from Dzindi Irrigation Scheme (2009) (from Manyelo, 2011)

Depending on the temperature regime that prevails during growth, green maize cultivars take between 3.5 and 4.5 months to grow from seed to the stage where the cobs are ready for harvest. From the data in Figure 8.1, it would appear that farmers at Dzindi discontinue planting green maize in December and only start planting again towards the end of May. This observation is supported by data on the planting dates of green maize used by farmers at Dzindi that were collected in 2004, which indicated that farmers commenced planting green maize in July and stopped planting the crop in December. Yet, theoretically, the temperature regime in large parts of the Vhembe District, where Dzindi is located, allows for year-round production of maize. The area is frost-free and Table 8.2 shows that in all months of the year, mean daily mean temperature exceeds 10 ^{o}C, which is the base temperature of maize. From a climatic perspective, therefore, the Vhembe area could allow for year-round production of green maize, offering an opportunity to increase farmer and trader incomes.

TABLE 8.2: Mean daily minimum, maximum and mean temperature in Thohoyandou

Month	Mean daily maximum temperature (°C)	Mean daily minimum temperature (°C)	Mean daily mean temperature (°C)
January	30.8	19.9	25.4
February	30.0	19.7	24.9
April.	29.6	18.9	24.3
April	27.6	16.4	22.0
May	26.2	12.7	19.5
June	23.6	9.9	16.8
July	23.7	9.8	16.8
August	25.4	11.7	18.6
September	27.2	14.2	20.7
October	27.5	16.3	21.9
November	28.9	17.6	23.3
December	30.0	19.4	24.7

When harvesting green maize in farmer fields, street traders broke the stem of the cob in such a way that a few nodes (one to three) were left attached to the ear. When the cob was broken off, the dark green outer leaves of husk, which were attached to the lower part of the stem of the cob, were discarded. The upper part of the stem of the cob and the light-green leaves that were attached to it were left deliberately by the traders to make the cobs appear long. Plate 8.1 shows green maize cobs as they are harvested by street traders.

Work conducted at Dzindi repeatedly showed that street traders only purchased green maize cobs that met particular quality criteria (Van Averbeke, 2008; Manyelo, 2011). To be suitable for selection, cobs could not show any visible damage. In the field, damage to cobs was caused by birds shredding the tip of the husks and by insects boring into the cobs to get at the developing grain. Cob length was the second important quality criterion determining the marketability of maize cobs. The relationship between cob length and marketability was determined by Van Averbeke (2008) and this again done during the conduct of the current project by purchasing multiple samples of cobs from street traders who had bought cobs from farmers at Dzindi.

PLATE 8.1: Green maize cobs (cultivar SC 701) as they are harvested by street traders

The results of the statistical analysis of the cob length measurements that were done are summarised in Table 8.3. Even though the 95% confidence interval around the mean of the measured lengths of grade-1 cobs indicates that the minimum length should be set at 33 cm (lower limit of the 95% confidence interval), it was decided to reduce the minimum length of a grade-1 cob by 2 cm to 31 cm. This minimum length was 1 cm longer than the upper limit of the 95% confidence interval around the mean of the measured lengths of grade-2 cobs (Table 8.3). It is also important to note that the length criteria were determined during mid-summer, when green maize cobs were abundantly available. Experience in the field, gained whilst conducting research on green maize at Dzindi, showed that less stringent criteria were used by street traders during times when cobs were scarce.

TABLE 8.3: Relationship between length and marketability of green maize cobs at Dzindi (2010 prices)

Statistic	Grade-1	Grade-2	Grade-3
Description	Easy to sell	Difficult to sell	Not suitable
Producer price	R2.00	R1.50	-
Mean cob length (cm)	34	29	25
Median (cm)	35	29	25
Range (cm)	29-41	21-35	18-34
95% confidence interval (cm)	33-36	29-30	23-26

Selected plot holders at Dzindi aim their maize production at the green maize market, because the monetary value of maize sold as green cobs is about three times higher than its grain value (Van Averbeke, 2008). However, before the start of the green maize research programme at Dzindi in 2006, plot holders rarely sold more than one-quarter of their crop as green maize, suggesting that farmers found it difficult to produce cobs that met the quality standards applied by street traders. This clearly indicated that improving green maize production practices would be of great benefit to farmers at Dzindi and other smallholder canal schemes in Vhembe, who were involved in this enterprise. At Dzindi in 2006 green maize growers made up about 20% of the total farmer population at Dzindi.

From the perspective of the farmer, optimising green maize production should be aimed at maximising the number of cobs that meet the cob size requirements of the local market per unit land. Most modern maize hybrids have been developed with a view of maximising grain yield under specific growing conditions and producing large ears was not a desirable trait in cultivars used for grain production, because small-eared hybrids tolerate suboptimal environmental conditions better than large-eared cultivars (Aldrich *et al*., 1975). Breeding for ear prolificacy, which refers to the ability of maize to produce multiple cobs under favourable conditions, has been another way in which the tolerance of maize to environmental variability has been improved (Aldrich *et al*., 1975; Varga *et al*., 2004). However, when producing maize for harvest as green cobs, production of small ears and ear prolificacy are undesirable traits. The market for green maize demands large ears and ear prolificacy is, therefore, disadvantageous, because the number of kernels on the primary ear of prolific hybrids tends to be lower than the number of kernels on the single ear of non-prolific hybrids (Varga *et al*., 2004). For this reason, cultivar selection is an important factor in green maize production and one of the first research activities undertaken by the team was to conduct a cultivar trial, in which the cultivar SNK 2147, which was being used by almost all farmers at Dzindi in 2006, was compared with three known South African green maize cultivars, namely PAN 93, ETZ 200 and SC 701. This trial made it clear that SNK 2147 performed poorly compared to the three other cultivars and needed to be replaced (Van Averbeke, 2008).

A review of existing knowledge (Van Averbeke, 2008) indicated that for a specific maize cultivar, cob size or cob length was expected to be closely related to kernel number per ear (KNE). The development of models to predict KNE based on knowledge of intercepted photosynthetically active radiation per plant (IPARP) suggested that it would be possible to model cob length. Entering the cob length specifications determined by the green maize market into these models would enable the prediction of the optimum planting density at which the number of marketable green maize cobs per unit area was expected to reach a maximum for a specific planting date-cultivar-locality combination. Prediction of optimum planting density would be a valuable decision support tool for green maize producers. Consequently, the following three hypotheses were formulated for testing in the field:

- In maize, cob length and KNE are closely related variables;
- Cob length, KNE and the relationship between these two variables are attributes that are cultivar specific;
- Planting date and planting density in maize interact to affect IPARP, KNE and cob length.

To test these hypotheses, a multi-factorial (cultivar x planting date x planting density) experiment was conducted, employing tow cultivars (PAN 93 and SC 701), four planting dates spaced three months apart, thus covering the entire year, and four planting densities (1.3 plants m^{-2}, 2.6 plants m^{-2}, 5.2 plants m^{-2} and 8.0 plants m^{-2}). Part of this work was already reported on in Van Averbeke (2008) but the study was only completed during the current project and a full set of results is presented here.

During the conduct of cultivar x planting date x planting density experiment it became evident that maize streak disease (MSD) was a major constraint to year-round production of green maize in Vhembe. It was also observed that the incidence of MSD was dependent on date of planting. With the exception of the September planting, MSD was observed in the plots, despite treatment of the seed with Gaucho, a practice recommended by the Department of Agriculture (2007) for the control of the leafhoppers, which are the vectors of the maize streak disease virus (MSV). This highlighted the need to identify and test ways of combating MSD. Two main ways of combating MSD were identified. One of these is to treat maize seed with a systemic insecticide, such as Gaucho, which is aimed at eliminating the vector, thus limiting the spread of the disease. The other way is to plant an MSV resistant or tolerant cultivar. For this reason, a study of MSV in green maize production in Vhembe was initiated.

The hypotheses tested in this study were:

- Incidence of MSD in green maize plantings at Dzindi is dependent on planting date;
- Seed treatment with Gaucho and use of MSV tolerant maize cultivars reduce the prevalence of MSD in green maize plantings at Dzindi.

The results obtained in the cultivar x planting date x planting density experiment indicated that planting green maize at planting densities of about 2 to 2.5 plants m^{-2} would best suit smallholder circumstances. However, at this particular planting density range, a significant proportion of the photosynthetically active radiation (PAR) is not intercepted by the maize canopy. This creates the opportunity to establish a second vegetation layer below the maize canopy but this second layer of plants should not compete for light with the maize plants as this would cause a reduction in cob size. Pumpkin was a minor crop that had particular potential for application on smallholder canal schemes in Vhembe. Pumpkin already features as a leafy vegetable in the local farming system (see Table 6.1). Intercropping relatively sparse green maize stands with pumpkins has the potential to increase the gross margin of green maize production and this potential was investigated empirically as part of this study. The hypotheses tested in this part of the study were:

- Relative to green maize planted as a sole crop, intercropping green maize with pumpkins has no effect on leaf area per plant, cob length, ear length and kernel number per ear of early planted green maize;

- The water use of sole green maize stand does not differ from that of the same green maize stand intercropped with pumpkins.

8.2 Review of literature

8.2.1 Planting density and cob size in maize

In maize, kernel number per plant is dependent on the net assimilation rate (rate of dry matter production) per plant (Edmeades & Daynard, 1979, Tollenaar, Dweyer & Stewart, 1992; Otegui *et al*., 1995). Net assimilation rate is function of a range of environmental factors, which included solar radiation, temperature, carbon dioxide concentration in the air and the availability of water and nutrients in the soil (Stoskopf, 1981). In the absence of any other limiting factors, net assimilation rate of a maize plant is function of the intercepted photosynthetically active radiation per plant (IPARP). IPARP depends on the photosynthetically active radiation (PAR), a locality and season dependent factor, and the extent to which neighbouring plants compete for PAR. Therefore, for a given PAR, net assimilation rate of individual maize plants is dependent on the level of competition among plants arising from plant spacing and size variability in the stand.

Several studies have shown that kernel number per ear (KNE) declines with increasing planting density due to a decline in IPARP, because low IPARP causes spikelet and kernel abortion (Van Averbeke & Marais, 1994; Otegui & Bonhomme, 1998; Westgate *et al*., 1996; Andrade, Otegui & Vega, 2000). Andrade, Otegui and Vega (2000) and Kiniry, Xie and Gerik (2001) developed models to simulate the relationship between IPARP, kernel set and kernel number per ear (KNE). According to Andrade, Uhart and Frugone (1993), Otegui and Bonhomme (1998) and Andrade, Otegui and Vega (2000), the critical period for kernel set in maize was about 30 days around silking, 15 days before and 15 days after. Sub-optimal assimilate supply during this period causes a reduction in KNE, initially by disturbing fertilisation and later on by causing kernel abortion (Cirilo & Andrade, 1994b; Otegui & Bonhomme, 1998; Andrade; Otegui & Vega, 2000).

Planting date is known to affect PAR and temperature, with late planting causing a decline in KNE due to reduced PAR and reduced temperature during the critical period of kernel set (Cirilo & Andrade, 1994a; Cirilo & Andrade, 1994b; Otegui & Melón, 1997). Low radiation and temperature after silking is known to reduce dry matter production, resulting in kernel abortion (Cirilo & Andrade, 1994b).

8.2.2 Maize streak disease

Maize is affected by a wide range of pathogens. CIMMYT Maize program (2004) lists 43 fungal diseases, three bacterial diseases, ten viral diseases and two diseases caused by mollicutes but the maize streak virus (MSV) (family *Geminiviridae*, genus *Mastrevirus*) is amongst the most important plant pathogens threatening food security in Africa (Harkins *et al*., 2009).

There are 11 known MSV strains but only the MSV-A strain infects maize plants, causing maize streak disease (MSD) (Harkins *et al*., 2009)[7]. A few sources indicate that MSD was first reported in East-Africa (CIMMYT Maize program, 2004; CRCPlantbiosecurity, 2010) but most refer to Fuller (1901) in Natal (South Africa) as the first scientist to describe this disease (Welz *et al*., 1998; Bosque-Pérez, 2000; Shepherd *et al*., 2009; Harkins *et al*., 2009). Fuller (1901) used the term 'mealie variegation' for MSD but did not relate the discolouration to a viral disease. Identification of this link was the contribution by Storey (1928). In Sub-Saharan Africa, MSV strains infect more than 80 plant species, mainly wild grasses belonging to the Poaceae family (Harkins *et al*., 2009). It is postulated that the maize-adapted MSV-A strain was generated by recombination between two grass-adapted MSV strains and that this occurred around 1850 (Harkins *et al*., 2009).

Six leaf hopper species in the genus *Cicadulina* are vectors of MSD (Van Rensburg, 2001) but the South African maize leaf hopper (*Cicadulina mbila* (Naudé)) and *Cicadulina storeyi* are the most important (Shepherd *et al*., 2009). Maize is the main host of maize leaf hoppers. These insects take up the virus from MSV-infected plants during phloem feeding and infect healthy plants by salivating (Mesfin & Bosque-Pérez, 1998).

Early symptoms of MSD occur in the form of small, round, scattered spots that appear in the youngest leaves about one week after infection. Over time, these spots become more profuse and later on, fully elongated leaves develop the typical broken streaky chlorosis, presented as yellowing along the veins, which contrast sharply with the normal dark green colour of the leaf tissue between the veins (Lucy *et al*., 1996). The only leaves that develop these MSD symptoms are those that were formed after infection (Shepherd *et al*., 2009). Damage is primarily done to plants younger than six weeks old.

[7] Harkins *et al*. (2009) stated that MSV strains other than the MSV-A strain cannot symptomatically infect any but the most MSV-susceptible maize genotypes.

MSD reduces photosynthesis and increases respiration, causing a reduction in leaf length and plant height. When infected at an early stage of growth, MSV-infected plants are typically stunted and produce small-sized cobs, or no cob at all, and when infected at the seedling stage, they are often killed (Shepherd *et al*., 2009; CRCPlantbiosecurity, 2010). Grain yield losses are directly related to the time of infection (Bosque-Pérez *et al*., 1998; Shepherd *et al*., 2009) and genotype susceptibility (Bosque-Pérez, 2000). Yield losses vary widely, from negligible to total yield failure (Bosque-Pérez *et al*., 1998; Bosque-Pérez, 2000; Magenya *et al*., 2008).

In Nigeria, Olaoye (2009) reported that MSD occurred mainly late in the season and that MSV infection was particularly severe following dry spells. Other researchers made mention that MSD occurred in the form of epidemics. For example, in 1974 and 1975 a major maize streak epidemic occurred in large parts of the maize producing areas of South Africa (Kühn & Van Rensburg, 1995). Rose (1972) reported that riverside vegetation and irrigation schemes were areas of high concentration of leaf hoppers.

Shepherd *et al*. (2010) listed three strategies that could be used to control MSD, namely,

- Disease avoidance by planting early when viral inoculums loads are lowest;
- Control leafhopper populations using insecticides;
- Planting streak-resistant or tolerant cultivars.

They indicated that the most promising strategy involved the development and use of streak-resistant cultivars.

The first breeding programme for the development of maize germplasm resistant to streak disease in South Africa was initiated at the Vaalharts Experimental Station in 1967 (Van Rensburg, 2001). This resulted in two resistant composites of white (VHCw) and yellow (VHCy) kernel type, which were referred to as the ‘Vaalharts composites’ (Kühn & Van Rensburg, 1995; Van Rensburg, 2001). These Vaalharts composites were used as the non-recurrent parent in crosses with the USA inbred lines Mo17 and B73 and South African elite breeding material to develop streak-resistant inbred lines with improved combing ability for yield (Kühn & Van Rensburg, 1995). Yield performance tests under streak conditions showed that a few of streak-resistant test crosses yielded more than CRN 3414, PAN 6528 and RS 5205, which were all prominent commercial hybrids at the time (1992-94) but somewhat less (10-20%) in the absence of streak conditions (Kühn & Van Rensburg, 1995). At present, the cultivar PAN 67 appears to be the only streak resistant maize cultivar that is commercially available but researchers have released several different MSV resistant lines (Van Rensburg, 2005), including virus-resistant transgenic maize, which was developed at the University of Cape Town (Shepherd *et al*., 2007).

8.2.3 Intercropping

Intercropping is a practice whereby two or more crops are grown in the same field (Machado, 2009). Other terms used to refer to intercropping are mixed cropping, multi-cropping, double cropping (arrangements involving two component crops) and poly-culture (Machado, 2009; Lithourgidis *et al.,* 2011). Using the spatial arrangement of component crops as the organising principle, Ouma and Jeruto (2010) citing Okigbo (1979), divided the different types of intercropping methods into four commonly used categories, namely,

- Strip intercropping, which involves the growing of two or more crops simultaneously on the same field in alternative strips of uniform width and spaced close enough for the different component crops to interact;
- Row intercropping, which refers to the growing of more than one crop on the same field in alternative rows;
- Mixed intercropping, which involves the simultaneous growing of two or more crops in the same field without a row arrangement;
- Relay intercropping, refers to the cultivation of two or more crops in the same field, whereby the second crop is planted after the first crop has been established and has reached a fairly advanced stage of development.

From a crop production perspective, the main justification for intercropping is to achieve more effective use of available resources, which include light, water and nutrients, and in this way increase total production per unit of land. (Seran & Brintha, 2010; Ghanbari *et al.* (2010); Ouma & Jeruto; 2010; Lithourgidis *et al.,* 2011). Intercropping does not always raise total production per unit land. Competition among component crops in an intercropping arrangement can also reduce total productivity (Lithourgidis, 2011) However, according to Jeranyama (2000), competition for growth resources among component crops in a mixed crop arrangement can be minimised through careful planning.

Canopy architecture, water use and nutrient availability are some of the important interactions among component crops in an intercropping arrangement that can explain observed differences in productivity between sole and mixed crop stands (Zhang *et al*., 2008; Ahmad *et al*., 2010; Dahmardeh *et al*., 2010; Seran & Brintha, 2010). Of particular relevance to the green maize-pumpkin intercropping arrangement to be tested in the current study were canopy architecture and water use, because benefits from mixed cropping in terms of improved nutrient availability are obtained mainly when a legume is included in the arrangement (Dahmardeh *et al.*, 2010; Ouma & Jeruto, 2010).

In a plant community, the canopy refers to the above-ground parts of the plants (leaves, stems and reproductive organs), also called the plant crowns. Canopy architecture refers to the three-dimensional geometry or spatial arrangement of the canopy. Different plant species tend to have different ways of displaying their stems and foliage bringing about differences in canopy architecture, which results in differences in light interception among different plant communities (Atwell *et al*., 1999). Leaf area index (LAI) is an important descriptor of canopy architecture. LAI is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area (Gobron, 2008). Generally, the proportion of light intercepted by a canopy increases as LAI is increased. Studies with maize have shown that at a LAI of about 3.5, the maize canopy intercepts 95% or more of the incident light. As the LAI of maize falls below this value, increasingly more incident light will not be intercepted by the maize canopy and reach the soil surface. Intercropping maize, which has a fairly high canopy, with pumpkin, which has a low canopy due to its creeping habit, and using a fairly sparse planting density in maize, which is expected to limit the LAI of maize to a maximum of about 2.0 at the end of the vegetative growth, could very well increase light interception and total biomass production without affecting growth and yield of maize, as also indicated by Seran & Brintha (2010). Under conditions where a significant proportion of radiation is not intercepted by the canopy and reaches the soil surface, much of this radiation is converted into heat energy when it reaches the soil surface. This heat energy is used to evaporate water when the soil surface is wet, or becomes latent heat energy that rises through the canopy when the soil surface is dry (Aubertin & Peters, 1961; Loomis 1983). Both processes result in water losses that are essentially non-productive. When a second vegetation layer (pumpkins) is established below the maize canopy to utilize excess light, evaporation losses of water from the soil surface are expected to decline, whilst transpiration losses are expected to increase. Of importance to the current study is whether the change in the way water is lost from the system has a significant net effect on water use.

Yield is an important indicator of crop productivity. Land equivalent ratio (LER) is a widely used approach to compare the productivity of intercropping arrangements with that of sole crop arrangements (Ghanbari *et al*., 2010). Clement *et al.* (1991) defined LER mathematically as:

$$LER = \Sigma_i \, [YI_i / YS_i]$$ ***equation 8.1***

Where:

YI_i : yield of intercropped species *i,*

YS_i : yield of sole-cropped species *i.*

Intercropping systems that produce LER values greater than 1 present a yield advantage over mono-cropping, those that produce an LER value smaller than 1 present a disadvantage, and those that produce an LER value of 1 neither an advantage nor a disadvantage. Published LER values obtained in maize-pumpkin include 1.34 (Silwana & Lucas, 2002) and 1.13 to 2.36 (Maereka, Madakadze and Nyakanda, 2009) but in both cases the fruit yield of pumpkins was considered, not the leaf yield as in the current study.

8.3 Materials and methods

8.3.1 Green maize cultivar x planting date x planting density interaction effects on cob size

The experiments were conducted on Plot 1 of Block 1 at Dzindi Irrigation Scheme. Details on soil, slope and other environmental variables have been reported by Van Averbeke (2008) and in Chapter 6. The same design was used for four different months of the year, namely September, December, April and June as shown in Table 8.4. The experiment employed a split plot design involving four planting densities (main plot) and two cultivars (splits).

TABLE 8.4: Planting dates used in the cultivar x planting date x planting density experiment

Planting	Planting date	Harvesting date	Duration of the growing period (days)
1	19 September 2006	02 January 2007	104
2	22 December 2006	03 April 2007	101
3	8 April 2008	22 August 2008	135
4	30 June 2008	11 November 2008	133

The two cultivars used were PAN 93 and SC 701. For each planting date, the two cultivars were planted at four planting densities, namely, 1.3 plants m^{-2}, 2.6 plants m^{-2}, 5.2 plants m^{-2} and 8.0 plants ha^{-1}. Table 8.5 shows the plant spacing used and the resulting plant population. Since farmers on canal schemes typically employ a row-spacing of 0.75 m, variability in planting density was achieved by varying plant spacing within the rows, as shown in Table 8.5. The plots were planned to have a width of 4.50 m and a length of 8.00 m but for each of the planting density treatments, minor modifications were made to the lengths of the plots to make these multiples of the plant spacing in the rows.

TABLE 8.5: Details of plot size and number of plants in the different planting density treatments (main plots) of the planting date x planting density experiment with maize at Dzindi

Planting density (plants m^{-2})	**Intra-row spacing** (m)	**Row length** (m)	**Area plant^{-1}** (m^{-2})	**Area plot^{-1}** (m^{-2})	**No. of plants plot^{-1}**	**Net plot area** (m^{-2})	**No. of plants net plot^{-1}**
1.3	1.03	8.24	0.77	37.08	48	18.54	24
2.6	0.51	8.13	0.38	36.72	96	21.42	56
5.2	0.26	8.06	0.20	36.27	186	22.62	116
8.0	0.17	7.99	0.13	35.96	282	22.44	176

A total of three soil preparation operations were carried out. The soil was first ploughed using a disk plough. This operation was followed by disking using a disk harrow to break large clods formed after ploughing and to level the soil. The final operation consisted of the construction of ridges using a tractor mounted ridger. Hand hoes were then used to close the ridges at the required length to form the plots. During the first experiment, the soils were ripped to a depth of 60 cm to break any subsoil compaction that could have been present.

During planting, a planting furrow was opened with a specially designed hand hoe that had a narrow (50 mm) blade. Fertilisers to be applied at planting in the band were then distributed homogeneously by hand in the furrow and then incorporated in the soil by dragging a stick along the length of the furrow. Thereafter water was applied in the furrow (about 1 ℓ m^{-1} of furrow) to assist germination of the maize seed and emergence of the seedlings. This was followed by planting the seed. The planting stations for each of the planting density treatments were identified using a marked chain. At each station, three seeds were pressed by hand into the wet soil. Once planting had been completed, Karate (supplied by Syngenta and containing *lambda cyhalothrin* as the active ingredient) was applied at the rate of 100 mℓ ha^{-1} or 7.5 mℓ per 1000 m row length. Finally, the furrows were filled with soil using a rake. This operation covered the seed with about 40 mm of soil. For the April and June plantings, the maize seed was treated with Gaucho to reduce the spread of maize streak virus (MSV) disease. Three weeks after planting, the stands were thinned to one plant per station.

After the land was ploughed, about two weeks before planting, cattle and poultry manure were applied broadcast, each at the rate of 2500 kg ha^{-1}, and then worked into the soil during the disking operation. At planting, the fertiliser mixture 2:3:2 (22) was applied in the planting furrow at a rate of 300 kg ha^{-1}. Lime ammonium nitrate (28% N) was band placed at the rate of 100 kg ha^{-1} when the maize reached knee height and this operation was repeated every two weeks until pollen shed. Accordingly, lime ammonium nitrate was applied four times.

In order to maintain adequate soil water availability at all times, soil water content in the plots was kept above 80% of plant available water (PAW). PAW was defined as the soil water between the drained upper limit (FC) and lower limit (PWP) of available water over the root depth of a crop. PAW, FC and PWP of the soil at the experimental plot were empirically determined. Important soil water characteristics are reported in Table 8.6.

TABLE 8.6: Field capacity (FC), permanent wilting point (PWP), and profile available water (PAW) of the soil at the experimental site (Plot 1, Block 1, Dzindi Irrigation Scheme)

Soil layer depth (mm)	**Bulk density** (g cm^{-3})	**Θ_v @ PWP**	**Θ_v @ FC**	**PAW (mm)**
0-150	1.226	0.15	0.33	22.5
150-300	1.436	0.18	0.34	24.0
300-450	1.422	0.21	0.40	28.5
450-600	1.414	0.20	0.42	33.3
600-750	1.405	0.20	0.42	33.3
750-900	1.370	0.19	0.40	31.5
900-1050	1.368	0.19	0.39	30.0
1050-1200	1.365	0.19	0.38	28.5
1200-1350	1.320	0.18	0.38	28.5
1350-1500	1.336	0.19	0.38	28.5

Arbitrarily restricting the rooting depth of maize on the experimental soil to 1500 mm, the PAW for maize was 288.6 mm. Compared to the profile water content at field capacity, the profile water content reached 80% of the PAW of maize when 57.7 mm of water had been extracted, at which stage the soil was irrigated. All plots were irrigated using short furrow irrigation, whenever the soil water content of the profile in one of the treatments had reached 80% of total plant available water. The level of allowable soil water depletion maintained in the experiment was about 70% of the PAWC value recorded for maize on the same soil by Nndwammbi (2009). Soil water content was monitored once a week using a neutron hydro probe (Waterman, model FY500, Geotech, Pretoria). Aluminium access tubes (two per plot) were inserted in 16 plots, which were representative of all treatments. The access tubes allowed for soil water monitoring to a depth of 1575 mm.

Weather data including minimum and maximum air temperature, global solar radiation were recorded at an automated weather station (Campbell Scientific) located about 500 m from the experimental plot. Measurements of maximum and minimum temperature and global solar radiation were done daily. By multiplying global radiation with a factor of 0.45, photosynthetically active radiation (PAR) was estimated (Monteith, cited by Madonni and Otegui, 1996). Interception of photosynthetically active radiation (PAR) by the plants in the different treatments was measured using a ceptometer (Model LP-80, Decagon devices, USA). In each plot one measurement above the canopy and five in predetermined, representative positions below the canopy were made between 11h00 and 14h00 on clear days, as recommended by Gallo and Daughtry, cited by Madonni and Otegui (1996). Daily fraction interception between observation dates were estimated by linear interpolation between midday values and these estimates were used to estimate the photosynthetically active radiation intercepted by the canopy (IPAR) during the period of kernel set (30 days around silking). The proportion of PAR that was intercepted by each of the treatments was calculated using the relationship proposed by Cirilo and Andrade (1994a) (equation 8.2).

$$IPAR\ (\%) = (1 - I_t / I_o) \times 100\% \qquad \textit{equation 8.2}$$

With IPAR % = proportion of incident PAR intercepted by the canopy

I_t = incident PAR below the canopy

I_o = incident PAR above the canopy

The developmental stage of the grain was monitored on 10 guard row plants by cutting a window in the husk to monitor the stage of grain development. Masking tape was used to close the husk window after every monitoring event. Cob length was measured at the time of harvest on 10 maize plants that had been randomly selected for monitoring and measurement in each plot. Selection of these plants was done immediately after thinning and each selected plant was tagged. However, in the April and June plantings some of the selected plants were infected by maize streak virus (MSV), despite seed treatment with Gaucho, and for the measurement of cob length and the counting of kernel number per ear, infected plants were replaced by visually unaffected plants.

Cob length was determined in accordance with the way green maize traders assessed cob length, described in the introduction of this chapter (section 8.1). As indicated, after harvesting a cob, green maize traders remove the top most husks by breaking off the stem of the cob leaving two to three nodes and the husk leaves attached to these nodes on the cob (see Plate 8.2).

PLATE 8.2: Measuring the length of a green maize cob

Cob length was the length measured from bottom of the remainder of the stem attached to the cob to the tip of the cob. Table 8.7 shows the cob length criteria employed to grade cobs in this study. Counting of kernels was done after measuring cob length as shown in Plate 8.3.

TABLE 8.7: Length limits for the three grades of green maize cobs and prices paid in 2010

Grade	**Length** (cm)	**Farm price**
1	>30	R2.00
2	27 to 30	R1.50
3	<27	Not marketable

PLATE 8.3: Counting the number of kernels on a maize ear

Data on IPARP and KNE, and KNE and cob length of the two cultivars used were subjected to regression analysis to quantitatively describe their relationships and to identify the optimum planting density for green maize production for each of the four planting dates.

8.3.2 Interaction effects of planting date, cultivar and seed treatment on maize streak disease

An experiment involving three commercially available cultivars (SC 701, PAN 93 and PAN 67) and two pre-plant seed treatments (Gaucho®[8] and control) was laid out using a split plot design with three replications using cultivar as the main plot and seed treatment as the split plot. The experiment was planted 13 times, more or less at monthly intervals, starting in March 2009 and ending in March 2010. The experiment was conducted at the Dzindi Irrigation Scheme (23^{o}01'S; 30^{o}26'E), Thulamela Municipality, Vhembe District, Limpopo Province, South Africa. Different plots were used for the conduct of the study, Most were located at Block 1 of the Scheme except for the plots used for the March to May 2009 experiments, which were located at Block 3. All

[8] Gaucho® contains the active ingredient imidacloprid and is a registered chemical for use in the control of leafhoppers in green maize (National Department of Agriculture, 2007:99).

experiments were planted on the dominant soil found at the scheme (Van Averbeke, 2008), which was classified as Hutton Suurbekom (Soil Classification Working Group, 1991) and Rhodic Ferralsol (ISSS-ISRIC-FAO, 1998) and had a depth that exceeded 1500 mm.

The gross plot size for all treatment was 3.75 m x 5.2 m, resulting in total area of 19.5 m^{-2}. Three maize seeds per hill were planted in rows spaced 0.75 m apart using an intra-row spacing of 0.42 m. Each plot consisted of five rows with 12 plants per row resulting in a total of 60 plants per plot. The resulting planting density was 31 746 plants ha^{-1}. Soil preparation and planting procedures were the same as in the planting date x planting density x cultivar experiment described in section 8.3.1.

Seed treatment with Gaucho® followed recommended practice (National Department of Agriculture, 2007:99), whereby seed was submerged in and mixed with a Gaucho® slurry, which was prepared by adding about 5 g of the pesticide to 1 L of water and once all kernels were coated with slurry they were on a plastic sheet in the shade to dry before planting.

Fertiliser application consisted of the application of the fertiliser mixture 2:3:2 (22) in the planting furrow at a rate of 150 g per row and the band application of limestone ammonium nitrate (28% N) at the rate of 70 g per row when the maize reached knee height and every two weeks thereafter until pollen shed, which involved four applications. In total, each maize planting received 224.2 kg N ha^{-1}, 36.3 kg P ha^{-1} and 24.2 kg K ha^{-1}.

In all experiments, soil water availability was kept at optimum level by irrigating the crop twice per week, unless more than 20 mm of rain was received since the last irrigation event, in which case irrigation was skipped.

The dates when the different cultivar x seed treatment experiments were planted and harvested are shown in Table 8.8.

TABLE 8.8: Dates of planting and harvest and the duration of the growing period of the different cultivar x seed treatment experiments at Dzindi (2009-10)

Experiment number	**Planting date**	**Date of final harvest**	**Duration of the growing period** (days)
1	16-Mar-09	17-Jul-09	123
2	15-Apr-09	16-Aug-09	123
3	15-May-09	08-Sep-09	116
4	17-Jun-09	30-Oct-09	135
5	15-Jul-09	25-Nov-09	133
6	17-Aug-09	10-Dec-09	115
7	15-Sep-09	23-Dec-09	99
8	15-Oct-09	19-Jan-10	96
9	16-Nov-09	23-Feb-10	99
10	15-Dec-09	23-Mar-10	98
11	15-Jan-10	14-Apr-10	89
12	15-Feb-10	13-May-10	87
13	14-Mar-10	28-Jun-10	106

Counts of plants with maize streak disease (MSD) using visual symptoms (streaky appearance of the leaves) were done at pollen shed, when all leaves were fully developed. The data was captured on a spread sheet using MS Office Excel® and analysis of variance using the SAS statistical package (Statistical Analysis Software Institute Inc., 2000) was performed to test for treatment effects and the Fisher’s protected LSD test (p=0.05) to separate treatment means.

8.3.3 Effects of intercropping green maize with pumpkins

Two field experiments were conducted on Plot 1 at Block 1 of the Dzindi Irrigation Scheme. The first experiment was conducted during the early summer of 2009 and the second a year later (2010).

The 2009 experiment involved three treatments only, namely,

- Sole maize;
- Sole pumpkins; and
- Maize-pumpkin intercrop.

The 2010 experiment involved ten treatments, namely,

- Sole maize treatment (MT),
- Sole pumpkin treatment (PT),
- Maize-pumpkin treatment planted simultaneously (MPT0),
- Maize with pumpkin planted 1 week later (MPT1),
- Maize with pumpkin planted 2 weeks later (MPT2),
- Maize with pumpkin planted 3 weeks later (MPT3),
- Maize with pumpkin planted 4 weeks later (MPT4),
- Maize with pumpkin planted 5 weeks later (MPT5),
- Maize with pumpkin planted 6 weeks later (MPT6), and
- Maize with pumpkin planted 7 weeks later (MPT7).

In both experiments treatments were laid out using a randomised complete block design. Treatments were replicated four times in the 2009 experiment and three times in the 2010 experiment. In both experiments, the sole maize treatment consisted of the maize cultivar SC701 planted at the density of 22 222 plants ha^{-1}. The sole pumpkin treatment consisted of the pumpkin land race (VOPI reference ex-Bushbuckridge) planted at the density of 5 555 plants ha^{-1}. The maize-pumpkin intercrop treatments consisted of the maize cultivar SC701 planted at the density of 22 222 plants ha^{-1}, to which was pumpkin (VOPI reference ex-Bushbuckridge) was added at the density of 5 555 plants ha^{-1}.

In the 2009 experiment, pumpkins were planted one month later than maize. Pumpkins in the sole pumpkins treatment and in the maize-pumpkin intercrop treatment were planted on the same date.

In the 2010 experiment, all maize was planted on the same date and the seven maize-pumpkin intercrop treatments differed in terms of the date of planting of pumpkin. Starting with simultaneous planting of both crops (MPT0) treatments involved delaying the planting of pumpkin by one week intervals, with the seven-week interval being the longest (MPT7).

The length of the plots was 9.6 m and the width 4.5 m, resulting in a gross plot size of 43.2 m^{-2}. Plots were separated from each other by a 1.4 m wide strip. The crops were planted in rows spaced 0.75 m apart. The net plot was obtained by discarding the two outer rows and the first and last plant in the four inner rows.

Soil preparation was done mechanically and consisted of three operations, namely ploughing, disking and ridging, using the same tractor service as is used by local farmers. Plots were laid out after ridging was completed.

In the 2009 experiment, maize was planted on the 13th of November 2009 and pumpkins on the 14th of December 2009. In the 2010 experiment, maize was planted on the 24th of September 2010 and pumpkins as explained earlier.

At planting, furrows were opened with a hand hoe and fertiliser was applied in the furrow and mixed with the soil by dragging a stick along the bottom of the furrow. Thereafter, 10 ℓ of water was poured in the planting furrow using a watering can, to provide the ideal conditions for emergence. Once the water had infiltrated the soil, the seed was planted at stations spaced 60 cm apart in the case of maize and 2.4 m apart in the case of pumpkins. The seed was then covered with about 5 cm of dry soil. Before planting, the seed was treated with Gaucho, to minimise the spread of maize streak virus. All maize and pumpkin stands were treated preventatively against cutworm damage by spreading Kombat cutworm (active ingredient *sodium fluosilicate*), manufactured by Starke Ayres (Pty) Ltd., on the soil surface at the rate of 10 g m^{-2}. Maize stands were thinned to the desired planting density when the plants had reached the 4th leaf stage and pumpkin stands when the plants had attained the second true leaf stage.

Nutrients were supplied at rates that were adequate to avoid any nutrient deficiencies. Nutrient supply consisted of the application of the fertiliser mixture 2:3:4 (30) + 0.5% Zn at the rate of 450 kg ha^{-1} at planting in the planting furrow, followed by a band-placed top dressing of the crop with LAN (28% N) at the rate of 107 kg LAN ha^{-1} at thinning. Top dressing of the crop with LAN at the rate of 107 kg LAN ha^{-1} was repeated every second week until pollen shed and a total of six applications were administered. Table 8.9 summarises the nutrients received by the crop. In the intercrop treatment, the application of fertilisers was split between the maize and pumpkin rows.

TABLE 8.9: Summary of nutrient application in the 2009 and 2010 irrigated maize-pumpkin intercrop experiments at Dzindi

Type of fertiliser	**Fertiliser application rate** (kg ha^{-1})	**Total N applied** (kg ha^{-1})	**Total P applied** (kg ha^{-1})	**Total K applied** (kg ha^{-1})
2:3:4 (30)	450	30	35	60
LAN (28% N)	6 x 107	180	0	0
Total	**-**	**210**	**35**	**60**

Plots were kept weed-free at all times by hand-hoeing and by manually removing the weeds growing close to the maize plants. At thinning, Tsunami (active ingredient *cypermethrin*), supplied by Tsunami Plant Protection (Pty) Ltd.), was applied at the rate of 5 mℓ 10 ℓ$^{-1}$ water using a knapsack spray for the control of American bollworm. When the plants had reached knee-height, granular dipterex (active ingredient *carbaryl* (carbamate), supplied by Starke Ayres (Pty) Ltd.), was applied in the whorl of the maize plants to control the first generation stalkborer (*Busseola fusca*).

Irrigation water was applied by means of the short-furrow method using the same procedure as local farmers. In the calculation of irrigation water applied. Initially it was assumed that each irrigation event added 20 mm of water to the soil but field measurements indicated that on average 25 mm was applied. Irrigation scheduling involved the application of four irrigations (total of about 100 mm) before planting, and 25 mm once or twice per week depending on the degree of depletion of the available soil water content thereafter until the end of the experiment.

The experiment was discontinued when the maize crop was ready for harvest as green cobs, which was on the 30th of December 2009 and the 29th of December 2010. At harvest, the maize cobs were pulled from the main stem with the husk intact. The outer leaves of the husk together with part of the stem to which the rachis was attached were then broken off, in line with trader practice. Harvesting of pumpkin leaves was done using the harvesting protocol described by Van Averbeke et al. (2012). Harvesting of leaves started when the plants had seven unfolded leaves and the eighth leaf started to appear. At this stage the fourth leaf from the base of the main stem was harvested by cutting off the leaf with a pair of scissors at the base of the petiole. The sixth leaf was the second leaf that was removed from the stem and this was done when the tenth leaf started to appear. This was followed by the harvest of the eighth leaf when the twelfth leaf started to appear. Harvesting of the even-numbered leaves was continued in this way. At the end of the experiment, all the leaves remaining on the main stem and the branches were harvested except the first three leaves on the main stem.

Data that were collected during the intercropping experiment included leaf area of maize, cob length, ear-length and kernel number per ear, photosynthetically active radiation (PAR) and fresh weight of pumpkin leaves. To these were added rainfall, soil water content measurements and above-ground biomass of both maize and pumpkin in the 2010 experiment. Rainfall data were collected on-site, using a plastic rain gauge mounted 1.2 m above the soil surface. Soil water content in the different treatments was monitored by means of a Neutron Moisture Probe (Waterman, model FY500, Geotech, Pretoria).

Leaf area development of the maize plants was monitored in the sole maize treatment and the maize-pumpkin intercrop treatments using the procedures described by Van Averbeke & Marais (1992). To that effect, in each plot that contained maize, 10 maize plants located within the net plot area were randomly selected for monitoring and their leaf area development was recorded. Measurements were done once per week and involved the determination of length and width of the leaves that had become fully developed during the seven day period that followed the previous leaf measurement. For each leaf, the product of length and width was multiplied by a correction factor to account for the shape of the leaves. The correction factors for the different leaf positions were obtained from Van Averbeke (1990:116-117). At any one stage during the season, total leaf area of a plant was the sum of the areas of all fully developed leaves minus the area of the leaves that had senesced by that time.

Interception of photosynthetically active radiation (PAR) by the crop canopy in the different treatments was measured using a ceptometer (Model LP-80, Decagon devices, USA). Measurements were taken on clear days between 11h00 and 14h00 and were done once a week. In the sole maize treatment, one measurement was taken outside the plot, representing PAR above the canopy and 10 measurements below the canopy just above the soil surface. The same measurements were made in the sole pumpkin treatment. In the maize-pumpkin intercrop treatment, measurements were made inside the maize canopy just above the pumpkin canopy and below the pumpkin canopy to determine light interception within this layered canopy.

The length of the main cob was determined in two ways. The first measurement was the length of the cob as it was being traded, with part of the stem and the inner husk still intact. This measurement is referred to as the cob length (see Plate 8.3). The second measurement followed the removal of the remainder of the husk and stem, leaving only the ear and this measurement is referred to as the ear length. Kernels per ear were counted following measurement of the ear length. The leaf yield of pumpkin consisted of the combined mass of the fourth to the last leaf removed from the main stem and all the leaves that appeared on the branches.

The significance of treatment effects were analysed for using analysis of variance using the SAS statistical software version 9.2 (SAS, 2000) and when these effects were statistically significant ($p \leq 0.05$), Fisher's protected least significant difference (LSD) test was used to separate treatment means. The data were analysed at the Biometric Division of the Agricultural Research Council.

8.4 Results

8.4.1 Green maize cultivar x planting date x planting density interaction effects on cob size

September planting

Table 8.10 summarises daily mean air temperature and incident solar irradiance for the entire growing season of the September planting and for the critical period for maize kernel set (30 days around silking).

TABLE 8.10: Selected climatic data describing conditions at Dzindi during the period September to December during the critical period of kernel set

Climatic variable	Season	30 days around silking (16 Nov to 15 Dec 06)
Mean daily minimum temperature (^oC)	18.05	18.45
Mean daily maximum temperature (^oC)	34.55	32.31
Mean daily mean temperature (^oC)	26.30	25.38
Mean daily solar radiation (MJ $m^{-2}day^{1}$)	18.00	15.78
Mean daily PAR (MJ $m^{-2}day^{1}$)	8.10	7.10

Figure 8.2 shows the average proportion of PAR that was intercepted by the two cultivars planted at the four planting densities during the 30-day period around silking. At silking, SC 701 intercepted a slightly higher proportion of PAR than PAN 93 (Fig. 8.2). Interception of PAR increased with increasing planting density. At the lowest planting density PAN 93 intercepted 55% and SC 701 58% of PAR. in the case at the lowest planting density (1.3 plants m^{-2}). For both cultivars PAR interception increased to about 92% when they were planted at the highest planting density of 8.0 plants m^{-2}.

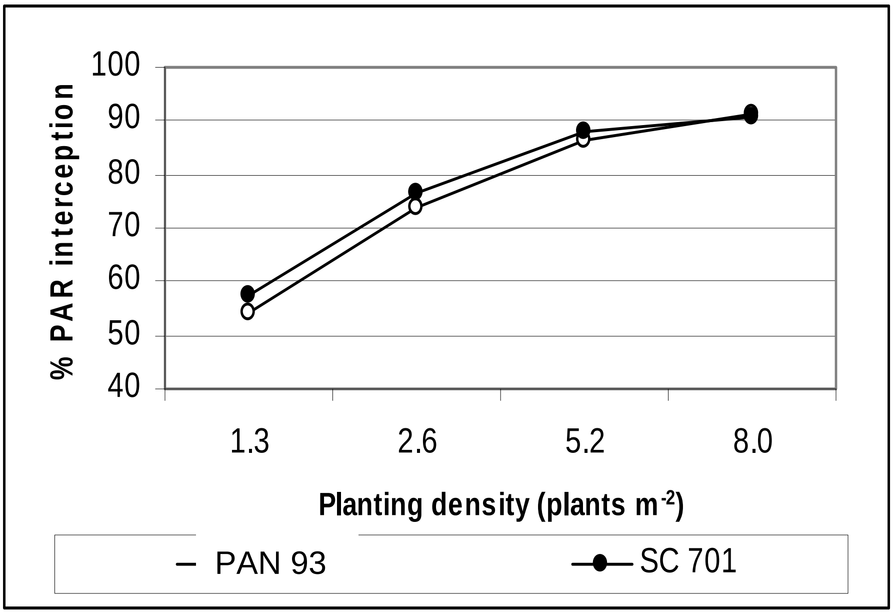


FIGURE 8.2: Effect of planting density on the proportion of photosynthetically active radiation intercepted by two maize cultivars planted in September at Dzindi

Table 8.11 quantifies the photosynthetically active radiation (PAR) (MJ m^{-2}) that was intercepted by the two cultivars planted at the four planting densities during the 30-day period around silking and also shows the mean daily intercepted photosynthetically active radiation per plant (IPARP) for all treatments. For both cultivars PAR interception per unit area increased with increasing planting density (Table 8.11) but IPARP declined as planting density was increased. Interception of PAR tended to be higher in SC 701 than in PAN 93 (Fig. 8.2). The daily amounts of IPARP corresponded with those reported in studies elsewhere. In the experiments of Kiniry, Xie and Gerik (2001) and Andrade, Otegui, Vega (2000), in which IPARP varied between 0.3 and 3.5 MJ day^{-1}, an IPARP of about 1.8 MJ day^{-1} was required for maize plants to produce maximum kernel number per ear. In their experiments the very low IPARP values were obtained by using shade nets.

TABLE 8.11: Effect of maize cultivar and planting density on intercepted photo-synthetically active radiation (IPAR) and on daily mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking in the experiment planted in September at Dzindi

Planting density (plants m^{-2})	**Total IPAR (±30days around silking)** (MJ m^{-2})	**Daily mean IPAR** (MJ m^{-2})	**Daily mean IPARP** (MJ $plant^{-1}$)
		PAN 93	
1.3	111.85	3.73	2.28
2.6	157.52	5.25	2.02
5.2	181.30	6.04	1.16
8.0	190.05	6.33	0.79
		SC 701	
1.3	121.94	4.06	3.13
2.6	164.64	5.49	2.11
5.2	189.09	6.30	1.21
8.0	191.71	6.39	0.80

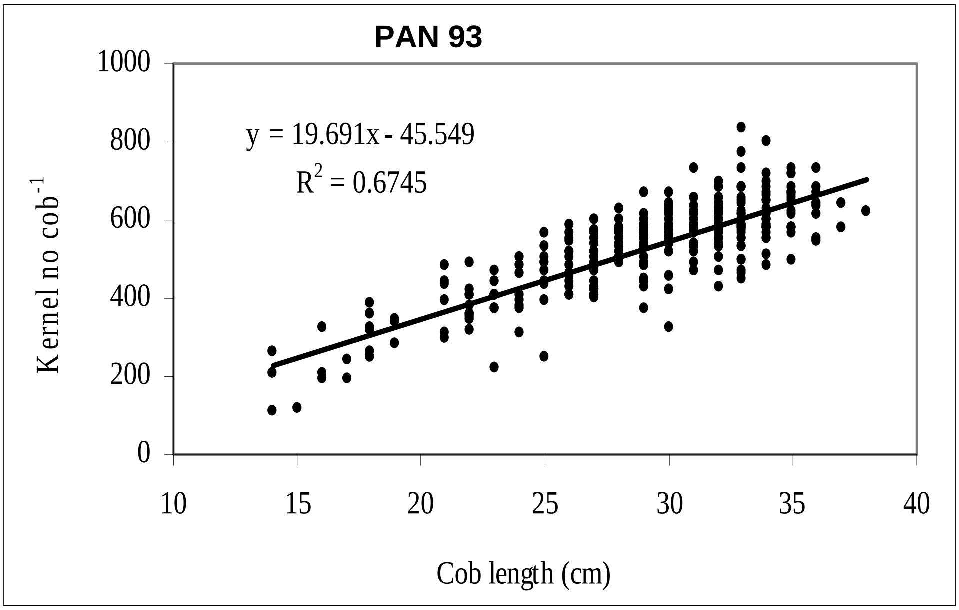
Table 8.12 presents summary statistics of cob length, number of kernels per row and number of kernels per ear that were recorded in the different treatments. Table 8.12 shows that mean cob length, kernel number per row and kernel number per ear declined with increasing planting density for both cultivars. The decline in these three variables resulting from increases in intra-specific competition was considerable when planting density was raised from 2.6 plants m^{-2} to 5.2 plants m^{-2}. The observed decline in cob length brought about by increased crowding is explained by the reduction in IPARP, which is associated with an increase in mutual shading of the maize plants, evident from Table 8.11. The considerable decline in the three variables concerned observed when planting density was increased from 2.6 plants m^{-2} to 5.2 plants m^{-2} coincided with a reduction of the IPARP to below 2.02 and 2.11 MJ $plant^{-1}$ day^{-1} for PAN 93 and SC 701, respectively (Table 8.11).

TABLE 8.12: Effect of planting density on mean cob length, number of kernels per row and number of kernels per ear for the PAN 93 and SC 701 maize cultivars planted in September at Dzindi

Planting density	**PAN 93**			**SC 701**		
	Cob length (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**	**Cob length** (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**
1.3	32.40	48	595	35.86	52	666
2.6	32.34	47	590	34.52	49	643
5.2	28.11	43	513	28.00	39	489
8.0	22.89	34	399	22.21	31	378

Cob length, kernel number per row and kernel number per ear obtained from the 1.3 and 2.6 plants m^{-2} planting density treatments were higher in SC 701 than in PAN 93 but when planting density was increased to 5.2 and 8.0 m^{-2}, PAN 93 performed better. These results suggested that SC 701 was more sensitive to crowding and the associated low IPARP levels than PAN 93.

The relationship between KNE and cob length was analyzed using linear regression, illustrated in Figure 8.3. The regression analyses illustrated in Figure 8.3 shows the linear relationship between cob length and KNE. The linear models in Figure 8.3 explained 67% of the variability in cob length of PAN 93 and 73% for SC 701, indicating that cob length and KNE were closely associated for both maize cultivars.



PAN 93

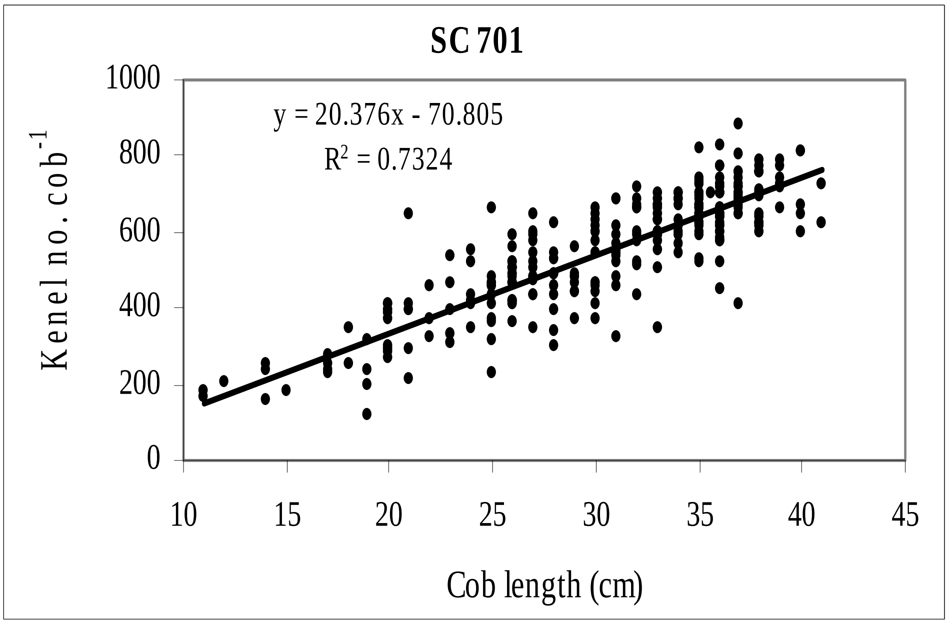
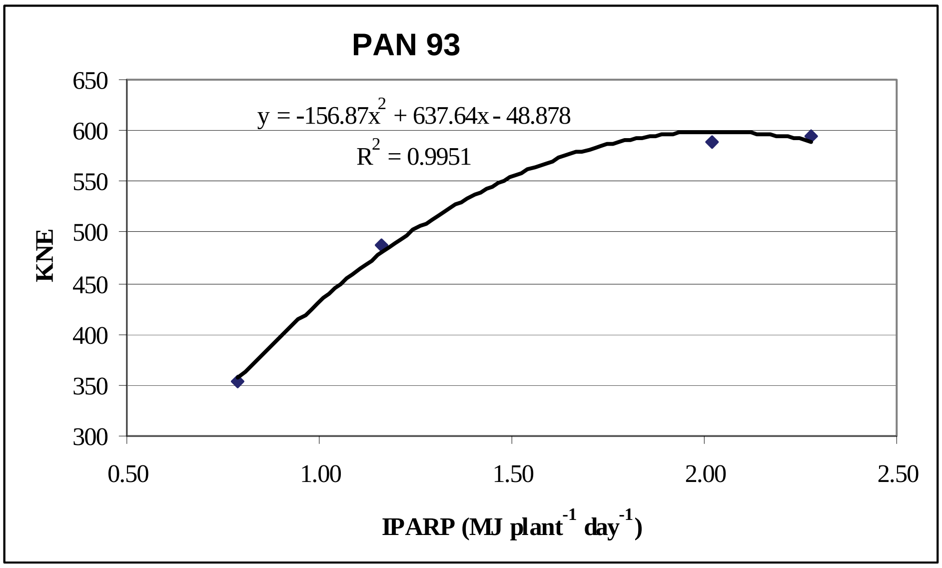


FIGURE 8.3: Relationship between mean KNE and cob length for the two maize cultivars planted at Dzindi in September 2006

Using the regression equations presented in Figure 8.3, the KNE of a 31 cm long cob was determined. The estimated KNE for a 31 cm cob was 565 for PAN 93 and 561 for SC 701. The polynomial regression analysis of the relationship between mean KNE and IPARP, presented in Figure 8.4, indicated that the minimum IPARP required for the production of a 31 cm long cob when planting maize in September in the study area was 1.58 MJ plant^{-1} day^{-1} for PAN 93 and 1.55 MJ plant^{-1} day^{-1} for SC 701.



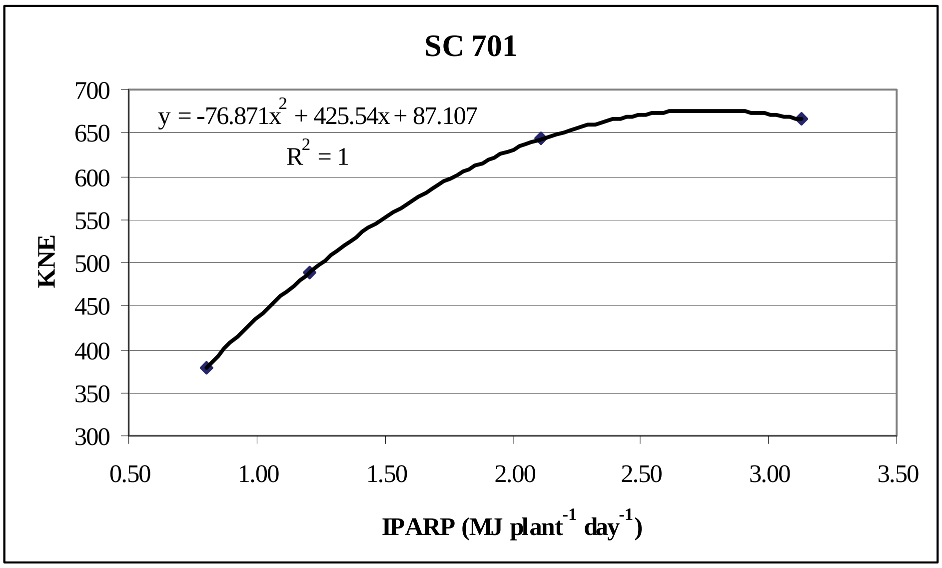


FIGURE 8.4: Relationship between mean IPARP during the 30-day period around silking and KNE for the two maize cultivars planted in September at Dzindi

The logarithmic regression analysis of the relationship between planting density and IPARP, shown in Figure 8.5, enabled estimation of the optimum planting density for green maize production for the two cultivars when planted in September at Dzindi. The estimated optimum planting density obtained in this way was 3.4 plants m^{-2} for PAN 93 and 4.2 plants m^{-2} for SC 701 for the September planting.

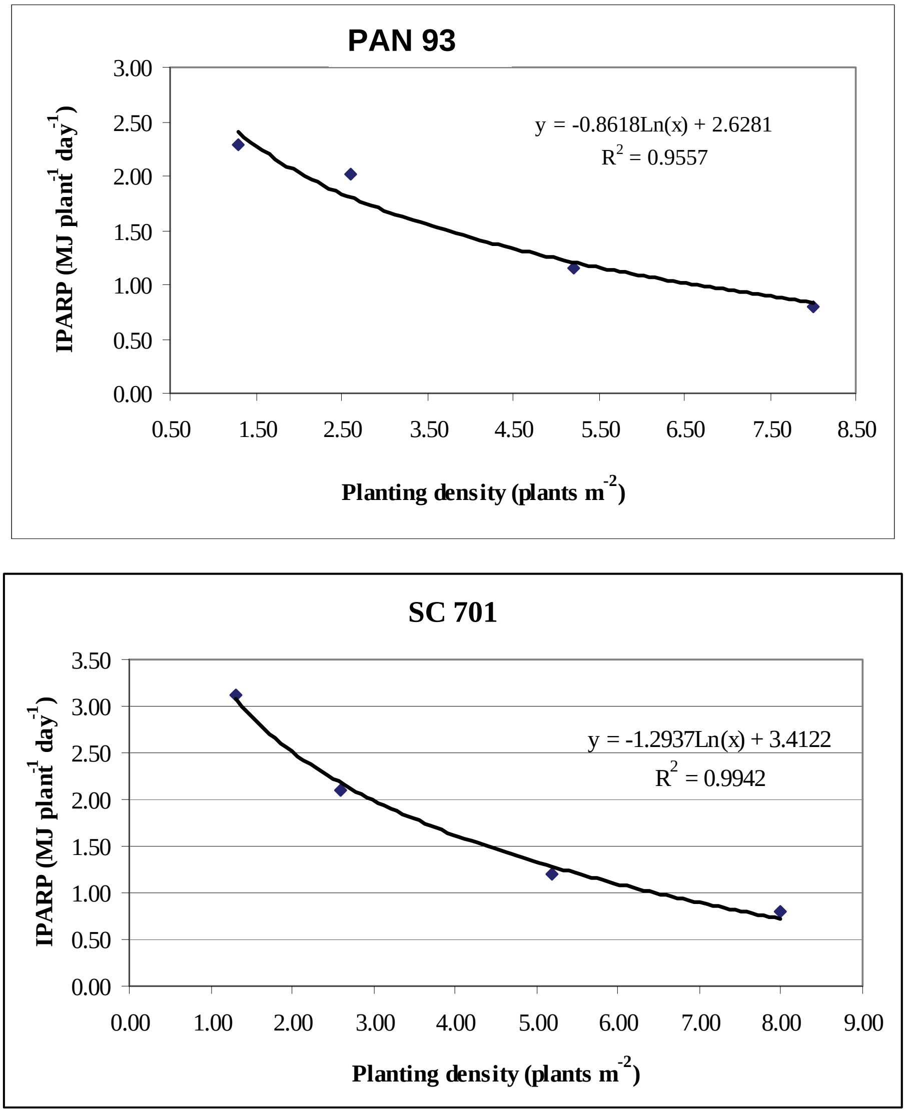


FIGURE 8.5: Relationship between planting density and IPARP during the 30-day period around silking for the two maize cultivars planted in September 2006 at Dzindi

In Table 8.13, the cobs obtained from the experimental plots were analyzed in function of the length criteria for the grading of cobs presented in Table 8.7.

TABLE 8.13: Effect of planting density and cultivar on length and marketability of green cobs in the September planting of the cultivar x planting density experiment at Dzindi

Cob length (cm)	**Number of cobs per grade from 1000** m^{-2}							
	1.3 plants m^{-2}		**2.6 plants** m^{-2}		**5.2 plants** m^{-2}		**8 plants** m^{-2}	
	% of total	No of cobs	% of total	No of cobs	% of total	No of cobs	% of total	No of cobs
				PAN 93				
Barren	0	0	0	0	5	650	13	1 000
< 27	3	35	3	65	20	3 640	70	5 600
27-30	19	243	20	520	46	520	10	800
>30	79	1 023	78	2 015	29	390	8	600
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**
				SC 701				
Barren	0	0	0	0	4	195	16	1 300
< 27	1	17	3	67	30	1 560	70	5 600
27-30	1	17	4	100	45	2 340	13	1 000
>30	97	1 267	94	2 433	21	1 105	1	100
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**

Table 8.13 shows that the proportion of cobs that met the grade 1 length criterion (31 cm or longer) declined as planting density was raised above 2.6 plants m^{-2}. SC 701 produced a higher proportion of marketable cobs in the 1.3 plants m^{-2}, 2.6 plants m^{-2} and 5.2 plants m^{-2} density treatments than PAN 93 but at the planting density of 8.0 plants m^{-2} PAN 93 produced the highest proportion of grade 1 cobs. This suggests that PAN 93 tolerated conditions of high intra-specific competition better than SC 701, as was already evident from Table 8.11.

In summary, the results obtained in the September planting date experiment showed that there was a relationship between planting density, IPARP, KNE and cob length. This allowed for the prediction of cob length of the two cultivars based on KNE and IPARP. IPARP declined when planting density was increased. Cob length and KNE declined when planting density was raised from 2.6 to 5.2 plants m^{-2} and higher. The study showed that the number of plants per unit area producing green cobs in the first grade, with a minimum length of 31 cm, could be maximized by optimizing planting density, and that optimum planting density was to an extent cultivar specific. For September plantings at Dzindi the optimum planting density for green maize production was estimated to be 3.4 plants m^{-2} for the cultivar PAN 93 and 4.2 plants m^{-2} for SC 701. These estimated optimum planting densities coincided with an estimated IPARP during the 30-day period around silking of 1.58 MJ $plant^{-1}$ day^{-1} in PAN 93, and 1.55 MJ $plant^{-1}$ day^{-1} in SC 701 plantings. The experiment showed SC 701 to be the most suitable cultivar for planting of green maize in September.

December planting

Table 8.14 summarises daily mean air temperature and incident solar irradiance for the entire season and for the critical period for maize kernel set (30 days around silking) and Figure 8.6 shows the average proportion of PAR that was intercepted by the four planting densities x two cultivars during the 30-day period around silking. The effect of planting density and cultivar on PAR interception observed in the December experiment (Fig. 8.6) was similar to that observed in the September planting (Fig. 8.2). At silking, SC 701 intercepted slightly more PAR than PAN 93 in all the planting density treatments except at the highest density of 8 plants m^{-2} (Fig. 8.6). Interception of PAR increased with increasing planting density from 28% (PAN 93) and 39% (SC 701) in the lowest planting density (1.3 plants m^{-2}) to about 88% for both cultivars in the highest planting density of 8 plants m^{-2}, which was lower than expected.

TABLE 8.14: Selected climatic data describing conditions at Dzindi during the period December 2006 to May 2007 and during the critical period of kernel set

Climatic variable	**Season**	**30 days around silking (10 Feb to 11 Mar)**
Mean daily minimum temperature (^oC)	19.74	19.95
Mean daily maximum temperature (^oC)	32.07	31.65
Mean daily mean temperature (^oC)	25.81	25.80
Mean daily solar radiation (MJ $m^{-2}day^{-1}$)	17.76	17.30
Mean daily PAR (MJ $m^{-2}day^{-1}$)	7.99	7.79

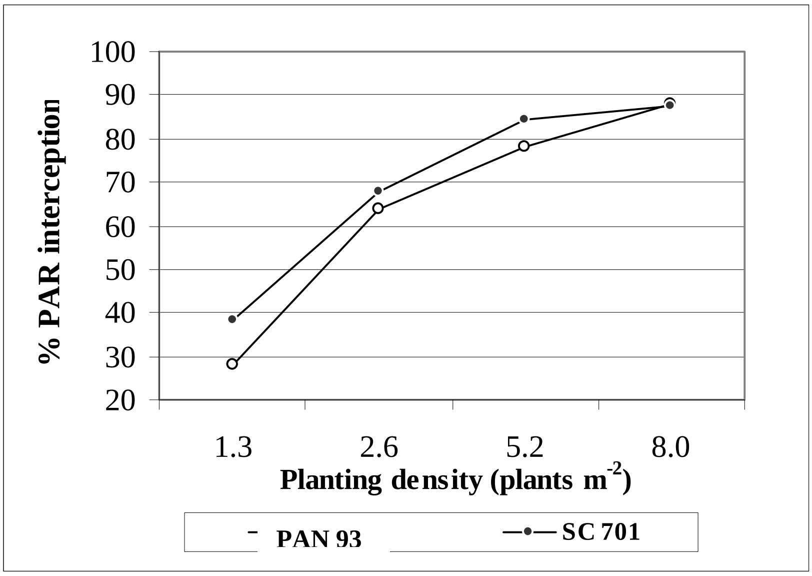


FIGURE 8.6: Effect of planting density on the proportion of photosynthetically active radiation (PAR) intercepted by two maize cultivars planted in December at Dzindi

Table 8.15 contains the amounts of PAR intercepted in the four planting density treatments at silking. Table 8.15 shows that interception of PAR per unit area increased with increasing planting density in both cultivars, whilst IPARP declined with increasing planting density. The trend was similar to that observed in the September planting.

TABLE 8.15: Effect of maize cultivar and planting density on intercepted photo-synthetically active radiation (IPAR) and on daily mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking in the experiment planted in December at Dzindi

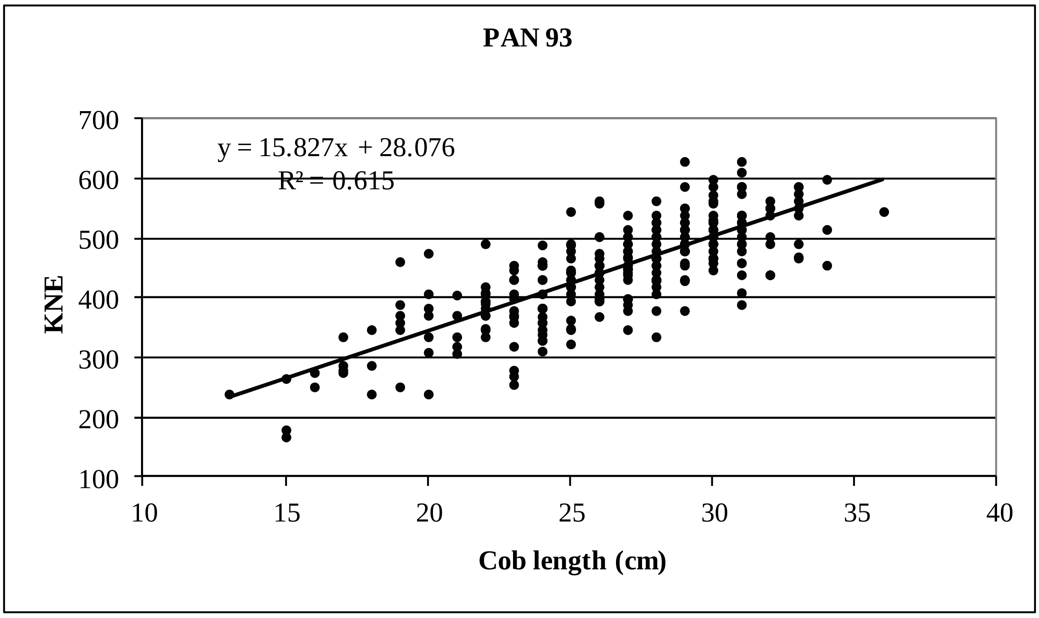
Planting density (plants m^{-2})	**Total IPAR (±30days around silking)** ($MJ\ m^{-2}$)	**Daily average IPAR** ($MJ\ m^{-2}$)	**Daily average IPARP** ($MJ\ plant^{-1}$)
		PAN 93	
1.3	74.12	2.47	1.90
2.6	155.99	5.20	2.00
5.2	168.48	5.62	1.08
8.0	189.92	6.33	0.79
		SC 701	
1.3	98.93	3.30	2.54
2.6	142.70	4.76	1.83
5.2	186.52	6.22	1.20
8.0	198.55	6.62	0.83

Table 8.16 presents summary statistics of cob length, number of kernels per row and number of kernels per ear recorded in the different treatments.

TABLE 8.16: Effect of planting density on cob length, number of kernels per row and number of kernels per ear for the PAN 93 and SC 701 maize cultivars planted in December at Dzindi

Planting density (plants m^{-2})	**PAN 93**			**SC 701**		
	Cob length (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**	**Cob length** (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**
1.3	30.09	42	505	32.20	45.68	580
2.6	27.72	41	476	31.22	44.97	584
5.2	26.21	36	423	27.54	38.14	490
8.0	21.66	32	381	23.30	34.54	433

Table 8.16 shows that cob length, kernel number per row and kernel number per ear declined with increasing planting density for both cultivars as observed for the September planting date. The relationship between KNE and cob length was analysed using linear regression (Figure 8.7).



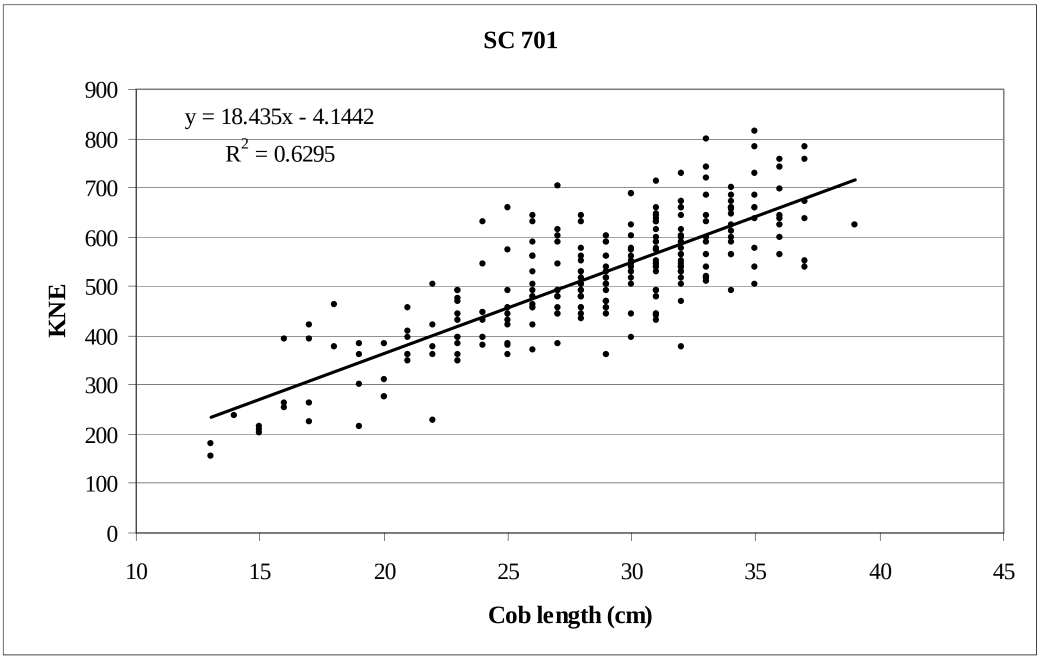
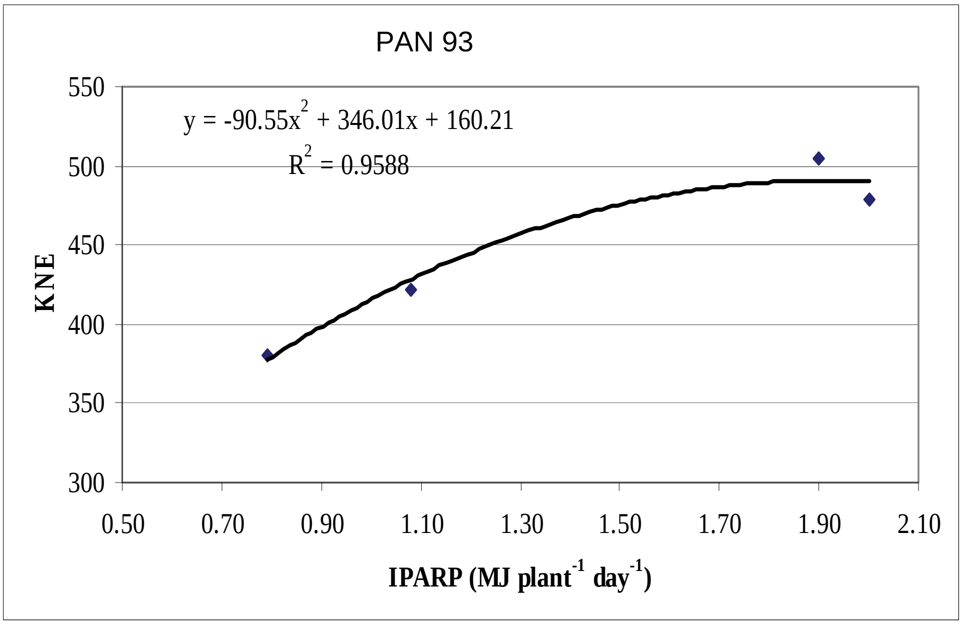


FIGURE 8.7: Relationship between kernel number per ear (KNE) and cob length for two maize cultivars planted in December at Dzindi

The regression analysis illustrated in Figure 8.7 confirms the linear relationship between cob length and KNE observed in the September planting. The linear regression models that were developed explained 62% of the variability in cob length in PAN 93 and 63% in SC 701. Using the regression equations presented in Figure 8.8, the KNE of a 31 cm long cob was determined.



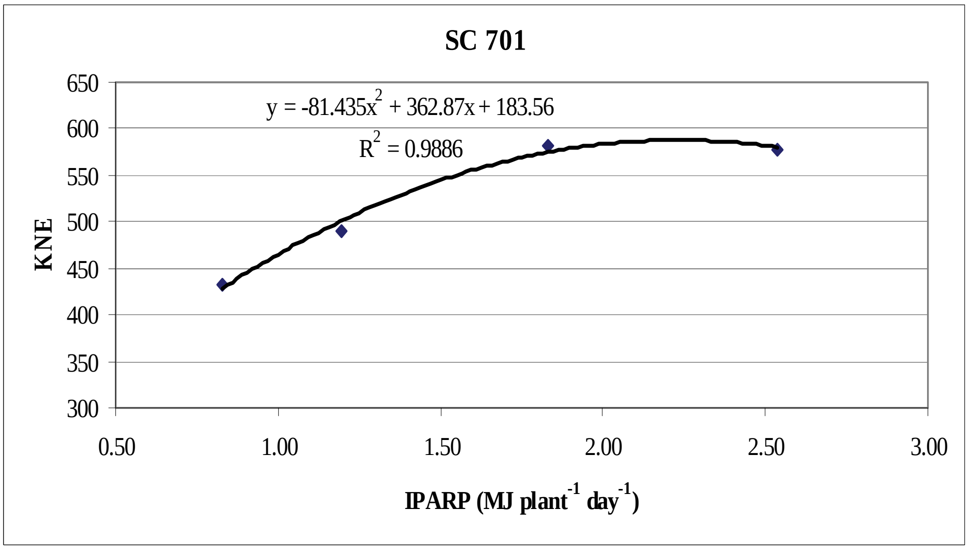


FIGURE 8.8: Relationship between mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking and kernel number per ear (KNE) for two maize cultivars planted in December at Dzindi

The estimated KNE of a cob with a length of 31 cm was 519 for PAN 93 and 567 for SC 701. A polynomial regression analysis of the relationship between mean KNE and IPARP presented in Figure 8.8 indicated that the minimum IPARP required for the production of a grade 1 cob when planting maize in December in the study area was 2.0 MJ plant^{-1} day^{-1} for PAN 93 and 1.72 MJ plant^{-1} day^{-1} for SC 701.

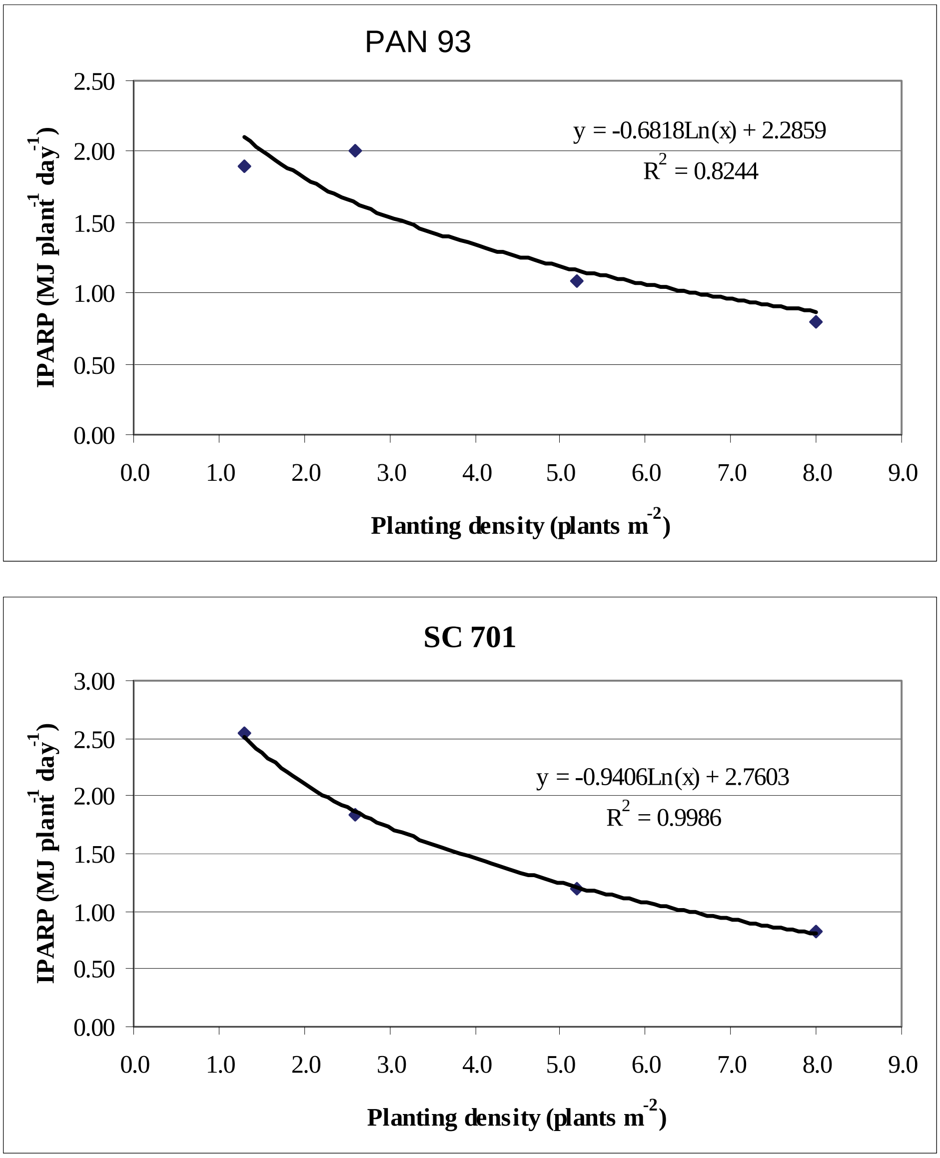


FIGURE 8.9: Relationship between planting density and intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking for the two maize cultivars planted in December at Dzindi

Logarithmic regression analysis of the relationship between planting density and IPARP, shown in Figure 8.9, enabled the estimation of the optimum planting density for green maize production for the two cultivars when planted in December at Dzindi. The estimated optimum planting density obtained in this way was 1.4 plants m^{-2} for PAN 93 and 3.0 plants m^{-2} for SC 701.

Table 8.17 shows the effect of planting density and cultivar on length and marketability of green cobs on the basis of the cob length criteria listed in Table 8.7. The results in Table 8.17 show that the proportion of cobs that were at least 31 cm long (grade 1 cobs) declined as planting density was increased, in line with the results obtained in the September planting date experiment. The number of grade 1 cobs per unit land declined when planting density was increased from 1.3 plants m^{-2} to 2.6 plants m^{-2} for PAN 93 and from 2.6 plants m^{-2} to 5.2 plants m^{-2} for SC 701. These results supported the optimum planting densities that were estimated for the two cultivars when planted in September, i.e. 1.4 plants m^{-2} for PAN 93 and 3.0 plants m^{-2} for SC 701. When planted in December SC 701 yielded more marketable cobs than PAN 93 in all four planting density treatments.

TABLE 8.17: Effect of planting density and cultivar on length and marketability of green cobs in the December planting of the cultivar x planting density experiment at Dzindi

Cob length (cm)	**Number of cobs per grade obtained from an area of 1000** m^{-2}							
	1.3 plants m^{-2}		2.6 plants m^{-2}		5.2 plants m^{-2}		8 plants m^{-2}	
	% of total	No of cobs	% of total	No of cobs	% of total	No of plants	% of total	No of cobs
				PAN 93				
Barren	0	0	0	0	16	845	19	1 500
<27	6	76	32	834	46	2 405	78	6 200
27-30	51	669	53	1 374	31	1 625	4	300
>30	43	554	15	392	6	325	0	0
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**
				SC 701				
Barren	0	0	0	0	10	520	16	1 300
<27	7	91	8	214	30	1 560	59	4 700
27-30	19	251	22	570	39	2 015	23	1 800
>30	74	958	70	1 816	21	1 105	3	200
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**

April planting

Table 8.18 presents daily mean air temperature and incident solar irradiance for the entire season and for the critical period for maize kernel set (30 days around silking) and Figure 8.10 the average proportion of PAR that was intercepted by the four planting densities x two cultivars during the 30-day period around silking.

TABLE 8.18: Selected climatic data describing conditions at Dzindi during the period April to August 2008 and during the critical period of kernel set

Climatic variable	Season	30 days around silking (20 June to 19 July)
Mean daily minimum temperature (^oC)	11.10	9.77
Mean daily maximum temperature (^oC)	25.65	24.93
Mean daily mean temperature (^oC)	17.74	16.89
Mean daily solar radiation (MJ $m^{-2}day^{-1}$)	11.15	9.33
Mean daily PAR (MJ $m^{-2}day^{-1}$)	5.02	4.20

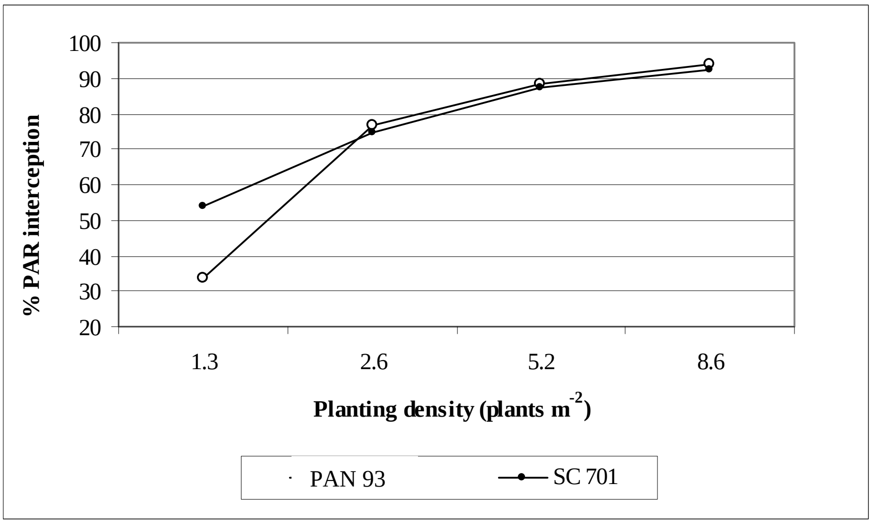


FIGURE 8.10: Effect of planting density on the proportion of photosynthetically active radiation intercepted by two maize cultivars planted in April at Dzindi

Figure 8.10 shows that interception of PAR at silking in the April planting differed slightly from that recorded in the September and December plantings. Except in the 1.3 plants m^{-2} planting density treatment, PAN 93 intercepted slightly more PAR than SC 701. This difference could be the results of differences in the growth response of the two maize cultivars to temperature.

Table 8.19 presents the amounts of PAR intercepted in the four planting density treatments at silking.

TABLE 8.19: Effect of maize cultivar and planting density on intercepted photo-synthetically active radiation (IPAR) and on daily mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking in the experiment planted in April 2008 at Dzindi

Planting density (plants m^{-2})	**Total IPAR (±30days around silking)** (MJ m^{-2})	**Daily average IPAR** (MJ m^{-2})	**Daily average IPARP** (MJ $plant^{-1}$)
		PAN 93	
1.3	57.52	1.92	1.47
2.6	100.31	3.34	1.29
5.2	111.20	3.71	0.71
8.0	114.20	3.81	0.48
		SC 701	
1.3	67.14	2.24	1.72
2.6	91.59	3.05	1.17
5.2	111.06	3.70	0.71
8.0	114.38	3.81	0.48

The interception of PAR per unit area increased and IPARP decreased with increasing planting density in both cultivars (Table 8.19), but was substantially lower than in the September and December plantings.

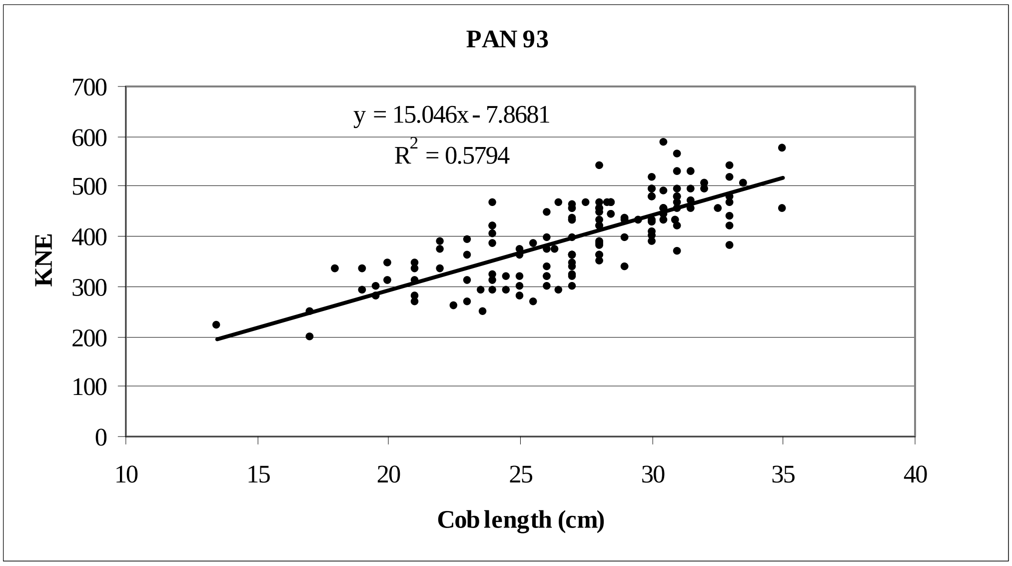
Table 8.20 contains the summary statistics of cob length, number of kernels per row and number of kernels per ear recorded in the different treatments.

TABLE 8.20: Effect of planting density on cob length, number of kernels per row and number of kernels per ear for the PAN 93 and SC 701 maize cultivars planted in April at Dzindi

Density (plants m^{-2})	**PAN 93**			**SC 701**		
	Cob length (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**	**Cob length** (cm)	**No. of kernels row^{-1}**	**No. of kernels ear^{-1}**
1.3	30.65	40	467	32.16	43	556
2.6	29.33	38	443	30.52	43	537
5.2	27.31	34	393	29.26	41	488
8.0	22.52	29	324	21.80	29	346

As was observed in the September and December plantings, Table 8.20 shows that mean cob length, kernel number per row and kernel number per ear declined with increasing planting density for both cultivars. Despite low interception of PAR, SC 701 yielded longer cobs and produced higher KNE than PAN 93.

The relationship between KNE and cob length was analyzed using linear regression (Figure 8.11). The linear regression analysis depicted in Figure 8.11 confirmed the linear relationship between cob length and KNE observed in the September and December plantings. The regression models explained 58% of the variability in cob length for PAN 93 and 70% for SC 701. Using the regression equations shown in Figure 8.11, the KNE of a 31 cm long cob was estimated to be 459 for PAN 93 and 534 for SC 701.



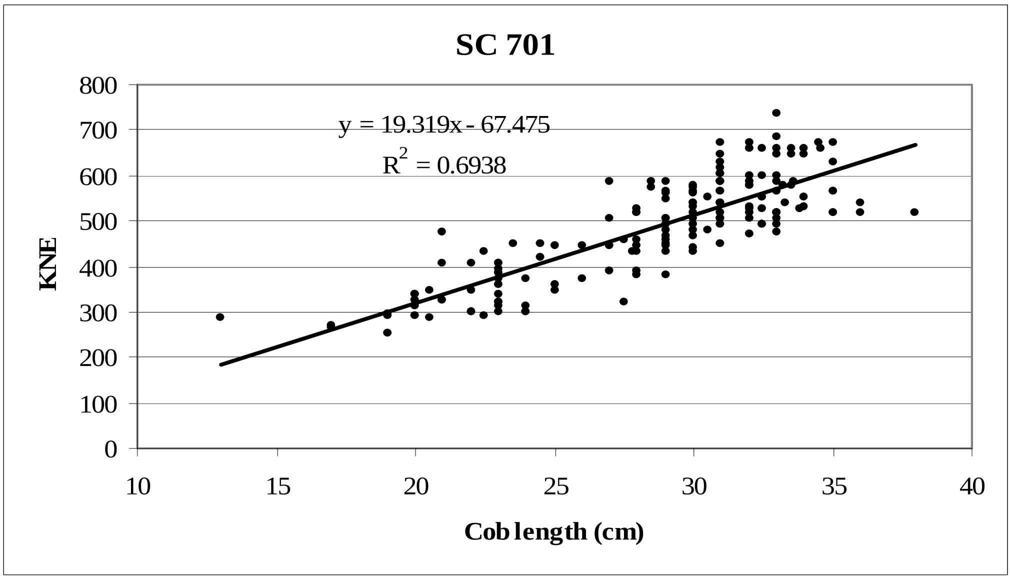
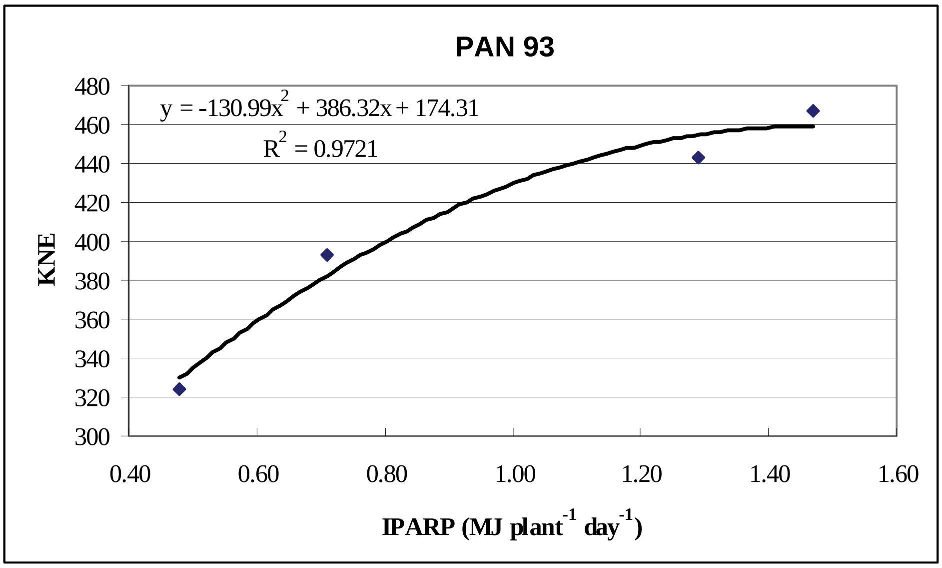


FIGURE 8.11: Relationship between kernel number per ear (KNE) and cob length for two maize cultivars planted in April at Dzindi

Polynomial regression analysis of the relationship between mean KNE and IPARP presented in Figure 8.12 indicated that the PARP required for the production of a 31 cm long cob was 1.44 MJ plant^{-1} day^{-1} for PAN 93 and 1.00 MJ plant^{-1} day^{-1} for SC 701.



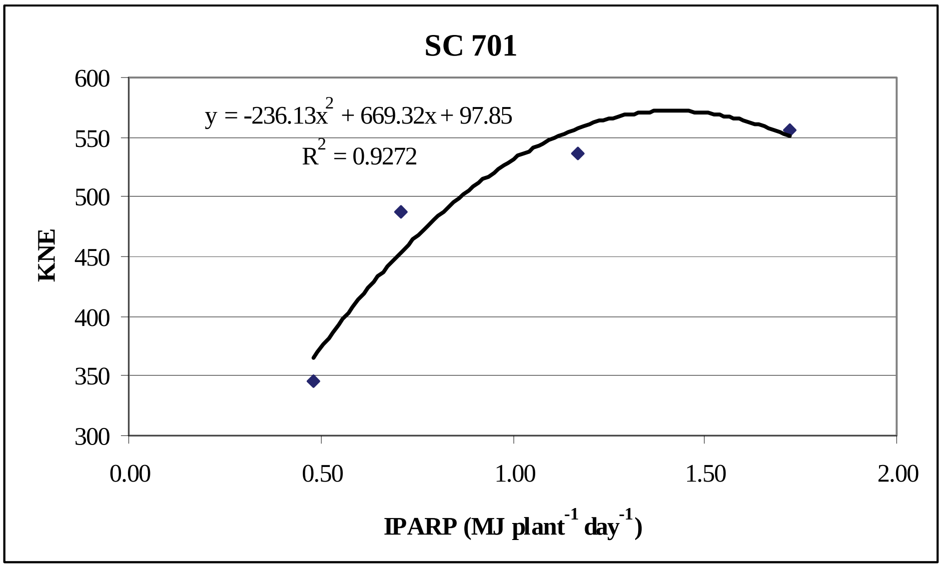
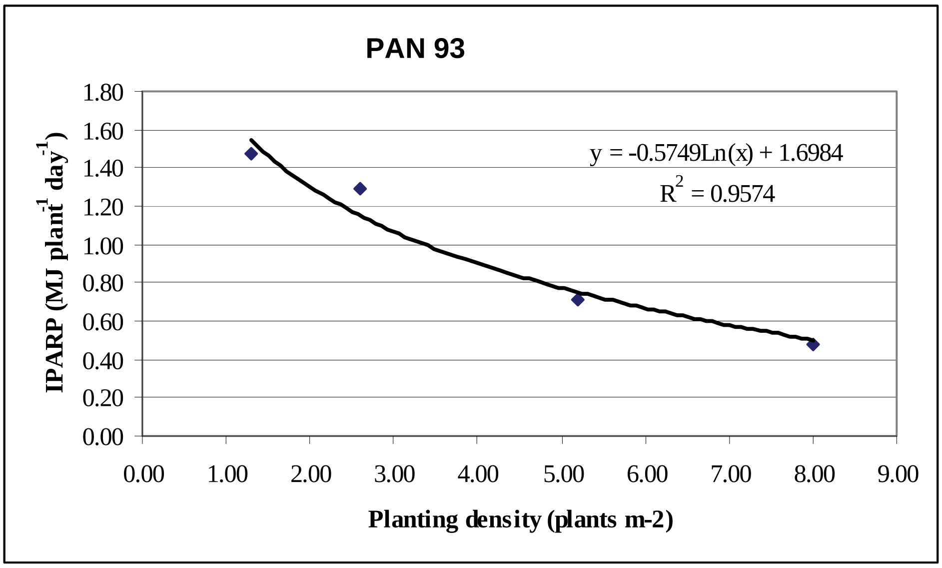


FIGURE 8.12: Relationship between mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking and kernel number per ear (KNE) for the two maize cultivars planted in April at Dzindi

The regression analysis of the relationship between planting density and IPARP, shown in Figure 8.13 was used to estimate the optimum planting density for green maize production for the two cultivars when planted in April.



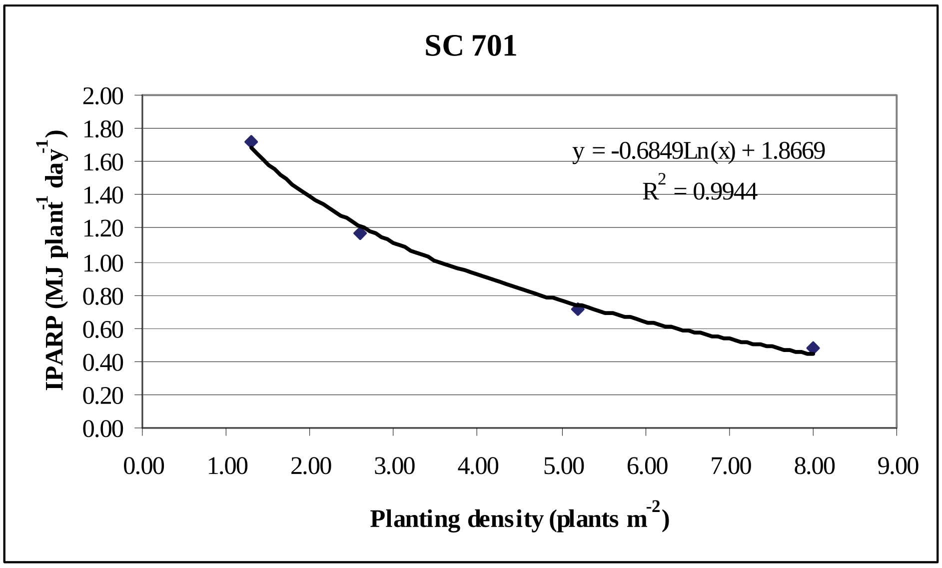


FIGURE 8.13: Relationship between planting density and intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking for the two maize cultivars planted in April at Dzindi

The estimated optimum planting density obtained in this way was 1.57 plants m^{-2} for PAN 93 and 3.54 plants m^{-2} for SC 701. Table 8.21 shows the effect of planting density and cultivar on cob length and marketability of green cobs obtained from the four planting densities.

TABLE 8.21: Effect of planting density and cultivar on length and marketability of green cobs in the April planting of the cultivar x planting density experiment at Dzindi

Cob length (cm)	**Number of cobs per grade from 1000** m^{-2}							
	1.3 plants m^{-2}		2.6 plants m^{-2}		5.2 plants m^{-2}		8 plants m^{-2}	
	% of total	No of cobs	% of total	No of cobs	% of total	No of cobs	% of total	No of cobs
				PAN 93				
<27	0	0	7	173	30	1 560	90	7 179
27-30	47	607	60	1 560	50	2 600	10	821
>30	53	693	33	867	20	1 040	0	0
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8000**
				SC 701				
<27	4	52	10	260	8	390	95	7 600
27-30	20	260	23	585	65	3380	5	400
>30	76	988	68	1 755	28	1430	0	0
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**

The results in Table 8.21 did not support the estimated optimum density of 1.57 plants m^{-2} identified for PAN 93. Instead, the highest number of marketable cobs per unit area was obtained at the planting density treatment of 5.2 plants m^{-2}. This suggested that the estimated optimum density for PAN 93 planted in April was too low. Another factor that could have affected the trustworthiness of the results was the relatively high incidence of plants affected by MSV, which is known to introduce size variability among plants in a stand. MSV affected plants were not sampled for cob length and KNE measurements, and since these plants tended to be taller than MSV infected plants, the normal planting density effect of crowding on cob length and MSV could have been obscured. For the April planting at Dzindi, the optimum planting density for green maize production using PAN 93 was estimated to be 1.54 plants m^{-2} but this estimate was not congruent with the number of cobs with a length of 31 cm or more that were counted in the plots as shown in Table 8.21. High incidence of MSV combined with sampling of the cobs of unaffected plants only could have been the cause of this lack of congruence. The cultivar SC 701 produced more cobs that met the 31 cm length requirement than PAN 93 in all three density treatments that yielded cobs with this length. The optimum planting density for green maize production using SC 701 was estimated to be 3.54 plants m^{-2} and this was supported by the number of cobs that met the 31 cm length requirement per unit area obtained from the different planting density treatments shown in Table 8.21.

June planting

Table 8.22 presents the daily mean air temperature and incident solar irradiance for the entire season and for the critical period for maize kernel set (30 days around silking).

TABLE 8.22: Selected climatic data describing conditions at Dzindi during the period June to November 2008 and during the critical period of kernel set

Climatic variable	Season	30 days around silking
Mean daily minimum temperature (^oC)	13.25	16.41
Mean daily maximum temperature (^oC)	25.82	-
Mean daily mean temperature (^oC)	20.22	22.78
Mean daily solar radiation (MJ $m^{-2}day^{-1}$)	15.04	19.08
Mean daily PAR (MJ $m^{-2}day^{-1}$)	6.77	8.59

Figure 8.14 shows the proportion of PAR that was intercepted by the four planting densities x two cultivars during the 30-day period around silking for maize planted in June at Dzindi.

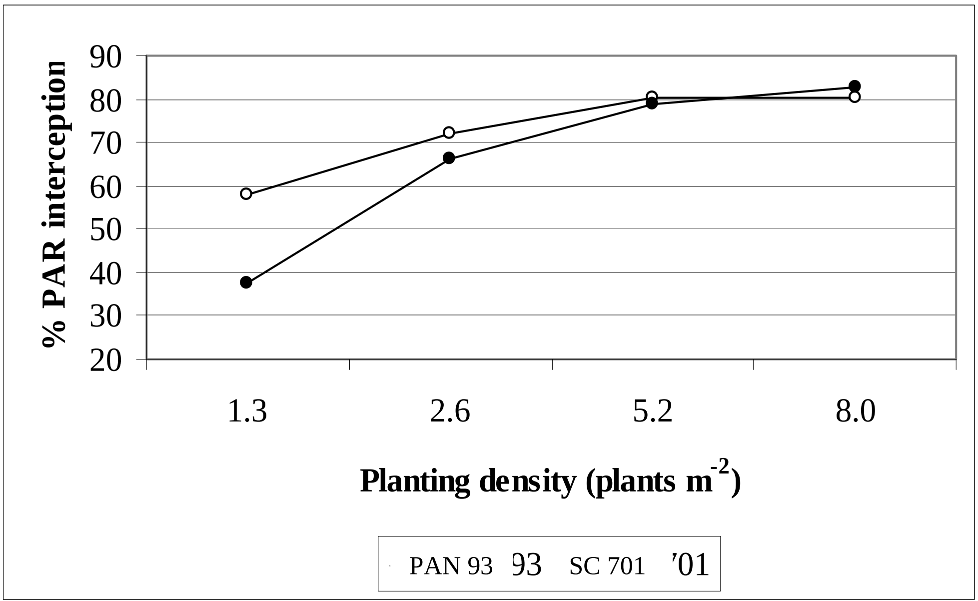


FIGURE 8.14: Effect of planting density on the proportion of photosynthetically active radiation (PAR) intercepted by two maize cultivars planted in June at Dzindi

As in the April planting, PAN 93 intercepted slightly more PAR than SC 701, particularly in the two lowest planting density treatments. This contrasted with the September and December plantings, in which SC 701 93 intercepted slightly more PAR than PAN 93.

Table 8.23 shows the amount of PAR intercepted by maize at silking in the four planting density treatments of the June experiment. The results indicated that PAR interception peaked in the 5.2 plants m^{-2} treatment and not the highest planting density treatment, which contrasted with the results obtained in the other three planting date experiments. Daily mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking was the highest among the four planting dates.

TABLE 8.23: Effect of maize cultivar and planting density on intercepted photosynthetically active radiation (IPAR) and on daily mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking in the experiment planted in June at Dzindi

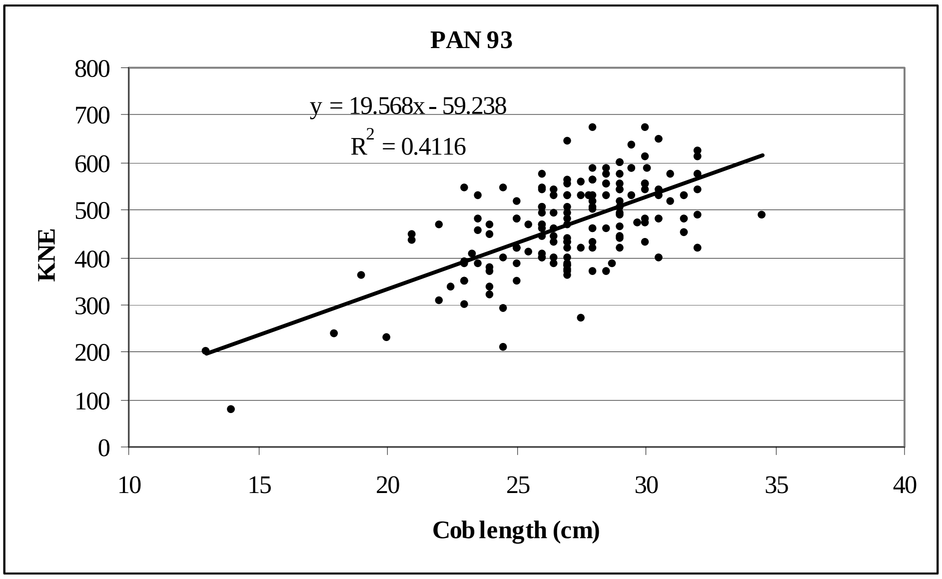
Planting density (plants m^{-2})	**Total IPAR (±30days around silking)** ($MJ\ m^{-2}$)	**Daily average IPAR** ($MJ\ m^{-2}$)	**Daily average IPARP** ($MJ\ plant^{-1}$)
		PAN 93	
1.3	131.93	4.40	3.38
2.6	162.69	5.42	2.09
5.2	197.65	6.59	1.27
8.0	190.24	6.34	0.79
		SC 701	
1.3	90.57	3.02	2.32
2.6	147.39	4.91	1.89
5.2	188.55	6.29	1.21
8.0	186.25	6.21	0.78

Table 8.24 presents the summary statistics of cob length, number of kernels per row and number of kernels per ear recorded in the different treatments.

TABLE 8.24: Effect of planting density on cob length, number of kernels per row and number of kernels per ear for the PAN 93 and SC 701 maize cultivars planted in June at Dzindi

Planting density (plants m^{-2})	**PAN 93**			**SC 701**		
	Cob length (cm)	**No. of kernels** $\mathbf{row^{-1}}$	**No. of kernels** $\mathbf{cob^{-1}}$	**Cob length** (cm)	**No. of kernels** $\mathbf{row^{-1}}$	**No. of kernels** $\mathbf{cob^{-1}}$
1.3	28.96	12	516	31.71	14	647
2.6	27.85	12	506	28.57	14	594
5.2	26.29	12	463	26.13	14	488
8.0	24.71	12	390	24.86	12	437

Table 8.24 shows that mean cob length, kernel number per row and kernel number per ear again declined with increasing planting density for both cultivars. The relationship between KNE and cob length was analysed using linear regression (Fig. 8.15).



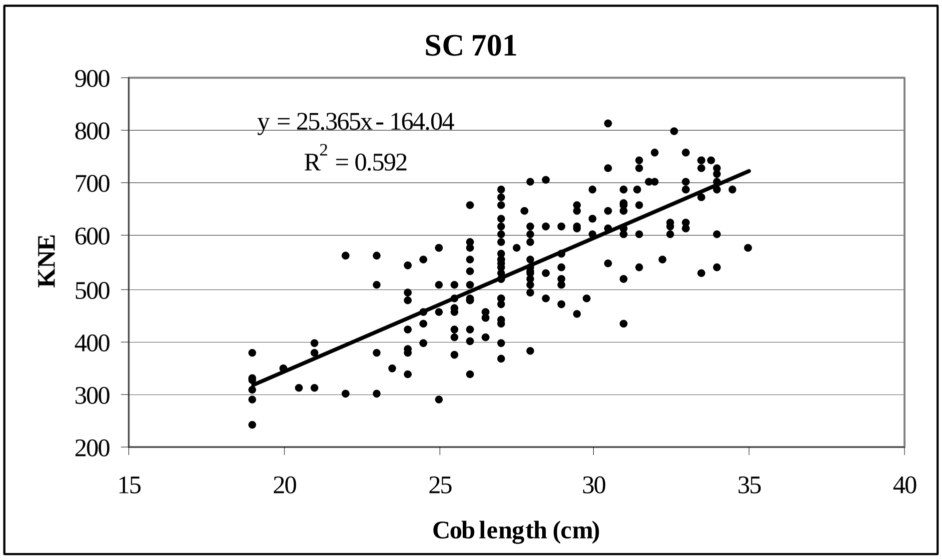
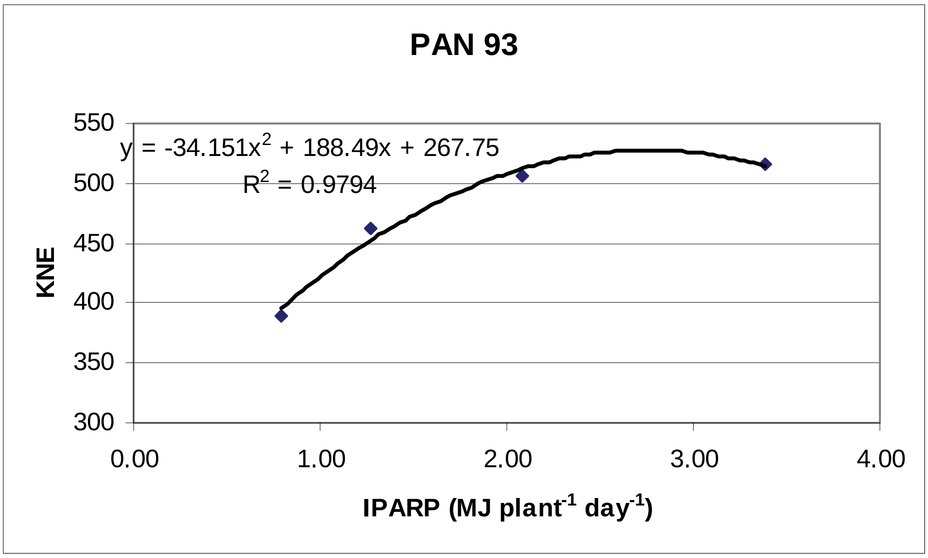


FIGURE 8.15: Relationship between mean kernel number per ear (KNE) and cob length for two maize cultivars planted in June at Dzindi

The regression analysis illustrated in Figure 8.15 confirmed the linear relationship between cob length and KNE that was observed in the other three experiments but the degree to which variability in cob length was explained by the model was lower, namely 41% for PAN 93 and 59% for SC 701. Using the regression equations presented in Figure 8.16, the KNE of a 31 cm long cob was determined for the two cultivars.



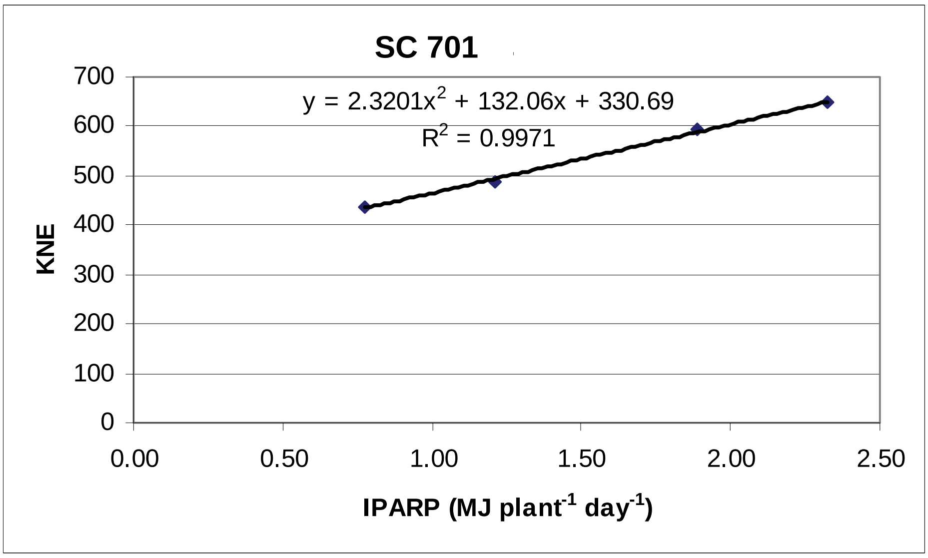
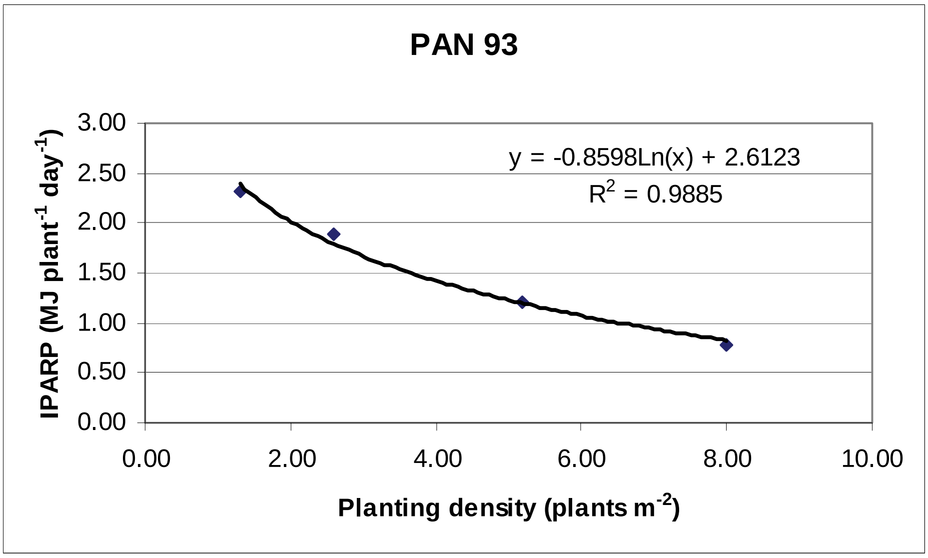


FIGURE 8.16: Relationship between mean intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking and kernel number per ear (KNE) for the two maize cultivars planted in June at Dzindi

The estimated KNE for a cob with a length of 31 cm was 547 for PAN 93 and 622 for SC 701. Using the regression equation that described the relationship between mean KNE and IPARP (Fig. 8.16), the IPARP required for the production of a 31 cm cob was estimated to be 2.80 MJ plant^{-1} day^{-1} for PAN 93 and 2.13 MJ plant^{-1} day^{-1} for SC 701. These values were both much higher than those calculated for the other three planting dates.

Figure 8.17 illustrates the relationship between planting density and IPARP during the 30-day period around silking for the two maize cultivars planted in June at Dzindi. The regression equations describing this relationship for the two cultivars indicated that the estimated optimum planting density was 1.7 plants m^{-2} for PAN 93 and 2.9 plants m^{-2} for SC 701.

Table 8.25 shows the effect of planting density and cultivar on length and marketability of green cobs in the June planting. As in the three other plantings, SC 701 produced considerably more marketable cobs than the cultivar PAN 93, in all four planting density treatments. PAN 93 produced the highest number of marketable cobs in the 5.2 plants m^{-2} treatment, which was not congruent with the estimated optimum planting density of 1.7 plants m^{-2}. A similar lack of congruence was observed in the April planting for PAN 93. In the case of SC 701, there was also a lack of congruence between the estimated optimum planting density (2.9 plants m^{-2}) and the density treatment that produced the highest number of marketable cobs per unit area (1.3 plants m^{-2}). No plausible explanation for this anomaly could be identified.



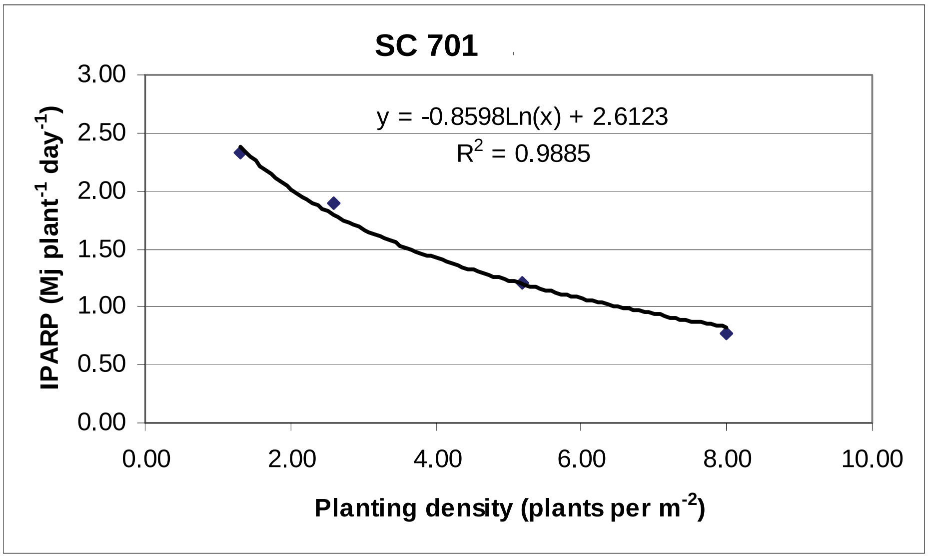


FIGURE 8.17: Relationship between planting density and intercepted photosynthetically active radiation per plant (IPARP) during the 30-day period around silking for the two maize cultivars planted in June at Dzindi

TABLE 8.25: Effect of planting density and cultivar on length and marketability of green cobs in the June planting of the cultivar x planting density experiment at Dzindi

Cob length (cm)	**Number of cobs per grade from 1000** m^{-2}							
	1.3 plants m^{-2}		2.6 plants m^{-2}		5.2 plants m^{-2}		8 plants m^{-2}	
	% of total	No of cobs	% of total	No of cobs	% of total	No of plants	% of total	No of cobs
				PAN 93				
<27	10	130	19	492	48	2 470	63	5 000
27-30	68	878	68	1 757	45	2 340	35	2 800
>30	23	293	14	351	8	390	3	200
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**
				SC 701				
<27	3	33	15	400	51	2 667	65	5 200
27-30	15	200	56	1 467	41	2 133	35	2 800
>30	82	1 067	28	733	8	400	0	0
Total	**100**	**1 300**	**100**	**2 600**	**100**	**5 200**	**100**	**8 000**

8.4.2 Interaction effects of planting date, cultivar and seed treatment on maize streak disease

The results of the experiment are shown in Table 8.26.

TABLE 8.26: Effect of planting date, cultivar and seed treatment with Gaucho® on the incidence of maize streak disease at pollen shed in green maize grown at Dzindi (2009-10)

Planting date	**Proportion of plants showing visual evidence of maize streak disease (%)**						
	Cultivar SC 701		**Cultivar PAN 93**		**Cultivar PAN 67**		**Planting date mean**
	Gaucho	No Gaucho	Gaucho	No Gaucho	Gaucho	No Gaucho	
March	82.2	87.8	82.2	87.8	63.3	73.9	**79.5**[a]
April	80.0	82.8	76.1	90.6	47.8	53.3	**71.8**[a]
May	6.7	5.6	9.8	15.4	2.0	11.8	**8.6**[ef]
June	1.7	0.6	3.3	0.0	1.1	1.1	**1.3**[f]
July	2.2	5.0	1.7	2.9	1.1	2.2	**2.1**[ef]
August	0.6	0.0	0.6	0.6	0.0	0.6	**0.4**[f]
September	1.1	0.0	0.0	0.0	0.0	0.6	**0.3**[f]
October	20.0	29.5	33.9	29.4	15.0	13.3	**23.5**[cd]
November	5.5	3.9	3.9	7.8	0.0	0.6	**3.6**[ef]
December	10.6	11.1	16.1	15.6	13.3	10.0	**12.8**[de]
January	22.8	34.4	31.1	38.9	11.7	11.1	**25.0**[c]
February	14.5	22.8	58.9	31.1	19.5	36.7	**30.6**[c]
March	30.5	62.8	45.0	71.1	12.8	28.9	**41.9**[b]
Mean	**21.4**[b]	**26.6**[a]	**27.9**[a]	**29.9**[a]	**14.4**[c]	**18.8**[bc]	
Cultivar mean	**24.0**[b]		**28.9**[a]		**16.6**[c]		**23.2**
Gaucho mean	Gaucho **21.2**[b]			No Gaucho **25.1**[a]			

Each of the three factors separately (planting date ($p<0.001$), cultivar ($p<0.001$) and the treatment of the seed with Gaucho® prior to planting ($p=0.002$) all had a highly significant effect on the incidence of maize streak disease at pollen shed in green maize grown at Dzindi. Two of the interaction effects were also significant, namely the planting date x cultivar effect ($p=0.010$) and the planting date x Gaucho® effect ($p=0.006$). The interaction effects of cultivar x Gaucho® ($p=0.541$) and planting date x cultivar x Gaucho® ($p=0.327$) were not significant. The overall mean proportion of plants that showed visual evidence of maize streak disease was 23.2%, which underlined the significance of this disease in green maize production at Dzindi.

The results (planting date means) indicated that the occurrence of maize streak disease (MSD) was negligible (1-3%) or virtually absent (<1%) when maize was planted from June to September. There was a significant increase in the incidence of MSD when maize was planted in October (23.5%) but an unexpected drop in the incidence of MSD occurred when the crop was planted in November. From December onwards, a steady increase in the incidence of MSD was observed. The proportion of plants showing visual evidence of maize streak disease (%) rose from 12.8% when planted in December to 25.0% when planted in January, 30.6% when planted in February, and 41.6% (March 2010) and 79.5% (March 2009) when planted in March. It remained high (71.8%) when the crop was planted in April but after that there was a sharp drop in the incidence of MSD to 8.6% when the maize was planted in May.

Table 8.26 shows that treatment of the maize seed with Gaucho® reduced the overall incidence of MSD from 25.1% to 21.2%, a reduction of 3.9%, which although significant statistically, appeared to be of limited practical benefit. The results in Table 8.26 show that cultivar selection was important. Across planting dates and seed treatment, the incidence of MSD was highest in PAN 93 (28.9%), significantly lower in SC 701 (24.0%) and lowest in PAN 67 (16.6%). This was to be expected since PAN 67 is known to be a MSV-resistant cultivar.

8.4.3 Effects of intercropping green maize with pumpkins

The results obtained in the 2009 maize-pumpkin intercropping experiment are presented in Table 8.27. The data show that intercropping green maize with pumpkin planted one month after the maize was planted did not have any material effect on leaf area of maize at pollen shed, cob length, ear length and kernel number per ear. Intercropping maize with pumpkin tended to increase interception of photo-synthetically active radiation (PAR) from about 49 days after planting maize (19 days after planting pumpkin) but at no stage were the differences in PAR between the sole maize and the intercropped maize treatments significant.

TABLE 8.27: Effect of intercropping green maize with pumpkin planted one month after maize on selected performance indicators in the 2009 green maize-pumpkin intercropping experiment at Dzindi

Variable	**Treatments**			**LSD**
	Sole maize	**Sole pumpkin**	**Maize-pumpkin intercrop**	(p=0.05)
Leaf area per maize plant at pollen shed (cm^2)	9386^a	0^b	9425^a	327
Cob length (cm)	36.03^a	0.00^b	35.95^a	1.05
Ear length (cm)	28.68^a	0.00^b	28.70^a	0.76
Kernel number per ear	660.0^a	0.0^b	661.5^a	20.1
Fresh pumpkin leaf yield ($g\ m^{-2}$)	0.0^c	1816.7^a	415.9^a	285.0
Intercepted PAR[1] at 34 DAP[2] (%)	31.0^a	1.3^b	27.6^a	8.36
Intercepted PAR[1] at 49 DAP[2] (%)	56.7^a	18.0^b	59.9^a	8.30
Intercepted PAR[1] at 73 DAP[2] (%)	68.1	72.8	73.5	-
Intercepted PAR[1] at 90 DAP[2] (%)	71.0	87.3	75.6	7.28

[1] PAR = photosynthetically active radiation; [2] DAP = days after planting maize

It follows that the pumpkin leaves harvested from the intercropped treatments (416 $g\ m^{-2}$) were a benefit derived from the minor crop without incurring any negative effect on the performance of the major crop (green maize).

The results obtained in the 2010 intercropping experiment are shown in Table 8.28.

TABLE 8.28: Effect of intercropping green maize with pumpkin planted at weekly intervals from 0 to 7 weeks after planting of maize on selected performance indicators in the 2010 green maize-pumpkin intercropping experiment at Dzindi

Variable	**Treatments**										**LSD (p=0.05)**
	Sole maize	Sole pumpkin	Maize-pumpkin PD0	Maize-pumpkin PD1	Maize-pumpkin PD2	Maize-pumpkin PD3	Maize-pumpkin PD4	Maize-pumpkin PD5	Maize-pumpkin PD6	Maize-pumpkin PD7	
Total consumptive water use (mm)	742.4	757.0	740.5	722.5	723.9	713.0	739.8	744.0	736.0	744.0	-
Leaf area per maize plant at pollen shed (cm^2)	11084^{ab}	0^{c}	10642^{a}	10585^{ab}	11141^{ab}	11481^{ab}	11016^{ab}	11280^{ab}	11003^{ab}	10349^{b}	1062
Cob length (cm)	35.9^{a}	0.0^{b}	36.0^{a}	35.7^{a}	36.1^{a}	35.7^{a}	35.6^{a}	35.7^{a}	35.2^{a}	36.0^{a}	1.3
Ear length (cm)	30.2^{a}	0.0^{b}	29.9^{a}	30.2^{a}	30.3^{a}	29.8^{a}	29.8^{a}	30.2^{a}	30.0^{a}	30.7^{a}	1.0
Kernel number per ear	669^{ab}	0^{c}	644^{ab}	658^{ab}	648^{ab}	675^{a}	644^{ab}	646^{ab}	625^{b}	659^{ab}	46.5
Dry biomass – Maize ($g\ m^{-2}$)	2074^{ab}	0^{c}	2091^{ab}	1906^{b}	2206^{a}	2101^{ab}	2040^{ab}	2106^{ab}	1935^{ab}	2046^{ab}	297.8
Dry biomass – Pumpkin ($g\ m^{-2}$)	0^{e}	340^{a}	233^{bc}	261^{ab}	148^{cd}	143^{cd}	82^{de}	60^{de}	17^{e}	18^{e}	99
Total dry biomass ($g\ m^{-2}$)	2074^{ab}	340^{c}	2323^{a}	2167^{ab}	2354^{a}	2244^{ab}	2121^{ab}	2166^{ab}	1952^{b}	2063^{ab}	343
Land Equivalent Ratio (LER)	1^{e}	1^{e}	1.597^{a}	1.503^{ab}	1.393^{bc}	1.483^{ab}	1.333^{c}	1.170^{de}	1.037^{de}	1.067^{de}	0.143
Fresh pumpkin leaf yield ($g\ m^{-2}$)	0^{e}	1757^{a}	1121^{b}	885^{bc}	742^{c}	815^{c}	638^{c}	348^{d}	175^{de}	140^{de}	254.9
Intercepted PAR[1] at 31 DAP[2] (%)	23.3	25.4	26.3	28.8	22.2	22.6	28.3	27.2	28.1	23.5	-
Intercepted PAR[1] at 43 DAP[2] (%)	52.1	63.8	58.8	62.2	54.0	48.8	51.8	47.0	42.7	44.7	-
Intercepted PAR[1] at 50 DAP[2] (%)	68.2	74.9	77.8	62.2	64.8	59.5	64.8	67.5	69.9	66.0	-
Intercepted PAR[1] at 61 DAP[2] (%)	73.4^{cd}	95.5^{a}	94.6^{a}	94.0^{a}	85.8^{ab}	75.3^{bcd}	82.2^{bc}	68.9^{d}	79.8^{bcd}	72.1^{cd}	11.6
Intercepted PAR[1] at 96 DAP[2] (%)	81.1^{bcd}	97.9^{a}	97.8^{a}	86.2^{b}	82.4^{bcd}	80.1^{bcd}	72.0^{d}	79.8^{bcd}	83.8^{bc}	73.2^{cd}	10.8

[1] PAR = photosynthetically active radiation; [2] DAP = days after planting maize

As was observed in the 2009 experiment, intercropping maize with pumpkins had no negative effect on the performance indicators of green maize. Cob length, ear length and kernel number per ear were not affected by the inclusion of pumpkins in the stand, irrespective of when pumpkin was planted relative to maize. In the sole maize treatment and all intercropped treatments the average cob length exceeded the minimum size limit for Grade 1 cobs by at least 4 cm. Differences in the leaf area per plant of maize were also not significant, except in the treatment in which pumpkins were planted seven weeks after maize, where a reduction in leaf area was recorded. Since there is no biological explanation why maize would become affected when pumpkins are planted so late, this observation was most probably the result of an unknown third factor. Including pumpkin in the green maize stand raised total dry biomass production but, as expected, the increase tended to become smaller as the planting of pumpkins was delayed. Planting pumpkins at the same time as maize provided the highest yield of fresh pumpkin leaves and the highest land equivalent ratio (LER). This was supported by the PAR interception data, which tended to be highest when pumpkins were planted at the same time as maize. Differences in PAR interception among treatments were significant from 61 days after planting of maize onwards. Also important was that the inclusion of pumpkin in the green maize stands, without changing the planting density of the maize, did not raise consumptive water use when compared with that of sole maize.

8.5 DISCUSSION AND CONCLUSION

8.5.1 Green maize cultivar x planting date x planting density interaction effects on cob size

The findings of the study in which the cultivar x planting date x planting density interactions effects on cob size in green maize production at Dzindi were investigated, demonstrated that there was a relationship between planting density, IPARP, KNE and cob length for the PAN 93 and SC 701 maize cultivars that were tested. The relationship between planting density KNE and cob length was linear and generally the association between cob length and KNE was stronger for the cultivar SC 701 than for PAN 93 as shown in Table 8.29.

TABLE 8.29: The strength of the relationship between cob length and kernel number per ear (KNE) expressed as R^2 values of the linear regression models that described this relationship for the four planting dates

Planting date	PAN 93	SC 701
September	67	73
December	61	62
April	57	69
June	41	59

The linear regression models that were developed to describe the relationship between KNE and cob length enabled estimation of cob length using KNE and IPARP for these cultivars. The KNE of a cob with a length of 31 cm, taken as the minimum length of a grade 1 cob, differed among the four planting dates and among the two cultivars, and so did the mean IPARP per day during the 30-day period around silking, as shown in Table 8.30.

TABLE 8.30: Estimated KNE of a 31 cm long cob and mean IPARP day^{-1} during the 30 day period around silking required by a maize plant to produce a 31 cm long cob as affected by planting date and cultivar

Planting date	Estimated KNE of a 31 cm long cob		Mean IPARP day^{-1} required to produce a 31 cm long cob (MJ)	
	PAN 93	**SC 701**	**PAN 93**	**SC 701**
September	565	561	1.58	1.55
December	519	567	2.00	1.72
April	459	531	1.44	0.98
June	547	622	2.80	2.13
Mean	**523**	**575**	**1.96**	**1.60**

No particular trend could be identified in the KNE and IPARP data, but in the case of the mean IPARP day^{-1} required to produce a 31 cm long cob, the trend in the values was similar for both cultivars. Across the four planting dates, a 31 cm long cob of SC 701 held 50 kernels more than a PAN 93 cob of the same length. SC 701 plants tended to require less IPARP day^{-1} to produce a 31 cm long cob than PAN 93, with the difference in the IPARP requirement between the two cultivars being least in the September planting and greatest in the April planting. Across the four planting dates, a PAN 93 maize plant needed to intercept 1.96 MJ day^{-1} to produce a 31 cm cob, whilst SC 701 only needed 1.60 MJ day^{-1}.

Table 8.31 shows the optimum densities for the four planting dates for the two cultivars as identified by the regression procedures that were applied to the experimental data.

TABLE 8.31: Effect of planting date on estimated optimum planting density for green maize production of two cultivars at Dzindi

Planting date	**PAN 93** (plants m^{-2})	**SC 701** (plants m^{-2})
September	3.4	4.2
December	1.4	3.0
April	1.4	3.6
June	1.7	2.9

Optimum planting density differed between the two cultivars and among the four planting dates. In the case of SC 701, the optimum planting density for green maize production was fairly stable, ranging from 2.9 plants m^{-2} in the June planting to 4.2 plants m^{-2} in the September planting. To find that the September planting had the highest optimum planting density was according to expectation, because the 30-day period around silking coincided more or less with the period of maximum day length. To find that the December and June plantings had optimum planting densities that were similar was also expected, because for both planting dates the day length during the 30-day period around silking was similar. The optimum planting density was expected to be lowest for the April planting, because the period around silking coincided with the period of shortest day length, but this was not supported by the estimated planting density for the April planting (3.6 plants m^{-2}), which was higher than the estimated optimum for the December (3.0 plants m^{-2}) and June (2.9 plants m^{-2}) planting dates.

For PAN 93, the estimated optimum planting densities for the different planting dates appeared to make less sense, not so much for the September planting date but definitely for the other three planting dates. For PAN 93 there was lack of congruence between the estimated optimum planting densities for the June and April plantings and the trend in the actual number of grade 1 cobs obtained in the different planting density treatments, with the latter suggesting optimum planting densities that were considerably higher than the estimated optima. For this reason, the validity of the optimum planting densities for the different planting dates for PAN 93 shown in Table 8.31 is in doubt.

In Table 8.32, the effect of planting date and planting density of the number of grade 1 cobs (cobs longer than 31 cm) produced on a plot of 1000 m^{-2} (roughly the size of a single irrigation strip at Dzindi) by the cultivar SC 701 is illustrated. Table 8.33 does the same for PAN 93. The results obtained in the highest planting density treatment (8 plants m^{-2}) were excluded because this planting density was shown to be too high for both cultivars in all four experiments.

TABLE 8.32: Effect of planting date and planting density of the number of grade 1 cobs (cobs longer than 31 cm) produced by the cultivar SC 701 on 1000 m^2

Planting date	**Number of grade 1 cobs from 1000 m^2**		
	1.3 plants m^{-2}	**2.6 plants m^{-2}**	**5.2 plants m^{-2}**
Potential	1 300	2 600	5 200
September	1 267	2 433	1 105
December	958	1 816	1 105
April	988	1 755	1 430
June	1 067	733	400
Mean	**1 070**	**1 684**	**1 010**

TABLE 8.33: Effect of planting date and planting density of the number of grade 1 cobs (cobs longer than 31 cm) produced by the cultivar PAN 93 on 1000 m^2

Planting date	**Number of grade 1 cobs from 1000 m^2**		
	1.3 plants m^{-2}	**2.6 plants m^{-2}**	**5.2 plants m^{-2}**
Potential	1 300	2 600	5 200
September	1 023	2 015	390
December	554	392	300
April	693	867	1 040
June	293	351	390
Mean	**641**	**906**	**530**

When the results in Tables 8.32 and 8.33 are compared it is immediately evident that the cultivar SC 701 performed much better that PAN 93 in terms of the number of grade 1 cobs it produced per unit area, irrespective of planting date or planting density. It can, therefore, be concluded that for the purpose of green maize production in Vhembe, the cultivar PAN 93 should not be recommended and that SC 701 should be used instead, until such time that cultivars with traits superior to SC 701 are identified. One of the major drawbacks of SC 701 is the high cost of the seed, which might be considered prohibitive by some farmers.

Turning the attention to the performance of SC 701, it is clear that this cultivar should be planted at a density lower than 5.2 plants m^{-2} in order to maximise the number of grade 1 cobs per unit area. This finding was also reflected in the estimated optimum planting densities listed for this cultivar in Table 8.31, which ranged between 2.9 plants m^{-2} and 4.2 plants m^{-2}, depending on planting date. Table 8.32 shows that planting date had a considerable effect on the performance of SC 701. The data clearly show that planting SC 701 in September produced the highest number of grade 1 cobs. Nearly all the plants in the lowest planting density treatment (1.3 plants m^{-2}) and 94% of plants in the 2.6 plants m^{-2} treatment produced grade 1 cobs. Planting in December reduced the number of plants producing grade 1 cobs to 74% of potential in the 1.3 plants m^{-2} treatment and to 70% of potential in the 2.6 plants m^{-2} treatment. The reductions in the number of plants producing grade 1 cobs observed when SC 701 was planted in April were similar to those observed when SC 701 was planted in December. When planted in June, SC 701 performed better than when planted in December or April at the lowest planting density but less well when planted at the density of 2.6 plants m^{-2}.

In the introduction to this chapter it was pointed out that farmers at Dzindi planted green maize from about June until December, and avoided planting from the end of December until late in May. Generally, the results of this study suggested that January to May was also the period during which it was most difficult to produce green maize. Maize streak virus (MSV) was identified as a major constraint to year-round production of green maize in Vhembe as the incidence of MSV was dependent on date of planting. The next section elaborates on this constraint.

8.5.2 Interaction effects of planting date, cultivar and seed treatment on maize streak disease

The results confirmed the importance of maize streak disease (MSD) in green maize production at Dzindi. As much as 90% of the plants of the most MSV-susceptible cultivar included in the study (PAN 93) developed MSD when planted in April, and MSD incidence above 80% were also recorded for SC701 (March and April 2009 plantings). These levels of infection exceeded those reported by Kühn & Van Rensburg (1995) at Vaalharts, where the highest incidence recorded for the cultivar RS 5205 was 73.5%.

Use of the MSV-resistant cultivar PAN 67 reduced MSD incidence significantly, as did treatment of the seed with Gaucho® before planting. However, from a practical perspective, Gaucho® treatment was of minor benefit and considering its cost, the use of this approach is probably not recommended for small-scale green maize producers.

Use of the MSV-resistant cultivar PAN 67 by farmers at Dzindi should be considered when green maize is planted from January to April, when the risk of MSD highest. For all other planting dates the use of SC 701 is probably the best option, because this cultivar tends to produce larger cobs than PAN 67.

8.5.3 Effects of intercropping green maize with pumpkins

The results of both green maize-pumpkin intercropping experiments showed that intercropping relatively sparse green maize stands (22 222 plants ha^{-1}) with pumpkins (5 555 plants ha^{-1}) had no negative effect on the performance indicators of green maize and did not increase consumptive water use relative to that of sole maize at the same planting density. However, intercropping green maize with pumpkin provided the benefit of a second crop raising gross enterprise income in green maize production. Planting green maize and pumpkin at the same time provided the greatest benefit and for this reason it is recommended practice.

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CHAPTER 9

9 Integrating crop and animal production: Grain and poultry

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9.1 Introduction

In integrated farming systems, livestock and crops are produced in a coordinated way. Integrated farming systems are characterised by exchanges of products and services between the crop and animal subsystems. They can provide benefits to the environment by cycling nutrients and energy and can also have positive economic and social impacts, because integration of crop and livestock subsystems can increase food production and improve the standard of living of farmers by raising incomes and reducing costs.

When the research agenda for WRC Project K5/1804//5 was developed, the research team contended that transforming locally produced grains into poultry feed by means of on-farm technology presented an opportunity to strengthen rural economies. The research team was of the opinion that local production of grains (yellow maize and pulses) and their transformation into poultry feed had the potential to plug the important backward economic linkage leak that arose when poultry feed was purchased through commercial networks (see Fig. 9.1). Economically, this leak is important, because feed contributes between 60% and 70% to total operating expenditure (excluding labour) in broiler production (Ralivhesa, 2011) and between 70% and 75% in egg production (Hlungwane, 2011). In the case of broilers (chicken grown for meat) the crude protein content of the feed needs to be about 22% for the birds to grow optimally, whilst in the case of layers the feed needs to contain about 14% of protein.

Yellow maize grain, the principal component of poultry feed in South Africa, only contains about 8% crude protein, necessitating the incorporation of ingredients that are richer in protein than maize. Legume grains are known for their high protein content but are known to contain anti-nutritional factors, which need to be inactivated before they can be fed to poultry. Heat treatment is commonly used for this purpose but methods used at an industrial scale are capital intensive and poorly suited for application under smallholder circumstances.

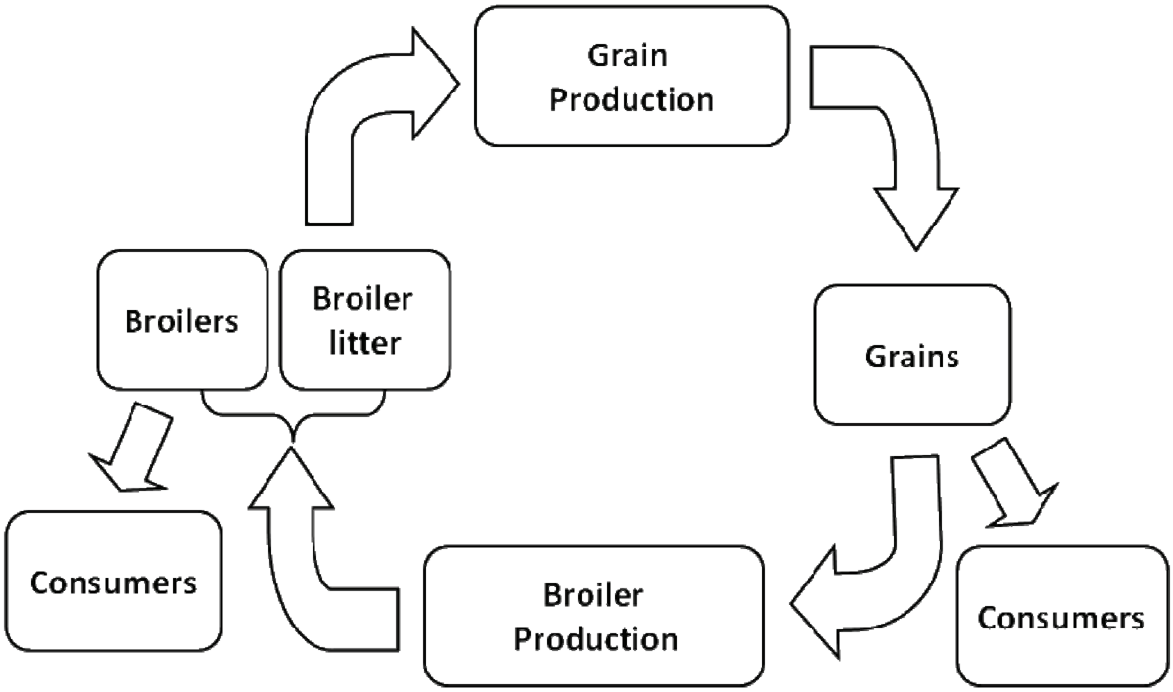

FIGURE 9.1: Integrated grain and broiler production system

As was indicated in Chapter 2, large numbers of smallholders on irrigation schemes in Vhembe produce maize but the production of legume grains is not common, perhaps with the exception of groundnuts and kidney beans, which are used for human consumption. Production of legume grains such as soya beans, cowpeas and pigeon peas would assist the integration of crop and animal production on irrigation schemes but the performance of these crops under local conditions is not known. Poultry litter is a waste product in poultry production, which has to be disposed. Poultry litter is known to contain different plant nutrients in fairly high concentrations and can be used as a fertiliser in crop production. However, not much is known about the response of the crops grown on smallholder irrigation schemes in Vhembe to application rate of poultry manure.

The research that explored different aspects of integrating crop and animal systems on canal schemes in Vhembe was aimed at three main objectives, namely:

1. To develop appropriate and effective processes for the inactivation of antinutritional factors in selected legume grains and for the manufacture of poultry feed on-farm under smallholder conditions.
2. To empirically test the yield potential of selected grain legumes under conditions found in Vhembe.
3. To determine the attributes and fertiliser value of poultry manure when used as a fertiliser in the production of the crops commonly grown on canal schemes in Vhembe.

Research towards the first objective considered both broiler and layer production.

With reference to broiler production, the specific objectives were:

- to develop a soya bean and maize grain processing procedure for on-farm use under smallholder circumstances;
- to compare the biological performance of the on-farm processed diet with a commercial multi-phase diet in a broiler growth trial; to determine possible effects of broiler diet (on-farm processed diet versus commercial multi-phase) on broiler litter, both quantitatively and qualitatively; and
- to compare the financial performance of a broiler enterprise that used the single-phase, on-farm processed feed with a similar enterprise that used a commercial multi-phase diet.

With reference to layer production, the specific objectives were:

- to determine the optimum boiling and germination times for the reduction of anti-nutritional factors in cowpeas;
- to determine whether germination as a treatment to reduce anti-nutritional factors yields similar results as optimally boiled cowpeas;
- to compare the performance of a home-mixed feed with a commercial feed in terms of egg production parameters; and
- to determine the nitrogen, phosphorus and potassium content in layer manure when laying hens are fed on a diet containing germinated cowpeas.

9.2 Review of literature

9.2.1 Legume grains as a source of protein in poultry feed

Legume grains are known for their high protein contents. This applies in particular to soya beans, which contain about 37% crude protein (Monari & Wiseman, 1996), making soya beans ideally suited for incorporation in broiler feed. Cowpeas, which contain about 23% and 25% crude protein (Singh, 2006), could be a useful ingredient in layer feed, because layer feed has a lower protein requirement than broiler feed. Legume grains are known to contain antinutritional factors, which increase the size of the pancreas and duodenum and reduce the consumption of feed and growth of the chick (Herkelman *et al*., 1993; Mogridge *et al*. 1996:1897). In soya beans and cowpea grain, antitrypsin, saponins, hemaglutinins and tannin are the important antinutritional factors (Monari & Wiseman, 1996:11-12, Singh, 2006:36). These need to be inactivated before soya beans and cowpeas can be fed to poultry and other mono-gastric animals (Monari & Wiseman 1996:2; Lázaro *et al.,* 2002:12).

In feed manufacturing, inactivation of antinutritional factors is usually achieved by means of heat treatment (Wiryawan & Dingle, 1999:185, Lázaro *et al.,* 2002:3-20). Techniques used in the industry include roasting, extrusion, expansion, wave emission and treatment with heated gasses (Monari & Wiseman, 1996:3; Lázaro *et al.,* 2002:3-20; Coetzee, 2003:13-15). All of these methods require considerable capital expenditure and sophisticated maintenance and are unlikely to suit smallholder circumstances.

9.2.2 Yield potential of selected grain legumes

Soya beans contain about 40% protein, which is of excellent quality and digestibility, and they are also a good source of energy and fatty acids for animals (Smit, 2000). These attributes make soya beans ideally suited for incorporation in animal feeds. The soya bean plant [*Glycine max* (L.) Merrill] is an annual summer legume that belongs to the Fabaceae family. It is probably the most important legume in the world. As with other members of this family, it bears its seed in pods. In South Africa, production of soya beans remained localised and relatively unimportant until the early 1970s, when soya beans were incorporated in a rotation with wheat on land where irrigation was available (Smit, 2000). Some 45 years ago, less than 10 000 ha were planted to the crop. Since then, production has increased steadily. In 2004/05, about 150 000 ha were planted to soya beans producing a total of about 272 500 ton of beans (National Department of Agriculture, 2008). In 2009/10, the area planted to soya beans had increased to 311 000 ha and total production to 566 000 ton beans (Department of Agriculture, Forestry and Fisheries, 2011). Despite substantial increases in local production, South Africa remains an importer of soya beans, mostly in the form of oil cake. In 2002, the country imported about 0.9 million tons of soya bean oil cake, mainly for use in animal feed (National Department of Agriculture, 2004). Importation of full-fat soya beans also occurs but has been declining. Zambia is the main source of imported full-fat soya beans (Department of Agriculture, Forestry and Fisheries (2011).

Cowpea (*Vigna unguiculata* L.) is an important grain legume in tropical and subtropical regions. It is indigenous to Africa, where it is mostly grown as a subsistence crop. It is a dual-purpose crop, which is mainly cultivated for its grain but during the vegetative growth stages it is also used for leaf harvests (Vorster, 2007). The crude protein content of cowpea grain is about 25% (Ragab *et al*., 2010; Hlungwani, 2011). According to Cisse & Hall (S.a.) the average world yield of cowpea grain is less than 0.3 t ha^{-1} and average cowpea grain yields in Africa vary from 0.05 to 0.55 t ha^{-1}, depending on a range of factors, which include variety, soil fertility, cropping system and growing conditions. In South Africa, grain yields of up to 2.5 t ha^{-1} have been achieved (Pule-Meulenberg *et al*., 2010). Cowpeas have been used in the formulation of layer diets with a degree of success (Hlungwani, 2011).

Pigeon pea (*Cajanus cajan* L. Millspaugh) is a grain legume, which typically grows as an erect, woody, short-lived, perennial shrub. It is well adapted to semi-arid and warm growing conditions. Pigeonpea cultivars are usually grouped in accordance with time to maturation of the seed. Groups include extra-short (<100days), short (100-150 days), medium (150-180 days) and long (>180 days) (Reddy, 1990). The long and medium duration types are photo-sensitive but the short-duration and extra-short duration types are relatively photo-insensitive (Reddy, 1990). The grain of pigeon pea contains about 21% protein and has multiple uses. Its main use is as *dhal* (dry, dehulled, split seed). It is also crushed for use as an animal feed and when still green and tender the grain is used as a vegetable. The green leaves of pigeonpea are used as fodder and the stems as fire wood (Mathews, 2008). In eastern and southern Africa, the crop is grown for local consumption and as a cash crop (Jones, 2000). According to Van der Maesen (1983) grain yields in Africa range between 0.4 t ha^{-1} and 0.75 t ha^{-1}, which is very low when compared with the yield potential of 3 to 4 t grain ha^{-1} for soya beans and 2 to 3 t ha^{-1} for cowpeas. Pigeon pea is rarely grown in South Africa and its occurrence is limited to the Provinces of KwaZulu-Natal, Limpopo and Mpumalanga, where the crop is found as single plants or as a hedge around home gardens (Mathews, 2008). Annually, South Africa imports about 1500 tons pigeon peas, mostly from Malawi, to satisfy local demand for the grain, which is mainly located in Asian communities (Mathews, 2008).

9.2.3 Poultry manure as a fertiliser

Prior to the widespread adoption of chemical fertilisers in South Africa, animal manure was used throughout the country. Malherbe (1964) estimated that before 1960, about 1.5 million tons of farm manure used to be applied annually to cropped land in South Africa. Animal manure continues to be available as fertiliser. In 1983, about 3 million tons of animal manure was available from feedlots where cattle, broilers, layers and pigs were being raised. At the time, it was estimated that the quantity of animal manure produced annually in South Africa was sufficient to meet 13.3%, 9.9% and 27.6% of the country's N, P and K requirements, respectively. However, only 25% of the 3 million tons manure was used as fertilisers (Fertiliser Society of South Africa, 1989). The bulk of the remaining 75% was mostly wasted, with a small portion used as energy in heating (Mkhabela & Materechera, 2003; Mkhabela, 2004).

As was pointed out by Vitosh *et al*. (1973), the benefits of animal manure applications in crop farming are well known. The main positive effect is improved growth and yield of crops resulting from plant uptake of the nutrients contained in manure (Maerere *et al*., 2001; Kihanda *et al*., 2004; Gosh *et al*., 2004). Applying animal manure has benefits that exceed those of adding plant nutrients (Fraser *et al*., 2006). Continuous use of chemical fertilisers in intensive agriculture has been associated with declining crop yield, increased soil acidity and soil nutrient imbalances. Raising organic matter content of cropped soils enhances their production capacity (Fatunbi & Ncube, 2009). Ayoola and Adeniyan (2006) provided evidence that crop response to applied fertiliser depended on soil organic material content, underlining the importance of maintaining soil organic matter at adequate levels. Soil organic matter content partially depends on the quantity of organic material that can be introduced into the soil, either by natural returns through roots, stubble, slough off root nodules and root exudates, or artificially through additions of organic material. Application of animal manure is one of the main ways in which organic material is added to cropped soils. It follows that animal manure has economic value both as a plant nutrient source and as a soil amendment (Wilkinson, 1979).

In the smallholder farming areas of South Africa, cattle and goats produce most of the animal manure but in the Eastern Cape, sheep are also important. These three types of animal manure typically accumulate in livestock enclosures called kraals. Increasingly smallholders also make use of poultry litter, which is purchased from large- and small-scale poultry production units (Mkile, 2001; Mkhabela & Materechera, 2003; Mkhabela, 2004). Among the types of animal manure commonly used by smallholders, poultry manure has the highest N and P content and the narrowest C:N and C:P ratios ((Maerere *et al*., 2001). Relative to ruminant manure, the nitrogen contained in poultry manure is also more readily available to plants, because it occurs mostly in easily decomposable compounds, such as urea and uric acid (Wilkinson, 1979; Lu & Edwards, 1994).

The term poultry manure is used to refer to the excrements of domesticated birds, primarily chickens (Gilmour *et al*., 2004). Poultry manure is also referred to as poultry litter, even though these two terms are not necessarily interchangeable, because poultry litter refers to the combination of excrements and any bedding material that was used during the production process. Poultry litter varies in composition but less so than manure from cattle, goats and sheep. Important sources of variability in the composition of poultry litter are production system (layer or broiler) and whether or not a bedding material is employed. Lu and Edwards (1994) differentiated between two main types of poultry litter, namely broiler and layer litters. Broiler litter is a mixture of manure and bedding material and typically has a moisture content of approximately 20%. Bedding materials used in broiler production include wood shavings, peanut hulls, the seed coat and husks of sunflowers and soya bean pods. The litter of layers kept in cages is free from bedding materials and can be referred to as poultry manure. It has an approximate moisture content of 75%.

When applied as a fertiliser on cropped land, the different nutrients present in animal manure may not all be available at the time they are required by the plant, because their release is dependent on the processes of organic matter decomposition, mineralisation and immobilisation (Dewes & Hunsche, 1998). This applies particularly to nitrogen. Mineralisation of N refers to the transformation of organic N to mineral N, whilst immobilisation of N refers to its incorporation into the tissues of the soil organisms that decompose organic matter (Blackmer, 1997). According to Wilkinson (1979), much of the N excreted in faeces requires mineralisation before it becomes available for plant growth. Wilkinson (1979) indicated that up to 61% of the nitrogen excreted by poultry occurred in the form of uric acid, which is readily converted to urea and ammonium salts. Wilkinson (1979) reported that the water soluble fraction of P in animal manure was 94% in broiler litter, 88% in layer litter and ranged between 36% and 58% in ruminant manure. In the case of K, Wilkinson (1979) reported that between 75% and 95% of the potassium in animal manure was water soluble and available for plant use.

As in the case of chemical fertilisers, applying animal manure in excess of the optimum rate can have detrimental effects on crop growth. Negative effects on plant growth resulting from applying animal manure at rates that are too high are particularly common in the case of poultry litter. Identified causes of such negative effects include high levels of soil alkalinity (Bierman & Rosen, 2005), soil salinity (Lu & Edwards, 1994), and possibly fatty acids that could have toxic effects on plants, particularly during the early stages of growth (Fujiwara *et al*., 2009).

9.3 Materials and methods

9.3.1 Legume grains as a source of protein in poultry feed

9.3.1.1 Soya beans and yellow maize for use in broiler feed

Development and testing of a simple on-farm broiler diet using yellow maize and full-fat soya beans

Ralivhesa (2011) provided a full account of the research and development work that was done to establish procedures to process grains on-farm and to develop an experimental broiler feed. This account reports on research done to determine the optimum cooking time of soya beans to denature the anti-nutritional factors and on the development of a key for the sensory evaluation of the moisture content of cooked soya beans for safe storage. This key is presented in Table 9.1.

TABLE 9.1: Key to the sensory assessment of the moisture content of cooked soya beans

Stage of drying	Drying stage designation	Bean size	Bean colour	Touch of seed coat	Effect of exerting force on bean			Moisture content (%)
					Orthogonal using thumb and index finger	**Orthogonal using thumb nail and index finger**	**Oblique using thumb and index finger**	
1	Early	At least twice as large as uncooked grain	Considerably lighter than uncooked grain	Slippery	First water appears and then the bean is squashed	Bean is sliced with ease	Seed lobes slip out of seed coat with ease	>50
2	Intermediate	Visible reduction compared to stage 1	Darker than in stage 1	Tacky or sticky	Water does not appear and more force is needed to squash the bean than in stage 1	Greater force is needed to slice the bean than in stage 1	Seed lobes no longer slip out of the seed coat	20-50
3	Advanced	Further reduction and wrinkly appearance	Same colour as uncooked grain	No longer sticky	Bean displays elastic resistance to force and can no longer be squashed	Slicing the bean requires great force	Seed coat is firmly attached to seed lobes	10-20
4	Dry	Same size as uncooked grain but wrinkled appearance	Same colour as uncooked grain	No longer sticky	Hard and resistant as for uncooked grain	Great force cracks the bean	Seed coat is firmly attached to seed lobes	<10

The procedure that was developed to manufacture the on-farm experimental broiler diet involved the soaking of soya beans for 24 hours in tap water at room temperature, followed by cooking the beans. For cooking, the soya beans were placed in a 200 ℓ steel drum, covered with fresh water and heated using a gas burner. Once boiling point had been reached, water and soya beans were kept boiling for 10 minutes, identified to be the optimum cooking time. Cooked soya beans were then allowed to cool before being spread out to dry in the sun. Once the beans were dry enough for safe storage (moisture content less than 11%), their size was reduced using a diesel power driven hammer mill, which was fitted with a 1 mm gauge screen.

Processing of the yellow maize grain was limited to hammer milling using the same procedure and equipment as for the dried boiled soya beans. The ground soya beans and maize grain were then mixed with the other constituents that made up the single-phase on-farm processed broiler diet, hereafter referred to as the experimental diet. The quality of the experimental diet was then tested by presenting it to broiler chicks and comparing the biological performance of the chicks with that of chicks fed on a three-phase commercial diet.

Broiler performance experiment

The broiler performance experiment was conducted in an open-sided poultry house at Dzindi Irrigation scheme (23° 01' S; 30° 26' E), located in the Thulamela Local Municipality of the Vhembe District of the Limpopo Province of South Africa. The experiment was carried out to study the effects of diet on the biological performance of broiler chicks (feed intake, body weight gain and feed conversion ratio); broiler litter (qualitatively and quantitatively); and the financial performance of broiler enterprises (total operating expenses, total cash receipts and net operating income). The experiment had two treatments, namely, an experimental broiler diet that consisted mainly of maize and soya beans and a commercial multiphase broiler diet (Meadow®), which served as the control treatment. The composition of the experimental diet is shown in Table 9.2. The composition of the commercial diets is a trade secret but for purpose of comparison, the analysed nutritive value of both the experimental and the commercial three-phase diets are presented in Table 9.3. The experiment was run twice in the same facility using the same feed ingredients.

TABLE 9.2: Composition and calculated nutrients of the experimental broiler diet

Ingredients	(%)
Yellow maize grain	64.25
Soya beans	30.00
Mono calcium phosphate	1.75
Limestone	2.26
L-Lysine HCl	0.68
DL-Methionine	0.33
Salt	0.48
Vitamin and mineral grower premix*	0.25
Total	100.00
Analysed composition	**(%)**
Dry matter	88.60
Ash	5.83
Protein	17.45
Fat (ether extract)	7.76
Crude fibre	3.27
Calculated composition	**(%)**
Dry matter	88.16
Ash	5.83
Protein	17.42
Fat (ether extract)	7.99
Crude fibre	3.06
Lysine	1.41
Methionine	0.59
ME (MJ kg^{-1})[#]	12.73
Ca	1.20
P	0.52

[#] ME = Metabolisable energy

TABLE 9.3: Analysed nutritive value of the experimental and control diets

Component	Experimental diet	Control diet		
		Starter	Grower	Finisher
	......................……………(%)………………….................			
Dry matter	88.60	89.20	89.10	91.30
Moisture	11.40	10.80	10.90	8.70
Ash	5.83	6.73	5.17	4.85
Protein	17.45	20.38	18.27	18.22
Fat (ether extract)	7.76	3.96	3.53	5.55
Crude fibre	3.27	4.07	5.18	4.03

During the first 21 days of the experiment, referred to as the pre-experimental period, two groups of 100 day-old 708 Ross broiler chicks were allocated to two separated enclosures heated with gas brooders. Each enclosure had a surface area of 3.12 m^2, which was covered with 7.5 kg of fresh pine wood shavings. Both compartments were equipped with an equal number drinking founts and day-old feed trays. After 21 days of brooding, a total of 96 chicks were randomly selected from each treatment group and sub-divided into smaller groups of 12 birds, using random allocation. As a result, each treatment was represented by eight pens (replicates), containing 12 birds each. Each pen provided a floor area of 1 m^2, which was covered with 3 kg of fresh pine wood shavings. The position of the feeders and drinkers was the same in each pen and was adapted regularly as the birds grew up. The test diets and tap water were provided for *ad libitum* consumption throughout the experimental period. Continuous 24 hours illumination was provided. Care and management followed the guidelines recommended by FASS (1999).

Chicks in the control treatment group were fed on starter crumbs during the first three weeks, followed by grower pellets during 4 to 5 weeks and finisher pellets during 6 and 7 weeks, while chicks on the experimental treatment group was fed on the single phase diet throughout the experimental period.

Data, which were either recorded or calculated, included feed intake, body weight gain, feed conversion ratio and carcass yield. Recorded and calculated data were subjected to an analysis of variance (ANOVA) using SAS Institute (2000).

Effect of diet on the elemental plant nutrient content of broiler litter

The effect of diet on broiler litter was only investigated for the second run of the broiler experiment. The floor and sides of the pens were covered with black plastic sheet to prevent broilers from throwing out the litter while scratching. Immediately after removing the birds at the end of 21-day pre-experimental period and again at 49 days of age, the litter that had accumulated on the floors was collected and weighed and representative samples were taken from each of the litters to determine their moisture content. Moisture content of the air dry wood shavings and the various broiler litters was determined by drying moisture samples of these materials in a forced-draught oven at 60^{o}C until constant mass. One combined and homogenised composite sample of all the litter that was obtained in each of the two diet treatments was taken from each diet treatment for analysis of N, P and K content at Laboratory for Analytical Services of the Agricultural Research Council in Irene. The data obtained were used to determine the dry mass of manure (excrements only) produced per bird in the two diet treatments during the first 21 days of growth and the dry mass of manure (excrements only) produced per bird in the two diet treatments from 22 days of growth until live weight of 2300 g, which involved linear extrapolation of broiler weight and litter data for each of the 16 pens.

Effect of broiler diet on the income statement of broiler enterprises

The experimental design that was used to assess the biological performance of broilers on the experimental and control diets was applied to enable statistical assessment of the effect of diet on the financial performance of broiler enterprises. Consequently, each of the two enterprises was represented by eight treatment pens containing 12 birds. Replication of the experiment enabled repeat assessments. Since the biological performance of broilers on the two diets was different, it was not possible to use growth period as a constant in the development of income statements for the two enterprises. For this reason the decision was made to work with constant live body weight of 2300 g and to estimate the duration of the growth period that was required for the average live body weight of the 12 broilers contained in particular pens to reach 2300 g. Estimates of the duration of these growth periods for the different pens were obtained by calculating the average body weight gain rate of the birds during the week in which their average body weight reached 2300 g. Once the duration of the growth period required by birds in a particular pen to reach the average body weight of 2300 g was estimated, total feed intake was determined using weekly feed intake data. The same procedures was also used to estimate the quantity of manure produced by the 12 birds contained in a particular pen at the time when they reached the average live weight of 2300 g. Since soya beans were not produced at Dzindi, the national producer price of soya beans, producer price of maize grain that applied at Dzindi at the time of the experiment and other supplements that constitute the experimental diet and was use to calculate the cost of experimental diet per kg. For the control diet, the cost of the starter feed was R3.00 kg^{-1}, the cost of the grower feed R2.80 kg^{-1} and the cost of the finisher feed R2.66 kg^{-1}. The calculated cost of experimental diet was R2.51 kg^{-1}.

All recorded and calculated data that described the effects of diet on the financial performance of the broiler enterprises were subjected to an analysis of variance (ANOVA) procedure using SAS Institute (2000).

Improving the simple on-farm broiler diet

Below-optimum protein content of the on-farm single phase diet during the starter and grower phases of broiler growth, and the presentation of the experimental diet in mash form throughout the growing period, instead of in crumble form during the starter phase and pelleted form during the grower and finisher phases, were identified as the likely causes for the sub-optimal biological performance of broilers on the experimental diet. Poor digestibility of the protein contained in the experimental diet was identified as a possible third limiting factor. Consequently, it was decided to test the following improvements to the simple on-farm broiler diet:

- The use of a multi-phase on-farm diet formulated to contain sufficient protein to meet the requirements of broilers during each phase;
- The use of soya bean oil cake to raise the protein content of the on-farm diet for use during the starter phase;
- The addition of enzymes to the on-farm diet to improve the digestibility of the proteins it contains
- The use of wet feeding to mitigate apparent problems experienced by chicks when presented with a mash diet (in the case of the on-farm diet) instead of a combination of crumb (commercial starter phase feed) and pellet (commercial grower and finisher phases) diets.

A broiler performance experiment was conducted to determine the effect of these various improvements to the simple on-farm diet on the biological performance of broilers.

Effects of diet on the growth performance of broilers were assessed experimentally. The experiment consisted of four treatment groups, namely,

- The commercial multiphase broiler diet (COM), which acted as the control;
- The on-farm single phase diet presented in dry form (OFD), which was the simple on-farm diet that was tested during the first phase of the project (see section 9.3.1)
- The on-farm single phase diet presented in wet form (OFW), which was aimed at removing the weakness of the simple on-farm diet arising from its presentation as a mash diet;
- The on-farm multiphase diet (OFM), which was formulated to meet the higher protein requirement of broilers during the starter and grower phases and included the addition of soya bean oil cake.

Regrettably, a critical error was made during the transformation of the grain for use in the on-farm diets. Instead of using a gauge of 0.7 mm as recommended (Nir *et al*., 1990:2177), a gauge of 7 mm was used. The resulting particle size of all three on-farm diets that were tested in the experiment was way too large for the chicks to eat.

The experiment was conducted over a period of seven weeks that started on 06 June 2011 and ended on 25 July 2011, in the same facility that was used in the broiler performance experiments described in section 9.3.1. A total of 208 day-old unsexed Ross 708 commercial broiler chicks were randomly divided into 16 experimental floor pens of 13 chickens each and allotted randomly to the four dietary treatment groups. Each treatment was represented by four pens (replicates). Each pen provided a floor area of 1 m^2, which was covered with 3 kg fresh dry pinewood shavings.

Chicks were brooded during the first three weeks using a gas brooder. They were vaccinated according to the standard vaccination program prescribed by the supplier. The birds were reared under standard management conditions. Feed and water were provided *ad libitum* throughout the experimental period.

The two treatment groups that were reared on multiphase diets (COM and OFM) received the starter diet for three weeks, (1 to 21 days), the grower diet for two weeks (22 to 35 days) and the finisher diet for the final two weeks of the experiment (36-49 days). The two treatment groups that were reared on single-phase diets (OFD and OFW) were fed with one diet throughout the experimental period. The composition of the three experimental diets is shown in Table 9.4. Information on the nutritive value of the feeds that constituted the commercial diet (COM) was presented in Table 9.3.

TABLE 9.4: Composition and calculated nutrients of the three experimental broiler diets used in the final broiler experiment

Ingredients	**OFD**	**OFW**		**OFM**	
Feed phase used	**Single**	**Single**	**Starter**	**Grower**	**Finisher**
Yellow maize grain	64.25	64.25	49.31	47.76	51.89
Soya beans	30.00	30.00	37.97	47.78	43.73
Soya bean oil cake 44	0.00	0.00	7.86	0.00	0.00-
Mono calcium phosphate	1.75	1.75	0.25	1.95	1.95
Limestone	2.26	2.26	0.39	0.27	0.15
Hemicell	0.00	0.50	0.50	0.50	0.50
L-Lysine HCl	0.68	0.68	0.25	0.25	0.25
DL-Methionine	0.33	0.33	1.52	1.52	1.52
Salt	0.48	0.48	0.50	0.50	0.50
Vitamin and mineral grower premix*	0.25	0.25	1.96	1.95	1.95
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Calculated composition	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Dry matter	88.16	88.16	88.62	88.65	88.50
Ash	4.49	4.49	4.45	4.43	4.30
Protein	17.42	17.42	22.24	22.00	20.74
Fat (ether extract)	7.99	7.99	9.01	10.65	10.06
Crude fibre	3.06	3.06	3.76	3.69	3.54
Lysine	1.41	1.41	1.44	1.26	1.18
Methionine	0.59	0.59	0.71	0.59	0.46
ME (MJ/kg)	12.73	12.73	12.60	13.05	13.03
Ca	1.20	1.20	1.00	1.00	1.00
P	0.52	0.52	0.50	0.50	0.50

OFM = multi-phase on-farm diet; **OFD** = single-phase on-farm diet presented dry; **OFW** = single-phase on-farm diet presented wet

The feed ingredients used in the formulation of experimental diets were analysed in triplicate for their DM (method number 926.08), CP (AOAC, 2000, method number 955.04), ether extract (AOAC, 2000, method number 954.02) and ash content (AOAC, 2000, method number 923.03). The N content was analysed in triplicate using the Kjeldahl procedure, and CP was calculated as N × 6.25. The fat content was determined in triplicate as ether extract using a Soxhlet apparatus. Ash content was determined in triplicate by ignition of a sample in an electric furnace and quantification of the ash by gravimetric analysis. Moisture content of the feed ingredients was determined in triplicate by loss of weight upon drying in a forced-draught drying oven at 100°C to constant weight. The two single-phase experimental diets (OFD and OFW) had protein contents below the optimum for diets used during the starter and grower phases of broilers (NRC, 1994:27). The metabolisable energy content of the OFD experimental diet was adequate for use during the starter phase but below the optimum for the grower and finisher phases. The hemicell enzyme ®, methionine, lysine, calcium and phosphorus were included to meet or exceed the nutrients required by broilers during 1-49 days. The ingredients used in the formulation of the OFW diet were exactly the same as those used in the OFD diet except that the OFW diet was supplemented with hemicell enzyme® and that the diet was served wet. The OFW diet were prepared daily by adding 1 kg tap water to each kg of air-dry feed and was offered to the chicks immediately after mixing.

The 1:1 mass ratio of feed and water was supposed to produce a feed with a "porridge-like" consistency, with no water layer forming over the feed, because this could deter consumption (Yasar & Forbes, 2000:297). However, this consistency was not achieved due to the error made during particle reduction of the grain (7 mm instead of 0.7 mm). After mixing, a layer of water above the solid ingredients was persistently observed. Each day, the wet feed that remained in each feeder was weighed and discarded to avoid mould growth. Containers were cleaned each day before being refilled. In the mass calculations of feed intake the 1:1 water:feed mass ratio was retained and water that was lost from the wet feed due to evaporation was not taken into account. Feed intake and body weight gain were measured at seven day intervals and feed conversion ratio was calculated using these measurements. The record of mortality was also maintained during both experiments.

Recorded and calculated data were subjected to an analysis of variance (ANOVA) using SAS Institute (2000). When significant treatment effects were observed, means were separated using the test of least-significant difference. A probability value of < 0.05 was required for statistical significance.

9.3.1.2 Cowpeas for use in layer feed

Growth assay

A growth assay involving day-old broiler chicks of the 788 Ross breed was conducted using a diet containing cowpeas. The cowpeas were subjected to seven treatments, namely three boiling duration treatments and four germination duration treatments. Boiling duration treatments were boiling cowpeas for 15 minutes, 30 minutes and 60 minutes. Germination duration treatments were germinating cowpeas for three days, four days, five days and six days. Boiling and germination treatments were as described by Hlungwani (2011:29-30). A total of 152 chicks were randomly allocated to the seven treatments. Six replicates of four chicks each were allocated to the three boiling treatments and five replicates of four chicks each to the treatment that contained germinated cowpeas. Each group of four chicks was kept in a separate cage. Each cage was equipped with one oval feeder and drinking fount. The cages were placed in a windowless room that was heated using electrical heaters. Light was provided for 24 hours for the entire duration of the experiment. The temperature of the room was kept at about 32ºC and the relative humidity at 51%.

Layer experiment

The layer experiment involved two treatments, namely an experimental diet containing mainly yellow maize grain and cowpeas germinated for four days, and a commercially available layer diet, supplied by Rustia Feed. Details on the composition of the experimental diet are presented in Tables 9.5 and 9.6.

A total of 96 layers of the Hy-Line Silver breed aged 18 weeks old were assigned randomly to the two treatments. The two treatment groups were subdivided into groups of 6 and allocated to a cage. Twelve cages (6 each per treatment) were used. The experiment was conducted for ten weeks. During the first seven days pullets were allowed to adapt to the diet and experimental condition. Ingredients prices in the layer diet: Maize was R2.00 per kg, cowpeas, R3.00 per kg, Germination process R0.00 Minerals, vitamins and exogenous enzymes R50.00 per pack.

TABLE 9.5: Ingredients and composition of the experimental layer diet

Ingredient	**Units**	**Composition**	**Ingredients (commercial diet)**
Maize	%	45.06	Yellow maize meal
Soya bean full fat	%	-	Soya bean oilcake
Cowpeas (Germinated)	%	42.92	Wheaten bran
DL methionine	%	1.46	DL methionine
Vitamin mineral premix[1]	%	0.15	Vitamin mineral premix
Limestone	%	8.13	Feed lime
Salt	%	1.00	Natuphos®
Monocalcium phosphate	%	1.10	Mono calcium phosphate
Mycofix®	%	0.10	Poultry feather and carcass meal
Ravobio™	%	0.02	Sunflower oilcake
Phyzyme®	%	0.02	
Albac®	%	0.05	

[1] Supplied per kg of diet: vitamin A, 7.333 MIU; vitamin D_3, 3.333 MIU; vitamin B_1 1.333 g; vitamin B_2 3.333 g; vitamin B_6 2.0 g; folic acid, 1.333; vitamin B_{12}, 6.667 mg; vitamin E, 40.0 g; choline chloride, 200.0 g; niacin, 33.333 mg; DL-Ca pantothenate, 8.0 g; vitamin K, 1.333 g; biotin, 66.667 mg; cobalt, 333.333 mg; iodine, 1.333 g; selenium, 133.333 mg, manganese, 73.333 g; copper, 6.667 g; zinc, 66.667 g; iron, 26.667 g; antioxidant, 83.333 g

TABLE 9.6: Analysed contents and composition of amino acids and energy of the experimental (cowpea) layer diet and the commercial control layer diet

Analyzed contents	Units	Experimental	Control	Recommended[4]
Amino acids and energy	MJ kg^{-1}	11.63	Not available	11.5
Crude fibre	%	3.39	Crude fibre 7 max[2]	5
Crude protein	%	10.77	Crude protein 15 min[3]	12.5
Lysine	%	0.61	Lysine	0.58
Methionine	%	0.3	Not available	0.25
Methionine+cystine	%	0.48	Not available	0.48
Threonine	%	0.44	Not available	0.39
Tryptophan	%	0.12	Not available	0.13
Arginine	%	1.69	Not available	0.58
Isoleucine	%	0.51	Not available	0.54
Leucine	%	1.24	Not available	0.68
Histidine	%	0.37	Not available	0.14
Phenylalanine	%	0.6	Not available	0.39
Phenylalanine+tyrosine	%	0.99	Not available	0.69
Valine	%	0.63	Not available	0.58
Ash	%	10.77	Not available	
Crude fat	%	2.61	Not available	
Calcium	%	3.41	Calcium 2.7% min[3], 4 max[2]	2.7
Available phosphorus	%	0.3	Phosphorus 0.6% max[2]	0.21
Sodium	%	0.23	Not available	0.13
Potassium	%	0.56	Not available	0.13
Linoleic acid	%	1.37	Not available	0.83

[2] Maximum. [3]Minimum.

[4]Recommended dietary inclusion level for layer hens at 100 g of feed intake per day.

9.3.2 Yield potential of selected grain legumes in Vhembe

9.3.2.1 Soya beans

To determine the yield potential of soya beans grown under irrigation on smallholder irrigation schemes in Vhembe, the National Soya Bean Cultivar Trial was planted thrice, namely early (last week of September), late (last week of December) and very late (first week of February). Cultivars, which constituted the treatments, were arranged in a complete randomised block design with three replications. Soya bean seed was procured from the ARC Grain Crops Institute in Potchefstroom. Prior to planting, the soil was prepared using three operations, namely, ploughing, disking and ridging, in line with standard farmers practice at Dzindi. Plots were 5 m long and 4.8 m wide, resulting in a gross plot area of 19 m^2. The crop was planted by opening furrows using a hand hoe. Prior to depositing the seed it was inoculated with *Bradyrhizobium japonicum* inoculants also supplied by the ARC Grain Crops Institute in Potchefstroom. At planting, superphosphate (10.5% P) was applied in the base of the furrows at the rate of 190 kg ha^{-1} and worked into the soil by dragging a stick along the base of the furrows. No other fertilisers were used. The crop was irrigated once per week, applying about 20 mm of water. Weeds were controlled by hand hoeing whenever they emerged. Data collection was guided by the National soya bean cultivar form. When the crop had reached physiological maturity, the pods were collected, shelled, dried and grain yield was determined. Data were captured on spread sheets using MS Office Excel ®, and analysed using the SAS statistical software version 9.2 (SAS, 1999). Statistical analysis of the data involved analysis of variance to identify treatment effects and when these effects were statistically significant ($p \leq 0.05$) the Fisher's Protected Least Significant Difference test ($\alpha = 0.05$) was used to separate treatment means. Statistical analysis of the data was done by the Biometric Division of the Agricultural Research Council in Hatfield, Pretoria.

9.3.2.2 Cowpeas and pigeon peas

During the summer of 2010/11, a field trial with two treatments (cowpeas and pigeon peas), which were arranged using a complete randomised block design replicated eight times, was conducted at Dzindi Irrigation Scheme. The experimental site was the same as for the soya bean trials. Prior to planting, the soil was prepared using three operations, namely, ploughing, disking and ridging, in line with standard farmers practice at Dzindi. Plots were 9.5 m long and 4.5 m wide, resulting in a gross plot area of 42.75 m^2. Both crops were planted in rows spaced 0.75 m apart. Planting of the field trial was planned for mid-November but had to be postponed to 3 January 2011, because of persistent rain which prevented land preparation. The crop was planted by opening furrows using a hand hoe. Prior to depositing the seed, superphosphate (10.5% P) was applied in the base of the furrows at the rate of 428 kg ha^{-1} and worked into the soil by dragging a stick along the base of the furrows. No other fertilisers were used. Both crops were planted by sowing a more than adequate number of seeds in the planting furrow, where after the seed was covered with about 2 cm of soil using a rake. Following emergence, the stand of cowpeas was thinned to 44 444 plants ha^{-1} (intra-row spacing of 0.3 m) and that of pigeon peas to 26 667 plants ha^{-1} (intra-row spacing of 0.5 m). Both crops were irrigated once a week, applying about 20 mm per irrigation event. Weeds were controlled by hand hoeing whenever they emerged. No preventative pest control measures were applied. Both crops were harvested by collecting the mature pods from all plants in the net plot. The pods were then shelled to obtain the grain and this was weighed.

The data was captured on spread sheets using MS Office Excel ®, and analysed using the SAS statistical software version 9.2 (SAS, 1999). Statistical analysis of the data involved analysis of variance to identify treatment effects and when these effects were statistically significant ($p \leq 0.05$) the Fisher's Protected Least Significant Difference test ($\alpha = 0.05$) was used to separate treatment means. Statistical analysis of the data was done by the Biometric Division of the Agricultural Research Council in Hatfield, Pretoria.

9.3.3 Poultry manure as a fertiliser

9.3.3.1 Effect of application rate on biomass production of selected African leafy vegetables grown in pots

The study involved four greenhouse pot experiments each using a different leafy vegetable as the test crop. In the four experiments, different rates of application of Promis® layer litter were used as treatments using a completely randomised design with six replications. A control treatment in which no fertiliser was added was included, as well as two chemical fertiliser treatments, referred to as ‘medium chemical’ and ‘high chemical’, that served as benchmarks. The different treatments are summarised in Table 9.7. The application rates of nutrients per unit area (t ha^{-1}) in Table 9.7 refer to the rates at which the fertilisers would need to be broadcast and worked into the upper 15 cm of the soil, also called the furrow slice, assuming that the mass of one hectare furrow slice was 2 240 t, as proposed by Schlossberg *et al*. (2007:855).

TABLE 9.7: Summary of the treatments in the pot experiments that explored crop response to application rate of Promis® manure using Chinese cabbage, amaranth, nightshade and pumpkin as test crops

Treatment	Fertiliser	Rate of fertiliser application		Rate of elemental nutrient application					
				(mg kg⁻¹ soil)			(kg ha⁻¹)		
		(g kg⁻¹soil)	(t ha⁻¹)	N	P	K	N	P	K
Control	None	..0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
MCF	LAN	0.55	1.18	149.1	0.0	0.0	333.8	0.0	0.0
	Supers	1.18	2.63	0.0	98.0	0.0	0.0	219.0	0.0
	KCl	0.20	0.44	0.0	0.0	95.4	0.0	0.0	214.5
HCF	LAN	1.10	2.35	298.1	0.0	0.0	667.5	0.0	0.0
	Supers	2.35	5.26	0.0	195.9	0.0	0.0	438.0	0.0
	KCl	0.40	0.87	0.0	0.0	190.7	0.0	0.0	429.0
PL1	Promis®	2.69	6.00	99.8	39.8	48.2	223.7	89.2	108.2
PL2	Promis®	5.38	12.00	199.6	79.6	96.4	447.5	178.3	216.5
PL3	Promis®	8.07	18.00	299.4	119.4	144.7	671.2	267.5	324.7
PL4	Promis®	10.76	24.00	399.3	159.3	192.9	894.9	356.6	432.9
PL5	Promis®	15.70	35.00	582.2	232.2	281.3	1305.1	520.1	631.3
PL6	Promis®	22.42	50.00	831.8	331.8	401.9	1864.5	743.0	901.9

MCF: medium fertiliser treatment; HCF: high fertiliser treatment; PL: poultry litter

Treatments of Promis® were selected to cover the range between 6 t ha^{-1} and 50 t ha^{-1}, as the results obtained in a pilot study (Azeez *et al*., 2010) suggested that the optimum biomass of pumpkin could be obtained when Promis® was applied at 17.1 t ha^{-1} and that of nightshade when Promis® was applied at 34.1 t ha^{-1}.

Promis®, the poultry litter used in the study, was a partly composted layer litter that was supplied by National Plant Food cc in Rustenburg. It was produced by layer hens reared by means of a floor system, which involved the application of bedding material. The purpose of this particular layer system was to supply eggs for the production of chicks. National Plant Food cc makes Promis® available commercially, as a registered organic fertiliser, which is sold in 30 kg bags. Before applying the manure to the soil in the pots, it was spread on plastic sheets in a cool shady place and air-dried, where after it was homogenised and the particle sizes reduced by hammer milling and passing it through a sieve with an aperture of 6.4 mm. Information on the composition of the Promis® manure processed in this way is presented in Table 9.8. The soil used in the pots was a yellowish red (5YR 4/5 [dry]), sandy clay loam soil of low fertility (Soil

Classification Working Group, 1991:138-139), which was sourced from JL Coetzer cc in Swartspruit. Selected chemical and physical properties of the soil are presented in Table 9.9.

TABLE 9.8: Chemical and physical properties of the Promis® layer litter used in the pot experiments (air-dry basis)

Property	**Unit**	**Promis®**
pH[1]		6.9
Moisture	%	12.1
Solids	%	87.9
Mineral content[2]	%	15.5
Organic matter content	%	72.4
Total organic carbon	%	35.5
Mineral content (dry)	%	17.7
Total Nitrogen	%	3.7
Carbon/Nitrogen ratio		9.6
Calcium (Ca)	%	2.5
Magnesium (Mg)	%	0.7
Phosphorus (P)	%	1.5
Potassium (K)	%	1.5
Sodium (Na)	%	0.5
Aluminium (Al)	%	0.1
Iron (Fe)	%	0.2
Copper (Cu)	mg kg^{-1}	99.1
Manganese (Mn).	mg kg^{-1}	759.5
Zinc (Zn)	mg kg^{-1}	545.3
Electrical conductivity[3]	(m Sm^{-1})	13.4

[1] The manure to water ratio used for pH measurement was 1 g manure: 5 mℓ water.
[2] With the exception of mineral content, all values in the table are reported on an air dry basis and are based on the dried and milled samples provided to the ARC-ISCW, 2008.
[3] The manure to water ratio for electrical conductivity determination was 20 ml manure: 40 ml (Peters *et al*., 2003:51)

TABLE 9.9: Chemical and physical properties of the test soil used in pots experiment

Soil property	Unit	Method	Measurement	Reference
Clay percentage	%	Pipette method	23.1	(NASAWC, 990:35/1)
pH (H_20 $_{[Water]}$)	-	1:2.5 soil: water mass ratio	5.7	(NASAWC, 1990:3/1)
pH (KCl $_{[Potassium\ chloride]}$)	-	1:2.5 soil:1M KCl solution mass ratio	5.3	(NASAWC, 1990:2/1)
Electrical conductivity	mS cm^{-1}	Saturated paste extract	17.5	(NASAWC, 1990:4/1)
NH_4^+-N (ammonium-nitrogen)	mg kg $soil^{-1}$	1 M KCl extraction	5.5	(NASAWC, 1990:33/1)
NO_3^-N (nitrate-nitrogen)	mg kg $soil^{-1}$	1 M KCl extraction	3.4	(NASAWC, 1990:33/1)
Phosphorus (P)	mg kg $soil^{-1}$	Bray 1 extraction	6	(NASAWC, 1990:20/1)
Potassium (K)	$cmol^{(+)}$ kg $soil^{-1}$	1 M ammonium acetate extraction	4.9×10^{-2}	(NASAWC, 1990:8/1)
Calcium (Ca)	$cmol^{(+)}$ kg $soil^{-1}$	1 M ammonium acetate extraction	1.19	(NASAWC, 1990:8/1)
Magnesium (Mg)	$cmol^{(+)}$ kg $soil^{-1}$	1 M ammonium acetate extraction	5.2×10^{-1}	(NASAWC, 1990:8/1)
Sodium (Na)	$cmol^{(+)}$ kg $soil^{-1}$	1 M ammonium acetate extraction	3×10^{-2}	(NASAWC, 1990:8/1)
Zinc (Zn)	mg kg $soil^{-1}$	0.5 M HCl extraction	6.4×10^{-1}	(NASAWC, 1990:14/1)
Copper (Cu)	mg kg $soil^{-1}$	0.5 M HCl extraction	1.87	(NASAWC, 1990:14/1)
Iron (Fe)	mg kg $soil^{-1}$	0.5 M HCl extraction	21.96	(NASAWC, 1990:14/1)
Manganese (Mn)	mg kg $soil^{-1}$	0.5 M HCl extraction	63	(NASAWC, 1990:14/1)

The four crops that were used as test crops were non-heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*), amaranth (*Amaranthus cruentus* L.), pumpkin (*Cucurbita maxima* Duchesne) and nightshade (*Solanum retroflexum* Dun.). The nightshade seed used in the experiment was obtained from Ms MT Ratshitanga, a small-scale seed producer in Ngulumbi village (Vhembe District). Amaranth seed was sourced from the Vegetable and Ornamental Plant Institute (VOPI) of the Agricultural Research Council (ARC), Roodeplaat, Pretoria. The pumpkin seed was obtained from VOPI, reference ex-Bushbuckridge. Chinese cabbage (*Brassica rapa* subsp. L. *chinensis*) seed was obtained from Mr Mabulannga, a smallholder farmer residing in Itsani village, Thulamela Municipality, Limpopo Province. The soil used in the experiments was the same as soil used in pot experiment by Van Averbeke *et al*. (2007) and Azeez *et al*. (2010).

The experiments were conducted in a greenhouse at the Tshwane University of Technology, Pretoria, which had a wet wall and two fans which engaged thermostatically when the temperature in the green house reached 30^{o}C to control the maximum temperature but no heating device to control minimum temperature. The general procedures for preparing the soil and fertiliser mixtures, filling the pots, planting the seed and watering the pots were exactly the same as those described by Van Averbeke *et al*. (2007) and Azeez *et al*. (2010). After transferring the dry soil/fertiliser mixtures to the pots, the water content of the soil was raised to field capacity. After irrigation, pots were covered with cling wrap and left for 16 days to allow the fertilisers to react with the soil and to allow for nutrient release from the poultry manure. Planting of the crops was timed to coincide with their normal growing season. Planting dates, final harvest date and duration of the growing period are shown in Table 9.10.

Biomass measurements were made using a portable electronic scale with a capacity of 120 g and an accuracy of 0.001 g. The fresh mass of the plant parts was determined immediately after their removal. Oven-dry biomass of plant material was determined by drying the material in a forced-draught oven at 60^{o}C until constant mass. Total oven-dry above-ground biomass was used as the indicator to determine crop response to application rate of the nutrient sources.

TABLE 9.10: Planting dates, harvest dates and duration of the growing period of the different crops

Crop	Planting date	Harvest date	Growth period
Chinese cabbage	8 July 2009	11 September 2009	9 weeks
Amaranth	15 September 2009	3 December 2009	12 weeks
Nightshade	15 October 2009	30 January 2010	15 weeks
Pumpkin	11 February 2010	25 March 2010	6 weeks

Harvesting of amaranth and pumpkin was in accordance with the protocol described by Van Averbeke *et al*. (2012). Harvesting of Chinese cabbage and nightshade was in accordance with the protocol described by Van Averbeke *et al*. (2007).

Data obtained were subjected to analysis of variance (ANOVA) using the GLM procedure of the Statistical Analysis Software Version 9.2 (SAS Institute Inc, 1999), to test for treatment effects. Treatment means were separated using the Fishers Protected Least Significant Difference (LSD) test ($p \leq 0.05$).

9.3.3.2 Effect of application rate on biomass production of nightshade under field conditions

An experiment was conducted at Dzindi Irrigation Scheme to determine the effect of Promis® application rate on biomass production of nightshade (*Solanum retroflexum* Dun.) under field conditions. The experiment had six treatments, which were arranged in a randomised complete block design with three replications. The treatments involved Promis® applied at four different application rates, a control without fertiliser application and a chemical fertiliser treatment shown to be close to optimum in another experiment on the same soil (Van Averbeke *et al*., 2012). The different treatments are summarised in Table 9.11.

TABLE 9.11: Experimental treatments and application rate per plot

Treatment	Application rate (t ha^{-1})	Application rate (g m^{-2})
Control	No fertiliser addition	No fertiliser addition
Promis® 1	5 t Promis®	500 g Promis®
Promis® 2	10 t Promis®	1000 g Promis®
Promis® 3	15 t Promis®	1500 g Promis®
Promis® 4	20 t Promis®	2 000 g Promis®
Chemical fertiliser	150 kg N; 80 kg P; 60 kg K	15 g N; 8 g P; 6 g K

The experimental site was located on Plot 1 of Block 1 of the Scheme on a south-facing, terraced slope of 15% and the soil at the experimental site consisted of a well drained, clayey Hutton Suurbekom type soil (Soil Classification Working Group, 1991:138). The seed of nightshade and the Promis® used in the experiment were obtained from the same sources mentioned in section 9.3.3.1 of this report. The soil was prepared using a disk plough. This operation was followed by disking using a disk harrow to break large clods. The plots were then demarcated and hand hoes and rakes were used to level the plots. Then Promis® was applied broadcast to the plots in accordance with treatment specifications (Plate 9.1), and worked into the soil using hand hoes.

PLATE 9.1: Broadcasting Promis® chicken manure on the plots

After applying the manure, the plots were irrigated. Once the water had drained, ridges spaced 75 cm apart were constructed to enable the use of short furrow irrigation during the growing period of the crop. Nightshade was planted on both sides of the ridges. For this purpose a planting furrow was opened with a specially designed hand hoe that had a narrow (50 mm) blade. In the plots representing the chemical fertiliser treatment 54 g of the chemical fertiliser mixture 2:3:4 (30) was applied evenly in the planting furrow and mixed with the soil using a stick. Subsequently, water was applied in the furrow (about 1 ℓ m^{-1} of furrow) to assist germination of the seed and emergence of the seedlings. To control cutworms (Agrotis spp.), Avalanche®, with *alpha-cypermethrin* as the active ingredient, was applied at the rate of 2.5 ml 10 L^{-1} water in the planting furrow, as recommended by the Directorate: Food Safety and Quality Assurance (2007), using a knapsack spray. Thereafter, nightshade seed was sprinkled evenly in the planting furrow and covered with a thin layer (5 mm) of soil. Following emergence, the nightshade seedlings were thinned to the desired intra-row spacing of 0.30 m, leaving 8 plants per 2.4 m row resulting in a total of 96 plants per plot. Nightshade received three topdressings of N. Each of these involved the band placement of 24 g limestone ammonium nitrate LAN) per planted row-length. This was done by opening a furrow about 10 cm below and to the side of the planted row, spreading the LAN evenly in this furrow, mixing fertiliser with soil by dragging a stick along the bottom of the furrow and then closing the furrow. The first application of LAN occurred after thinning, the second after the first shoot harvest and the final application after the second shoot harvest. All plots were irrigated twice per week, applying about 25 mm per irrigation event, which was shown to be more or less optimal for the production of Chinese cabbage (Van Averbeke & Netshithuthuni, 2010). Weeds were removed manually or by hand hoeing. Pest control measures during growth were limited to the knapsack sprayer application on the foliage of the nightshade of Aphox, with *pirimicarb* as the active ingredient, at the rate of 5 g 10 L^{-1} water to control aphids (Aphididae spp.), whenever these were observed during scouting (Directorate: Food Safety and Quality Assurance, 2007). The nightshade experiment was terminated after the third harvest.

The biomass response of nightshade to Promis® application rate was determined using four indicators, namely the mass of the edible portion (fresh and oven-dry) and total above-ground biomass (fresh and oven-dry). Biomass data were collected from the plants growing in the net plot. The net plot was obtained by excluding the two outer rows of the gross plot and the first and last plant in each of the remaining four rows. The total size of the net plot was 3 m x 1.8 m resulting in total net plot area of 5.4 m^2. The net plot contained a total of 48 plants. Harvesting of nightshade and the procedures for weighing and drying the biomass were the same as described for the green house experiment in section 9.3.3.1 of this report. The data were captured on spread sheets using MS Office Excel ® and this was followed by analysis of variance to test for treatment effects.

9.3.3 Fertiliser value of poultry manure

9.3.3.1 Incubation experiment

An incubation experiment involving four treatments, which were arranged in a completely randomised design and replicated four times, was conducted under laboratory conditions at Tshwane University of Technology. Samples of 300 g of air dried soil were transferred into 350 mL polystyrene containers. Two application rates of Promis® chicken manure equivalent to 30 kg N ha^{-1} and 210 kg N ha^{-1} and two chemical fertiliser treatment with N and P content being equivalent to that contained in the two chicken manure treatment were weighed, added and mixed with soil in the containers assuming that the mass of the furrow slice was 2240 t ha^{-1}. Then distilled water was added into the soil-fertiliser mixture in the pots such that the water content is at field capacity. The field capacity of the soil was determined gravimetrically using methods described by Tshikalange (2006:35-36). The 300 g of soil in the pots contained 42.9 g of water at field capacity. Soils were then incubated for 70 days with moisture content being occasionally adjusted to field capacity by adding distilled water. For chemical fertiliser treatments, limestone ammonium nitrate (LAN) which contained 28% nitrogen and single superphosphate with a phosphorus content of 8.3% were used. The treatments employed in the study are shown in Table 9.12. The soil that was used in the incubation studies was the same as was used in the pot experiments described in section 9.3.3.1.

A total of 64 experimental units were used for this incubation study. The samples were incubated for different timings and destructive sampling method was used to collect samples. This was achieved by removing 16 units of the experiment at different sampling times; that is during days 0, 14, 42 and 70. Samples of all treatments were analysed for NO_3-N, NH_4^+-N and plant available phosphorus. The NO_3-N and NH_4^+-N concentrations were extracted by shaking 7.5 mL soil (moist) with 20 mL of 0.5 M potassium sulphate (K_2SO_4) for 30 minutes on a Labcon Micro-processor Controlled Platform Shaker® adjusted to 160 oscillations per minute; followed by filtration through Whatman No.1 filter paper. The filtrate was then analyzed for both NO_3^--N and NH_4^+-N colorimetrically (Anderson & Ingram, 1993:73-74) using A Lasec Cecil 1000 series, CE1021 diode array spectrophotometer® set at a wavelength 410 nm and 655 nm for NO_3^--N and NH_4^+-N detection respectively. The concentration of nitrates and ammonium were determined on moist soils to minimize loss of nitrogen in a gas form, which is a process that is facilitated by the drying of soils. The remaining soil was then left to air dry inside the pots before crushing the soil with a pestle and mortar. Air dried soil, sifted with a 2 mm mesh sieve, was then analysed for plant available phosphorus. The extraction of phosphorus was done using 0.5 M sodium bicarbonate ($NaHCO_3$), at pH 8.5 (NASAWC, 1990:24/1) because of its adaptability to a wide range of tropical soils (Anderson & Ingram, 1993:81). For this purpose, 2.5 g soil was shaken in 50 mL of 0.5 M $NaHCO_3$ for 30 minutes on a Labcon Micro-processor Controlled Platform Shaker® adjusted to 180 oscillations per minute. The mixture was then filtered using double Whatman No. 1 filter paper followed by the preparation of the Murphy-Riley colour-developing solution by adding 1% ascorbic acid and molybdate reagent as described by Anderson & Ingram (1993:87). Plant available phosphorus was determined colorimetrically using Lasec Cecil 1000 series, CE1021 diode array spectrophotometer® set at a wavelength 880 nm.

The nitrogen fertiliser value of the poultry manure was the ratio of the sum of the NO_3-N and NH_4^+-N concentrations recorded in the samples containing poultry manure and those in the samples containing chemical fertiliser (LAN) at the same N application rate. The phosphorus fertiliser value of the poultry manure was the ratio of the available P concentrations recorded in the samples containing poultry manure and those in the samples containing chemical fertiliser (superphosphate) at the same P application rate.

9.3.3.2 Pot experiments

Using greenhouse pot experiments, the nitrogen and phosphorus fertiliser values of poultry manure were determined using maize, pumpkin and kidney beans as the test crops. The basic idea behind these experiments is that the fertiliser value of organic materials with known content of N or P can be determined by comparing the biomass production obtained using this organic material at a known rate of application with the biomass production obtained using a chemical source containing the same nutrient and applied at the rate that adds exactly the same quantity of that nutrient to the soil as the organic material.

Two greenhouse pot experiments were conducted to determine the nitrogen and phosphorus fertiliser value of Promis® poultry manure. Treatments consisted of various application rates of the different fertiliser materials and were arranged in a completely randomised design with five replicates per treatment. Treatments used in the nitrogen fertiliser value experiment included the application of 30 kg N ha^{-1}, 60 kg N ha^{-1}, 90 kg N ha^{-1}, 120 kg N ha^{-1}, 150 kg N ha^{-1}, 180 kg N ha^{-1} and 210 kg N ha^{-1} in the form of urea and in the form of Promis® chicken manure. All treatments were supplied with super-phosphate at the rate of 80 kg P ha^{-1} and potassium chloride at the rate of 60 kg K ha^{-1}. The modified Hoagland solution comprising salts of calcium, magnesium, zinc and sulphates was added to the irrigation water and used as described by Arnon and Hoagland (1940) to ensure availability of micro-nutrients in all treatments.

Treatments used in the phosphorus fertiliser equivalence value experiment consisted of the application rates of 0 kg P ha^{-1}, 25 kg P ha^{-1}, 50 kg P ha^{-1}, 75 kg P ha^{-1} and 100 kg P ha^{-1}, applied in the form of super-phosphate and in the form of Promis®. All treatments were supplied with urea at the rate of 120 kg N ha^{-1} and potassium chloride at the rate of 60 kg K ha^{-1}. As in the case of nitrogen fertiliser equivalence the modified Hoagland solution was added to the irrigation water. A single plant of maize, kidney beans and pumpkin were grown together in each of the pots in the phosphorus fertiliser value experiment but in the nitrogen fertiliser value experiment kidney bean was left out. The maize cultivar PAN 67 was obtained from Panar; the Flat white Boer Van Niekerk variety of pumpkin from Obaro (Pty) Ltd., and the Kranskop variety of kidney bean from Gellman's Seed. Oven-dry above-ground biomass was used as the crop response indicator and was determined by drying the above-ground biomass of the three crops material in a forced-drought oven at 65°C until constant mass was obtained. The experimental procedures that were used were the same as described in section 9.3.3.1.

For each of the application rates and fertiliser materials used, the mass of fertiliser applied to the 8 kg soil in the pots was proportional to the mass of fertilisers applied to 1 ha furrow slice to achieve the desired rate of application, whereby the mass of 1 ha furrow slice was taken as 2.24 x 10^6 kg, as recommended by Schlossberg *et al.* (2008). At the time of planting (see Table 9.12), the water content of the soil in the pots was raised to field capacity and the test crops were planted the same day. Five seeds of each crop were planted. Thinning was carried out one week after emergence leaving a single healthy plant of each of the test crops in each pot. Soil water availability was maintained at optimum level by irrigating the pots regularly using the procedure described by Van Averbeke, Juma and Tshikalange (2007), which involved weighing the pots once or twice per day to determine water use, followed by refilling the soil water content to field capacity. The experiments were terminated when all maize plants in the best-performing treatment had seven fully developed leaves, which occurred after 35 days of growth (Table 9.12). A maize leaf was considered fully developed when the ligule at the base of the leaf was clearly visible (Van Averbeke, 1991).

TABLE 9.12: Planting and harvest dates with the duration of the growing period of the different crops in the nitrogen and phosphorus experiments

Crop	Planting date	Final harvest date	Growing period (days)
Maize (*Zea mays* L)	10 Dec 2010	15 Jan 2011	35
Pumpkin (*Cucurbita maxima*)	10 Dec 2010	15 Jan 2011	35
Kidney bean (*Phaseolis vulgaris)*	10 Dec 2010	15 Jan 2011	35

The mean total oven-dry above-ground biomass for all the test crops used in the study was used as an indicator of the biomass response of the three crops to application rate of the different fertiliser materials used. This involved the drying of the plants that were cut at the base in a Labcon forced draught oven (manufactured by Laboratory Marketing Services cc and supplied by Geo-Tech, Pretoria) at 65^{o}C until constant mass was obtained.

For each of the three test crop, the nitrogen fertiliser value of the poultry manure was the ratio of the average biomass recorded in the pots containing poultry manure and that recorded in the pots containing chemical fertiliser (LAN) at the same N application rate (Shröder, 2005). The same procedure was used to calculate the phosphorus fertiliser value of the poultry manure

9.4 Results

9.4.1 Legume grains as a source of protein in poultry feed

9.4.1.1 Effect of diet on the biological performance of broilers

A summary of the effects of diet on weekly feed intake, body weight gain and feed conversion ratio of broilers observed in the two runs of the experiment are shown in Table 9.13.

In both runs of the experiment, broilers on the control diet demonstrated higher rates of feed intake than broilers on the experimental diet during the first five weeks of growth. During the finisher phase, which started in the sixth week, the effect of diet on feed intake of the broilers declined and virtually disappeared during the final week of growth. Differences in feed intake between the two treatment groups were accompanied by differences in body weight gain and feed conversion ratio. In general, broilers on the control diet exhibited superior biological performances. Since all growth factors except diet were the same for both treatment groups of broilers, the causes for the suboptimal performance of broilers on the experimental diet had to be diet related.

Two main factors were identified as possible causes for the suboptimal performance of broilers on the experimental diet, namely, the nutritional value of the diet and the form in which the feed was presented to the birds during the different stages of growth. Protein content of the experimental diet was deficient during the starter and grower phases and these were also the phases during which the performance of broilers on the experimental diet was most affected.

TABLE 9.13: Effect of diet on the total feed intake (TFI), body weight gain (BWG) and feed conversion ratio (FCR) of broilers during the different growing phases

Diet treatment	TFI (g)	BWG (g)	FCR	TFI (g)	BWG (g)	FCR	TFI (g)	BWG (g)	FCR	TFI (g)	BWG (g)	FCR
	Starter phase (1-21 days)			**Grower phase (22-35 days)**			**Finisher phase (36-49 days)**			**All phases (1-49 days)**		
Experiment 1												
Control	1266	654	1.96	2284	1182	1.93	2866	1104	2.61	6426	2940	2.19
Experimental	1193	462	2.59	1764	836	2.11	2707	1045	2.60	5664	2343	2.42
Significance level of treatment effect	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.03	p=0.19	p=0.09	p<0.001	p<0.001	p<0.001
Experiment 2												
Control	1071	764	1.40	2270	885	2.57	2872	1100	2.65	6213	2749	2.26
Experimental	928	471	1.97	1940	597	3.25	2804	1097	2.55	5672	2166	2.62
Significance level of treatment effect	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p=0.39	p=0.93	p=0.47	p<0.001	p<0.001	p<0.001

A review of existing knowledge on the effect of reduced dietary protein in starter phase broiler diets indicated that protein contents of two to three percent below the recommended content of 20% to 21% reduced feed intake by a maximum of 5%, weight gain by a maximum of 9% and feed conversion ratio by a maximum of 8% (Ciftci & Ceylan, 2004; Rezaei *et al.,* 2004; Khajali & Maghaddam, 2006; Latshaw, 2008). For the grower phase it was reported that reductions in protein content of the same magnitude reduced feed intake by a maximum of 3%, weight gain by a maximum of 12% and feed conversion ratio by a maximum of 11% (Ferguson *et al.,* 1998; Sterling *et al.,* 2002; Cifci & Ceylan, 2004 & Rezaei *et al.,* 2004). From the accounts provided by other researchers, it would appear that the magnitude of the effect of reduced protein content in starter and grower diets on the performance of broilers recorded by other researchers was insufficient to fully explain the reduction in performance of broilers on the experimental diet relative to that of broilers on the control diet, suggesting that additional limiting factors were at work.

There is general agreement that for optimal biological performance, presentation of feed to broiler chicks should be in the form of crumble during the starter phase and in the form of pellets during the grower and finisher phases of growth (NRC, 1994; Aviagen, 2002). The experimental diet was presented in mash form throughout the growing period. Research on the effect of feed form on broiler performance indicated that feeding a mash diet during the starter phase reduced feed intake by a maximum of 10%, and weight gain and feed conversion ratio by a maximum of 16% compared to broilers on a crumble diet (Nir *et al.,* 1990 & Kenny *et al.,* 2005). This suggests that mash form presentation of the experimental diet could possibly explain the reduction in feed intake of the chicks during the starter phase observed in the current study but was insufficient to explain the magnitude of the reduction in body weight gain and feed conversion ratio. Research on the effect of feed form on broiler performance during the grower phase indicated that feeding a mash diet reduced feed intake by a maximum of 5%, weight gain by maximum of 19% and feed conversion by maximum of 15% compared to broilers that received pelleted diets (Munt *et al.,* 1995, Koster, 2005; Jahan *et al.,* 2006).

Table 9.14 examines the magnitude of the combined effects of both reduced protein and the use of a mash diet during the starter and grower phases on selected broiler performance indicators. The values shown in Table 9.14 were obtained by subtracting the maximum reduction of each factor reported in the literature from 100% for each of the three performance indicators used. This yielded an indicator of the relative performance of broilers subjected to the different factors individually compared to broilers on the optimum diet. To assess the combined effects of both factors, the relative performance indicators were then multiplied.

TABLE 9.14: Maximum effects of reduced protein content and the use of a mash diet on selected broiler performance indicators reported in the literature

Factor	Starter phase			Grower phase		
	TFI	**BWG**	**FCR**	**TFI**	**BWG**	**FCR**
	Minimum broiler performance relative to the optimum					
Reduced protein content (A)	95	91	92	97	88	89
Mash diet (B)	90	84	84	95	85	85
Combined effect (A x B)	86	76	77	92	75	76

TFI = total feed intake; **BWG** = body weight gain; **FCR** = feed conversion ratio

As indicated earlier, use of a mash diet instead of a crumble diet appeared to explain the reduction in total feed intake during the starter phase observed in the first run of the experiment and combined with reduced protein content, apparent full explanations were obtained for the reduced feed intake during this phase in both runs of the experiment. The results presented in Table 9.14 also tended to go a long way in explaining the reduction in body weight gain and feed conversion ratio during the starter phase of the first run of the experiment but fell short of explaining the reduction in these two indicators recorded during the second run, suggesting that on the whole, a third limiting factor might have been at play. For the grower phase, the combined effects of reduced protein content and use of a mash diet appeared to explain reduced feed conversion ratio of broilers on the experimental diet in both runs of the experiment, but not the reductions in total feed intake and body weight gain that were observed. These results again suggested the presence of a third limiting factor.

The most likely third limiting factor identified in the literature was poor digestibility of the protein contained in the experimental diet. Further evidence of protein digestibility limitations in the experimental diet was provided by the analysis of the nutrient content of the broiler litter produced by the two treatment groups, discussed later on, which showed that the litter produced by broilers on the experimental diet was higher in N content than that produced by broilers on the control diet, despite the control diet being higher in protein content. Leeson (2005) pointed out that young birds' digestive capacity is immature during the early phases of growth and that this capacity improves with age. Immature digestive capacity of the broiler chicks causing poor digestion of the protein contained in the experimental diet during early growth and progressively maturing digestive capacity as growth proceeded could possibly explain why the performance indicators of broilers on the experimental diet improved dramatically during the finisher phase.

If low protein content during the starter and grower phase, presentation of the diet in an inferior mash form and problems with the digestibility of the protein during the early phases of growth of the broilers were indeed the three limiting factors that caused the sub-optimal biological performance of broilers on the experimental diet, could these three factors be addressed under smallholder circumstances? The obvious way in which to increase the protein content of the experimental diet would be to increase the total soya bean content but Malan (2006) warned that, in order to avoid leg problems soya beans should not make up more than 30% of the mass of poultry feed when full fat soya beans are used. However, soya bean content of the experimental diet could be increased by replacing part of the full fat soya with soya oil cake. This approach could be used to augment protein content of the broiler diet during the early phases of growth by adopting a phase-feeding approach instead of using a single diet throughout. Crumbling and pelleting of diets is not possible under smallholder circumstances but wet feeding of the mash diet could improve broiler performance.

Mai (2007) pointed out that feeding a coarsely ground diet in a wet state significantly improved feed intake, feed conversion and body weight gain relative to feeding the same diet in a dry state. Moreover, the beneficial effect of wet feeding was most pronounced during the starter phase of broiler growth, which was a phase of relatively poor performance in the current study. Poor digestion of the protein contained in the experimental diet could possibly be addressed by adding selected enzymes to the diet. Supplementation of broiler diets with enzymes has been reported to improve the digestibility of nutrients and performance of broilers during the early stage of growth (Noy & Sklan, 1994; Zanella *et al*., 1999; Sklan, 2002). In commercial broiler production this approach to improving protein digestibility has been incorporated in practice by adding a pre-starter feed to the conventional three-phase diet, with the pre-starter feed containing enzymes known to improve nutrient digestibility (Leeson, 2005).

Effect of diet on broiler litter

The effect of diet on the mass of manure produced per bird is shown in Table 9.15 and the effect of diet on the composition of manure in Table 9.16.

TABLE 9.15: Effect of diet on the mass of manure (excrements only) produced by broilers

Growth period of broilers	Broiler diet		Significance level of treatment effect
	Control	Experiment	
	---(kg air-dry manure bird^{-1})---		
Day 1 to 21 days	0.440	0.313	-
Day 22 to 2300g live weight	1.219	1.313	p=0.24
Day 1 to 2300g live weight	1.659	1.626	p=0.74

Table 9.15 shows that a broiler chick produced approximately 1.64 kg air-dry manure during the period needed to rear it from day-old to the live weight of 2300 g. The N, P and K contents of the litter produced by broilers on both the experimental and the control diets, shown in Table 9.16, were comparable with those obtained under similar circumstances by Leeson and Summers (1997) and Tennakoon and Hemalala Bandara (2003). Diet appeared to mainly affect the N and K content of the broiler litter. Litter obtained from broilers on the experimental diet contained 15.7% more N than that obtained from birds on the control diet.

TABLE 9.16: Effect of diet on the nitrogen, phosphorus and potassium content of broiler litter (excrements and wood shavings combined)

Elemental composition of air-dry litter	Broiler diet	
	Control	Experimental
	------------(%)----------	
Nitrogen	3.97	4.71
Phosphorus	1.46	1.45
Potassium	1.79	1.39

Effect of diet on the income statement of broiler enterprises

Using the data obtained in the two experiments, simplified income statements were compiled for a broiler enterprise that made use of the commercial control diet and for one that used the on-farm diet. These simplified income statements are presented in Tables 9.17 and 9.19. The results show that differences between the two enterprises in net operating income were only significant in one of the two runs of the experiment. Biologically, broilers on the experimental diet clearly exhibited inferior performance but from a financial perspective differences between the two diet treatments were less distinct, even though the control diet tended to perform better in both runs of the experiment.

TABLE 9.17: Effect of diet on the income statement of broiler enterprises using data obtained in experiment 1

	Broiler diet			
Operating expenses	**Control**		**Experimental**	
	R per bird	*(%)*	*R per bird*	*(%)*
Chick	3.66	18.59	3.66	18.17
Feed	12.74	64.70	13.19	65.49
Heating	1.92	9.75	1.92	9.53
Lights	0.34	1.73	0.34	1.69
Vaccines and medicines	0.70	3.56	0.70	3.48
Water and disinfectant	0.15	0.76	0.15	0.74
Wood shavings	0.18	0.91	0.18	0.89
Total	**19.69**	**100.00**	**20.14**	**100.00**
Receipts				
Sale of broiler	R 26.00		R 26.00	
Sale of broiler manure (R 0.74 kg^{-1})*	R 1.23		R 1.20	
Total	R 27.23		R 27.20	
Net operating income	**R 7.54**		**R 7.06**	

* Income from broiler manure was estimated using the results obtained in the second experiment.

TABLE 9.18: Effect of diet on the income statement of broiler enterprises using data obtained in experiment 2

Operating expenses	Broiler diet			
	Control		Experimental	
	R per bird	*(%)*	*R per bird*	*(%)*
Chick	3.66	17.86	3.66	17.48
Feed	13.55	66.09	15.00	66.80
Heating	1.92	9.37	1.92	9.17
Lights	0.34	1.66	0.34	1.62
Vaccines and medicines	0.70	3.42	0.70	3.34
Water and disinfectant	0.15	0.73	0.15	0.72
Wood shavings	0.18	0.88	0.18	0.86
Total	**20.50**	**100.00**	**21.95**	**100.00**
Receipts				
Sale of broiler	R 26.00		R 26.00	
Sale of broiler manure (R 0.74 kg^{-1})*	R 1.23		R 1.20	
Total	R 27.23		R 27.20	
Net operating income	**R 6.73**		**R 5.25**	

In both experiments, cost of feed contributed between 64% and 67% to the total operating expenses of the two types of enterprises. This result confirmed that feed is the principal backward growth linkage leak in the case of enterprises that use feed purchased from the national feed industry through a local distributor. For this reason, the main benefit derived from small-scale broiler enterprises using the experimental diet, which is formulated from locally produced grains and processed on-farm, is the added value to the local rural economy.

In a study of small and medium broiler enterprises in KwaZulu-Natal, Wynne and Lyne (2004:2) found that the contribution of broiler production to the local economy arose primarily from the retail mark-up and little else. In the current study, the income statements of the broiler enterprises in which the commercial control diet was used shows that the retail mark-up amounted to about 26% of the retail price of a broiler. This represented the monetary contribution of broiler production to the local economy. The other 74% was lost to the local economy, because it was used to pay for goods (chicks, feed, inoculants, gas and electricity) that were produced outside the local economy. When on-farm feed (experimental diet) was used, this contribution was raised to about 74% of the retail price of a broiler, nearly three times as large as the contribution of broiler enterprises that used commercial feed.

At this stage, the technology that was developed appeared to be suitable for application on farm units that are managed privately and have the land and infrastructure needed to integrate crop and broiler production. Even when the technology can only be applied partially, for example by producing just the maize grain on-farm and purchasing soya bean grain or oil cake to prepare the on-farm broiler diet, considerable increases in farm income can be realised, as a result of improved farming systems integration. In addition, relative to commercial feed, use of on-farm feed is expected to become progressively advantageous economically as degree of remoteness of the farm increases, because of the rising cost of transporting purchased feed.

Application of the technology in the context of canal irrigation schemes, where privately managed enterprises are expected to produce the grain for transformation into broiler feed is also a viable option, when the broiler enterprise serves the collective. In such cases, the benefit derived from the integrated system which provides farmers with a ready market and a fair price for the grain they produced is sufficient justification to accept a reduction in net operating income of the broiler enterprise brought about by using the on-farm feed instead of commercial feed, as long as the broiler enterprise remains financially viable.

Application of the technology in an open economy, where broiler enterprises would elect to purchase local grains and transform these grains into broiler feed, because it makes financial sense, was not yet expected to occur. The results obtained showed that using the on-farm option reduced net operating income of broiler enterprises. Therefore, the challenge was to improve the on-farm diet to such an extent that net operating income of broiler enterprises using the on-farm diet would be higher than those of enterprises using commercial diets. This then became the objective of follow-up work, which is reported on in the next section.

Improving the simple on-farm diet

In this section, the results obtained in the experiment aimed at improving the simple on-farm diet are presented. Three experimental diets were tested. Effects of diet on the biological performance of broilers are shown in Tables 9.19 and 9.20.

TABLE 9.19: Effect of diet on growth performance of broiler fed different diets over a 42 day growing period

Treatment	**Body weight gain (g bird^{-1})**				**Feed intake (g bird^{-1})**				**Feed conversion ratio (g g^{-1})**			
	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall
	1-21 d.	22-35 d.	36-42 d.	1-42 d.	1-21 d.	22-35 d.	36-42 d.	1-42 d.	1-21 d.	22-35 d.	36-42 d.	1-42 d.
COM	598^{a}	1498^{a}	571	2668^{a}	1455^{a}	3365^{a}	1015^{b}	5836^{a}	2.46	2.27^{a}	1.86^{a}	2.19^{a}
OFM	314^{b}	816^{b}	578	1708^{b}	897^{b}	2811^{b}	1381^{b}	5089^{b}	2.86	3.46^{c}	2.42^{a}	2.98^{c}
OFD	241^{c}	554^{c}	499	1294^{c}	705^{c}	2101^{c}	1509^{a}	4314^{c}	2.94	3.83^{c}	3.04^{b}	3.34^{d}
OFW	214^{c}	539^{c}	420	1174^{c}	597^{d}	1617^{d}	884^{c}	3098^{d}	2.80	3.00^{b}	2.14^{a}	2.65^{b}

COM = commercial multiphase diet; **OFM** = multi-phase on-farm diet; **OFD** = single-phase on-farm diet presented dry; **OFW** = single-phase on-farm diet presented wet; Means with different superscripts in the same column differed significantly ($p \leq 0.05$)

TABLE 9.20: Effect of diet on the growth performance of broilers fed different diets over a 49 day growing period

Treatment	Body weight gain (g bird^{-1})				Feed intake (g bird^{-1})				Feed conversion ratio (g g^{-1})			
	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall
	1-21 d.	22-35 d.	36-49 d.	1-49 d.	1-21 d.	22-35 d.	36-49 d.	1-49 d.	1-21 d.	22-35 d.	36-49 d.	1-49 d.
COM	598^{a}	1498^{a}	-	-	1455^{a}	3365^{a}	-	-	2.46	2.26^{a}	-	-
OFM	314^{b}	816^{b}	1082	2212^{a}	897^{b}	2811^{b}	1885^{a}	5593^{a}	2.86	3.45^{c}	1.75^{a}	2.53^{b}
OFD	241^{c}	554^{c}	947	1743^{b}	705^{c}	2101^{c}	1957^{a}	4763^{b}	2.94	3.83^{c}	2.07^{b}	2.74^{b}
OFW	214^{c}	539^{c}	913	1667^{b}	597^{d}	1617^{d}	1377^{b}	3591^{c}	2.80	3.00^{b}	1.52^{a}	2.17^{a}

COM = commercial multiphase diet; **OFM** = multi-phase on-farm diet; **OFD** = single-phase on-farm diet presented dry; **OFW** = single-phase on-farm diet presented wet; Means with different superscripts in the same column differed significantly ($p \leq 0.05$)

The results in Tables 9.19 and 9.20 show that diet treatment had a significant effect on the feed intake of broiler chicks. During the starter phase (measuring days 7, 14 and 21) all four diet treatment means differed significantly. Feed intake by chicks was highest in the COM group, followed by the OFM, group and the OFD group and was lowest in the OFW group. The same pattern was observed during the grower phase (measuring days 21, 28 and 35). During the finisher phase, as reported on in Table 9.19 (measuring day 35 and 42), the OFD group recorded the highest feed intake, followed by OFM and COM and lastly OFW. The difference between OFD and OFM was significant but the difference between OFM and COM was not. Feed intake by the OFW group during the finisher phase was significantly lower than that of the other three treatment groups. The relatively low feed intake of the COM group during the finisher phase was probably the result of broilers in this group reaching the end of the period of rapid growth (see also previous section). When expanding the finisher phase to two weeks (Table 9.20), and excluding the COM group, which had already exceeded the target weight of 2300 g after 43 days of growth, it can be seen that feed intake of the OFM and OFD groups were similar and significantly higher than that of the OFW group. Total feed intake by broilers over a 42-day growing period (Table 9.19) was highest for COM, followed by OFM, OFD and OFW, with all treatment means differing significantly from each other. The same significant trend was observed among the three on-farm diet groups when the growing period was extended to 49 days (Table 9.20).Body weight gain of the broiler chicks in the four treatment groups also showed important differences. The COM group gained significantly more body weight during the starter phase and particularly during the grower phase than the three other treatment groups. During these two growth phases, the OFM group gained significantly more weight than both the OFD and OFW groups, which recorded similar body weight gains. During the short finisher phase (from day 36 to day 42 as shown in Table 9.19), body weight gain among the four treatment groups did not differ significantly but numerically it was highest in the OFM group, followed by COM, OFD and OFW. When the finisher phase was expanded by one week (Table 9.20), differences among the OFM, OFD and OFW were again not significant but the numerically the order was the same as observed for the short finisher phase.

The feed conversion ratio data also highlighted the superiority of the COM diet, even though differences among the four treatment groups were not significant during the starter phase. However, during the grower phase, the short finisher phase and also during the full 42-day period of growth (Table 9.19), the feed conversion ratio of the COM group was substantially lower than those of the three on-farm diet treatment groups. The trend among the on-farm diet treatment groups was somewhat unexpected, with the OFW group recording a lower feed conversion ratio than the OFM and OFD groups. It should be remembered that a large proportion of the feed that was offered to the chicks in these three groups was not consumed, because the particles were too large. This ‘wasted’ feed was recovered and its mass was deducted from the mass of the feed that was presented to the birds. Consequently the conversion ratios apply to the difference between what was offered and what was recovered. Birds on the OFM and OFD diets were seen scratching the feed, which caused some of the feed to drop out of the feeder. Such losses were not observed in the OFW treatment, which could explain the apparent superior feed conversion ratio achieved in the OFW treatment.

Considering the critical error that was made during the transformation of the grain and the substantial effect this had on feed intake and body weight gain of the broilers in the three on-farm diet treatments that were affected, no financial analysis of the data was conducted.

9.4.1.2 Evaluation of cowpeas for use in layer feed

Growth assay

The results obtained in the growth assay are presented in Table 9.21.

TABLE 9.21: Effect of duration of boiling and germinating cowpeas contained in a poultry diet on selected growth performance indicators (mean ± standard error) of chicks from 7 to 14 days

Treatments	**Feed intake(g)**	**Body weight gain**	**Feed conversion**
15 minutes boiling	126.2 ± 17.3^{bc}	77.4 ± 8.6^{bc}	1.4 ± 0.07
30 minutes boiling	161.8 ± 10.1^{b}	85.7 ± 12.3^{b}	1.5 ± 0.08
60 minutes boiling	141.7 ± 15.0^{b}	84.2 ± 7.5^{b}	1.6 ± 0.12
3 days germination	76.1 ± 7.3^{c}	38.5 ± 3.7^{c}	1.6 ± 0.17
4 days germination	271.7 ± 7.0^{a}	172.0 ± 7.1^{a}	1.5 ± 0.03
5 days germination	179.3 ± 12.1^{b}	104.0 ± 7.2^{b}	1.6 ± 0.03
6 days germination	180.0 ± 9.9^{b}	107.0 ± 6.5^{b}	1.5 ± 0.08

$^{a, b,c}$ values within a column not sharing a common superscript differ significantly ($p \leq 0.05$)

The results in Table 9.21 show that boiling cowpeas for 30 minutes tended to be optimal and also that germinating cowpeas improved the growth performance of chicks relative to boiling them for 30 minutes, but only when the cowpeas were germinated for four days. Germinating cowpeas for three days reduced growth performance relative to germinating them for four days and germinating the cowpeas for longer than four days also reduced the growth performance of the chicks.

Layer experiment

Table 9.22 and 9.23 present a summary of the performance of layer hens on the experimental diet containing cowpeas germinated for four days and that of layer hens on the commercial control.

TABLE 9.22: Daily feed intakes (g) of the layer hens during the laying period

Week	Experimental diet		Control diet		Probability
	Mean	SD*	Mean	SD*	
1	93.3	13.4	124.9	15.4	≤0.0001
2	85.2	8.4	110.8	11.7	≤0.0001
3	76.5	9.2	114.8	8.0	≤0.0001
4	73.9	8.8	116.5	7.7	≤0.0001
5	70.0	12.7	112.5	10.4	≤0.0001
6	71.6	8.3	121.5	6.9	≤0.0001
7	79.5	8.6	122.3	11.3	≤0.0001
8	84.0	6.1	107.5	13.3	≤0.0001
9	83.9	10.5	99.0	12.0	≤0.0001
10	83.6	10.6	103.4	14.5	≤0.0001

*SD = standard deviation

Over the entire period of 70 days, feed intake of layer hens on the experimental diet was significantly lower ($p<0.01$) than that of layers on the control diet. The layer hens were imposed to cowpeas diet at 18 weeks of age. Any diet imposed during the last few weeks prior to onset of egg production had a negative effect on egg production parameters. This explains why layers on the experimental diet had lower feed intake compared to the control group. However, during week eight onwards there was numerical increases in feed intake, but still significant to the control group. The slight increase in feed intake of the layer hens fed on the experimental diet could be due to a prolonged period of feeding in which the layer hens adapted to the treated cowpeas. Lewis and Gous (2006) reported that a pullet rapidly moves from pullet weight to mature adult weight just prior to onset of lay in a very short period of time (approximately 2 to 3 weeks). Due to low feed intake, the layer hens on cowpeas diet did not gain any weight, whilst hens in the control group gained 0.2 kg on average. This implies that sexual maturity of the layers on the experimental cowpea diet was retarded.

TABLE 9.23: Effect of diet on selected performance indicators of laying hens from 21 to 31 weeks of age

Indicator	Diet		Significance level (p)
	Experimental	Control	
Egg production (no per hen day)	0.57	0.83	<0.0001
Egg weight (g)	48.5	52.9	<0.0001
Egg mass (g per hen day)	27.6	43.9	<0.0001
Feed intake (g per hen day)	86.2	107.7	<0.0001
Ratio of feed intake to egg mass	3.1	2.4	<0.0001
Initial body weight per hen (kg)	1.5	1.6	0.4
Final body weight per hen (kg)	1.5	1.8	<0.0001
Body weight change per hen (kg)	0	0.2	<0.0001
Cracked eggs (%)	0.1	1.6	<0.0001
Dirty eggs (%)	0.5	0.4	NS
Mortality (%)	0.0	0.0	NS
Feed required per egg laid (g)	151.2	128.8	<0.0001

Egg production hen^{-1} day, egg weight (g) and egg mass (g hen^{-1} day) of the layer hens on the experimental diet were all significantly lower ($p<0.05$) than in the control group. This was attributed to the reduced feed intake by the layer hens on the experimental diet, resulting in relatively low nutrient intake. In addition, due to the failure of the layer hens to rapidly progress from pullet weight to mature weight, sexual maturity was delayed and this delay in maturity meant that some of the nutrients provided during that period were used for growth instead of being used for egg production. However, when assessing hen-day egg production over time (Figure 9.3), an increase in egg production was evident for hens on the experimental diet from about eight weeks onwards. In fact, during weeks eight to ten differences in hen-day egg production between the two treatment groups were no longer statistically significant (p>0.05). Egg weight and egg mass followed the same trend. The apparent improved performance from eight weeks onwards suggests adaptation and progressively more efficient utilisation of the experimental cowpea diet by the layer hens. This suggests that over prolonged periods, layer hens adapt well to the experimental diet.

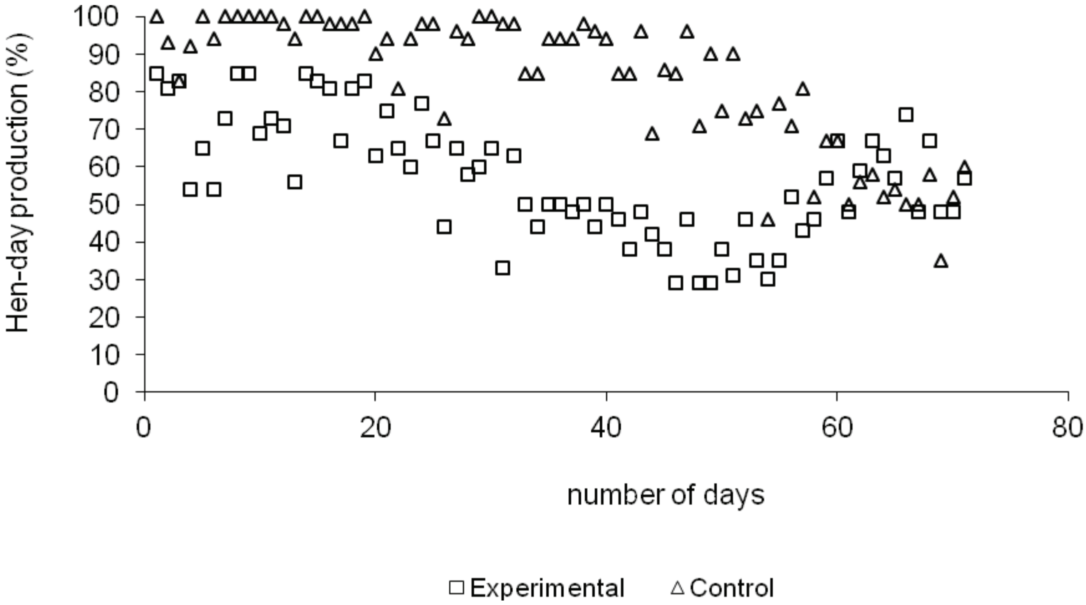

FIGURE 9.2: Hen-day production percentages in control and experimental group of hens during laying period (Hlungwane, 2011)

The absence of mortality and the low percentage of cracked and dirty eggs among layers on the experimental diet could be the result of supplementation of this diet with exogenous enzymes. Lacin *et al.* (2008) concluded that body weight does not affect egg production parameters, but laying periods affects egg production parameters. The higher egg output by the layer hens fed on control diet over the experimental period was due entirely to the earlier maturity of these layer hens. The results suggested that once the gastrointestinal tract of the birds was adapted to the cowpea diet, reproduction performance was no longer compromised but the duration of the trial (100 days) might have been too short to arrive at a firm conclusion on this.

Effect of diet on elemental plant nutrient content of layer litter

Chemical analysis of layer poultry manure (Table 9.24) showed that layers fed on treated cowpeas produced manure that was richer in N and P than layer hens fed on the commercial diet.

TABLE 9.24: Effect of diet on the nutrient content of layer litter (mg 100 g^{-1})

Nutrient	Control diet	Experimental diet
Potassium (K)	899	919
Phosphorus (P)	500	877
Nitrogen (N)	4030	4627

Cowpeas have higher mineral contents than soya beans (Ragab *et al*., 2010). When the digestibility of pulses is low, high concentrations of minerals can be expected in the poultry droppings (Boye, Zare & Pletch, 2010). The results in Table 9.24 suggest that phosphorus and nitrogen were not completely liberated by the addition of the enzyme complex Phyzyme® to the experimental diet.

Effect of dietary treatment on feed margin of egg production

The effect of dietary treatment on feed margin of egg production is shown in Table 9.25.

TABLE 9.25: Effect of dietary treatment on feed margin of egg production

Financial indicator	Control diet	Experimental diet
Cost of feed (R kg^{-1})	R4.20	R2.93
Feed intake (g hen^{-1} day^{-1})	107.70	86.20
Total feed cost over 70 days (R hen^{-1})	R45.23	R25.26
Money leaking out of the local economy	R45.23	R8.22
Egg production during 70 production period (eggs hen^{-1})	83	57
Average egg size category	Large	Medium
Average egg price (R egg^{-1})	R1.20	R1.10
Total income over 70 days (R hen^{-1})	R99.60	R62.70
Feed margin over 70 days (R hen^{-1})	R54.37	R37.44

Differences in feed cost between treatment diets occurred because of differences in the feed ingredients. Apart from different ingredients, the method used to process cowpeas also affected daily feed cost, whereby germinating cowpeas reduced the cost of feed relative to boiling (not shown). Table 9.25 shows that feed cost of layer hens on the commercial control diet was higher than that of hens on the experimental diet.

9.4.2 Yield potential of selected grain legumes in Vhembe

9.4.2.1 Soya beans

Late September planting of soya bean cultivar trial

The grain yields obtained in the cultivar trial that was planted during the last week of September are presented in Table 9.26.

TABLE 9.26: Results obtained in the National Soya Bean Cultivar Trial planted during the last week of September

Cultivar	Plant population (plants m^{-2})	Plant height (cm)	Lodging (%)	Green stems (%)	Mean grain yield (kg ha^{-1})	Position based on grain yield
Egret	10.7	47.8	15.7	37.3	537	6
Heron	17.3	57.9	24.9	60.5	766	2
Ibis 2000	14.7	46.1	3.4	7.2	671	3
LS 677	7.9	45.6	12.4	7.7	647	4
LS 678	5.3	41.2	8.4	12.8	288	7
LS 6050	4.7	47.9	-	-	278	8
PAN 535	8.6	45.0	3.2	48.1	143	9
PAN 660	-	-	-	-	-	
PAN 626	-	-	-	-	-	
PAN 809	13.5	55.8	10.3	35.9	784	1
PAN 1652	-	-	-	-		
SNK 440	3.4	40.7	55.4	70.6	88	10
SNK 500	-	-	-	-		
Stork	13.6	44.1	12.4	45.5	611	5
All	**10.8**	**47.6**	**15.0**	**34.3**	**481**	
Significance	0.17	0.93	0.02	0.18	0.02	

At Dzindi, planting soya beans late September was expected to be close to the optimum, because planting this early allows for a long growing period. The soya beans germinated reasonably well as is evident from the overall plant population density of 10.8 plants m^{-2} but performed very poorly. Heavy rain, which started soon after planting and which persisted throughout the growing season, was identified as the only plausible reason for the poor performance of the crop. Rain particularly affected the crop during the reproductive stages. Leaves became diseased, stems lodged, especially in SNK440, and grain turned mouldy inside the pods (all cultivars). The disease that affected the crop was not diagnosed but it could well have been *Rhizoctonia* Aerial Blight, a fungal disease caused by *Rhizoctonia solani* Khün, which is assisted by hot and humid weather. This disease can be controlled using seed treatment and foliar application of fungicide.

For consumption purposes, the crop was a total failure but grain yields were recorded for interest sake. PAN 809, Heron and Ibis 2000 were the top three performers, but among these three cultivars, Ibis 2000 appeared least affected by lodging and green stem. The mouldy grain was separated from the clean grain by hand to identify whether cultivar had an effect on the susceptibility of the grain to mould infestation. The mean mass percentage of visibly mouldy grain over all cultivars was 67%. The grain of Stork (42%) and Heron (47%) was least affected and the grain of PAN 535 (79%), Ibis 2000 and SNK 440 (78%) most, but the differences among cultivars were statistically not significant ($p>0.05$).

Late December planting

The results obtained in the cultivar trial that was planted during the last week of December are shown in Table 9.27. Although the overall mean grain yield obtained from the December planting was more than double that obtained in the September planting (Table 9.26), it was still very low considering that under irrigated conditions, soya beans have the potential of producing a grain yield of 3000 kg ha^{-1}. Heron, SNK 440 and Egret were the top three performers.

TABLE 9.27: Results obtained in the National soya bean cultivar trial planted during the last week of December

Cultivar	Plant population (plants m^{-2})	Plant height (cm)	Lodging (%)	Green stems (%)	Mean grain yield (kg ha^{-1})	Position based on grain yield
Egret	30.0	61	6	1	1433	3
Heron	31.5	70	16	1	1769	1
Ibis 2000	35.3	62	5	3	1086	8
LS 677	28.3	63	4	1	1011	9
LS 678	18.3	52	7	2	1103	7
LS 6050	6.1	48	0	1	459	10
PAN 535	17.3	45	9	1	1130	6
PAN 660	-	-	-	-	-	-
PAN 626	-	-	-	-	-	-
PAN 809	28.8	63	4	1	1172	5
PAN 1652	-	-	-	-	-	-
SNK 440	27.5	66	11	1	1477	2
SNK 500	-	-	-	-	-	-
Stork	44.8	62	4	5	1313	4
All	**26.8**	**59**	**7**	**2**	**1195**	**-**
Significance	0.40	0.26	0.84	0.07	0.19	

Early February planting

The results obtained in the cultivar trial that was planted during the first week of February are shown in Table 9.28. Of all three planting dates that were employed, the February planting date should have produced the lowest overall yield but the opposite was observed. The overall mean grain yield was 1 847 kg ha^{-1} and several cultivars produced a grain yield in excess of 2 000 kg ha^{-1}. PAN 1652, SNK 500 and SNK 440 were the top three performers.

TABLE 9.28: Results obtained in the National soya bean cultivar trial planted during the first week of February

Cultivar	Plant population (plants m^{-2})	Plant height (cm)	Lodging (%)	Green stems (%)	Mean grain yield (kg ha^{-1})	Position based on grain yield
Egret	14.3	62	6.3	27	1781	6
Heron	11.7	64	10.8	12	1367	10
Ibis 2000	15.3	60	8.7	15	1722	9
LS 677	8.5	54	11.4	19	1800	5
LS 678	5.9	51	2.4	32	1134	11
LS 6050						-
PAN 535						-
PAN 660	9.2	45	3.7	23	1595	8
PAN 626	9.1	73	1.5	28	2033	4
PAN 809	-	-	-	-	-	-
PAN 1652	18.4	71	4.5	3	2758	1
SNK 440	13.3	77	2.3	9	2143	3
SNK 500	2.4	43	9.5	33	2241	2
Stork	11.7	53	21.7	42	1742	7
All	**10.9**	**58**	**7.5**	**22**	**1847**	
Significance (p)	0.023	<0.0001	0.91	0.73	0.24	-

In Table 9.29, the different cultivars are ranked in accordance with their yield performance in the three cultivar trials. From the data in Table 9.29 it is evident that there was no single cultivar with a superior yield performance across planting dates. Heron appeared particularly well suited for planting dates up to the end of December, SNK performed well when planted during the last week of December or later, whilst the relative yield performance of Stork and Egret appeared not to be affected by planting date.

TABLE 9.29: Ranking of soya bean cultivars in accordance with their yield performance in three trials planted on different dates at Dzindi

Cultivar	**Planting date**		
	Last week of September	Last week of December	First week of February
Egret	6	**3**	6
Heron	**2**	**1**	10
Ibis 2000	**3**	8	9
LS 677	4	9	5
LS 678	7	7	11
LS 6050	8	10	-
PAN 535	9	6	-
PAN 660	-	-	8
PAN 626	-	-	4
PAN 809	**1**	5	-
PAN 1652	-	-	**1**
SNK 440	10	**2**	**3**
SNK 500	-	-	**2**
Stork	5	4	7

9.4.2.2 Cowpeas and pigeon peas

The seed of both cowpeas and pigeon peas germinated and emerged satisfactorily. Early on, cowpea plants grew more vigorously than pigeon pea plants but as season progressed the pigeon pea plants also grew very rapidly. Cowpeas were harvested 98 days after planting on 11 April 2011. Pigeon peas took 142 days from planting to flowering. The first pigeon pea pods were ready for harvest around May but were attacked by birds as they started to ripen and no grain could be harvested. A second flush of pods was harvested 304 days after planting but only a portion of the pods and grain could be secured, because bird damage continued unabated. . The grain yield obtained from the cowpeas and pigeon peas grown at Dzindi are shown in Table 9.30.

TABLE 9.30: Grain yield of cowpeas and pigeon peas obtained at Dzindi

Variables	Cowpeas	Pigeon peas
Number of days from planting to harvest	98	304
Average number of pods per plant	18	-
Average grain yield (kg ha^{-1})	890	150

Whereas cowpeas and pigeon peas appeared to be very well adapted to the local conditions and required little in the form of maintenance, grain yields were very low (890 kg ha^{-1} for cowpeas and 150 kg ha^{-1} for pigeon peas). At this yield level, neither of the two crops would generate anywhere near the monetary returns that farmers achieve from other summer crops, such as green maize (see Chapter 8).

9.4.3 Poultry manure as a fertiliser

9.4.3.1 Effect of application rate on biomass production of selected African leafy vegetables grown in pots

The effect of application rates of Promis® chicken manure on total oven-dry above-ground biomass of the four vegetables species is shown in Table 9.28. Statistically, treatment effect on total oven-dry above-ground biomass was highly significant ($p<0.0001$) for all four crops. The results in Table 9.28 show that without adding any source of nutrients to the soil (control treatment), biomass production was extremely limited for all crops except pumpkin. The medium chemical fertiliser treatment (MCF) produced the highest biomass production for Chinese cabbage, nightshade and pumpkin but the highest biomass production of amaranth occurred in the high chemical fertiliser treatment.

Non-heading Chinese cabbage: Relative to the control treatment, addition of Promis® increased biomass production of Chinese cabbage, except when Promis® was applied at the rate of 50 t ha^{-1} (Table 9.31). Biomass production increased progressively as application rate of Promis® increased up to 24 t ha^{-1}, which was the optimum application rate. Biomass production declined drastically when application rate of Promis® was raised in excess of 24 t ha^{-1}. Relative to the 24 t Promis® ha^{-1} treatment, raising the application rate of Promis® to 35 t ha^{-1}, reduced biomass production and statistically, the reduction was significant ($p\leq0.05$). The biomass production achieved at the apparent optimum rate of 24 t Promis® ha^{-1} was significantly lower than that achieved in both the medium chemical fertiliser treatment (MCF) and the high chemical fertiliser treatment (HCF). The biomass production in the 24 t Promis® ha^{-1} amounted to about 47% of that achieved in the medium chemical fertiliser treatment.

TABLE 9.31: Effect of application rate of different fertilisers on total oven-dry above-ground biomass of crops

Treatment	**Nutrient source**	**Application rate**	**Total oven-dry above-ground biomass**			
			Chinese cabbage	**Amaranth**	**Nightshade**	**Pumpkin**
		(t ha^{-1})	---------------(g plant^{-1})---------------			
Control	None	0	0.03^{g}	0.00^{f}	0.06^{h}	11.67^{h}
MCF	Chemical fertiliser	1.18 LAN, 2.63 supers,0.44 KCl	30.46^{a}	30.88^{b}	46.50^{a}	43.99^{a}
HCF.	Chemical fertiliser	2.35 LAN, 5.26 supers,0.87 KCl	18.55^{b}	35.50^{a}	41.61^{b}	28.99^{b}
PL1	Promis®	6	7.08^{f}	9.64^{ij}	11.42^{ij}	15.22^{f}
PL2	Promis®	12	9.50^{e}	19.28^{e}	17.52^{ef}	25.23^{c}
PL3	Promis®	18	11.90^{d}	25.12^{c}	30.76^{d}	21.44^{d}
PL4	Promis®	24	14.35^{c}	23.45^{cd}	34.38^{c}	17.29^{e}
PL5	Promis®	35	6.40^{f}	21.03^{de}	16.08^{f}	13.60^{g}
PL6	Promis®	50	0.97^{g}	19.55^{e}	8.90^{g}	8.34^{i}
Mean			**11.03**	**20.49**	**23.03**	**20.64**
LSD** ($p \leq 0.05$)			1.98	3.13	1.67	0.66
Coefficient of variation (%)			16.88	15.3	7.50	3.12

Treatment means followed by different letters differed significantly ($p \leq 0.05$); **LSD = least significant difference

Amaranth: Compared to the control treatment, applying Promis® to the soil increased biomass production of amaranth, irrespective of application rate (Table 9.31). The trend was that biomass production increased progressively as the application rate of Promis® was raised from 6 t ha^{-1} to 18 t ha^{-1} and then biomass production declined gradually as the application rate was raised above 18 t Promis® ha^{-1}. Biomass production of amaranth in the 18 t Promis® ha^{-1} treatment amounted to about 71% of that obtained in the high chemical fertiliser treatment, which produced the highest biomass of all treatments included in the experiment.

Nightshade: Relative to the control treatment, adding Promis® to the soil increased biomass production of nightshade, regardless of rate of application (Table 9.31). The trend was that biomass production increased gradually and near-linearly as application rate of Promis® was increased from 6 t ha^{-1} up to 24 t ha^{-1} and biomass production declined when application rate of Promis® was raised in excess of 24 t ha^{-1}. Biomass production in the 24 t Promis® ha^{-1} amounted to about 74% of that achieved in the medium chemical fertiliser treatment, which produced the highest biomass of all the treatments used in this experiment.

Pumpkin: Relative to the control treatment, addition of Promis® increased biomass production of pumpkin in all application rate treatments, except for the 50 t Promis® ha^{-1} treatment. The trend was that biomass production increased as application rate of Promis® was increased from 6 t ha^{-1} to 12 t ha^{-1} and then biomass production declined when the application rate of Promis® was raised in excess of 12 t ha^{-1}. Biomass production in the 12 t Promis® ha^{-1} application rate amounted to about 57% of that achieved in the medium chemical fertiliser treatment which had the highest biomass production among all the treatments used in the pumpkin experiment.

9.4.3.2 Effect of application rate on biomass production of nightshade under field conditions

The results obtained in the field experiment aimed at investigating the effect of application rate of Promis® poultry manure on the yield of nightshade are presented in Table 9.32. All biomass indicators tended to increase as application rate of Promis® poultry manure was raised, but treatment effects were not statistically significant (p=0.15), despite large differences among treatment means. The reason for the absence of statistically significant differences among treatment means was primarily due to the considerable within-treatment variability in the control and the lowest Promis application rate treatments. The probable cause of this was most probably variability in the residual nutrient content of the soil, which could have been the results of differences in previous land use.

Despite the absence of significant treatment effects, the results do indicate a general trend in the biomass response of night shade to application rate of Promis®. The results show that biomass tended to increase linearly as application rate was raised up to the highest rate of 2 kg Promis® m^{-2}. At this rate (2 kg Promis® m^{-2}), the highest total fresh above-ground biomass of

3.084 kg m^{-2} was recorded, and this yield exceeded that of the chemical fertiliser treatment (2.282 kg m^{-2}) by 35%.

TABLE 9.32: Effect of application rate of Promis® poultry manure on yield of nightshade (*Solanum retroflexum* Dun.) at Dzindi

Treatment	Total above-ground biomass		Total mass of leaves	
	Fresh	Oven-dry	Fresh	Oven-dry
	(g m^{-2})			
Control	1188	194.3	607	120.0
Promis® 1	1136	111.6	558	77.9
Promis® 2	1898	201.3	947	112.5
Promis® 3	1955	208.4	957	110.0
Promis® 4	3084	317.8	1497	169.0
Chemical	2282	251.6	1175	145.2

Generally, the results obtained in the field experiment supported the findings in the greenhouse experiments presented earlier in this chapter (section 9.4.3.1), which indicated that biomass production of nightshade increased with application rate of Promis® up to the rate of 24 t ha^{-1} or 2.4 kg m^{-2}.

9.4.4 Fertiliser value of poultry manure

9.4.4.1 Incubation experiment

Nitrogen fertiliser equivalence value

The effect of duration of incubation on the nitrogen fertiliser equivalence value of Promis® chicken manure is shown in Figure 9.3 for the 30 kg N ha^{-1} application rate treatment and in Figure 9.5 for the 210 kg N ha^{-1} application rate treatment. In the 30 kg N ha^{-1} application rate treatment (Fig. 9.3), the N-fertiliser equivalent value of Promis® chicken manure increased over time from an initial value of 37% immediately after application (0 days of incubation) to 70% after 70 days of incubation. This suggested that slightly more than one-third (37%) of the N contained in the poultry manure was present in mineral plant-available form, and by implication, 63% of the N in organic form. The continuous rise in the fertiliser equivalence value as incubation proceeded indicated that decomposition and mineralisation of organic nitrogen was occurring. The results showed that after 70 days, more than half (57%) of the organic nitrogen had been mineralised.

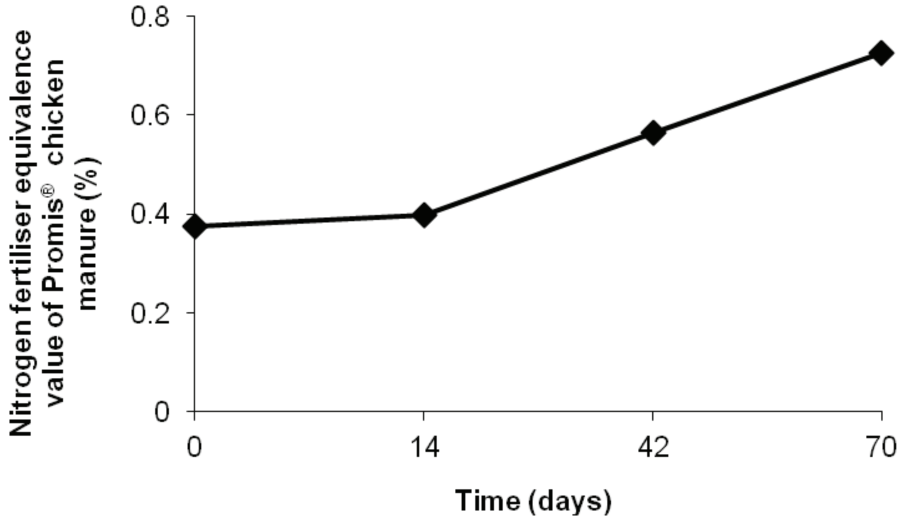

FIGURE 9.3: Nitrogen fertiliser equivalence value of Promis® chicken manure when applied at the rate of 30 kg N ha^{-1}

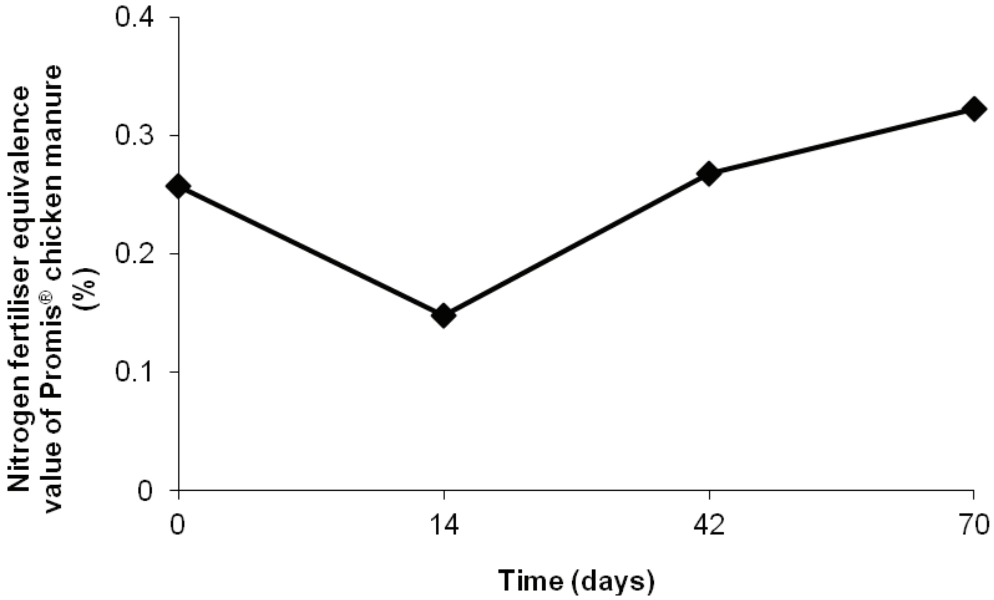

FIGURE 9.4: Nitrogen fertiliser equivalence value of Promis® chicken manure when applied at the rate of 210 kg N ha^{-1}

In the 210 kg N ha^{-1} application rate treatment (Fig. 9.4), the patterns in the results were somewhat different. Firstly, the initial N-fertiliser equivalent value was lower (26%) than the 37% measured in the 30 kg N ha^{-1} application rate treatment. Secondly, the N-fertiliser equivalent value dropped during the first two weeks of incubation, from 26% to 15%, to rise thereafter and reach a value of 44% after 70 days of incubation. The initial decline in the N-fertiliser equivalent value in the 210 kg N ha^{-1} application rate treatment suggests that during the first two weeks of incubation immobilisation of mineral N occurred. Later on, this immobilised N was released, explaining the rise in N-fertiliser equivalent value. Overall, the results indicated that between 40% and 70% of the N contained in poultry manure was initially in mineral and plant available form or was transformed into that form over a period of 70 days of incubation.

Phosphorus fertiliser equivalence values

The effect of duration of incubation on the phosphorus fertiliser equivalence value of Promis® chicken manure is shown in Figure 9.5 for the 12 kg P ha^{-1} application rate treatment and in Figure 9.6 for the 85 kg P ha^{-1} application rate treatment.

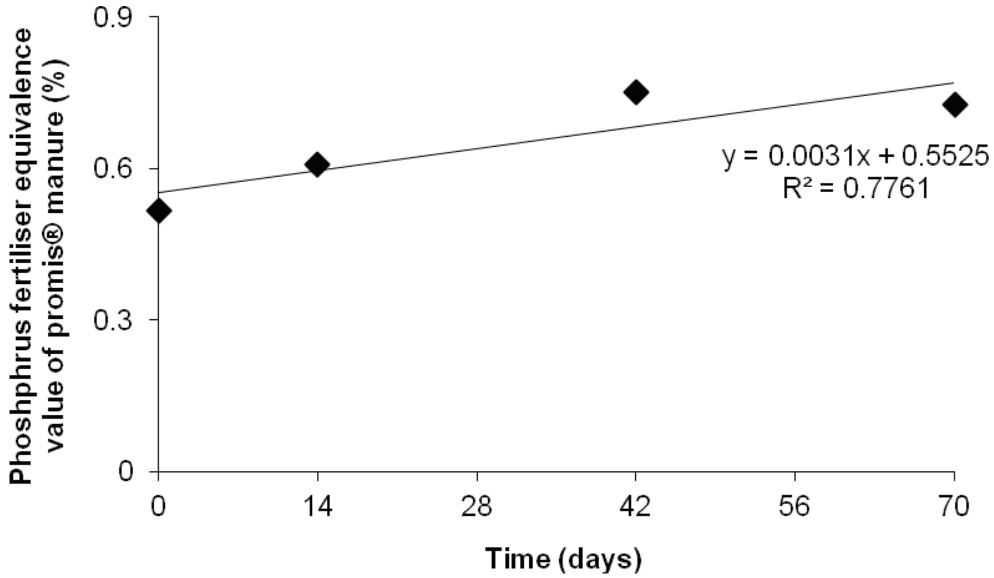

FIGURE 9.5: Phosphorus fertiliser equivalence value of Promis® chicken manure when applied at 12 kg P ha^{-1}

At both the low (Fig 9.5) and the high (Fig 9.6) application rate of Promis® chicken manure, the P-fertiliser equivalence value of the poultry manure increased over time. In the 12 kg P ha^{-1}

application rate treatment (Fig 9.5), the P-fertiliser equivalent value increased from 0.51% upon application (0 days of incubation) to about 70% after 70 days of incubation.

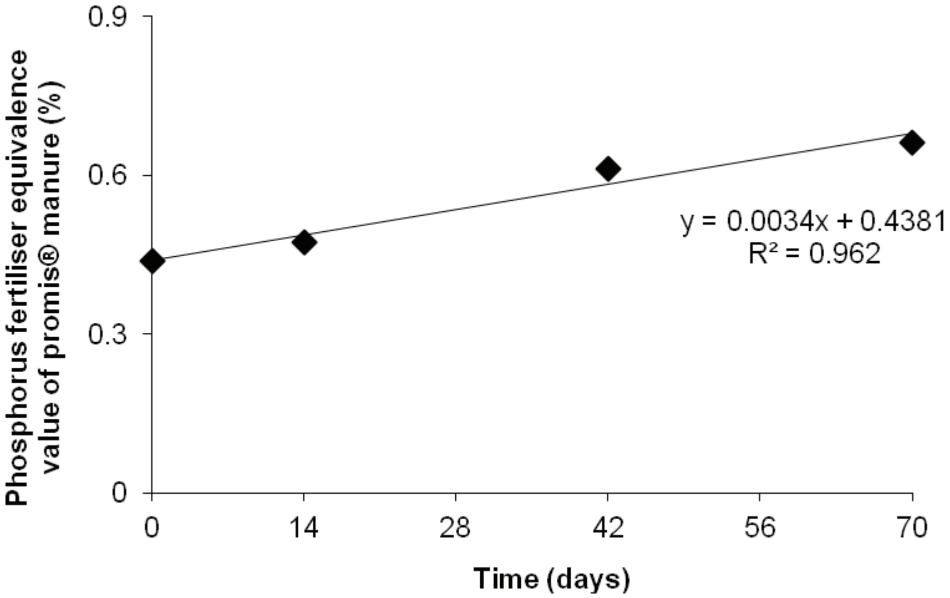

FIGURE 9.6: Phosphorus fertiliser equivalence value of Promis® chicken manure when applied at 85 kg P ha^{-1}

In the 85 kg P ha^{-1} application rate treatment (Fig 9.6), the P-fertiliser equivalent value increased from 43% (day 0) to 65% after 70 days of incubation. Both start and end values were somewhat lower than in the low application rate treatment. Generally, the results indicated that the P-fertiliser value of Promis® was between 40 and 50% at the time of application and between 65% and 70% after 70 days of incubation. This indicates that at time of application, the P contained in the poultry manure was more readily available than the N, but after 70 days of incubation the difference in plant availability between these two nutrients had largely disappeared.

9.4.4.2 Pot experiments

Nitrogen fertiliser equivalence value of Promis® poultry manure

Figure 9.7 shows the effect of application rate on the nitrogen fertiliser equivalence value of Promis® poultry manure using pumpkin and maize as the test crops.

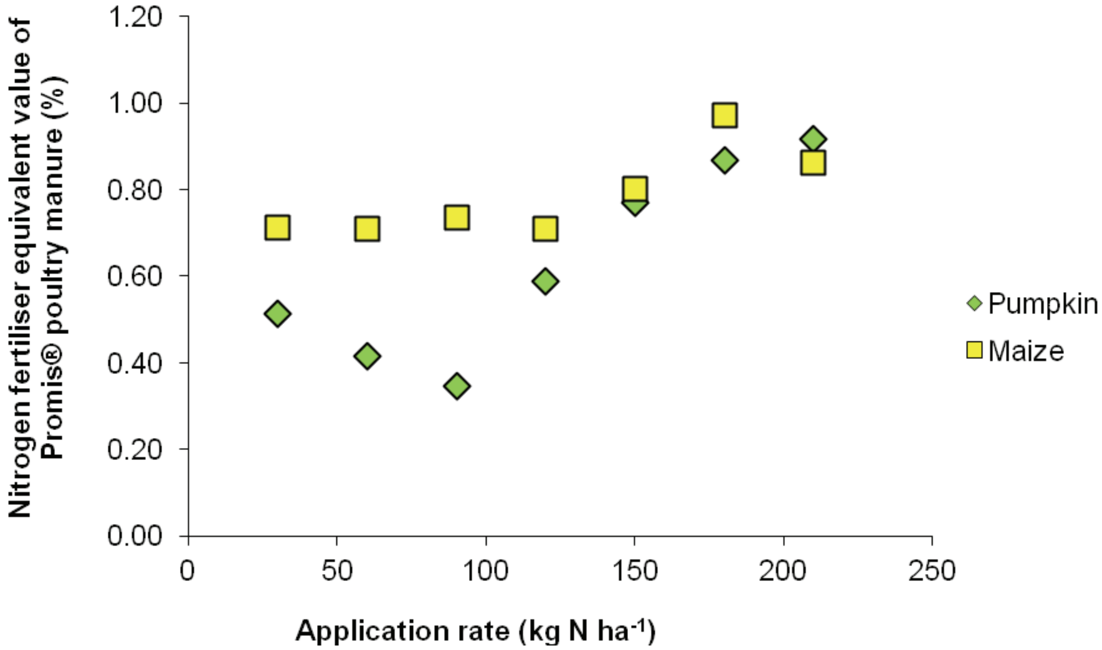

FIGURE 9.7: Effect of application rate on the nitrogen fertiliser equivalence value of Promis® poultry manure

In the case of pumpkin, the nitrogen fertiliser equivalence value of the Promis® poultry manure decreased from 51% to 35% when the rate of application was raised from 30 t ha^{-1} to 90 t ha^{-1} and then increased steadily to 92% as the rate of application was raised to the highest application rate of 210 kg N ha^{-1}. In the case of maize, the nitrogen fertiliser equivalence value of the Promis® poultry manure ranged between 71% and 87%. At application rates below 150 kg N ha^{-1}, the nitrogen fertiliser equivalence value was less than 80%, but it increased to levels above 80% when application rate was raised to 180 kg N ha^{-1} and higher. Across application rates the mean nitrogen fertiliser equivalence value of the Promis® poultry manure was 63% in the case of pumpkin and 79% in the case of maize. Combing the results obtained for the two crops, the average N-fertiliser equivalent value was 71%.

Phosphorus fertiliser equivalence value of Promis® poultry manure

Figure 9.8 shows the effect of application rate on the phosphorus fertiliser equivalence value of Promis® poultry manure using pumpkin, maize and kidney bean as the test crops.

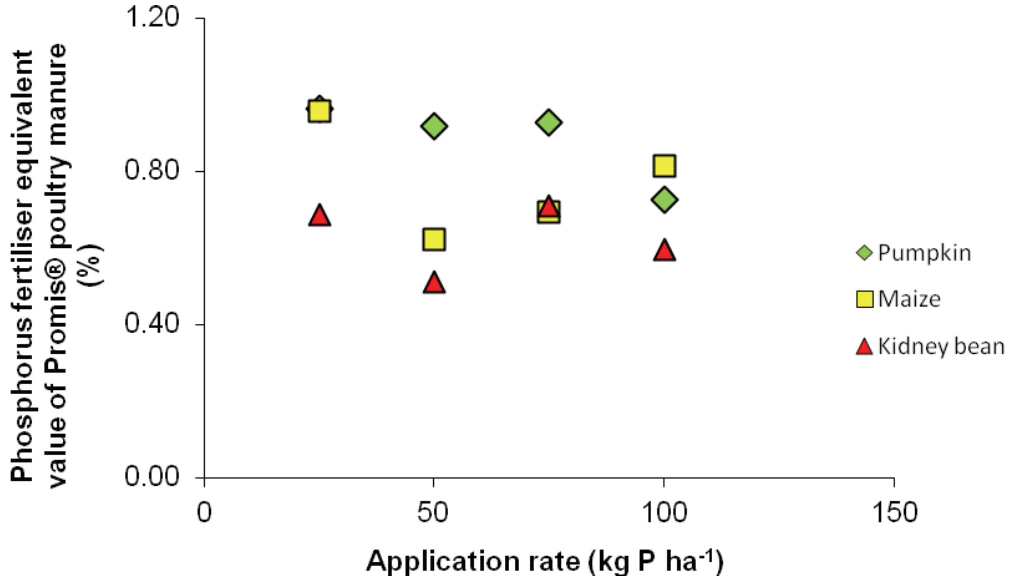

FIGURE 9.8: Effect of application rate on the phosphorus fertiliser equivalence value of Promis® poultry manure

The trend describing the effect of application rate on the phosphorus fertiliser equivalence value of Promis® poultry manure differed among the three crops. In the case of pumpkin, the P-fertiliser equivalent value tended to decline as application rate was raised from a value of 96% at the application rate of 25 kg P ha^{-1} to a value of 73% at the application rate of 100 kg P ha^{-1}. In the case of maize, an initial decline in the P-fertiliser equivalent value was observed from 95% to 62% when the rate of application was raised from 25 kg P ha^{-1} to 50 kg P ha^{-1}. As application rate was raised above 50 kg P ha^{-1}, the P-fertiliser equivalent value of Promis® manure gradually increased, attaining a value of 81% at the highest application rate of 100 kg P ha^{-1}. In the case kidney bean, the P-fertiliser equivalent value of Promis® varied considerably, from a low of 51% at the application rate of 50 kg P ha^{-1}, to a high of 71% at the application rate of 75 kg P ha^{-1}, but there was no evidence of a trend in the relationship between application rate of poultry manure and its P-fertiliser equivalent value. Across application rate treatments, the mean P-fertiliser equivalent value of Promis® manure was 88% for pumpkin, 77% for maize and 63% for dry bean. Combing the results obtained for the three crops, the average P-fertiliser equivalent value was 76%.

9.5 Discussion and conclusion

9.5.1 Legume grains as a source of protein in poultry feed

9.5.1.1 Broiler studies using soya beans

The research and development work that formed part of this study yielded a procedure that enabled on-farm processing of soya beans and maize grain for use in a broiler diet under smallholder circumstances. Boiling raw soya beans for 10 minutes was shown to be optimal from the perspective of adequately denaturing urease and minimising energy use for boiling.

A key that enables sensory assessment of the moisture content of cooked soya beans during drying was developed for use by smallholders to identify the drying stage at which the beans were sufficiently dry for safe storage without diagnostic equipment. Using on-farm processed yellow maize grain and soya beans as the primary ingredients and selected additives to address deficiencies in important nutrients; a single-phase broiler diet was formulated to more or less meet the nutritional requirements of rapidly growing broilers.

Broilers fed on the simple single-phase on-farm diet (experimental diet) did not perform as well as broilers on the control. They demonstrated lower rates of feed intake and body weight gain, particularly during the first five weeks of growth, and feed conversion ratio was also lower. As a result, broilers on the experimental diet took about seven to eight days longer to reach the target live weight of 2300 g and required about 8 to 10% more feed to do so. Below-optimum protein content of the experimental diet during the starter and grower phases of broiler growth, and the presentation of the experimental diet in mash form throughout the growing period instead of in crumble form during the starter phase and pelleted form during the grower and finisher phases, were identified as the likely causes for the sub-optimal biological performance of broilers on the experimental diet. Poor digestibility of the protein contained in the experimental diet was identified as a possible third limiting factor.

Diet had no material effect on the quantity of manure produced by broilers during the growing period needed by the day-old broilers to reach the target live weight of 2300 g. Diet also had no material effect on the phosphorus content of the broiler manure obtained from both treatment groups, but did affect the nitrogen and potassium content of the broiler manure. Broilers on the experimental diet produced manure that contained 0.7% more nitrogen and 0.4% less potassium than broilers on the control diet. Since nitrogen is usually more of a limiting factor than potassium in soils used by South African smallholders for the production of crops, the manure produced by broilers on the experimental diet could be considered to be of better quality for use as fertiliser than the manure produced by broilers on the commercial control diet. The relatively higher nitrogen content of the manure produced by broilers on the experimental diet, which had lower protein content than the control diet, was identified as further evidence that broilers probably experienced difficulties in digesting the protein contained in the experimental diet, particularly during the early stages of growth.

Financial analysis showed that total operating expenses of broiler enterprises using the experimental diet were higher than that of similar enterprises using the control diet, but differences in net operating income were only significant in one of the two runs of the experiment. The main economic benefit of using the experimental diet was the added value to the local economy. The current study showed that using the on-farm feed (experimental diet) the contribution of broiler production to the local economy increased from about 26% of the monetary value of a broiler in the case of enterprises using commercial feed (control diet) to about 74%. Moreover, relative to the commercial diet, use of the on-farm diet was expected to become increasingly advantageous with degree of remoteness, because of the rising cost of transporting purchased feed.

The broiler experiment aimed at improving the simple experimental broiler diet showed that the biological performance of broilers on the on-farm multiphase diet (OFM), which was formulated to meet the higher protein requirement of broilers during the starter and grower phases and included the addition of soya bean oil cake, was found to be substantially better than the performance of broilers on the simple on-farm diet that was tested first. However, an error in the particle size reduction precluded the reaching of definitive conclusions. It is, therefore, recommended that the experiment in which potential improvements to the simple on-farm diet that was formulated and tested during the first phase of the study be repeated.

In conclusion, the results of the study showed that the biological performance of broilers provided with diets that contained legume grains that were processed on-farm was sub-optimal compared to that of broilers on a commercial multi-phase diet. Indications were that the simple, single-phase on-farm broiler diet that was tested first could be improved but the experiment in which this proposition was tested failed due to an error in the particle size reduction of the grain. Apart from this error, which affected all on-farm diet treatments, the multiphase diet (OFM), which was formulated to meet the higher protein requirement of broilers during the starter and grower phases and which included the addition of soya bean oil cake, appeared superior to the simple, single-phase on-farm broiler diet that was tested first, which was encouraging and supported the idea that the simple, single-phase on-farm broiler diet could be improved.

The income statements of the broiler enterprises in which the commercial control diet was used shows that the retail mark-up amounted to about 26% of the retail price of a broiler. This represented the monetary contribution of broiler production to the local economy. The other 74% was lost to the local economy, because it was used to pay for goods (chicks, feed, inoculants, gas and electricity) that were produced outside the local economy. When on-farm feed (experimental diet) was used, this contribution was raised to about 74% of the retail price of a broiler, nearly three times as large as the contribution of broiler enterprises that used commercial feed.

At this stage, the technology that has been developed is thought to be suitable for application on farm units that are managed privately and have the land and infrastructure needed to integrate crop and broiler production. Even when the technology can only be applied partially, for example by producing just the maize grain on-farm and purchasing soya bean grain or oil cake to prepare the on-farm broiler diet, considerable increases in farm income can be realised, as a result of improved farming systems integration. In addition, relative to commercial feed, use of on-farm feed is expected to become progressively advantageous economically as degree of remoteness of the farm increases, because of the rising cost of transporting purchased feed.

Application of the technology in the context of canal irrigation schemes, where privately managed enterprises are expected to produce the grain for transformation into broiler feed is also a viable option, when the broiler enterprise serves the farmers' collective. In such cases, the benefit derived from the integrated system which provides farmers with a ready market and a fair price for the grain they produced is sufficient justification to accept a reduction in net operating income of the broiler enterprise brought about by using the on-farm feed instead of commercial feed, as long as the broiler enterprise remains financially viable.

Application of the technology in an open economy, where broiler enterprises would elect to purchase local grains and transform these grains into broiler feed, because it makes financial sense, is not yet expected to occur. The results obtained in this study showed that using the on-farm option reduced net operating income of broiler enterprises. Therefore, the challenge is to improve the on-farm diet to such an extent that net operating income of broiler enterprises using the on-farm diet would be higher than those of enterprises using commercial diets.

To improve the biological performance of broilers on diets that use on-farm processed soya beans and yellow maize grain as principal ingredients and to reduce feed cost to the level where the net operating income of broiler enterprises using this type of diet matches that of similar enterprises that make use of commercial feed, testing of three proposed interventions is recommended. These interventions are:

- Increasing the soya bean content combined with replacing part of the full fat soya with soya bean oilcake so as to increase the protein content of the experimental on-farm broiler diet for use during the starter and grower phases.
- Wet feeding the experimental broiler diet, especially during the early phases of growth of the broilers, in order to address the problems arising from the mash presentation of the experimental diet.
- Supplementation of the experimental diet with enzymes during the early stages of growth so as to address problems arising from apparent poor digestibility of the proteins contained in diets that use on-farm processed soya beans and yellow maize grain as principal ingredients.

9.5.1.2 Layer studies using cowpeas

Cowpeas were shown to be a useful source or protein for inclusion in layer diets. For broiler production the low protein content of cowpeas would necessitate the inclusion of soya beans to ensure rapid growth but in the formulation of layer diets cowpeas can be used without adding soya beans. Statistically, the study failed to identify the optimum boiling time for anti-nutritional factor reduction in cowpeas but numerically boiling for 30 minutes appeared to be optimal. The study showed that germinating cowpeas over a period of four days at room temperature was at least as effective in reducing anti-nutritional factors as boiling for 30 minutes because in a broiler growth assay, broiler chicks on a diet that contained germinated cowpeas grew more rapidly than chicks on a diet that contained the same proportion of boiled cowpeas. Feed intake results in the layer experiment indicated that using cowpeas as the single protein source in a simple layer diet could not be recommended at this stage. However, from a local economic development perspective, the use of locally produced cowpeas for inclusion in layer diets was highly advantageous because it went a long way in plugging the backward linkage leak that arose from purchasing layer feed commercially. This important advantage warrant further investigation aimed at improving feed intake of layers on diets based on processed cowpeas.

In conclusion, that study showed that cowpeas can be used as the source of protein for inclusion in layer diets. Boiling cowpeas for 30 minutes and germinating cowpeas over a period of four days at room temperature were identified as effective methods to reduce the anti-nutritional factors they contained. Feed intake results in the layer experiment indicated that using cowpeas as the single protein source in a simple layer diet could not be recommended at this stage. However, from a local economic development perspective, the use of locally produced cowpeas for inclusion in layer diets was highly advantageous because it went a long way in plugging the backward linkage leak that arose from purchasing layer feed commercially.

To improve the egg production performance of layer hens fed on diets containing treated cowpeas as a protein source to the level where the net operating income of broiler enterprises using this type of diet matches that of similar enterprises that make use of commercial feed, testing of two proposed interventions is recommended. These interventions are:

- To provide the pullets with a transition diet consisting of a combination of the on-farm and the commercial diet during the run-in period, to give the pullets adequate time to adjust from commercial diet to on-farm diet and maintain adequate feed intake.

To delay onset of egg production to allow the layer hens to adapt to the on-farm diet which in turn will improve the physiological condition and body fats so that pullets will be able to withstand the nutritional stress associated with egg production.

9.5.2 Yield potential of selected grain legumes in Vhembe

The research work aimed at incorporating grain legumes in the cropping systems of smallholders on canal schemes in the Vhembe District did not produce the results that were hoped for. Soya beans, the preferred choice of crop, because of its high protein content, performed poorly compared to elsewhere in South Africa. High temperatures and high humidity appeared to be the reason why the crop that was planted during the expected optimum planting period (September to December) performed poorly. Grain of good quality and reasonable grain yields were obtained only when the crop was planted in February, which caused grain filling to occur during the dry autumn and early winter months. However, the average grain of less than 2 t ha^{-1} does not warrant the production of the crop under irrigated conditions. Cowpeas and pigeon peas were tried out as alternatives to soya beans. Both crops appeared very well adapted to conditions at Dzindi but the grain yields that were obtained (<1 t ha^{-1}) were too low to consider the introduction of either of these two grain legumes as a cash crop for smallholder irrigators. The very low grain yield obtained from pigeon peas was partly due to bird damage.

9.5.3 Poultry manure as a fertiliser

9.5.3.1 Effect of application rate on biomass production of selected African leafy vegetables grown in pots and in the field

The results of the greenhouse pot experiments indicated that application of Promis® poultry manure had a positive effect on biomass production of all of the four African leafy vegetables that were tested when applied at rates that did not exceed 12 t ha^{-1}. When Promis® was applied at rates that were too high, it had a negative effect on plant growth. The application rate at which this negative effect became evident differed among the four crops. Pumpkin was most sensitive too heavy applications of Promis®. Evidence of a negative effect of Promis application became evident as soon as the application rate exceeded 12 t ha^{-1}. Nightshade was the least sensitive as the negative effect of applying Promis only became evident when the application rate exceeded 24 t ha^{-1}. The cause of the negative effect of heavy applications of Promis on plant growth was not identified but indications were that factors other than salinity were responsible. The results obtained in the field experiment in which nightshade was used as the test crop supported the findings in the greenhouse experiments Biomass production of nightshade increased with application rate of Promis® up to the highest rate of 20 t ha^{-1} used.

9.5.3.2 Fertiliser value of poultry manure

The results obtained in the incubation studies indicated that between 40% and 70% of the N contained in poultry manure was initially in mineral and plant available form or was transformed into that form over a period of 70 days of incubation. With reference to phosphorus, the results indicated that the P-fertiliser value of Promis® was between 40 and 50% at the time of application and between 65% and 70% after 70 days of incubation. This indicates that at time of application, the P contained in the poultry manure was more readily available than the N, but after 70 days of incubation the difference in plant availability between these two nutrients had largely disappeared.

The results obtained in the pot experiments, in which maize and pumpkin were the test crops, indicated that on average, the nitrogen fertiliser equivalence value of the Promis® poultry manure ranged between 63% and 79% in the case of maize and the average N-fertiliser equivalent value across application rate treatments was 71%, which compares very well with the results obtained in the incubation experiments. The mean P-fertiliser equivalent value of Promis® manure was 88% for pumpkin, 77% for maize and 63% for dry bean. Combining the results obtained for the three crops, the average P-fertiliser equivalent value was 76%, a value that was also quite similar to the value recorded in the incubation experiment. The variability in the N-fertiliser value and the P-fertiliser value of Promis® observed in both the incubation experiments and the pot experiments challenges the general assumption that these values are constant. Considerably more work is needed before hypotheses that explain the findings of this study can be formulated.

In conclusion, the objective of this part of the research was to determine the value of poultry manure for use as a fertiliser in crop production. The results of incubation studies, greenhouse pot experiments with a range of different crops, and finally a field experiment, all confirmed that poultry manure is a valuable fertilizer material. It contains important plant nutrients, particularly N and P, in concentrations that are higher than in many other types of animal manure. The results show that the plant availability of nitrogen and phosphorus contained in poultry manure immediately or shortly after application tends to be high and increases over time. From a practical perspective, the study indicated that applying poultry manure at rates exceeding 12 t ha^{-1} is not recommended, because of possible negative effects associated with high application rates of poultry manure in certain crops, such as pumpkins. Other crops, particularly nightshade, were shown to respond positively to application rate of poultry manure up to rates of 20 t ha^{-1} under both greenhouse and field conditions, but these high rates should not be used in practice. Instead, poultry manure could be applied once at rates of 10 to 12 t ha^{-1} to bring the nutrient status of depleted soils to appropriate levels, where after the application rate should be adjusted to the nutrient requirements of the subsequent crop. The average fertilizer values of

Promis® referred to earlier could be used as an initial approximation to calculate the appropriate application rate of poultry manure to meet the nutrient requirements of specific crops.

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CHAPTER 10

10 Improving smallholder canal Irrigation in Vhembe: Conclusions

Wim Van Averbeke

The general aim of the research presented in this report was to make a contribution to rural development. The focus was on identifying ways in which the livelihoods of plot holders on canal schemes in Vhembe District could be improved, as well as overall productivity of these schemes. Whilst the main thrust of the work was aimed at testing a number of farming system innovations to improve use of water, land, labour and other resources on smallholder irrigation schemes, attention was also given to social resource constraints, particularly institutional and organisational.

To set the scene for the project, a survey of all registered smallholder irrigation schemes in the Vhembe District was conducted. The results of this survey confirmed the continued relevance of canal irrigation and showed that gravity-fed canal schemes were more likely to be operational and to last longer than pumped schemes. This finding questions the desirability of converting canal schemes into pumped schemes, as has been the norm in the RESIS Recharge Programme of the Limpopo Department of Agriculture. Rehabilitating existing canal systems would most probably more sustainable. Cropping intensity on smallholder schemes in the District was well below the optimum values of 1.5 to 2.5 that could be achieved in the area. Water restrictions were a significant factor in determining cropping intensity. Degree of commercialisation was associated with the location of schemes in relation to local urban centres. In the absence of external interventions, commercialisation among farmers on smallholder schemes was more likely to occur when schemes were located close to urban centres, because proximity made it financially viable for street traders to travel between scheme, as the place of purchase, and town, as the place of retail, using public transport. This is important when the development of new schemes is being considered. For remote schemes, external intervention aimed at supporting market access appears to be necessary to enhance commercialisation. At this stage, few of the farmer-managed schemes received marketing support from external agencies. Efforts to that effect are recommended and should be facilitated by public extension services in collaboration with the private sector. Many smallholder irrigation schemes in Vhembe had a dedicated public extension officer, but few had made any contribution towards improving produce marketing on their schemes.

Smallholder irrigation occurs within an overall institutional framework and depends on effective functioning of organisations to ensure that rules and regulations are adhered to. Institutional uncertainty and organisational weaknesses have a negative effect on the sustainability of smallholder irrigation. Whilst it can be regarded as positive that plot holders manage their own affairs, being part of an irrigation scheme comes with obligations, which relate to the essence of being a member of a scheme, and that is shared responsibility of the water distribution infrastructure. Chapter 3 presents detailed evidence of a rapidly decaying water distribution system at Dzindi, which is at least partially due to neglect on the part plot holders, who have allowed the collective organisation that was responsible for routine maintenance of the system to collapse. Inadequate routine maintenance and loss of water due to leaks caused by the poor state of the concrete canals, furrows, regulating devices and the night-storage dam that supplies the last irrigation block, are directly responsible for the worsening problem of water shortage at Dzindi Irrigation Scheme during recent times. As elsewhere on canal schemes, water shortages are felt first by tail-enders, and some plots at the end of the canal no longer receive water. A similar phenomenon, but on a much larger scale was observed at Tshiombo Irrigation Scheme, where an entire irrigation block no longer received water from the canal. For this reason, establishment of an effective routine maintenance system was identified as a critical condition for the sustainability of Dzindi, and other canal schemes for that matter.

Trust tenure has long been regarded as the most insecure of tenure systems that applied to land held by black people in South Africa. The particular Trust tenure system that applied to irrigation schemes located in the Bantu Areas, as elaborated in Proclamation No. R5 of 1963, was no exception. It provided the state with the power to cancel the user rights of plot holders who failed to comply with the many terms and conditions for occupation of an irrigation allotment. Evidence from Dzindi shows that up until about 1970, the state effectively used its power to evict plot holders for reasons of non-compliance. There were also elements in the system that provided a high degree of security. One of these was the detailed specification of exclusion rights, which served to protect occupants of irrigation schemes from ‘outside’ interference. Compliance with the terms and conditions for occupation of irrigation allotments was relaxed during the homeland era and this removed the threat of eviction for non-compliance. Following the unification of South Africa during the run-up to the first democratic elections of 1994, the Limpopo Department of Agriculture was mandated to represent the state on the smallholder irrigation schemes located within the province. Soon after, this Department adopted a policy of Irrigation Management Transfer (IMT), which provided for the plot holder communities on smallholder irrigation schemes to assume responsibility for the management of their schemes. The empirical work presented in Chapter 4 identifies an important weakness in the way in which IMT has been implemented, namely the lack of a legal framework that enables plot holder communities to assert their rights. The absence of such a framework has left these communities vulnerable to outside interference and has rendered their tenure rights more insecure than before. Their land is being taken away to accommodate demand for residential land. For this reason the tenure status of 'registered irrigation schemes' in Limpopo Province is identified as a priority issue for government attention. If land rights in irrigation schemes are not protected, the recommendation to develop schemes in proximity to urban centres to provide access to markets, which encourages commercialisation and tends to enhance scheme productivity, is no longer valid. Furthermore, inadequacies in security offered by the prevailing land exchange system, or at least the perception of such shortages, among land holders and people seeking to lease were identified as the one of the reasons why the land exchange market on canal schemes is imperfect. The development of improved scheme-based land administration institutions and systems could enable plot holders to use their land more flexibly, including renting it to others, and protect the land rights of both the plot holders and the people who obtain permission to make use of land that belongs to others by removing most of the uncertainties surrounding land rights and lease contracts.

The work presented in Chapters 5 and 6 explored the potential of using animal draught as an alternative to tractors as a source of draught power in land cultivation. The findings were that animal draught enterprises tended to achieve better field efficiency and turning times than tractors on canal schemes. Tractor enterprises had higher work rates, field capacity, speed, ploughing width and ploughing depth than animal draught enterprises. Replacement of tractor enterprises by animal draught enterprises would depend on the establishment of four to nine animal draught enterprises for every tractor enterprise, to compensate for the lower field capacity and work rates of animal draught enterprises. Consequently, besides reducing the carbon footprint of farming, replacement of tractor enterprises by animal draught enterprises would also have a positive effect on rural employment. For this reason, new implements were provided to a selection of animal draught enterprises to enable them to plough, disk and ridge land as required by plot holders. It was postulated that exposure to improved service provision by animal draught enterprises would result in positive perceptions of animal draught among plot holders. Generally, this was not the case. On the contrary, the change in perception tended towards the negative instead of the positive. However, increased scepticism among plot holders about animal draught enterprises presenting a suitable alternative to tractor enterprises was not extreme and there were a minority of plot holders who developed more positive perceptions of animal draught enterprises following exposure. It was concluded that there is a market for the land preparation services provided by animal draught enterprises but this market is limited and considerably smaller than the market for tractor enterprises. Feedback from plot holders indicated that the main advantage of using animal draught was a reduction in the cost of preparing land. This advantage is expected to gain in significance as the cost of diesel rises.

Quality concerns raised by plot holders about the service of animal draught enterprises were real, indicating the urgent need to improve the technical capabilities of animal draught enterprises through research and development. Inadequacies in the technical skills of some operators, which have a negative effect on the quality of the different land preparation operations; and inadequacies in the management skills of some owners of animal draught enterprises, which affect the reliability of the service, also need attention. Skills could be improved through training. The unavailability of animal draught enterprises during winter, apparently the result of the poor condition of the animals, suggests that working animals are being treated in the same way as other livestock in the smallholder areas of South Africa, and are largely left to fend for themselves to satisfy their nutritional needs. Education and training of enterprise owners should assist in solving this problem as well.

Chapters 7, 8 and 9 focused on issues of production, with chapter 7 dealing with irrigation scheduling of both leafy vegetables and (green) maize. The findings for maize were that the once-per-week irrigation schedule practised by farmers is best practice, especially on schemes where the availability of irrigation water is limited. The farmers' approach to irrigation scheduling of (green) maize used less water and gave the highest irrigation water use efficiency of all the methods that were tested. In the case of leafy vegetables, this was not the case. For optimum growth and leaf yield, leafy vegetables, which were represented by non-heading Chinese cabbage in the field experiments, the soil water content in the upper part of the profile had to be maintained at or close to field capacity. This required the crop to be irrigated at least twice per week, which is more often than farmers have access to irrigation water. On canal schemes where the water flows continuously and is not diverted in night storage dams, farmers could increase irrigation frequency from once to twice or thrice per week by irrigating at night.

Green maize is one of the most important cash crops on canal schemes in Vhembe. For this reason, considerable research attention was given to the development of best practices for use by local irrigation farmers. The findings of this work are presented in Chapter 8. The cultivar SC 701 was shown to be superior but it was also the most expensive seed. The optimum planting density for green maize production using SC 701 ranged from 2.9 plants m^{-2} in June to 4.2 plants m^{-2} in September, but a relatively sparse stand of 2.22 plants m^{-2} was recommended for use by farmers, irrespective of the planting date. Maize streak virus (MSV) was a major constraint to year-round production of green maize in Vhembe. The incidence of MSV depended on date of planting. For the cultivar SC701, maize streak disease (MSD) incidences in excess of 80% were recorded in the March and April plantings. Use of the MSV-resistant cultivar PAN 67 reduced MSD incidence significantly, as did treatment of the seed with Gaucho® before planting, but Gaucho® treatment was of minor benefit only. Use of the MSV-resistant cultivar PAN 67 by farmers at Dzindi is recommended when green maize is planted from January to April, when the risk of MSD highest. For all other planting dates the use of SC 701 is probably the best option, because this cultivar tends to produce larger cobs than PAN 67. Intercropping relatively sparse green maize stands (2.22 plants m^{-2}) with pumpkins (0.55 plants m^{-2}) had no negative effect on the performance indicators of green maize and did not increase consumptive water use relative to that of sole maize at the same planting density. However, intercropping green maize with pumpkin provided the benefit of a second crop raising gross enterprise income in green maize production. Planting green maize and pumpkin at the same time provided the greatest benefit and for this reason it is recommended practice.

In Chapter 9 the opportunity of integrating crop and livestock production on canal schemes in Vhembe was explored, using the production of maize and grain legumes as crops and the production of poultry as livestock. For that purpose technology was developed to process grain on-farm for the purpose of formulating poultry diets. It was found that the biological performance of broilers provided with diets that contained legume grains that were processed on-farm was sub-optimal compared to that of broilers on a commercial multi-phase diet. Use of the on-farm feed also reduced net operating income of broiler enterprises. Indications were that the simple, single-phase on-farm broiler diet that was tested first could be improved. The challenge is to improve the on-farm diet to such an extent that net operating income of broiler enterprises using the on-farm diet would be higher than those of enterprises using commercial diets. Three possible ways of improving the on-farm diet were identified.

Research also showed that cowpeas can be used as the source of protein for inclusion in layer diets. Boiling cowpeas for 30 minutes and germinating cowpeas over a period of four days at room temperature were identified as effective methods to reduce the anti-nutritional factors they contained. However, using cowpeas as the single protein source in a simple layer diet could not be recommended at this stage. Recommendations were made for additional research.

Soya beans, the preferred choice of crop, because of its high protein content, performed poorly compared to elsewhere in South Africa. High temperatures and high humidity appeared to be the reason why the crop that was planted during the expected optimum planting period (September to December) performed poorly. Grain of good quality and reasonable grain yields were obtained only when the crop was planted in February, which caused grain filling to occur during the dry autumn and early winter months. However, the average grain of less than 2 t ha^{-1} did not warrant the production of the crop under irrigated conditions. Cowpeas and pigeon peas were tried out as alternatives to soya beans. Both crops appeared very well adapted to conditions at Dzindi but the grain yields that were obtained (<1 t ha^{-1}) were too low to consider the introduction of either of these two grain legumes as a cash crop for smallholder irrigators. The very low grain yield obtained from pigeon peas was partly due to bird damage.

Various experiments aimed at determining the value of poultry manure for use as a fertiliser in crop production showed that poultry manure contained important plant nutrients, particularly N and P, in concentrations that were higher than in many other types of animal manure. Plant availability of nitrogen and phosphorus immediately or shortly after application tended to be high and increased over time. From a practical perspective, the study indicated that applying poultry manure at rates exceeding 12 t ha^{-1} could not recommended, because of possible negative effects associated with high application rates of poultry manure in certain crops, such as pumpkins. Other crops, particularly nightshade, were shown to respond positively to application rate of poultry manure up to rates of 20 t ha^{-1} under both greenhouse and field conditions, but these high rates should not be used in practice. Instead, poultry manure could be applied once at rates of 10 to 12 t ha^{-1} to bring the nutrient status of depleted soils to appropriate levels, where after the application rate should be adjusted to the nutrient requirements of the crops being grown. Fertilizer values of poultry manure were determined and these could be used as an initial approximation to calculate the appropriate application rate of poultry manure to meet the nutrient requirements of specific crops.

CHAPTER 11

11 Improving smallholder canal Irrigation in Vhembe: Policy recommendations

Wim Van Averbeke

Several policy recommendations were derived from the findings presented in this report. These recommendations have been structured in line with the mandates of specific departments within the South African government.

11.1 Planning

Recommendation 11.1.1: It is recommended that when planning and designing new smallholder irrigation schemes, the gravity-fed canal irrigation option be considered first before looking at pumped schemes. Compared to pumped schemes, canal schemes are more durable, cost much less to operate, are not affected by the cost of energy, and are easier to maintain. When used effectively, canal schemes can achieve water use efficiencies that are comparable with pumped systems.

Recommendation 11.1.2: It is recommended that proportional flow division devices be part of both the design of new canal schemes and the refurbishment of existing canal schemes. Preferably these devices should be closed off to avoid tampering. Proportional flow division devices can eliminate or at least reduce the front-end tail-end differences in access to irrigation water commonly encountered on existing canal schemes.

Recommendation 11.1.3: It is recommended that planning of new irrigation schemes avoids projects larger than 100 farm units. Plot holder populations greater than about 100 make effective collective organisation difficult. Dysfunctional collective organisations are unable to maintain social order and stability and this has negative effects on scheme operation and maintenance.

Recommendation 11.1.3: It is recommended that where possible, new smallholder irrigation schemes be located within a radius of about 15 km from an urban centre, because this favours the spontaneous development of local fresh-produce value chains involving street traders, which enhances the local economic development impact of smallholder irrigation schemes.

11.2 Land and water

Recommendation 11.2.1: It is recommended that the land tenure and land administration systems on existing irrigation schemes be revisited as a matter of priority. The current systems are ambiguous from both the legislative and the administrative perspective.

Recommendation 11.2.2: In line with current legislation, it is recommended that the separation of land rights and water rights is implemented effectively on both existing and new schemes.

Recommendation 11.2.3: On existing smallholder schemes, it is recommended that communities are encouraged to form a communal property association and apply for freehold title to both irrigation land and the commonage attached to the irrigation scheme. Scheme communities who elect to pursue the communal property association option should be assisted with the legal processes of drawing up an appropriate constitution and obtaining title deed to their land. Freehold title is recommended, because it offers superior protection against land grabs, which appear particularly likely when scheme land is located in the periphery of expanding urban centres (see Recommendation 11.1.3). Freehold also enables irrigation communities to enter into negotiations with other agencies concerning the sale of land, such as parts of the commonage, and create revenue in this way. Crafting of the constitution must give attention to institutions and administrative systems that govern land exchange arrangements (renting in and renting out of land) on the scheme and the selling of plots. Subdivision of irrigation allotments should not be allowed.

Recommendation 11.2.4: On new irrigation schemes it is recommended that a leasehold land tenure system be implemented during the start-up period. During this interim period, which should last about 10 years, and which should be characterised by intensive training, the state remains the owner of the land. Self-elimination should be the principle governing exit of plot holders from the scheme. Transition from leasehold to freehold should be introduced once the plot holder population has stabilised. Uninterrupted payment of the land lease over a period of 10 years could be used as the criterion for transferring plot ownership to a leaseholder.

Recommendation 11.2.5: It is recommended that Water User Associations operating in areas that incorporate smallholder irrigation schemes, become actively involved in the management of water on these projects. Thus far, these Associations have not been effective. In the case of canal schemes, Water User Associations should be given the authority and means to monitor operation and maintenance of the water distribution infrastructure. Payment for water should form part of this arrangement, but organs of the state could consider partial subsidisation. Part of the water payments should be in the form of a contribution to the maintenance of the water distribution system. Routine maintenance is necessary for optimum functioning of the water distribution system. Sub-optimal functioning of this system reduces discharge and leads to land being withdrawn from irrigation.

11.3 Agriculture

Recommendation 11.3.1: It is recommended that an expert smallholder irrigation advisory service system be established in Districts with significant numbers of smallholder irrigation schemes, such as Vhembe. Besides general expertise in irrigation systems and practice, and in the agronomy of locally produced crops, including their water requirements, this advisory system should meaningfully assist smallholder irrigators with advice on marketing. The results of this study showed that the public extension system in Vhembe offered very little advice on crop choice and associated marketing strategies. Sustainable commercialisation of smallholder irrigation is dependent on such advice being available.

Recommendation 11.3.2: It is recommended that when the establishment of expert smallholder irrigation advisory service systems are contemplated, tertiary education institutions be called upon to design and present the training programme. Engagement of a consortium of tertiary institutions would probably be advisable, because this would enhance access to the different fields of expertise required.

Recommendation 11.3.3: It is recommended that the Departments of Agriculture at District level become involved in the conduct of applied research that responds to practical problems and opportunities emanating from the changing circumstances in local irrigated agriculture.

Among others, such research should include the conduct of cultivar trials, planting date experiments, irrigation experiments, plant protection experiments and trials in which mixed cropping and rotational arrangements are tried out.

11.4 Economic development

Recommendation 11.4.1: It is recommended that Local Municipalities provide opportunities to smallholder irrigator communities for the marketing of produce by assisting these communities to apply for procurement tenders to supply public entities, such as schools and hospitals, with produce.

11.5 Public works

Recommendation 11.5.1: It is recommended that revitalisation of canal schemes (special and deferred maintenance) be incorporated in the infrastructural development programmes of local municipalities, districts and provinces. Canal revitalisation projects are relatively simple and they offer excellent opportunities for local employment. The expected benefits of investing in canal scheme revitalisation are improved water use efficiency and enhanced agricultural production.

11.6 Science and technology

Recommendation 11.6.1: Considering the call for a green(er) economy, and the persistently rising cost of fossil fuel, it is recommended that research and development funding be channelled towards the development of improved implements for use with animal draught. These implements should be able to satisfy the cultivation requirements of farmers on irrigation schemes. The overall aim should be to create room for animal draught enterprises to replace some or all of the existing small-scale tractor enterprises. In addition to improving implements, the introduction of specialised draught animals, such as mules deserves consideration. Guidelines and training for the management of new types of working animals, such as mules, will need to be developed for local conditions.