LOW RATES OF NITROGEN AND PHOSPHORUS AS FERTILIZER OPTIONS FOR MAIZE (*Zea Mays L.*) IN DRIER REGIONS

BY

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DECLARATION

I declare that the full dissertation hereby submitted to the University of Limpopo for Degree of Master of Agricultural Management (Agronomy) has not been previously been submitted by me for a degree at this or any other University; that it is my own work in design and in execution, and that all material contained herein has been duly acknowledged.

M.C. KGONYANE (MR) 05 AUGUST 2010

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ABSTRACT

On-farm rain-fed experiments to investigate low rates of nitrogen and phosphorus fertilizer options for maize (*Zea mays L*.) production were conducted in drier regions of Limpopo province in the 2006/07 and 2007/08 rainy seasons at eight localities. These sites have a varying rainfall gradient which is helpful in assessing fertilizer responses and evaluating APSIM capabilities. Most of the soils were sandy, typical of Limpopo communal areas. The experiments were laid out as a 4 x 4 factorial arrangement in a randomized complete block design (RCBD) with three replications at each location**.** The experiments evaluated four levels of nitrogen (0, 14, 28 and 56 kg ha^{-1}) and four levels of phosphorus (0, 5, 10 and 20 kg ha^{-1})

There were no grain and total biomass yield (TBM) response to phosphorus application rates despite the low soil P tests across all sites and seasons. There was also no interaction between nitrogen and phosphorus on grain and total biomass yield for both seasons at all sites. Grain yield was affected by the rates of nitrogen application. These effects were statistically significant ($P < 0.05$) for Bokgaga, Perskebult and Mothiba. However, there was no significant difference in grain yield between treatments at Mafarana. There were significant differences of total biomass yield to nitrogen application rates over the four sites. The N application level did not significantly ($P<0.05$) influence the TBM yield at Mafarana. The most responsive site on maize grain yield to N inputs was Perskebult (1330 kg ha^{-1}) followed by Bokgaga (1068 kg ha^{-1}). Similar to grain yield, the TBM yield increased with an increase in N applications, irrespective of the site. The general high yields at Mafarana can be attributable to higher temperature, soil organic carbon and rainfall effects. The high level of N (56 kg N ha^{-1}) at Perskebult out yielded the preceding N level (28 kg N ha^{-1}) by 63 %. One explanation is split application of high N rate interacting with rainfall distribution.

APSIM has shown some capabilities in simulating maize to response N application rates. Simulation of maize yields was generally good over the four sites that were simulated; r^2 values were 0.758 and 0.865 for grain and total biomass yields, respectively. The results of this study show that APSIM maize model is able to predict the observed crop yields and give a long term impact of the N fertilizer application rates on maize yield

Recommended fertilizer rate (56 kg N ha^{-1}) gave highest value cost ratio (VCR) at Bokgaga only, while low rate (14 kg N ha^{-1}) resulted in the highest VCR at other three sites. The highest VCR of 2.36:1 was obtained on the low rate at Mothiba, while the lowest VCR of 0.52:1 was obtained on the low rate at Bokgaga. For Mafarana, 10 -15 % of seasons will give a negative return on N investment. With a VCR benchmark of 2:1, the 14 and 28 kg N ha^{-1} exceeded the benchmark in 80 % and 70 % of years, respectively, with little difference between sand and clay soil. The 56 kg N ha^{-1} on clay soil and sandy soil exceeded the benchmark in 48 % and 42% of years respectively.

An application rate of 14 Kg N ha^{-1} is recommended for those environments, especially in the semi-dry seasons for the farmers who have never used fertilizers before. Long term simulations showed that maize productivity at both Mafarana and Perskebult under semi-arid conditions can be improved significantly through addition of N. However, the significant improvement was more evident on the clay loam soil. The results of these trials in drier regions of Limpopo province have confirmed the profitability of low rates of N fertilizer in the smallholder (SH) sector. These trials conducted over two seasons at four sites, clearly showed little increase in crop response to N fertilizer top dressing beyond 50 kg of Limestone Ammonium Nitrate (LAN 28) per ha, the equivalent of only 14 kg N ha^{-1}. The return on investment at this level for these farmer-managed trials was as high as R2.36:R1.

LOW RATES OF NITROGEN AND PHOSPHORUS AS FERTILIZER OPTIONS FOR MAIZE IN DRIER REGIONS

1. GENERAL INTRODUCTION

Maize (*Zea Mays L.*) is the most important grain crop in South Africa and is produced throughout the country under diverse environments. Approximately 13.0 million tons of maize grain was produced in South Africa on approximately 3.3 million ha of land (Dept. of Agric, 2009). About 60 % of the maize produced is white, mostly for human consumption, and about 40 % is yellow maize, mostly for animal feed (Dept. of Agric, Land Reform, 2009). Out of the whole area planted, only about 0.5 million ha is planted in the smallholder (SH) farming sector with approximately 465 000 tons of maize grain produced. Maize is the main staple and a cash crop for the majority of SH farmers in South Africa. Despite the dry and drought prone agro-ecology in much of Limpopo Province, maize is the dominant cereal grain. A survey conducted in the central region of the Limpopo Province suggests that most of the land cultivated by smallholders is under maize, with 84 % of households attempting to grow this staple food crop (Schuh, 1999).

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Maize yields in the dry areas of Limpopo are generally low, due to a combination of low and erratic rainfall, late planting, poor pest control, poor soil fertility and soil acidity resulting in very low water-use efficiency. SH farmers in these areas typically harvest only 500 – 1000 kg/ha, resulting in continued food insecurity, lack of saleable surpluses and poverty. In most instances, low productivity is attributed to inadequate amounts of water during a growing season, but even in several areas with adequate amounts and even distribution of rainfall, or even under irrigated conditions, good crop growth and yield cannot be maintained because of low soil fertility (Ayisi, 2004).

Most soils in the dry regions of Limpopo are low in nitrogen (N) and phosphorus (P) due to inherent low fertility status and continuous maize production over

many seasons without replacing depleted nutrients. The use of monoculture cropping systems in dry areas can result in reduced yields, particularly when a field is cropped every year (Elliot *et al.*, 1978). Duivenbooden *et al.,* (1995) reported that nutrients are often the most limiting factor for crop growth in the drier parts of the world. Apart from water, the low N and P status of the soil constitutes a serious constraint to crop production (Mc Collough *et al*., 1994). If the level of these nutrients in the soil is not increased there is little or no likelihood of improving crop productivity.

Farm yard manure and green manure are known to increase crop yields if these resources are managed well. Legume crops reduce N fertilizer requirement for any non legume crop that follows (Voss and Shrader, 1979; Classen, 1982).These alternative nutrient inputs are not the answer because of limited supply, low quality of animal manure and impractical farming system with green manure (Mwangi, 1995). Green manure is impractical and difficult because of small size of land being cultivated by SH farmers. Limited supply of organic matter is caused by the fact that not all SH farmers in Limpopo own animals and most of those who do not own cattle do not have access to manure.

Application of inorganic fertilizers is the most feasible way of correcting nutrient deficiencies on farmers' fields, but due to financial constraints, majority of the SH farmers in the province hardly apply fertilizers in their field crop production and even those who do apply it do so at levels much lower than the recommended rates.

Fertilizer guidelines for maize in South Africa are based on crop response curves targeted at commercial maize production systems. These experiments were conducted mainly on high fertility soils (% organic carbon > 1.0) under optimum management conditions which are not similar to the ones of SH farmers (FSSA Fertilizer Handbook, 2003). Currently, government extension services and fertilizer companies adjust recommendations taken from the guidelines of these

high fertility soils areas. The common recommendation for application of fertilizer given to resource-poor farmers in Limpopo Province is approximately 200 kg 2:3:2 (22) and 100 kg LAN (28) per hectare, an outlay in excess of R 900 at 2007/08 prices (www.fssa.org.za). With the recent rapid increase in fertilizer prices, most farmers find this level of investment unaffordable and too risky given the unreliable rainfall and limited investment capacity for timely land preparation, sowing and weed and pest control.

The International Crop Research Institute for Semi Arid Tropics (ICRISAT), an international research institute working on dry land farming, has developed an alternative fertilizer management system known as micro-dosing (Twomlow *et a*l., 2006). Extensive testing in Malawi and Zimbabwe in dry, drought-prone areas similar to Limpopo has shown that even small quantities of nitrogen fertilizer can give substantial benefits (Dimes and Kgonyane, 2005). South African soils are generally low in P, especially in the marginal soils, and therefore there is a need to also investigate the effects of small quantities of P, as well as N and P interactions.

1.2 PROBLEM STATEMENT

Formal fertilizer recommendations for maize production in Limpopo are inappropriate to the resource constraints and climatic risks of SH maize farmers in drier regions. Current fertilizer recommendations have focused on obtaining maximum yields in these environments and in the process, have assumed away the resource constraints of poor farmers and their ability to invest at these high levels of inputs. At the same time, research has ignored the high marginal returns at lower rates of fertilization as a means of promoting fertilizer use in climatically risky environments and which are most often applied by those few farmers who do use fertilizer in these environments (Ahmed *et al.,* 1997; Dimes *et al.,* 2003).

Analyzing technology responses in farming systems characterized by highly variable seasonal rainfall patterns poses major constraints for research as well. Crop-soil simulation models, in conjunction with long-term climate data, offer a cost effective tool for dealing with rainfall variability in season and between seasons and is a useful tool for adding value to field experimentation by providing a means by which the observed technology responses can be extrapolated across soils, seasons and crop management options.

1.3 MOTIVATION OF THE STUDY

There is very limited information on crop response to fertilizer inputs across regions of Limpopo Province. The most widely used and relevant reference is the FSSA Fertilizer Handbook (FSSA Fertilizer Handbook, 2003). However, fertilizer recommendations within this publication are targeted at commercial farming and can be pursued only by the wealthiest of small-scale farmers.

Fertilizer technology can help raise the productivity and water use efficiency in dry-land farming if more affordable and less risky fertilizer options are available to promote fertilizer use by resource-poor farmers.

1.4 AIMS AND OBJECTIVES OF THE STUDY

1.4.1 Aim

The general aim of this study was to generate fertilizer technology options that encourage investment in soil fertility by SH farmers producing maize in dry areas. Low rates of fertilizer will achieve higher production because of the following reasons: (i) more affordable to SH farmers, (ii) higher marginal rates of return can compensate for higher climatic risks, and (iii) it will encourage experimentation with fertilizer, especially for farmers who have never used fertilizer previously.

Since currently there is no research-based information on the low rates of fertilizer recommendations for dry regions of Limpopo Province, the specific objectives of this study were:

(i) To quantify the response to low amounts of nitrogen and phosphorus by maize across a rainfall gradient and contrast it with recommended rates.

(ii) To evaluate N x P interaction at low rates of application of both nutrients.

(iii) To evaluate economic returns of different fertilizer application rates on maize using partial economic analysis and value cost ratios.

(iv) To evaluate Agricultural Production System Simulator (APSIM) to simulate maize response to low inputs of nitrogen and phosphorus for dry regions.

1.5 GENERAL HYPOTHESIS

Lower doses of fertilizer will improve maize yields achieved by SH farmers in dry areas. Low rates of fertilizer will achieve this high production because of the following reasons: (i) affordable to smallholder farmers, (ii) less risky and (iii) will encourage experimentation with fertilizer, especially by farmers who had never used fertilizer before. Most researchers tend to promote high rates of fertilizer applications.

1.5.1. Specific hypotheses

(i) There is no potential to increase maize production with lower doses of N and P in drier regions than at current fertilizer recommendations

(ii) There is no N x P interaction at lower application rates in drier regions

(ii) The Value Cost Ratio of fertilizer investments for maize production in drier regions will not be favourable for low doses of N and P compared to current recommended rates.

(iii) APSIM can not adequately simulate the observed maize response to N and P inputs at low and high application rates

2. LITERATURE REVIEW

2.1 Soils and climate for maize production

Maize (*Zea mays L.*) is an important cereal crop and it is produced largely in many countries. Maize ranks third world-wide after wheat *(Triticum aestivum L.*) and rice (*Oryza sativa*) in terms of production, and it is widely distributed (Dean, 1994). Maize belongs to the family Gramineae and originated in the Tropics of Latin America. Although maize originated in semi-arid regions, it is not a reliable crop under variable rainfall conditions and will usually be outperformed by crops such as sorghum (FSSA Fertilizer Handbook, 2003). In South Africa, the crop occupies about 3.1 millions hectares of the country's arable land and about one third of South African farmers produce maize (Van Rensburg, 1978). Approximately 13, 0 million tons of maize grain was produced in South Africa on approximately 3, 3 million ha of land in 2007/08 season (www.nda.agric.za) and of this area, 0.5 million hectares were cultivated by SH sector with expected mean yield of 0.9 ton ha^{-1}.

The most suitable soil for maize is one with a good effective depth, favourable morphological properties; good internal drainage, optimal moisture regime, and sufficient and balanced quantities of plant nutrients (du Plessis, 2003). Bland (1971) also reported that maize does well on soils with high water holding capacity that are well drained and have high organic matter and fertility status. Maize does extremely well under irrigation in the drier areas, and will produce higher yields than virtually all other grain crops. It is grown over a wide range of climatic conditions than other important grain crops such as wheat and rice, even though it is limited to warmer areas (FSSA Fertilizer Handbook, 2003).

South Africa is classified as a water-scarce country (Bruwer and Van Heerden, 1995) with most agro ecological zones characterized by low and erratic rainfall, which subjects crops to frequent water shortage during the growing season. According to the United Nations Convention to Combat Desertification (UNCCD)

index (FAO, 2005) for defining dry lands, 80 percent of South Africa is semi-arid to arid, and only 18 percent is dry sub-humid to humid (Figure 2.1). Most of the arable land in Limpopo Province of South Africa is subject to unreliable rainfall. The Limpopo Province is generally semi-arid with rainfall generally ranging from 300 to 1000 mm per year (Fig 2.2). Most of the province faces a high probability of drought, with a greater portion of the region receiving less than 600 mm of annual rainfall and high summer temperatures (Ayisi, 2004).

Limpopo province has a wide range of soil types (Fig. 2.3) but production practices among farmers are fairly similar across the range of soils. Soils in the province are variable tending to be sandy in the west, but with a higher loam and clay content toward the east. Most soils in the dry regions are low in N and P because of inherent low soil fertility status and continuous maize production over many seasons without replacing depleted nutrients. If the level of these nutrients in the soil is not increased there is a little or no likelihood of improving productivity. Poor nitrogen and phosphorus nutrition, low soil organic matter as well as poor weed control are considered major factors limiting crop growth and yield, beside water (Ayisi, 2004). However, it was established by Odhiambo (2005) that crop growth and yield is often poor even in areas with adequate amounts and even rainfall distribution or even under irrigated conditions. This reveals the fact that other factors, besides water, contribute to low crop productivity; these include soil fertility and crop management practices.

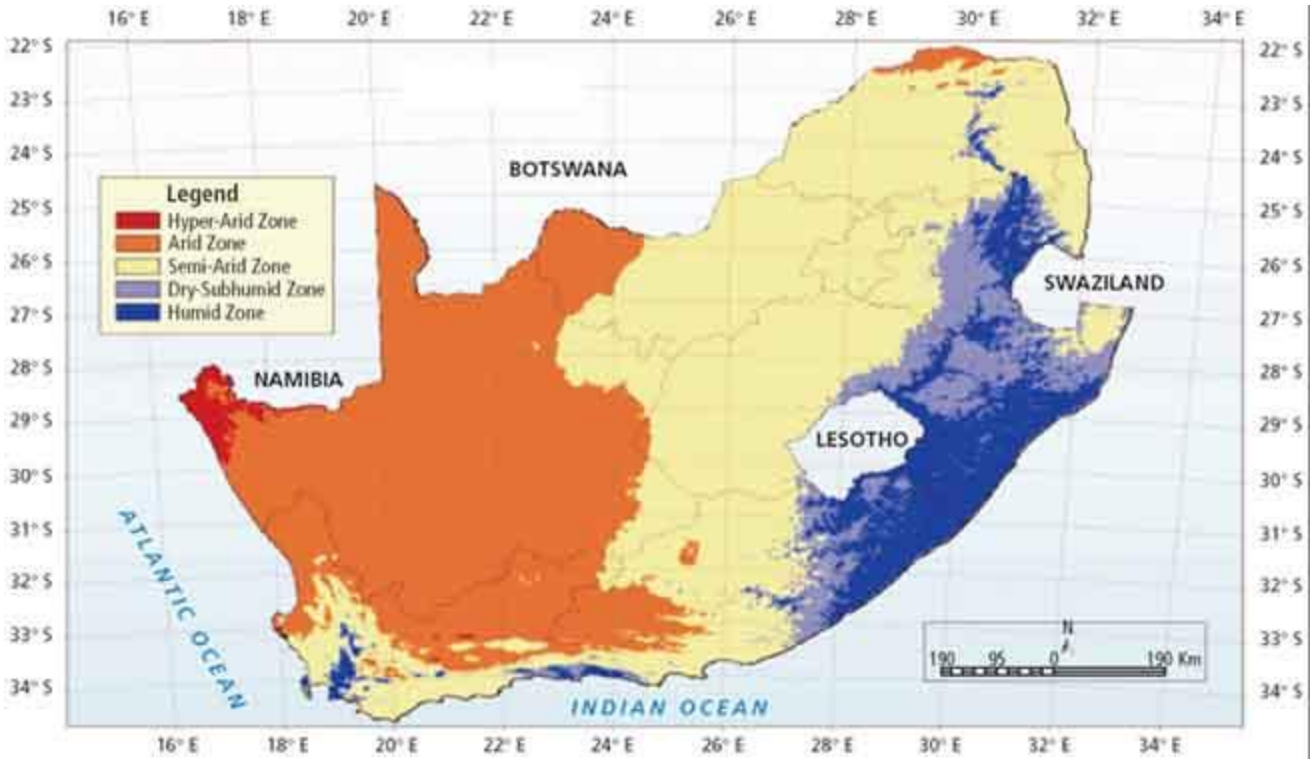

Fig. 2.1. Agro-ecological zones of South Africa (FAO, 2005).

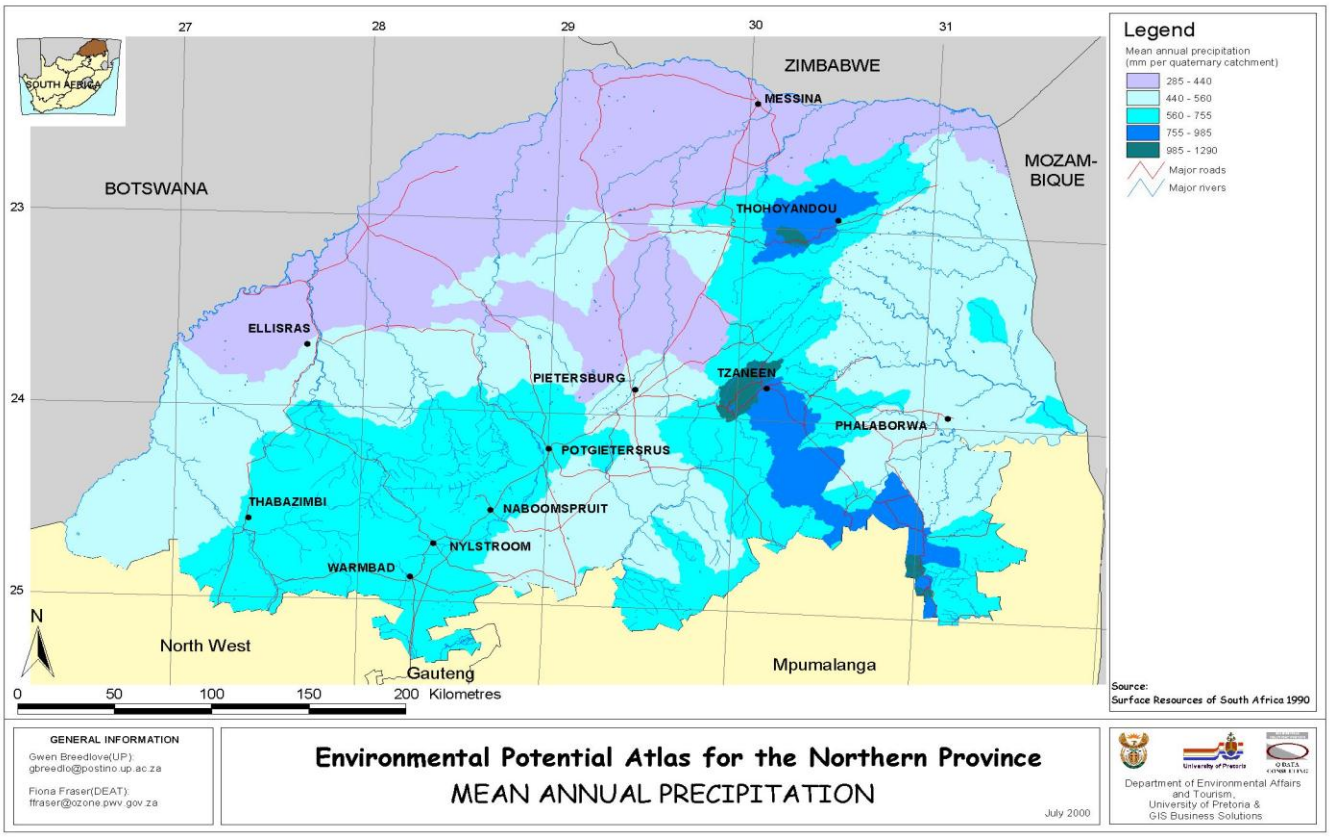

Fig. 2.2. Rainfall distribution in the Limpopo Province (Ayisi, 2004)

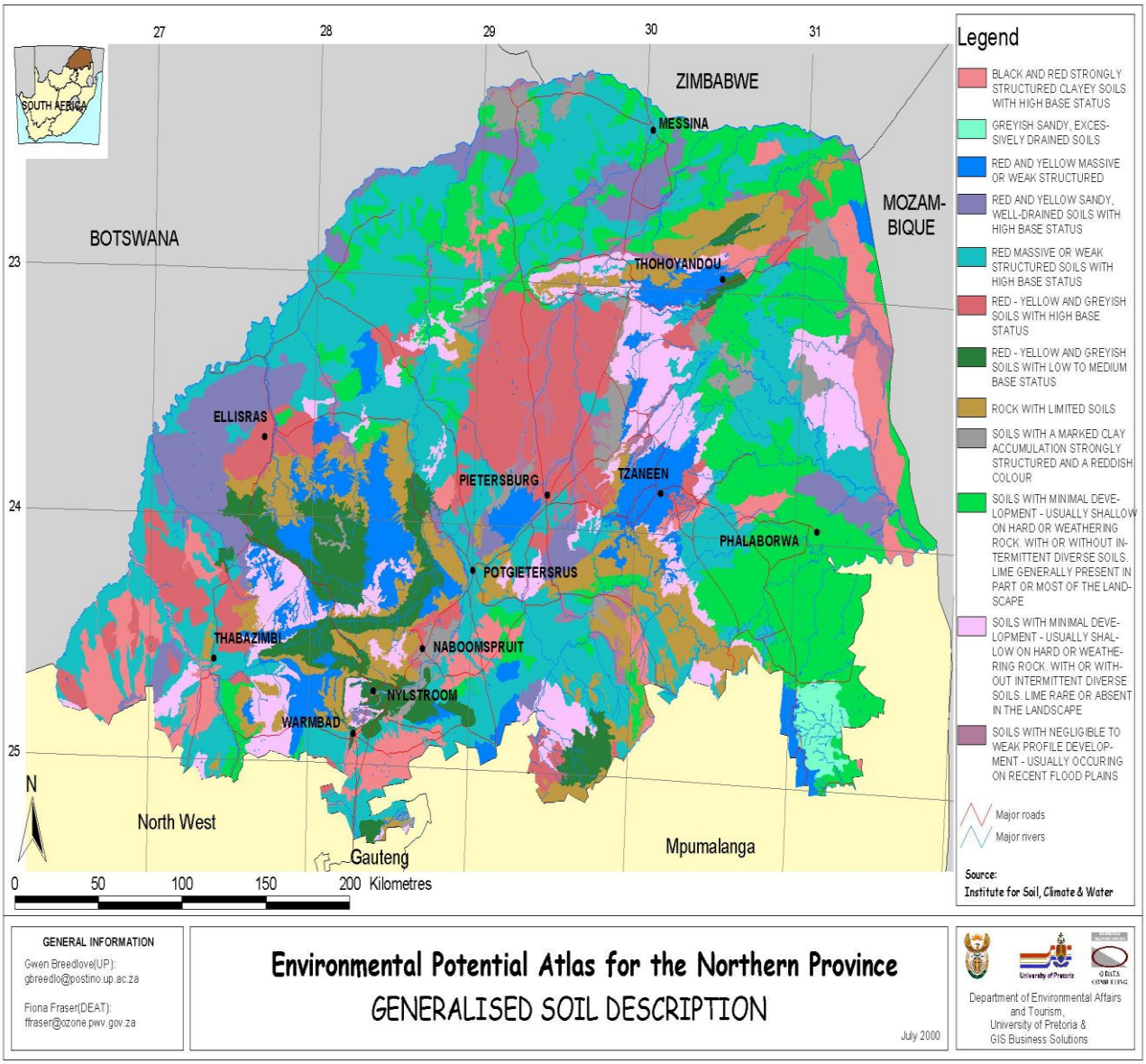

Fig. 2.3. Soil types of the Limpopo Province (Ayisi, 2004)

2.2 Fertilizer recommendations for dry regions

Du Plessis (2003) suggests that assimilation of nitrogen, phosphorus and potassium by maize plant reaches a peak during flowering. At maturity of a single, well grown maize plant, the total nutrient uptake is about 8.7 g of nitrogen, 5.1 g of phosphorus and 4.0 g of potassium. Each ton of maize grain produced removes 15.0 to 18.0 kg of Nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg potassium from the soil.

Soil fertility depletion in SH farms has been stated as 'the fundamental biophysical root cause of declining per capita food production in Africa' (Sanchez *et al.,* 1996). This statement includes the semiarid tropics of South Africa, the environment targeted by the study. Fertilizer is an important yet under-utilized technology for addressing this per capita decline in food production in Africa. Yet, despite substantial resources having been invested by National Agricultural Research and Extension Systems (NARES) of the Southern African Development Community (SADC) in developing fertilizer recommendations for SH farmers, surveys suggest that fertilizer usage by SH farmers in Southern Africa remains extremely low (Mapfumo and Giller , 2001).

For example, surveys in southern Zimbabwe, indicated that less than 5% of farmers commonly used fertilizer (Ahmed *et al.,* 1997; Rusike *et al.,* 2003). Sixty percent of households owning cattle did not even use cattle manure as an amendment for crop production. Current and past use of inorganic fertilizer and manure and average rates of application for Malawi and Zimbabwe are summarized in Table 2.1. Similar data have been reported for South Africa and other countries in sub-Saharan Africa.

Table 2. 1. Typical fertilizer use in sub-Saharan Africa (data for Zimbabwe Semi Arid Tropics (SAT), Rusike, unpublished data)

Fertilizer type	% of farmers	Application rate,	Recommended
Inorganic	5	50 kg ha^{-1}	250-350 kg ha^{-1}
Manure	40	4 t ha^{-1}	20-40 t ha^{-1}

While organic fertilizing (kraal manure) is practiced to a similar extent in northern and central regions of Limpopo Province (around 13% of the households) the application of mineral fertilizer is very little in the northern region (only 16.9%) while in the central region more than half of the households (52.7%) are using mineral fertilizer (Schuh 1999).

According to FSSA Fertilizer Handbook (2003), fertilizer guidelines for maize in South Africa are based on crop response curves which are derived from broad based experimental data. These results were gained from more than 15 years of calibration experiments on the highveld and currently, extension agents and fertilizer companies adjust recommendations taken from these guidelines. A guideline can never make provision for all variables and should be regarded as a general point of departure. FSSA Fertilizer Handbook (2003) further recommends that specialist advisers should be consulted according to local conditions.

The common recommended rate of starter fertilizer given to resource-poor farmers in Limpopo Province is about 200 kg ha^{-1} of starter fertilizer 2:3:2 (22) and 100 kg ha^{-1} of top-dress fertilizer LAN (28). These recommendations are derived from assumed average yield potential and management. With the recent rapid increase in fertilizer prices, coupled with low maize prices, most farmers in the dry areas find this recommended rate too high, too risky, or completely unaffordable. These farmers in Limpopo are mainly dependent on pension money and remittances from migrant workers with almost no income derived from maize production. The money they get can only satisfy their basic

household needs and cannot afford to buy expensive inputs (Ramaru *et al.*, 2000).

The underlying problem of existing fertilizer recommendations given to resource–poor farmers is illustrated in Figure 2.4 (Dimes *et al.,* 2003). The recommendations are generally too high, being aimed at agro-climatic production optima that are realistically only affordable by the wealthiest of farmers. Farmers' application rates generally lie at the lower end of the response curve (e.g. Fig. 2.4), reflecting their limited resources to invest and risk management perspective since the highest marginal returns are at the lower input levels. Hence, lower recommendations are more likely to be adopted by farmers in the first instance because they are more affordable, and in the case of drier regions, the higher marginal returns offset the risks of poor crop yields due to inadequate rainfall. Hence, lower rates will increase the likelihood of positive outcomes from farmer experimentation, thereby encouraging further investment in the technology (e.g. moving to higher application rates or purchasing other types of fertilizer)

Use of inorganic fertilizer is minimal (about 8 kg ha^{-1} in sub-Saharan Africa compared to 100 kg, 120 kg, and 70 kg ha^{-1} for the World, Asia and India, respectively) (Table. 2.1) and farmers with access to manure commonly do not use it on their croplands because of its poor quality and/or labour shortages for handling (Probert *et al.,* 1995; Ahmed *et al.,* 1997). Inorganic fertilizers are mainly sold in the major towns and resource poor farmers cannot easily access them.

The gap in the traditional fertilizer research for maize has been an absence of very low rates of N and P (typical treatments for maize research normally include 0, 40, 80, 120 and 160 kg N/ha and 0, 15, 30, 45 and 60 kg P/ha) (Schmidt *et al.,* 2004). According to Dimes and Kgonyane (2005) ICRISAT, an international research institute working on dry land farming, has developed an alternative known as micro-dosing. The term has come from ICRISAT work in West Africa

(Tabo *et al.*, 2006). Crop production was doubled and farm incomes increased through the uptake of fertilizer micro dosing in West Africa. Extensive testing in Malawi, Zimbabwe and South Africa – in dry, drought-prone areas very similar to Limpopo, have shown that even small quantities of nitrogen fertilizer can give substantial benefits (Twomlow *et al.*, 2008).

However, there are no robust and statistical data to back-up this work in South Africa. South African soils are also generally low in phosphorus and therefore, there is a need to also investigate the effect of small quantities of phosphorus and nitrogen x phosphorus interaction in dry areas of Limpopo Province to formulate more robust fertilizer recommendations.

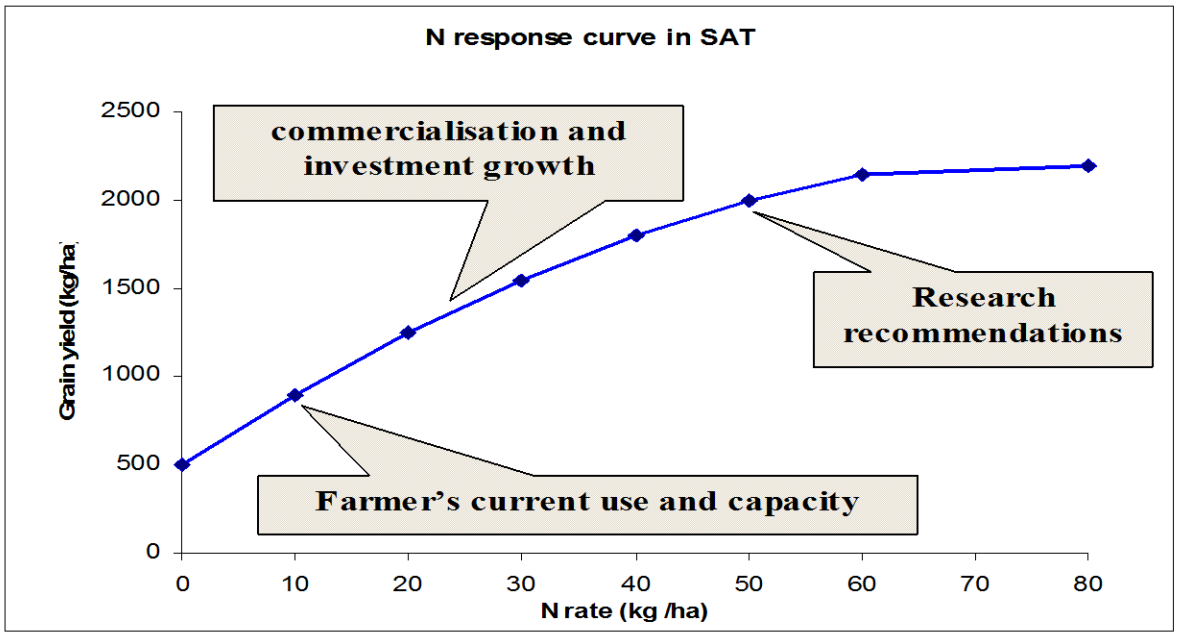

Figure 2.4. A typical fertilizer N response curve in relation to researcher recommendations, existing capacity of smallholder farmers to invest, and growth path for increased use (Dimes *et a*l., 2003).* SAT = Semi Arid Tropics

2.3 Use of Models

Computer simulation modeling is the latest and probably the best addition to the scheduling methods. A simulation model can be described as the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Sinclair and Seligman, 1996). Most of the models allow the user to make adjustments by means of observations like, leaf area and soil water content. Graves *et al.,* 2002 reported that models play an important role in scientific research and resource management, and have been used to help understand, observe, and experiment with crop systems. In South Africa, the use of computer models is still very limited, but it promises to improve rapidly.

2.3.1 Use of APSIM Model

2.3.1.1 APSIM Model description

Agricultural Production System Simulator (APSIM) is a modular modeling framework that has been developed by the Agricultural Production Systems Research Unit (APSRU) in Australia. APSIM is a software system that provides a flexible structure for the simulation of climatic and soil management effects on the growth of crops and changes in the soil resource (Keating *et al.,* 2003).

It is a well tested model that provides reasonably accurate prediction of maize production in relation to plant, soil, climate and management modules, whilst addressing long-term resource management issues in farming systems (Keating *et al.,* 2003). Using APSIM to investigate maize production systems in climatically risky environments has been extensively tested in Kenya and Zimbabwe (Keating *et al.,* 1999; Shamudzarira and Robertson 2002). The suitability of APSIM in simulating crops in SH farming systems in Semi Arid Tropics of Africa has been tested over several years and in a number of regions. Building on the precursor simulation work of Keating *et al.,* (1991) in Kenya, the APSIM model has been tested and used to simulate N fertilizer response (Dimes *et al.,* 1999; Shamudzarira *et al.,* 1999), manure and P responses (Carberry *et al.,* 1999),

crop-weed interactions (Keating *et al.,* 1999; Dimes *et al.,* 2002) and extrapolation of research findings to other sites (Rose and Adiku, 2001).

A study conducted by Kwach *et al.,* (2003) has revealed that the response of maize to fertilizer varied with seasonal rainfall. Grain yields were depressed when nitrogen was added to maize during the poorer seasons. With higher seasonal rainfall, APSIM predicted a sharp increase in grain yields at lower rates of nitrogen. A gradual response to nitrogen was predicted in sandy soil, up to 30 kg N ha^{-1}. Sandy soils proved superior to clay in poorer seasons, while the reverse was true during high rainfall seasons.

A prototype version of the APSIM-Maize model responsive to soil P has been developed in the APSIM framework (Probert, 2004). Whitbread *et al.,* (2004a) also mention that this P- aware crop module represents the plant P uptake process, estimates P process in the crop, and the consequent restrictions to the key plant growth processes – photosynthesis, leaf expansion, phenology and grain filling. It is used in association with a new module (APSIM Soil P) that simulates the dynamics of P in soil and is linked to the modules simulating the dynamics of carbon and nitrogen in the soil organic matter, crop residues, etc in order that the P present in such materials can be accounted for.

Based on these features and abilities, APSIM will be used in this study to simulate maize response to low inputs of nitrogen and phosphorus for dry regions of Limpopo for the purpose of extrapolating the experimental responses to other sites and seasons.

2.3.1.2 Quantifying climatic risk of fertilizer options using simulation modeling

Simulation models provide a means to test, without expensive and time-consuming field trials, the risk and returns to various rates of fertilizer application, across seasons and locations. These tools have increasingly been used to analyse a range of crop fertility management issues in African SH farming systems (Keating *et al.,* 1991; Thorton *et al.,*. 1995, Shamudzarira *et al.,* 1999; Bontkes and Wopereis, 2003). Figure 2.5 shows the results of a simulation analysis of maize grain yield in the drought-prone Masvingo province of Zimbabwe, in various years (using historical rainfall data) under various fertilizer application rates. The simulation tool used in this case is APSIM (Dimes *et al*., 2002).

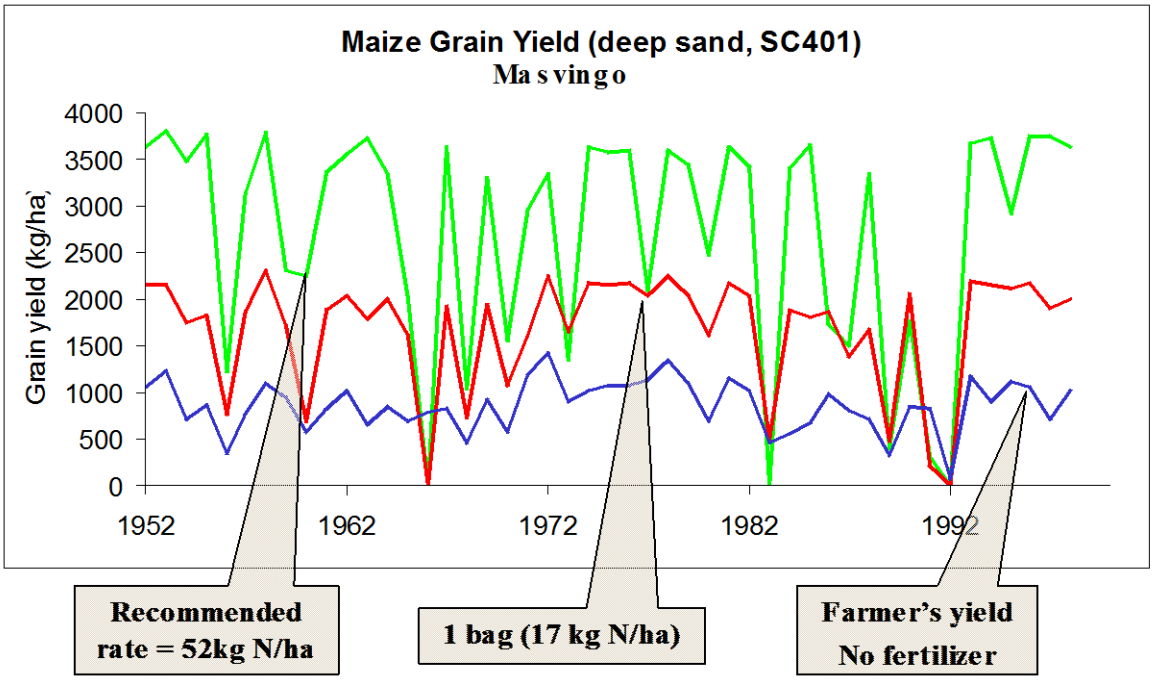

Figure 2.5. Simulated maize yield (cultivar SC401) on a deep sand soil at Masvingo, Zimbabwe, for climate records 1952 to 1998 and N inputs of 0, 17 and 52 kg N ha^{-1} (Dimes et al., 2003).

With no fertilizer inputs, simulated yields reflect the current low levels obtained by farmers, while the addition of only 1 bag/ha of ammonium nitrate fertilizer (17 kg N ha^{-1}) is sufficient to double yields in most seasons. Application of the

recommended fertilizer rate (3 bags/ha or 52 kg N ha^{-1}) can substantially further increase yield in some seasons, but the additional response is very uncertain compared to that for the lower application rate. These results provide illustrative rationale for researchers and extension agents to re-align fertilizer recommendations for drier regions lower down the nitrogen response curve (Fig 2.4) in order to match farmers' investment capacity and risk aversion.

2.4 Return on investment by using fertilizer

The low maize price combined with recent increase in fertilizer prices cause farmers to closely examine the amount of nitrogen and phosphorus they apply on their crop. The very best rate of nitrogen to apply is the optimum economic rate because the last unit of nitrogen added just pays for itself with additional yield. This rate maximizes the rand returns per hectare to the farmer (Kelling and Bundy, 1994). However, this economic approach assumes that the farmer has access to the capital resources that allow for this last unit of investment. This is not the case for resource-poor farmers in Limpopo.

2.4.1 Value Cost Ratio

The value cost ratio or VCR is a measurement that researchers use to assess the viability of technology adoption (ICRISAT highlights, 2008). It is calculated from the value of extra grain produced relative to the control and the cost of the additional inputs. If the VCR is more than 2:1, in other words, if the value of the extra grain produced is double the cost of the fertilizer needed to boost the yields, the technology is more likely to be adopted. According to ICRISAT highlights (2008), the VCR for small doses of fertilizer in on-farm baby trials replicated across farms in Limpopo Province easily exceeded the 2:1 threshold in all three seasons of 2004 to 2006. In comparison, the VCR for the blanket recommended rates only reached 2:1 in the better rainfall seasons and was 1:1 or less in other seasons. There is a need for controlled experiments to provide robust statistical data, to back-up this work in Limpopo.

3. COMMON MATERIALS AND METHODS

3.1 Study sites

Replicated on-farm rain-fed field experiments were conducted in the dry areas of Limpopo Province during 2006/07 and 2007/08 growing seasons at eight locations. During the 2006/07 growing season, experiments were planted at four locations namely; Perskebult, Phaudi, Tshebela and Bokgaga. For the second season (2007/08), experiments were repeated at four localities namely; Perskebult, Phaudi, Mothiba and Mafarana. Mothiba and Bokgaga are in close proximity to Tshebela and Mafarana respectively. These sites have a varying rainfall gradient which is helpful in assessing fertilizer responses and evaluating APSIM capabilities. The study sites are described in *Table 3.1.*

Table 3.1. Description of the study sites in the Limpopo Province during the 2006/07 and 2007/08 seasons

Location	Soil type	Latitude & Longitude	Altitude	LT rain	LT Temp
Phaudi	Sandy Loam	-23^{o} 30. 668 South	1117 m	319.6	Max. 27.6
		29^{o} 07. 898 East			Min. 13.7
Perskebult	Sandy Loam	-23^{o} 47. 893 South	1279 m	335.6	Max. 26.8
		29^{o} 19. 995 East			Min. 13.0
Tshebela	Loamy Sand	-24^{o} 1. 553 South	1157 m	432.5	Max. 25.7
		29^{o} 44. 054 East			Min. 11.9
Mothiba	Sandy Loam	-23^{o} 50. 519 South	1230 m	432.5	Max. 25.7
		29^{o} 44. 054 East			Min. 12.0
Bokgaga	Sandy Clay Loam	-24^{o} 1. 604 South	1138 m	746.4	Max. 28.3
		30^{o} 40. 087 East			Min. 16.5
Mafarana	Sandy Clay	-23^{o} 57. 590 South	653 m	746.4	Max. 28.3
		30^{o} 22. 217 East			Min. 16.5

LT Rain = Long term seasonal rainfall (mm) from 01 October to 31 May
LT Temp = Long term seasonal temperature (^{0}C) from 01 November to 30 June

3.2 Climatic data of the two seasons

Rainfall data for the sites was recorded for the months of November to end of June from rain gauges placed at each experimental site. The temperature and radiation records were obtained from the nearest local meteorological station of the Agricultural Research Council, Institute for Soil Climate and Water (ARC-ISCW) as follows: Bokgaga and Mafarana (Letsitele station), Perskebult (Polokwane station), Phaudi (Dendron station) and Mothiba (University of the North station)

3.3 Treatment factors, trial layout and experimental design

The experiments evaluated four levels of nitrogen (0, 14, 28 and 56 kg ha^{-1}) and four levels of phosphorus (0, 5, 10 and 20 kg ha^{-1}, see Table 3.2). The experiments were laid out as a 4 x 4 factorial arrangement in a randomized complete block design (RCBD) with three replications at each location in both seasons. All P was applied at sowing and N was applied as a top-dressing except the highest rate (56 kg N ha^{-1}) which was split, half at sowing and half at top-dressing (4 to 6 weeks after emergence). According to du Plessis (2003), 40 kg N ha^{-1}, band-placed at planting 5 cm to the side of the seed and 5 cm below the seed, should not be exceeded at 90 cm row spacing. A blanket dose of potassium chloride fertilizer (12.75 kg ha^{-1}) was applied at sowing. The N and P fertilizer formulations were Limestone Ammonium Nitrate (28% N) and Supergrow (20.3% P) +Ca+S respectively. Maize cultivar Pan 6479 (a three way drought tolerant hybrid) was planted in all experiments and the genetic coefficients for this cultivar have been paramatized in the APSIM model (Dimes and Carberry, 2008). Each treatment plot had 5 rows of maize, each 7m in length. Row spacing was 90cm and plant spacing within row was 50cm. There was a 1m gap between replications, and no gap between treatments in a replication.

Table 3.2 Trial Layout

Treatment randomization

Rep 1

N1P0 5	N0P1 2	N3P0 13	N0P3 4	N2P1 10	N3P1 14	N2P3 12	N1P2 7
N2P2 11	N3P2 15	N2P0 9	N3P3 16	N1P1 6	N0P2 3	N1P3 8	N0P0 1

1 metre gap

Rep 2

N0P3 4	N2P3 12	N1P2 7	N1P3 8	N2P0 9	N3P2 15	N3P0 13	N0P2 3
N3P1 14	N1P1 6	N2P2 11	N2P1 10	N0P0 1	N1P0 5	N0P1 2	N3P3 16

1 metre gap

Rep 3

N3P0 13	N1P3 8	N0P0 1	N1P2 7	N3P3 16	N2P0 9	N0P3 4	N1P0 5
N2P3 12	N0P1 2	N3P2 15	N0P2 3	N3P1 14	N2P2 11	N1P1 6	N2P1 10

Key:

N0 =	0 kg N ha $^{-1}$	P0 =	0 kg P ha $^{-1}$
N1 =	14 kg N ha $^{-1}$	P1 =	5 kg P ha $^{-1}$
N2 =	28 kg N ha $^{-1}$	P2 =	10 kg P ha $^{-1}$
N3 =	56 kg N ha $^{-1}$	P3 =	20 kg P ha $^{-1}$

3.4 Soil measurements

All sites were sampled pre-season (generally October, at 0 to 20 cm) to determine background soil status of pH, phosphorus and potassium, calcium, magnesium, sodium, zinc, cation exchange capacity, organic carbon and clay content. Organic carbon was measured by the wet chemical oxidation procedure of Walkey and Black, (1934) and soil pH was measured in water. A spectrophotometer with light band was used to determine the concentration of phosphorus in the soil extract; potassium, magnesium and calcium were determined using standard ammonium acetate (1 N ammonium acetate at pH 7) by means of an atomic absorption spectrophotometer (Jackson, 1967).

Subsequent soil sampling was done at sowing, tasselling (zero and N3P3) and harvesting at 0-10cm, 10–30cm, 30-60cm and 60-90cm to determine residual nitrogen and phosphorus ($N0_3^-$, NH_4^+, and extractable PO_4) using soil cores at selected sites. Two samples bulked together per replication were taken to test the distribution of nitrogen in the soil profile. Nitrogen (NO_3^- + NH_4^+) was determined by an auto-analyzer using KCl extraction method, available phosphorus was extracted using the Bray1 procedure and the phosphorus content of the extract was measured by the molybdate-blue method as described by Olsen and Sommers (1982)**.** Some soil analytical results for the different sites are given in Tables 3.3 and 3.4.

From the same soil samples, gravimetric moisture content were determined by oven drying at 60^{oC} for four days to a constant weight instead of 24 hours at 105^{oC}. Bulk density was estimated based on soil texture class for the conversion of gravimetric to volumetric water content and to calculate the mass of soil nutrients. Bulk density is required as an input to the model and likewise, it is needed to determine the soil water parameters (in volume units) as inputs to the model.

Table 3.3 Soil pH and nutrient content at four sites at the beginning of the trial in 2006/07 season.

Location	Depth	pH	NH_4^+	$N0_3^-$	P	Total N	0rganic Carbon
	Cm	(H_2O)	……. (mg kg^{-1})……				
Perskebult	0-20	4.98	10.03	0.79	3	122	0.39
Phaudi	0-20	5.64	17.24	9.38	3	173	0.64
Tshebela	0-20	4.94	10.60	4.04	34	103	1.2
Bokgaga	0-20	5.18	10.15	2.21	1	63	0.44

Table 3.4 Soil pH and nutrient content at four sites at the beginning of the second season, 2007/08

Location	Depth	pH (H_2O)	NH_4^+	$N0_3^-$	P	K	0rganic Carbon
	Cm		……. (mg kg^{-1})……				
Perskebult	0-20	5.18	*	*	4	66	0.10
Phaudi	0-20	5.08	9.95	7.82	4	201	0.51
Mothiba	0-20	4.94	2.85	2.39	6	109	0.37
Mafarana	0-20	6.21	4.39	4.5	4	204	1.25

* Not measured

3.5 Land preparation and planting methods

Experimental fields were ploughed as soon as there was enough moisture in the soil. A tractor drawn mould board plough was used to cultivate the soil to a depth of at-least 30cm. Planting holes were made in row 50 cm apart (with hoe approximately 75mm deep). Two maize seeds were placed in planting hole and covered with approximately 50 mm soils. Seedlings were thinned to one at two to three weeks after emergence. The target plant population was 22222 plants ha^{-1}.

3.6 Fertilizer application and weed control

All P and K were applied during sowing. 1.13 gram of KCL fertilizer was placed in each planting hole and covered with approximately 25mm soil. Fertilizers were applied according to treatments. Planting fertilizer was applied during sowing at 2.5 cm below the seed and covered with soil. Top-dress fertilizer was applied at the base of each plant and covered, 4-6 weeks after sowing (after 5-6 leaf stage, or knee high) when soil was wet or rainfall was expected. Weeding was done once by hoeing and hand pulling at 26, 34, 35 and 45 days after planting (DAP) for Phaudi, Mothiba, Bokgaga and Perskebult respectively. At the Mafarana site, the maize stand was weeded three times at 35, 63 and 90 DAP, due to the high weed infestation. In all trial sites top-dress fertilizer was applied after the first weeding event.

3.7 Phenological development

During 2006/07 flowering was determined visually and days to flowering were recorded when 50% of the plants on control and N3P3 plot had flowered. Number of days to physiological maturity (PM) was scored. PM was scored when the kernel milk line disappeared and as the kernel black layer forms at the tip of the kernels.

3.8 Dry matter production

Above ground plant samples of maize biomass were taken at tasselling/silking and harvesting at Bokgaga and Phaudi sites in 2006/07 and at Mothiba and

Mafarana sites in 2007/08. Dry matter samples of the plants were taken from a 2.7 m^2 area from each plot at tasselling at the selected locations. Maize plants were cut at ground level to determine above ground dry matter. Maize plant materials were oven dried at 50-55 ^oC until weight loss was no longer detected on selected samples distributed throughout the ovens.

3.9 Harvest Area

The yield sample area was one meter by three middle rows at flowering (tasselling) and three middle rows by three meters of row at harvesting. That is, the border area was one row on each side of the yield sample area. The sample areas at either end of plot were one meter of row at tasselling and skip another one meter of row at harvesting. Final yield harvesting was done at harvest and weighed in the field using tripod-held suspension weighing balance. Three plants and five cobs were randomly sub-sampled and placed in a brown bag weighed fresh on a battery scale and taken to the laboratory for oven drying. Both samples (stover and cobs) were oven dried at 50-55^oC until they were completely dry. Cobs were shelled when completely dry and weighed separately for the calculation of shelling percentage. The grain weight are analysed and reported at oven dry weight (0 % moisture content) to facilitate comparison of grain yield outputs from the APSIM model. The dry stover samples were also weighed.

3.10 Data analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model procedure of Statistical Program for Social Science (SPSS). Differences between treatment means were separated using the Least Significant Difference ($LSD_{0.05}$) procedure by using Genstat Discovery Edition 9.1 (*www.vsni.co.uk*)

3.11 Initial soil water content in the profile for the two seasons

Rainfall data for the sites was recorded for the months of November to end of June from rain gauges placed at the each experimental site. Soil sampling was done at sowing, tasselling (zero and N3P3) and harvesting at 0-10cm, 10–30cm, 30-60cm and 60-90cm to determine the initial soil water content. From these soil samples, gravimetric moisture content (Fig. 3.2) were determined by oven drying at 60^{o}C for four days instead of 24 hours at 105^{o}C. Bulk density was estimated based on soil texture class for the conversion of gravimetric to volumetric water content (Fig. 3.1) and to calculate the mass of soil nutrients.

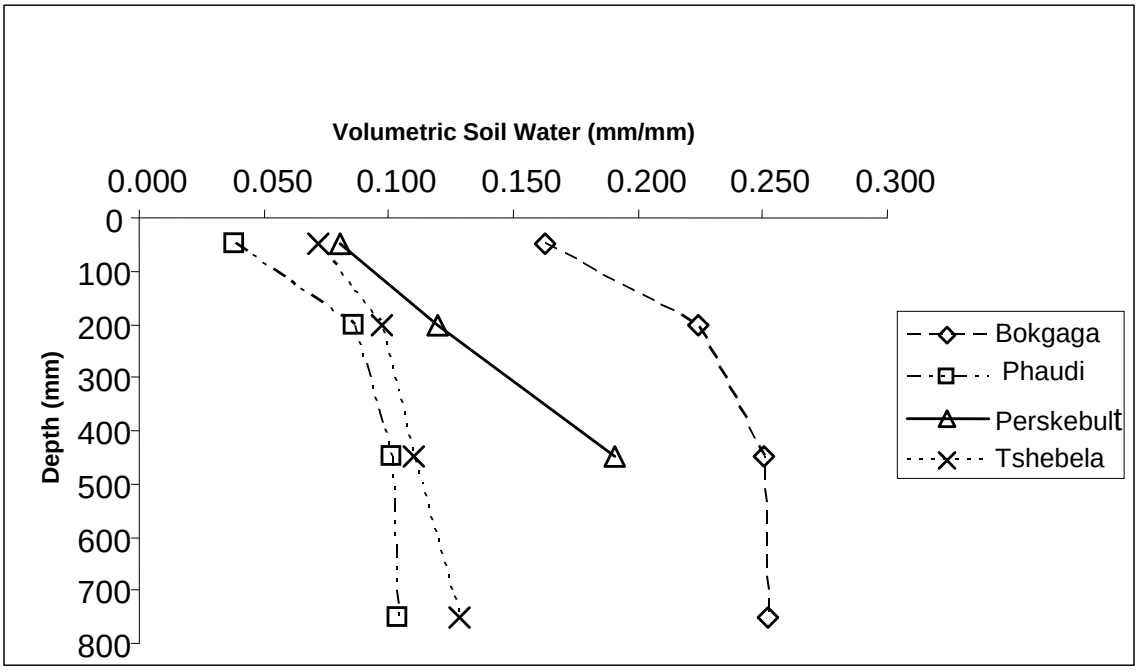

Fig.3.1. Initial soil water in the profile of four trial sites at 50, 200, 450 and 750mm depths in the 2006/07 season

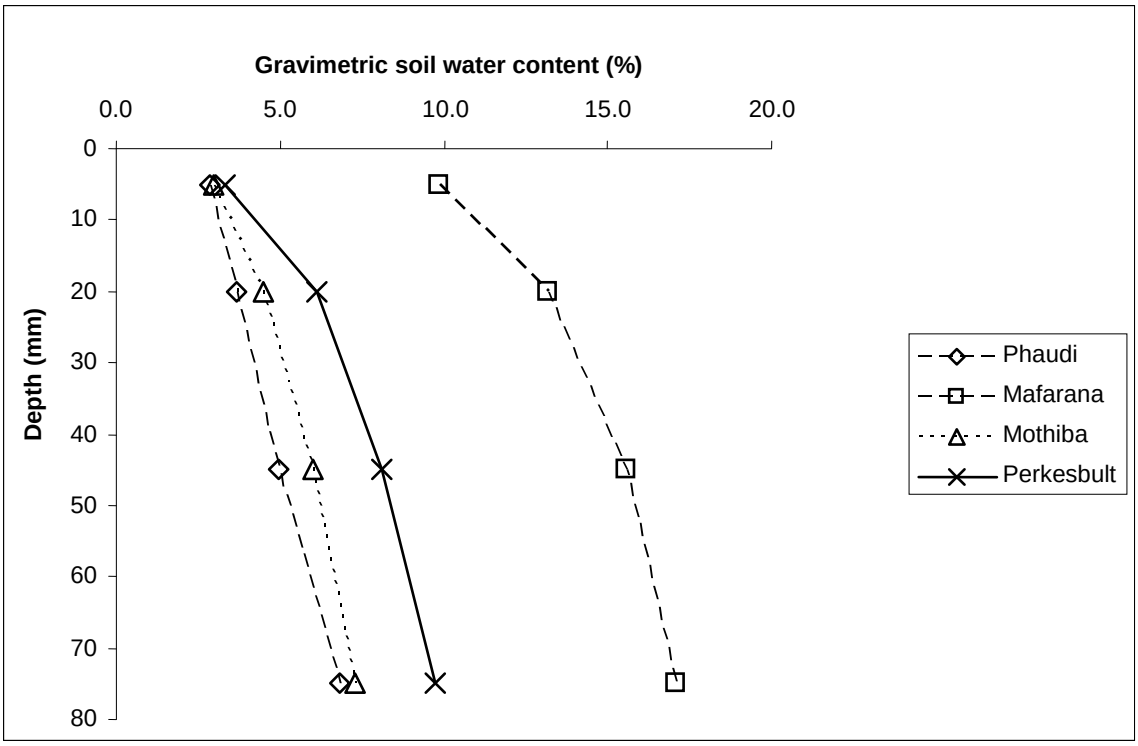

Fig.3.2. Initial soil water in the profile of four trial sites at 50, 200, 450 and 75mm depths in the 2007/08 season

4. THE RESPONSE OF MAIZE YIELD TO LOW AMOUNTS OF NITROGEN AND PHOSPHORUS FERTLIZER

4.1 Introduction

An inorganic fertilizer application rate is one of the important aspects of crop management that affects fertilizer use efficiency (FUE) and crop yields (Mahler *et al*., 1994). Nitrogen management decisions affect crop N use efficiency in some way. Traditionally, scientists use tagged-N fertilizers or compare N fertilizer with unfertilized control plots to calculate how much of the fertilizer was used by the crop. Both these methods require special considerations when interpreting data, because there are other sources of N (i.e. manure, residual N, mineralization) in addition to fertilizer. There are also other demands for N fertilization within the soil system (i.e. microbial immobilization). These considerations all tend to decrease the measured N use efficiency because they either dilute the fertilizer with other sources or temporarily reduce fertilizer availability to the crop (Schepers *et al*., 1993).

Limpopo is generally semi-arid with rainfall ranging from 300 to 1000 mm per year. Most of the province faces a high probability of drought, with a greater portion of the region receiving less than 600 mm of annual rainfall and experience high summer temperatures (Ayisi 2004). There is great potential of increasing crop yields and water use efficiency by increased use of fertilizer and improved crop management such as improved varieties. Effect of selection for drought tolerance on performance of tropical maize under range of N levels was examined by Banziger *et al.,* (1999) and significant differences were found between genotypes under severe N stress. A strong association was found between grain yield and harvest indexes of tropical maize in drought stress (Edmeads *et al.,* 1999). However, Liang and MacKenzie (1984) reported that, under climatically unfavourable conditions, the returns on these investments are uncertain.

N and P are the two most important nutrients elements with great potential of increasing crop yields. According to Ayisi and Whitbread (2004), most of the SH farming sector in Limpopo is located on infertile degraded soils, where nutrient deficiencies, predominantly of N and P, limit crop production. SH farmers in these areas typically harvest only 500 – 1000 kg/ha, resulting in continued food insecurity, lack of saleable surpluses and poverty.

Farm yard manure and green manure are known to increase crop yields if these resources are managed well. Legume crops reduce N fertilizer requirement for any non legume crops that follow (Voss and Shrader, 1979; Classen, 1982).These alternative nutrient inputs are not the answer because of limited supply, low quality of animal manure and impractical farming system with green manure (Mwangi, 1995). Green manure is impractical and difficult because of small size of land being cultivated by SH farmers. Limited supply of organic matter is caused by the fact that not all SH farmers in Limpopo own livestock and most of those who do not own cattle do not have access to manure.

Application of inorganic fertilizers is the most feasible way of correcting nutrient deficiencies on farmers' fields, but due financial constraints, majority of the SH farmers in the province hardly apply fertilizers in their field crop production and even those who do apply it do so at levels much lower than the recommended rates.

The common recommended application of fertilizer given to resource-poor farmers in Limpopo Province is approximately 200 kg 2:3:2 (22) and 100 kg LAN (28) per hectare, an outlay in excess of R 900 at 2007/08 prices. With the recent rapid increase in fertilizer prices, most farmers find this level of investment too expensive and too risky given the unreliable rainfall and limited investment capacity for timely land preparation, sowing, and weed and pest control.

The International Crop Research Institute for Semi Arid Tropics (ICRISAT), an international research institute working on dry land farming, has developed an alternative fertilizer management system known as micro-dosing (Twomlow *et a*l., 2006). Extensive testing in Malawi and Zimbabwe in dry, drought-prone areas similar to Limpopo has shown that even small quantities of nitrogen fertilizer can give substantial benefits (Dimes and Kgonyane, 2005). South African soils are generally low in P, especially in the marginal soils, and therefore there is a need to also investigate the effects of small quantities of P, as well as N and P interactions.

The objective of this study was to contrast the growth and yield response of maize to low and recommended amounts of N and P across a rainfall gradient in Limpopo Province. The objective is based on the hypothesis that the potential increase in maize production with inputs of N and P fertilizer is largely attained at lower doses of N and P in drier regions than at current fertilizer recommendations.

4.2. Materials and Methods

Trial sites, experiment layout and treatments were similar to what is reported in chapter 3 of common materials and method. Cropping operations carried out at eight trial sites during the two seasons of field experimentation are shown in Table 4.1.

Table 4.1 Dates of cropping operations carried out at eight trial sites during the two seasons of field experimentation

Season	Site	Sowing	N split 1 (56 N kg ha^{-1})	N split 2 (top-dress)	Harvest
2006/07	Bokgaga	12/12/2006	12/12/2006	17/01/2007	19/04/2007
	Perskebult	15/12/2006	15/12/2006	01/01/2007	*
	Tshebela	06/12/2006	06/12/2006	26/01/2007	03/04/2007
	Phaudi	28/12/2006	28/12/2006	31/01/2007	04/05/2007
2007/08	Mafarana	12/12/2007	12/12/2007	17/01/2008	24/04/2008
	Mothiba	14/12/2007	14/12/2007	17/01/2008	30/04/2008
	Phaudi	13/12/2007	13/12/2007	16/01/2008	10/04/2008
	Perskebult	18/01/2008	18/01/2008	17/03/2008	13/06/2008

* = Not harvested

4.2.1 Grain yield

Data for grain were taken from three middle rows by center 3 meter of row at harvesting. That is, the border area was one row on each side of the yield sample area. Grain yield samples of the plants were taken from 8.1 m^2 area from each plot at all sites. The harvest was weighed in the field using a tripod-held suspension weighing balance. Five cobs were randomly sub-sampled and placed in a brown bag weighed fresh on a battery scale and taken to the laboratory for oven drying.

4.2.2 Total biomass yield

Above ground plant samples were taken at tasselling/silking and harvesting at all sites. Dry matter samples of the plants were taken from a 2.7 m^2 area from each plot at tasselling and 8.1 m^2 at harvest across all sites. Maize plants were cut at ground level to determine aboveground dry matter. Three plants were randomly sub-sampled and cut into smaller portions and placed in a brown bag weighed fresh on a battery scale and taken to the laboratory for oven drying. Maize plant materials were oven dried at 50 - 55 ^oC until they were completely dry. The dry plant material samples were also weighed.

4.2.2 Harvest index

Harvest index (HI) of maize was determined by randomly sub-sampling five cobs and three plants from the main sample at physiological maturity. Both (cobs and stover) were dried at 50-55^oC until they were completely dry. Cobs were shelled when completely dry and weighed separately for determination of grain yield.

$$\text{HI was calculated as: HI} = \frac{\text{Grain yield} \times 100}{\text{Total biomass yield}}$$

Total biomass yield comprised of the whole above-ground plant mass (leaves, stalks, unshelled ear, husks and grain)

4.2.3 Shelling percentage (%)

Shelling % of maize was determined by randomly sub-sampling five cobs from the main sample at physiological maturity. Five cobs were oven dried at 60^oC until they were completely dry. Cobs were shelled when completely dry and weighed separately for the calculation of shelling percentage. The grain weight is reported at oven dry weight and un-adjusted (to 12.5%) to facilitate comparison of grain yield predicted by APSIM.

Shelling percentage of maize was calculated as*:*

$$\text{Shelling \%} = \frac{\text{Weight of shelled grain (kg)} \times 100}{\text{Weight of unshelled cob (kg)}}$$

4.2.4 Agronomic nitrogen use efficiency

Crop N uptake from plots that received N fertilizer was compared with unfertilized control plots to calculate how much of the fertilizer was used by the crop.

Agronomic nitrogen efficiency was calculated as:

$$\text{AUE} = \frac{\text{N treatment- control (kg/ha)}}{\text{N treatment applied (kg/ha)}}$$

4.2.5 Rainfall use efficiency (RUE)

Rainfall use efficiency (RUE) is defined by Ehdaie (1995) as the ratio of grain yield to total water used. The grain yield (kg) from each N level was used. The total water was derived from in crop rainfall in mm recorded from on-farm rain gauges and nearest weathers stations.

Rainfall use efficiency was calculated as:

$$\text{RUE} = \frac{\text{grain yield (kg)}}{\text{In crop rainfall (mm)}}$$

Where in crop rainfall is total rainfall between sowing date and harvest date

4.2.6 Data analysis

TBM and grain yield data were subjected to analysis of variance (ANOVA) using the General Linear Model procedure of Statistical Package for Social Science (SPSS statistics 17.0). Differences between treatment means were separated using the Least Significant Difference ($LSD_{0.05}$) procedure by using Genstat Discovery Edition 9.1 (*www.vsni.co.uk*)

4.3. Results

4.3.1 Site Characteristics

4.3.1.1 Soil Characterisation

The results of soil analyses done by SGS Agri-Laboratory (private laboratory) and ARC-Institute for Soil Climate and Water are shown in Table 4.2. Guidelines to the interpretation of soil analytical data are shown in Appendix 3. The soils are generally sandy with low CEC with the exception of Mafarana and Bokgaga which are within the eastern catena of the northern Drakensberg watershed and experience higher annual rainfall compared to the other sites that occupy the highveld west of the Drakensberg. The soils also have organic carbon of less than 1.0 % (low fertility) with the exception of Mafarana and Bokgaga. Mafarana had higher total nitrogen compared to other sites. Phosphorus was below approximate optimum values (Appendix 1) for maize at seven sites except Tshebela. Potassium levels were also analysed and were observed to be sufficient for plant growth with a minimum of 55 mg kg^{-1} and maximum of 173 mg kg^{-1} across sites. Tshebela, Bokgaga and Perskebult had slight lower pH values while Mafarana, Phaudi and Mothiba had acceptable pH value ranges for maize (Appendix 1).

The soils are well drained with good infiltration and an effective depth of up to 90 cm, which is ideal for maize production. However, due to the sandiness of six trial sites, sand with very low clay content, the soils have a low water holding capacity and have a greater chance of drying out relatively quickly. This limits crop growth, especially during the January and February dry spells which coincide with the critical growth stage of maize (tasselling).

Table 4.2 Soil pH and nutrient content across 8 sites at the beginning of the trials for two seasons

	2006/07				2007/08			
Parameter	Phaudi	Perskebult	Tshebela	Bokgaga	Phaudi	Perskebult	Mothiba	Mafarana
OC (%)	0.64	0.39	1.2	0.44	0.51	0.10	0.37	1.25
Total N (mg kg^{-1})	173	122	103	63	229	*	232	425
Ext P (mg kg^{-1})	3	3	34	1	4	4	6	2.4
NH_4^+ (mg kg^{-1})	17.24	10.03	10.60	10.15	3.18	*	2.85	4.39
$N0_3^-$ (mg kg^{-1})	9.38	0.79	4.04	2.21	8.33	*	2.39	4.5
Texture	SaLm	SaLm	LmSa	SaClLm	LmSa	Sa	SaLm	SaCl
pH (H_20)	5.64	4.98	4.94	5.18	5.89	5.18	5.83	6.3
K (mg kg^{-1})	173	122	103	63	115	66	71	55
CEC (cmol (c) kg^{-1})	3.15	2.53	2.24	8.55	2.96	2.37	2.95	7.62

Key: * = not measured
SaLm = Sandy Loam
Sa = Sandy
SaCl = Sandy Clay
SaClLm= Sandy Clay Loam
LmSa = Loam Sandy
CEC = Cation Exchange Capacity
OC = Organic Carbon
EXT = Extractable

4.3.1.2 Rainfall

The 2006/07 seasonal rainfall totals for Phaudi, Tshebela and Bokgaga were 150, 262 and 494 mm, respectively (Table 4.3). Perskebult was abandoned because of post-sowing moistures stress and poor crop establishment. There was a low moisture status in Phaudi especially during silking and tasselling stages, and the rains terminated early. This translates to 113 % lower than the long term average rainfall at Phaudi. The crops suffered terminal moisture stress and there was no grain filling. Tshebela received 65 % less seasonal rainfall than the long term averages. At Bokgaga, seasonal rainfall was 51 % less compared to the long term average, however crops received the bulk of the rainfall (90 %) during sowing to tasselling. The low rainfall and poor distribution resulted in poor response to tested fertilizer factors, and very low average maize yields (777 kg ha^{-1}) in the 2006/07 season

The 2007/08 seasonal rainfall totals for Phaudi, Perskebult, Mothiba and Mafarana were 266.7, 444.9, 467.8 and 786.1 mm, respectively (Table 4.3). This translates to 32% and 8% higher than the long term averages at Perskebult and Mothiba, respectively. At Phaudi, seasonal rainfall was 25% less compared to the long term average. At Mafarana, seasonal rainfall compared very well with the long term average with a difference of only 5 %. The rainfall data in Mafarana showed a comparatively higher concentration in the first two months of the 2007/08 growing season while Perskebult reflected higher rain in November 2007. The peak at Mothiba was in March, whereas at Phaudi it was in November and December 2007. Due to the early peak and a drop during February and March at Phaudi, crop growth was adversely affected.

Both Phaudi and Mafarana received 35 % of the total rain, before sowing, while Perskebult and Mothiba received 60 % and 32 %, respectively, for the same period. Perskebult trial was planted very late in the season. From planting to tasselling, Mothiba and Mafarana obtained 42 % and 50 % respectively, while Phaudi and Perskebult received 48 % and 27 %, respectively, of the seasonal

rainfall totals. The rainfall percentages from tasselling to harvesting were 26, 17, 15 and 13 % for Mothiba, Phaudi Mafarana and Perskebult, respectively, of the total seasonal rainfall.

4.3.1.3 Temperature

The 2006/07 seasonal temperatures are shown in (Table 4.3). Perskebult and Tshebela had comparable seasonal maximum and minimum temperatures but Phaudi and Bokgaga had higher maximum and minimum temperatures. The 2006/07 season was generally hotter than the 2007/08 season and completely different from the long term seasonal temperature. All sites had higher seasonal maximum and minimum temperatures compared to long term seasonal temperatures (Table 3.1).

The 2007/08 seasonal maximum and minimum temperatures for Phaudi, Perskebult and Mothiba had comparable ranges but Mafarana had much higher maximum and minimum temperatures (Table 4.3). Minimum seasonal temperature was 1^0C lesser than the long term minimum temperatures of 11.9^0C at Mothiba (Table 3.1), while the maximum temperatures was the same at 25.7^0C. At Mafarana, seasonal maximum temperature was similar compared to long-term temperature of 28^0C, whereas the minimum temperatures differed by less than 1^0C. Phaudi had comparable ranges of maximum and minimum temperatures with the long term temperatures of 27^0C and 13^0C. Maximum and minimum seasonal temperatures at Perskebult were 26.1^0C and 12.3^0C, respectively, and were both lower by 0.7^0C compared to long term temperatures of 26.8^0C and 13^0C, respectively.

Table 4.3 Meteorological data across eight sites during the trial period in the two seasons

	2006/07				**2007/08**			
Parameters	Phaudi	Perskebult	Tshebela	Bokgaga	Phaudi	Perskebult	Mothiba	Mafarana
Rain pre-sowing (mm) 01 Nov	34*	**	78*	13*	90.8	264.8	154.3	278.7
Rain Sowing - Tasselling (mm)	86*	**	153*	441*	130.2	120.8	193.9	399.3
Rain Tasselling-Maturity (mm)	30*	**	31*	40*	45.7	59.3	119.6	108.1
Totals for the growing season	**150 ***	****	**262***	**494***	**266.7**	**444.9**	**467.8**	**786.1**
Max.T (^{o}C) 01 Nov- 30 June	28.2	27.7	27.0	29.7	26.9	26.1	25.8	28.7
Min.T (^{o}C) 01 Nov- 30 June	13.4	12.5	12.6	17.2	13.4	12.3	10.9	16.9
Ave. T (^{o}C) 01 Nov- 30 June	20.8	20.1	19.8	23.4	20.1	19.2	18.4	22.8

* =Actual figures from on-farm rain gauges, others are taken from nearby (15-60 km) Meteorological Station records

** = Abandoned

Table 4.4. Mean monthly maximum and minimum temperatures during the 2007/2008 growing season at the four trial sites

	Phaudi		Perskebult		Mothiba		Mafarana	
Months	Max (^{o}C)	Min (^{o}C)	Max (^{o}C)	Min (^{o}C)	Max (^{o}C)	Min (^{o}C)	Max (^{o}C)	Min (^{o}C)
November	27.4	15.3	27.0	15.0	26.4	14.8	29.6	18.3
December	26.6	16.4	26.2	16.3	25.4	15.3	28.4	19.5
January	27.4	16.9	27.0	16.7	26.9	15.5	29.0	20.2
February	30.5	16.3	29.3	16.0	29.3	13.7	31.9	19.8
March	28.1	15.7	26.7	14.9	26.3	12.9	29.8	19.2
April	26.6	10.7	25.7	8.9	25.1	6.8	27.8	14.3
May	25.3	9.8	24.5	6.8	24.2	5.1	27.2	13.3
June	23.4	6.4	22.5	3.6	22.4	3.2	25.5	10.9

4.3.2 Crop yields

4.3.2.1 General performance

On-farm trials were conducted at four sites in 2006/07. Final yield results were disappointing, however. One site (Perskebult) was abandoned because of post-sowing moisture stress and poor crop establishment. Another (Tshebela) was re-planted but seed loss by birds resulted in highly variable plant stands. The third (Phaudi) was planted late and suffered terminal moisture stress and no grain yield or biomass is presented. The fourth (Bokgaga) was harvested for grain and biomass and the results showed significant treatment differences and are presented in Tables 4.9 and 4.10. Grain yield at Bokgaga and TBM at Bokgaga and Phaudi were very low due to general poor rainfall distribution.

On-farm trials were repeated at four sites in 2007/08 and three of four sites were harvested for grain and biomass yield. The fourth (Phaudi) again suffered terminal moisture stress and was harvested for TBM only. The yields this season were better than average farmer yields but still relatively low growth with above average rainfall.

There were no response to P application or were there N x P interaction on grain yield and TBM at all sites. Grain yield and TBM were only significantly affected by nitrogen rates.

4.3.2.2 Phosphorus response

There were no grain and total biomass yield response to phosphorus application rates despite the low soil P tests across all sites (Fig 4.1 and 4.2). There was also no interaction between nitrogen and phosphorus on grain and total biomass yield for both seasons at all sites.

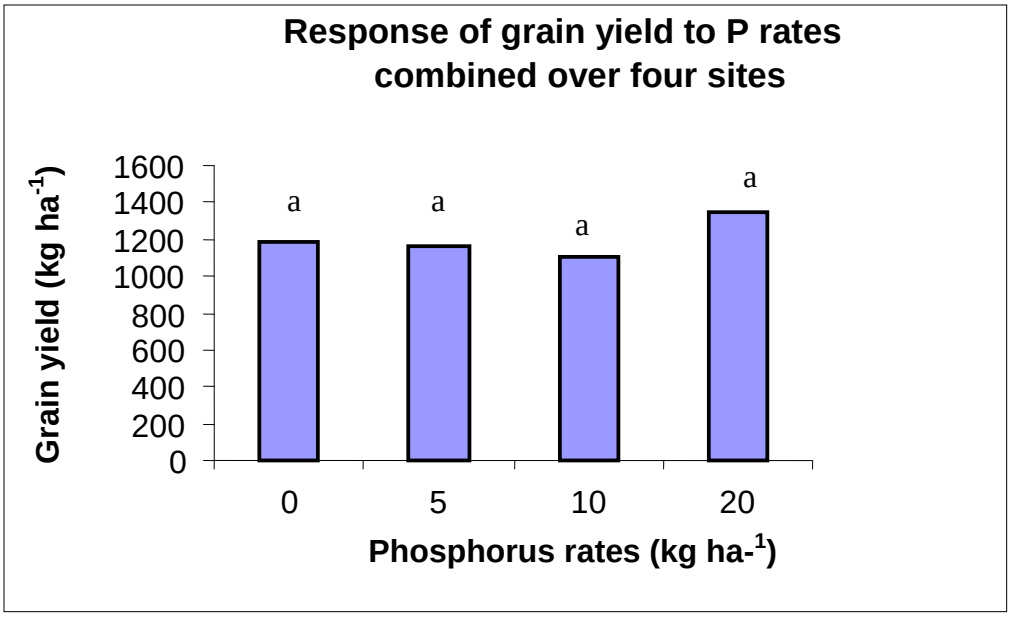

Fig. 4.1 Grain yield response to phosphorus application rates combined over four sites in 2006/07 and 2007/08 seasons. Bars followed by the same letter are not significantly different from each other at 5% level

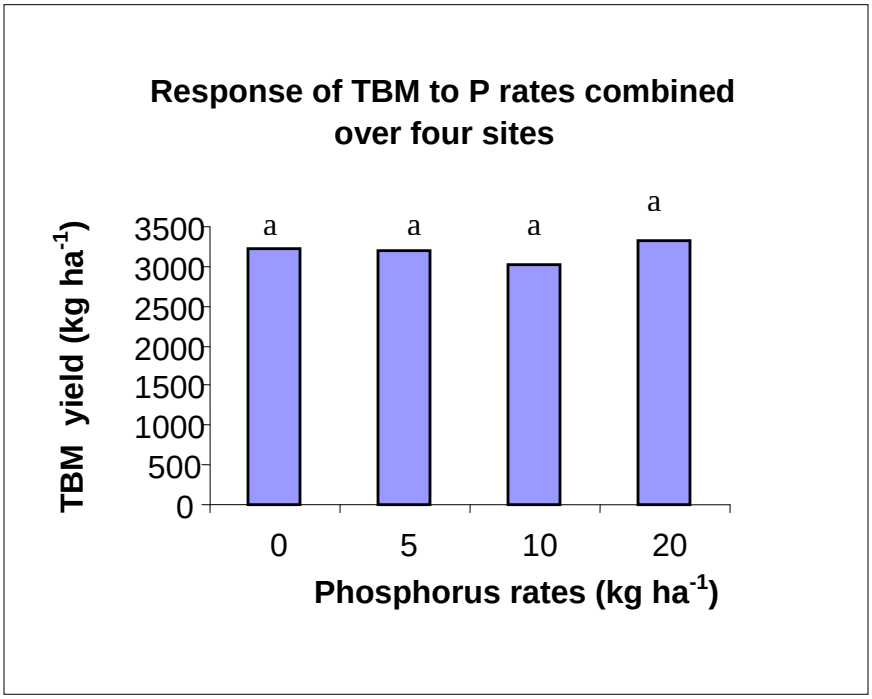

Fig. 4.2. Total biomass response to phosphorus application rates combined over five sites in 2006/07 and 2007/08 seasons. Bars followed by the same letter in the same column are not significantly different from each other at 5% level

4.3.2.3 Nitrogen response

There were significant differences of grain and total biomass yield to nitrogen application rates over the four sites (Table 4.5 and 4.8).

4.3.2.3.1 Grain yield

Grain yield was affected by the rates of nitrogen application (Table 4.5). These effects were statistically significant ($P < 0.05$) for Bokgaga, Perskebult and Mothiba. However, there was no significant difference in grain yield between treatments at Mafarana. The most responsive site was Perskebult (780 kg ha^{-1}) followed by Bokgaga (590 kg ha^{-1}) and Mothiba (520 kg ha^{-1}). The highest grain was produced with 56 kg N ha^{-1}, while the lowest grain was produced in the treatment that received no N fertilizer at all sites. In general, a progressive increase in grain yield was measured with incremental levels of N applied. Across the sites, grain yield ranged from 527 to 1351 kg ha^{-1} at zero kg N ha^{-1} and from 1146 to 1870 kg ha^{-1} at 56 kg N ha^{-1} level. The response of grain yield was more pronounced with the first increment than the second increment of N application at Mothiba and Perskebult. It clearly shows that the response of grain yield to N levels was different for every site with Bokgaga and Perskebult having produced relatively lower grain yields as compared to Mothiba and Mafarana. At Mothiba there was no response to additional N inputs above 14 kg N ha^{-1} level. The application of 14 kg N ha^{-1} was significantly superior to zero kg N ha^{-1} , and 14 kg N ha^{-1} was on par with the 28 kg N ha^{-1} and 56 kg N ha^{-1} application at this site. At Bokgaga the response of grain yield to N levels was more pronounced with the last increment than the first and second N application. The first and the last increment resulted in a more pronounced grain yield response at Perskebult.

Table 4.5. Maize grain yield response to nitrogen application rates at one location in 2006/07 and three locations in 2007/08 season

	Locations			
	2006/07	2007/08		
Nitrogen rates	Maize grain yield (kg ha^{-1})			
	Bokgaga	Perskebult	Mothiba	Mafarana
0	558b	527c	1351b	1185a
14	626b	846b	1765a	1422a
28	778ab	799bc	1805a	1493a
56	1146a	1305a	1870a	1661a
SED	179.5	122.6	157.9	204.4
$LSD_{(0.05)}$	367.9	252.6	325.3	ns
CV (%)	56.6	34.6	22..8	34.8

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level

In 2006/07 and 2007/08 seasons, maize grain yield was significantly ($P<0.05$) affected by the nitrogen application rates (Table 4.6). A combined analysis over sites showed that the zero treatment produced less maize grain yields than other treatments. The 56 kg N ha^{-1} level produced more grain (1491 kg ha^{-1}) than other treatments. The 14 kg N ha^{-1} and 28 kg N ha^{-1} levels achieved similar maize grain yields. There was a substantial grain yield increase of 63 % from control to the highest treatment.

Table 4.6. Effects of nitrogen application rates on maize grain yield in the 2006/07 and 2007/08 seasons – combined over sites

Nitrogen rates	Grain yield (kg ha^{-1})
0	911c
14	1177b
28	1218b
56	1491a
SED	88.7
LSD (0.05)	175.2
CV %	36.2

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level

4.3.2.3.2 Total biomass yield (TBM)

TBM was measured as an indicator of overall plant growth. The summary of TBM yield of each site at different N level ranges is shown in Table 4.7. The N application level did not significantly ($P<0.05$) influence the TBM yield at Mafarana. By contrast, in Bokgaga, Phaudi, Mothiba and Perskebult, there were significant differences ($P<0.05$) in TBM yield between N application rates. The most responsive site to N inputs was Perskebult (1330 kg ha^{-1}) followed by Bokgaga (1068 kg ha^{-1}). Similar to grain yield, the TBM yield increased with an increase in N applications, irrespective of the site. Across the sites, TBM yield ranged from 1764 to 3918 kg ha^{-1} at zero kg N ha^{-1} and from 2662 to 4580 kg ha^{-1} at 56 kg N ha^{-1} level. The response of TBM yield was more pronounced with the first increment than the second increment of N application at Bokgaga. The application of 14 kg N ha^{-1} was significantly superior to zero kg N ha^{-1}, and 14 kg N ha^{-1} was on par with the 28 kg N ha^{-1} and 56 kg N ha^{-1} application at Bokgaga. At Perskebult the response of TBM yield to N levels was more pronounced with the last increment than the first and second N application.

Table 4.7. Maize total dry matter yield response to nitrogen application rates at one location in 2006/07 season and four locations in 2007/08 season

	Locations				
	2006/07	2007/08			
Nitrogen rates	Total biomass yield (kg ha $^{-1}$)				
	Bokgaga	Perskebult	Mothiba	Mafarana	Phaudi
0	1764b	2110b	3918b	3071a	2209b
14	2402ab	2473b	4309b	3213a	2253b
28	2730a	2516b	4612a	3486a	2186b
56	2832a	3438a	4580a	3671a	2662a
SED	345.1	273	315.9	331.9	136.8
LSD $_{(0.05)}$	712.2	559.2	648	ns	397.1
CV (%)	34.8	25.4	17.8	24.2	20.4

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level.

Dry matter production at harvest responded significantly (P<0.05) to nitrogen rates combined over sites (Table 4.8). The lowest dry matter yield was obtained at zero kg N ha $^{-1}$ combined over all five sites. A combined analysis of the sites showed that fertilizer rates at 14 kg N ha $^{-1}$ and 28 kg N ha $^{-1}$ produced similar dry matter yields, and both rates produced more dry matter than the zero kg N ha $^{-1}$ which produced 2689 kg ha^{-1}. The highest dry matter yield of 3633 kg ha^{-1} was produced at the 56 kg N ha $^{-1}$. This is 35 % higher than the control treatment.

Table 4.8. Effects of nitrogen application rates on total biomass yield in the 2006/07 and 2007/08 seasons – combined over sites

Nitrogen rates	Total biomass yield (kg ha^{-1})
0	2689c
14	3124b
28	3322ab
56	3633a
SED	170.9
LSD (0.05)	337.6
CV %	26.2

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level

4.3.2.3.3 Harvest Index (HI)

The nitrogen application rates did not significantly (P<0.05) influence the HI of maize at Bokgaga, Mothiba and Mafarana. By contrast, at Perskebult, there were significant (P<0.05) differences in the HI between the application rates (Table 4.9). The 56 kg N ha $^{-1}$ rate exhibited a higher HI compared to other treatments.

Table 4.9. Maize harvest index response to nitrogen application rates at one locationin 2006/07 season and three locations in 2007/08 season

	Locations			
	2006/07	2007/08		
Nitrogen rates	(HI)			
	Bokgaga	Perskebult	Mothiba	Mafarana
0	0.225a	0.271b	0.365a	0.394a
14	0.228a	0.327ab	0.407a	0.421a
28	0.268a	0.315b	0.391a	0.416a
56	0.264a	0.371a	0.406a	0.420a
SED	0.028	0.02	0.02	0.026
LSD $_{(0.05)}$	ns	0.04	ns	ns
CV (%)	27.6	15.3	14.6	15.6

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level.

Harvest index responded significantly (P<0.05) to nitrogen rates combined over sites (Table 4.10). The lowest HI was exhibited at zero kg N ha $^{-1}$ combined over all four sites. A combined analysis of the sites showed that fertilizer rates at 14 kg N ha $^{-1}$ and 28 kg N ha $^{-1}$ attained similar HI, and both rates produced HI higher than the zero kg N ha $^{-1}$ which had a HI of 0.318. The highest HI achieved was 0.374 at the 56 kg N ha $^{-1}$.

Table 4.10. Effects of nitrogen application rates on harvest index in the 2006/07 and 2007/08 seasons – combined over sites

Nitrogen rates	Total biomass yield (kg ha^{-1})
0	0.318c
14	0.348b
28	0.345b
56	0.374a
SED	0.012
LSD (0.05)	0.025
CV %	18

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level

4.3.2.3.4 Shelling percentage and cobs per plant

Shelling % increased with the increase in nitrogen rates at Mothiba, Mafarana and Perskebult, whereas, at Bokgaga there was no significant increase. At Perskebult and Mafarana significant (P>0.05) increase occurred at 56 kg N ha $^{-1}$ while at Mothiba significant (P>0.05) increase occurred at 28 kg N ha $^{-1}$ (Table 4.11). Generally, Perskebult, detected lower shelling % compared to other three sites despite being significant different.

There N application level did not significantly (P<0.05) influence the number of cobs per plant Mafarana, Bokgaga and Mothiba (Table 4.12). By contrast, in Perskebult, there were significant differences (P<0.05) in the number of cobs per plant between N application rates and the significant increase occurred at 56 kg N ha $^{-1}$.

Table 4.11. Maize shelling percentage response to nitrogen application rates at one location in 2006/07 season and three locations in 2007/08 season

	Locations			
	2006/07	2007/08		
Nitrogen rates	Maize shelling (%)			
	Bokgaga	Perskebult	Mothiba	Mafarana
0	78.1a	73.9b	80.1b	79.1b
14	78.5a	75.2ab	81.4ab	81.9ab
28	78.4a	74.6b	82.4a	80.6ab
56	78.1a	76.2a	82.1a	82.2a
SED	1.4	0.7	0.8	1.2
LSD $_{(0.05)}$	ns	1.5	1.7	2.3
CV (%)	4.5	2.4	2.6	3.5

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level.

Table 4.12. Maize cobs per plant response to nitrogen application rates at one location in 2006/07 season and three locations in 2007/08 season

	Locations			
	2006/07	2007/08		
Nitrogen rates	Number of cobs per plant			
	Bokgaga	Perskebult	Mothiba	Mafarana
0	0.774a	1.001ab	0.945a	0.799a
14	0.759a	0.999ab	0.982a	0.910a
28	0.896a	0.951b	1.020a	0.849a
56	0.835a	1.158a	1.008a	0.874a
SED	0.107	0.089	0.041	0.073
LSD $_{(0.05)}$	ns	0.183	ns	ns
CV (%)	32.1	21.4	10.2	20.7

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level.

Shelling % responded significantly (P<0.05) to nitrogen rates combined over sites (Table 4.13). The lowest shelling % was shown at zero kg N ha $^{-1}$ combined over all four sites. A combined analysis of the sites showed that fertilizer rates at 14 kg N ha $^{-1}$, 28 kg N ha $^{-1}$ and 56 kg N ha $^{-}$ attained similar shelling %, and all three rates produced shelling % higher than the zero kg N ha $^{-1}$ which had a shelling % of 77.8. The highest shelling % achieved was 79.6 at the 56 kg N ha $^{-1}$.

Cobs per plant responded significantly (P<0.05) to nitrogen rates combined over sites (Table 4.13). In general, a progressive increase in the number of cobs per plant was obtained with incremental levels of N applied. The lowest number of cobs per plant was shown at zero kg N ha $^{-1}$ combined over all four sites. A combined analysis of the sites showed that fertilizer rates at 0 kg N ha $^{-1}$, 14 kg N ha $^{-1}$ and 28 kg N ha $^{-}$ attained similar cobs per plant, and all three rates produced cobs per plant lower than the 56 kg N ha $^{-1}$ which had 0.97 cobs per plant. The lowest number of cobs per plant achieved was 0.88 at zero kg N ha $^{-1}$.

Table 4.13. Effects of nitrogen application rates on shelling percentage and cobs/plant in 2006/07 and 2007/08 seasons – combined over sites

Nitrogen rates	Shelling %	Cobs/plant
0	77.8b	0.88b
14	79.3a	0.91b
28	79.0a	0.93b
56	79.6a	0.97a
SED	0.59	0.04
LSD (0.05)	1.16	0.08
CV %	3.7	21.7

SED =Standard errors of differences
LSD= Least significant difference
CV (%) = Coefficient of variation
ns = Non significant (P≤0.05)
Means followed by the same letter in the same column are not significantly different from each other at 5% level

4.3.2.3.5 Agronomic Nitrogen Use Efficiency (ANUE)

ANUE tended to be greater at Perskebult and Mothiba at lower N levels (Table 4.14) . ANUE decreased with an increase in N treatment level at Mothiba and Mafarana, while at Bokgaga it increased with increase in N treatment level.

Table 4.14. Maize grain agronomic nitrogen use efficiency response to nitrogen application rates at one location in 2006/07 season and three locations in 2007/08 season

	Locations			
	2006/07	2007/08		
Nitrogen rates	(kg grain/ kg N applied)			
	Bokgaga	Perskebult	Mothiba	Mafarana
0	n/a	n/a	n/a	n/a
14	4.9	22.8	29.6	16.9
28	7.9	9.7	16.2	11.0
56	10.5	13.9	9.3	8.5

n/a = Not applicable

4.3.2.3.6 Rainfall Use Efficiency (RUE)

Rainfall use efficiency (RUE) was higher at sites which received low rainfall i.e. Perskebult and Mothiba and lower at sites which received relatively high rain fall i.e. Bokgaga and Mafarana (Fig. 4.3). RUE was improved by the application of nitrogen fertilizer across all sites. At Bokgaga, RUE ranged from 1.13 kg mm^{-1} at 0 kg N ha^{-1} to 2.21 at 56 kg N ha^{-1} compared to Perskebult which had a range of 7.22 kg mm^{-1} at 0 kg N ha^{-1} to 17.17 kg mm^{-1} at 56 kg N ha^{-1}.

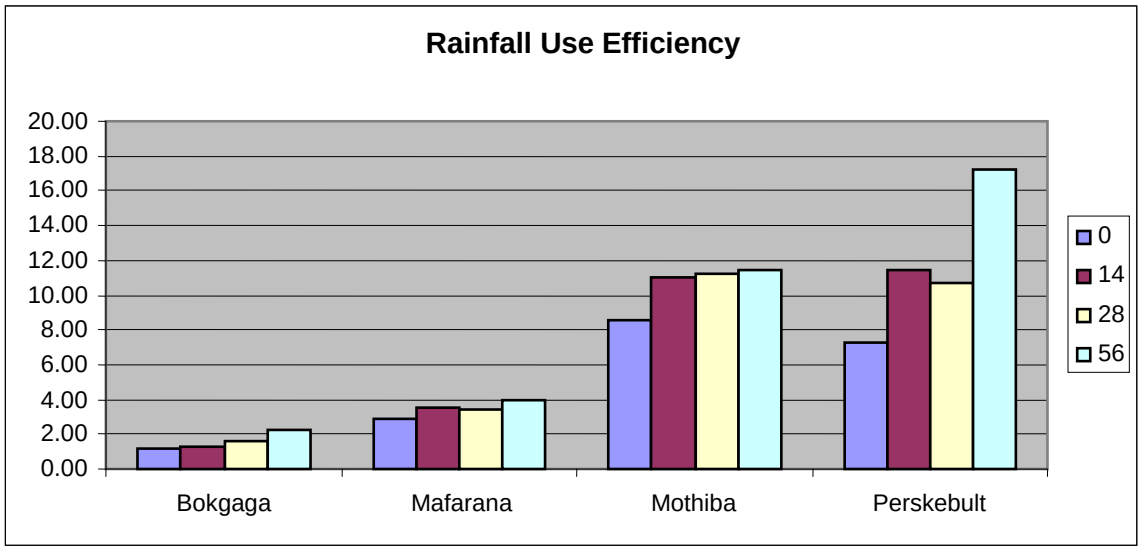

Fig 4.3. Rainfall use efficiency at four rates of nitrogen application rates at one location in 2006/07 season and three locations in 2007/08 season

4.4 Discussion

4.4.3 Grain yield and total biomass yield (TBM)

There was no N x P interaction response at lower application rates at all sites in both seasons, despite low levels of P in the soil and response of grain yield and TBM to N application rates in most sites.

The results indicated that there is no yield advantage in application of low rates of phosphorus at all sites in both seasons despite low levels of P in the soil. The phosphorus application rates studied resulted in the same yield at all the sites. Research conducted on communal fields of Zimbabwe indicated that there are problems with P response even on P deficient soils (Agronomy institute, 1989/90; Hikwa *et al*., 1990). This can be attributed to low rates of P applied and low and poorly distributed rainfall during the season (Fig. 4.1). Hikwa *et al***,** (1990) further stated that the response to fertilizer depends primarily on the moisture availability and inherent fertility of the soil. This is in agreement with what was reported by Jonga, *et a*l., (1996) that grain yields were similar with basal fertilizer, but there was a general increase in grain yield as the basal application rate increased where rainfall was low but better distributed. This is also supported by the work done by Ncube *et al.,* (2009) that there was a strong interaction of nutrient response to seasonal rainfall and its distribution. The low pH can limit maize response to applied fertiliser. For example, Eghball *et al.*, 1990 state that, applied P can be precipitated and made unavailable to the crop in acidic soils.

Notwithstanding the numerous reports cited above, the SH farmer still need to manage P either by regular application of low rates or by regular addition of organic manure given that the yield attained in the study show possible extraction of 20 kg P/crop. This is important for sustainability of the soil resource, and in turn, farmer livelihoods.

There was a response of grain yield to N fertilizer application across sites except for Mafarana which had inherent high soil organic carbon and therefore high soil

N supply. The general high yields at Mafarana can be attributable to higher temperature, soil organic carbon and rainfall effects. The high level of N (56 kg N ha $^{-1}$) at Perskebult out yielded the preceding N level (28 kg N ha $^{-1}$) by 63 %. One explanation is split application of high N rate interacting with rainfall distribution. For example, the application of 28 kg N ha $^{-1}$ at sowing of 56 kg N ha $^{-1}$ treatment meant that maize was able to utilize the full profile of moisture existing at sowing, whereas the 0, 14 and 28 kg N ha $^{-1}$ treatments had insufficient N supply to exploit the available moisture until top-dressing. This explanation is consistent with the TBM yield. Mothiba experienced an average (semi-dry) rainfall season (Table 4.3). The similar grain yields produced by 14, 28 and 56 kg N ha $^{-1}$ treatments at Mothiba, suggest that there maybe no yield advantage during semi-dry years in applying 28 and 56 kg N ha $^{-1}$. The application of 14 kg N ha $^{-1}$ proved to be more economic under such conditions that prevail in most areas of the Limpopo province. The maize response to highest N rate only at Bokgaga was again attributed to split application, but TBM yield at this site is not consistent with this explanation.

The total biomass (TBM) response to N inputs at Bokgaga is attributed to high in-crop rainfall and at Perskebult to low soil organic carbon (low N supply).TBM at Mafarana did not respond to N inputs and this is attributable to high soil organic carbon. The similar TBM yields produced by 14 kg N ha $^{-1}$ and 28 kg N ha $^{-1}$ at Phaudi is attributed to low and poorly distributed rainfall that was experienced during the latter parts of the season (Table 4.3).

4.5 Conclusion and recommendation

There was no yield response to applied phosphorous application rates despite the low soil P tests across all sites. There was a difference in maize yields between plants receiving N rates and those receiving no N application. Regarding the importance of nitrogen, application of nitrogen is required for improved maize growth and grain yields in the semi arid areas. An application rate of 14 kg N ha^{-1} achieved similar yields to that of 28 and 56 kg N ha^{-1} during the semi dry season. However, under high soil organic carbon (high fertility) and high rainfall conditions the low levels of 14 to 56 kg N ha^{-1} may not outperform 0 kg N ha^{-1}. Split application of high N (56 kg N ha^{-1}) rate interacting with rainfall distribution, enabled maize plant to utilize the full profile of moisture existing at sowing, whereas the 0, 14 and 28 kg N ha^{-1} treatment had insufficient N supply to exploit the available moisture until top-dressing, hence high yields in Bokgaga and Perskebult.

Subsequent studies should focus on demonstration trials on farmers' fields where large blocks of maize, fertilized at 14 kg N ha^{-1} are compared with unfertilized controls under semi arid conditions. An N rate of 14 kg ha^{-1} can be recommended for semi-arid environments, especially in the dry seasons for the farmers who never used fertilizers before. However, the use of simulation models can aid in making final recommendations on long term nitrogen fertilization.

5. EVALUATION OF AGRICULTURAL PRODUCTION SYSTEM SIMULATOR (APSIM) TO SIMULATE RESPONSE TO LOW INPUTS OF NITROGEN AND PHOSPHORUS

5.1 Introduction

In semi-arid regions, high rainfall variability presents a big challenge to rain-fed SH agriculture. Sivakumar (1992) suggested that reduced crop yields and total crop failure is common in semi-arid farming systems. However, high crop yields cannot be maintained in growing seasons with above average rainfall also due to poor soil fertility constraints of the predominantly marginal soils on the SH farms.

Maize production dominates the smallholder farming system in Limpopo Province of South Africa, although crop yields in these systems are very low. Most of these farmers are located on infertile degraded soils, where nutrient deficiencies, predominantly N and P limit crop production (Whitbread and Ayisi, 2004). Because the price of fertilizer has increased in recent times, a stronger case for expanding low rates of N and P in climatically risky areas, as a means of increasing N and P inputs into these cropping systems is emerging. This process can be fast-tracked by the use of simulation models. These models will add value to the field experimentations by providing a means by which the observed technology responses can be extrapolated across soils, seasons and crop management options.

Some of the simulation models that are available include PUTU, BEWAB, CERES-Maize and only a few producers operate their own system. The ARC-Roodeplaat has developed the SWB ("Soil Water Balance") model in association with the University of Pretoria that is modified for the irrigation scheduling of potatoes under local conditions (Steyn, 1999). However, the Agricultural Production Simulator (APSIM) model is a well tested model that provides reasonably accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst addressing long-term resource

management issues in farming systems (Keating et al., 2003). APSIM is considered to be one of the most appropriate models for use in tropical soil and crop management (Delve and Probert, 2004). The model is useful in capturing the interactions between climatic conditions, soil types and nutrient dynamics in cereal-based farming systems in Africa and Australia (Whitbread et al., 2004b).

Based on these strengths, APSIM was selected as an appropriate model to use in analysis of the effects of low dose of N fertilization under dry conditions. APSIM was first used to assist in explaining the observed experimental results. The objectives were to establish local performance of APSIM (version 6.1) cropping systems model by (i) Evaluating APSIM capability in predicting the observed site and seasonal effects of low N rates on maize grain and total biomass yields; (ii) using the model to quantify the long term payoffs to using low and recommended rates of nitrogen under highly variable rainfall conditions of Limpopo province.

5.2. Materials and Methods

Trial sites, experiment layout and treatments were similar to what is reported in the common materials and methods of chapter 3. The soil water data were analysed using Microsoft Excel.

5.2.1 Set up of the model

5.2.1.1 Soil and water characteristics

All simulations were started and initialised at day 305 (01 November) in the same year that the experiments were sown and using the data in Tables 5.1 – 5.4. The exception was simulation at the Perskebult site which was initialised on the sowing date of 18 January 2008. Otherwise, soil water and soil mineral N at sowing were determined by APSIM's simulation of the N and water balance in response to climate inputs from 01 November start date. The starting soil water and nitrogen levels were determined by calibrating the predicted grain yield of the N0 treatment to the observed yield for each site. (The measured mineral N in Table 4.2 was found to be unreliably high, consistently over-predicting the N0 treatment). Hence, at Mafarana and Mothiba, initialising plant available water on November 1st at 0mm (following the long dry season) and at 15 and 20 kg mineral N ha^{-1} in the profile, gave good prediction of the observed grain yield for the N0 treatments. For the lighter textured soils at Bokgaga, Phaudi and Perskebult, initial soil water was set at 23, 33 and 38mm PAW in the profile (representing 40, 50 and 80% PAWC, 0-90cm) while starting mineral N was set at 6, 7 and 6 kg N ha^{-1}, respectively. As land preparation across sites involved tractor-mounted ploughing, surface plant residues were initialised at zero.

Simulations used actual rainfall data measured on-farm at Bokgaga (recorded by the extension officer), while other sites used nearby weather station data. Simulation using the farmer records for these sites resulted in persistent crop failures, suggesting farmers didn't record all rainfall events. A plant density of 2.3 plants per m^2 for Mothiba and Mafarana was used and 1.9 and 1.7 for Bokgaga and Perskebult respectively. Simulations were conducted assuming no weed

competition across sites. The APSIM model simulated maize yields until the crop was mature.

Measurements of crop lower limit (LL15) and drained upper limit (DUL), and the calculation of the plant available water capacity (PAWC) at four field sites, were undertaken using the methods described in Dalgleish and Foale (1998). The crop lower limit (LL15) measures the amount of water left in the soil at a suction of 15 bar and represent the lowest limit at which plant roots can remove soil water. DUL is the amount of water that is held by the soil after drainage has ceased and is equivalent to soil water content at field capacity. The difference between the DUL and the LL15 is the theoretical plant available water held by the soil (Whitbread *et al*, 2004b).

Table 5.1 Soil chemical and physical properties and initial values at Bokgaga site by soil depth

Layer number	**1**	**2**	**3**	**4**
Layer depth (cm)	0- 10	10-30	30-60	60-90
Bulk density (gcm^{-3})	1.5	1.4	1.3	1.3
SAT (mm/mm)	0.25	0.26	0.27	0.28
DUL (mm/mm)	0.19	0.2	0.22	0.24
Air-Dry weight (mm/mm)	0.085	0.1	0.153	0.195
LL (mm/mm)	0.1	0.12	0.153	0.195
SWCon (0-1)	0.7	0.6	0.5	0.5
FBiom (0-1)	0.04	0.015	0.01	0.01
Finert (0-1)	0.4	0.6	0.9	0.99
Organic carbon (%)	0.8	0.4	0.2	0.1
pH (H_20)	6.0	6.0	6.0	6.0
Initial SW (mm/mm)	19.00	19.22	15.30	19.50
NO3 (ppm)	1.146	0.573	0.287	0.143
NH4 (ppm)	0.206	0.103	0.052	0.052

* LL = Maize lower limit in all instances

Table 5.2 Soil chemical and physical properties and initial values at Mafarana site by soil depth

Layer number	**1**	**2**	**3**	**4**
Layer depth (cm)	0- 10	10-30	30-60	60-90
Bulk density (gcm^{-3})	1.5	1.4	1.3	1.3
SAT (mm/mm)	0.334	0.372	0.409	0.409
DUL (mm/mm)	0.23	0.25	0.26	0.27
Air-Dry weight (mm/mm)	0.08	0.12	0.17	0.2
LL (mm/mm)	0.12	0.15	0.17	0.2
SWCon (0-1)	0.4	0.3	0.2	0.2
FBiom (0-1)	0.03	0.015	0.01	0.01
Finert (0-1)	0.4	0.6	0.9	0.99
Organic carbon (%)	0.72	0.61	0.42	0.29
pH (H_20)	6.0	6.0	6.0	6.0
Initial SW (mm/mm)	12.00	15.00	17.00	20.00
NO3 (ppm)	2.292	1.146	0.573	0.287
NH4 (ppm)	1.031	0.515	0.258	0.781

* LL = Maize lower limit in all instances

Table 5.3 Soil chemical and physical properties and initial values at Mothiba site by soil depth

Layer number	**1**	**2**	**3**	**4**
Layer depth (cm)	0- 10	10-30	30-60	60-90
Bulk density (gcm^{-3})	1.6	1.5	1.4	1.4
SAT (mm/mm)	0.2	0.22	0.25	0.28
DUL (mm/mm)	0.12	0.13	0.14	0.15
Air-Dry weight (mm/mm)	0.03	0.05	0.07	0.073
LL (mm/mm)	0.05	0.06	0.07	0.073
SWCon (0-1)	0.8	0.6	0.5	0.5
FBiom (0-1)	0.04	0.02	0.01	0.01
Finert (0-1)	0.4	0.6	0.9	0.99
Organic carbon (%)	0.45	0.36	0.37	0.38
pH (H_20)	6.0	6.0	6.0	6.2
Initial SW (mm/mm)	5.00	6.00	7.00	7.30
NO3 (ppm)	2.344	1.562	1.172	0.390
NH4 (ppm)	0.781	0.417	0.298	0.298

* LL = Maize lower limit in all instances

Table 5.4 Soil chemical and physical properties and initial values at Perskebult site by soil depth

Layer number	**1**	**2**	**3**	**4**
Layer depth (cm)	0- 10	10-30	30-60	60-90
Bulk density (gcm^{-3})	1.6	1.6	1.5	1.5
SAT (mm/mm)	0.2	0.22	0.25	0.263
DUL (mm/mm)	0.12	0.13	0.16	0.18
Air-Dry weight (mm/mm)	0.02	0.04	0.109	0.14
LL (mm/mm)	0.04	0.05	0.12	0.14
SWCon (0-1)	0.7	0.7	0.7	0.7
FBiom (0-1)	0.03	0.02	0.02	0.01
Finert (0-1)	0.4	0.6	0.75	0.9
Organic carbon (%)	0.5	0.3	0.25	0.2
pH (H_20)	6.0	6.0	6.0	6.2
Initial SW (mm/mm)	10.4	11.4	15.20	17.20
NO3 (ppm)	0.836	0.557	0.279	0.139
NH4 (ppm)	0.248	0.050	0.049	0.049

* LL = Maize lower limit in all instances

5.2.1.2 Climate parameters

Weather information (daily rainfall, temperature and radiation) was collected from Agricultural Research Council, Institute for Soil, Climate and Water (ARC-ISCW) weather stations. Actual rainfall data was also obtained through farmer recording using on-farm rain gauges. The most reliable on-farm rainfall data was from Bokgaga and was used in the simulation. For the other three sites, daily rainfall data from the nearest station were used. The climate records used for APSIM calibration was from 01 November 2006 to 30 June 2008.

5.2.1.3 Crop parameters and management

APSIM model contains description of a medium hybrid variety Pan 6479 which is commonly used by most SH farmers in Limpopo province. The same maize variety was planted in all experiments and the genetic coefficients have been described for the APSIM model (Dimes and Carberry, 2008). The variety is drought tolerant and recommended for dry areas of South Africa.

The simulations at all sites and seasons were according to the actual sowing dates, the timing of N application and management information. There was no attempt to include weeds in the model simulations and it was assumed during field experimentation the weed population was always kept low and did not limit plant growth.

5.2.2 Long term simulation

For the long term simulations, Mafarana and Perskebult soil descriptions were used in this study (Tables 5.2 and 5.4). The 30 year climatic records (1975-2005) obtained from both Polokwane station 30630 and Letsitele station 19935 were used in the long term simulation. These two weather stations were closest to the two trial sites. The following combination of soil description, climate and N rates as used in field experiments were evaluated in long term simulation:

(i) Letsitele climate, clay loam soil plus four N rates (0, 14, 28 and 56 $kgha^{-1}$)

(ii) Letsitele climate, sand soil plus four N rates (0, 14, 28 and 56 $kgha^{-1}$)

(iii) Polokwane climate, clay loam soil plus four N rates (0, 14, 28 and 56 $kgha^{-1}$)

(iv) Polokwane climate, sand soil plus four N rates (0, 14, 28 and 56 $kgha^{-1}$)

Top dressing with LAN (28) was done at 35 days after sowing in both sites and soil types. The highest N rate was applied in two applications, 50% each at sowing and 35 days after sowing. Each year, the maize crop was sown between 25 November and 15 January when at least 20 mm of rain was received over three consecutive days. A plant density of 2.5 plants per m^2 into 90 cm rows was used for the 30 year simulation. Soil water, soil nitrogen and surface organic matter were reset to the initial conditions on November 1st each year

5.2.3 Reporting frequency

The model was set to report the selected variables on daily time basis for the on-station experiments. Those reported variables for the on-station experiments were total biomass and grain yield. Total biomass and grain yields were expressed at 0% moisture content and are compared to observed yields at this moisture content. In the long term simulation, the model was set up to report variables at harvest stage of the maize crop. Only grain yield was reported in the long term simulation at two sites with two soil types.

The root mean square deviation (RMSD) and modeling efficiency (ME) values were calculated for comparison of observed and predicted data. The RMSD is the weighted difference between predicted and observed and is calculated as follows.

$RMSD = [1/n\sum(x_i - y_i)^2]^{0.5}$ *Equation 1*

where $\mathbf{x_i}$ is the observed yield, $\mathbf{y_i}$ is the predicted yield and **n** is the number of observations.

Modeling Efficiency (ME) was calculated as follows:

$$ME = \frac{\left[\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{n}\left(P_i - O_i\right)^2\right]}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}$$

Equation 2

where Pi and Oi are predicted and observed values respectively, Ō is observed mean value (Rinaldi et al., 2003).

5.3 Results

5.3.1 Grain yields

The seasonal rainfall totals for Bokgaga, Perskebult, Mothiba and Mafarana were presented in Chapter 4. A time series plot for the four sites shows simulated grain yield increase and the observed final yields for the four levels of nitrogen (Fig.5.1). At Mafarana and Bokgaga the maize plants reached grain filling and physiological maturity stages earlier than Perskebult and Mothiba. For example, Mafarana reached grain filling at 61 days after planting (DAP) followed by rapid growth phase until maturity while Mothiba only reached grain filling until 90 DAP. Seasonal effects on grain (RSMD = 292) production were simulated relatively well for the four trial sites with different rainfall patterns. The simulation predicted grain production well at Mafarana on all treatment levels which was average season in terms of rainfall received. At Bokgaga the model over predicted grain yield at 14, 28 and 56 kg N ha^{-1}. The model tended to over-predict the N response to grain yield at high levels (56 kg N ha^{-1}) at Mothiba and Perskebult.

The simulated and observed data for grain yield measurements during harvesting of maize at four sites were combined (Fig. 5.2). The simulated grain yields were generally well predicted with the exception of over prediction of three N rates plots at Bokgaga which are highlighted in three blank points. Of the four sites, Bokgaga was observed to have the most weed competition which was not included in the simulation. However, the overall r^2 = 0.758 is high even if is lower that the one for total biomass.

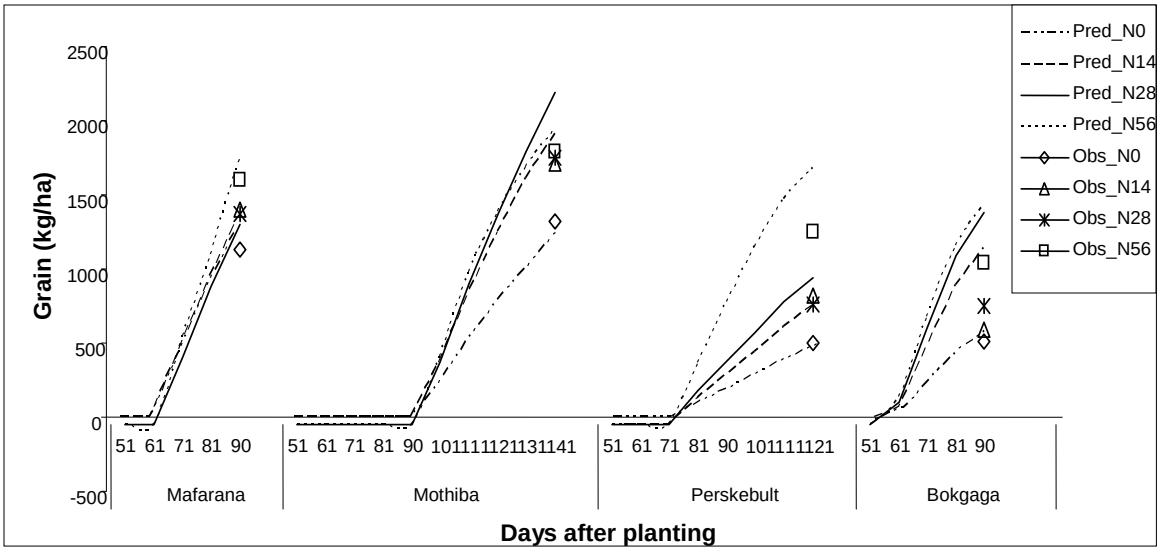

Fig 5.1 Observed and predicted grain yield from four nitrogen application rates over four sites

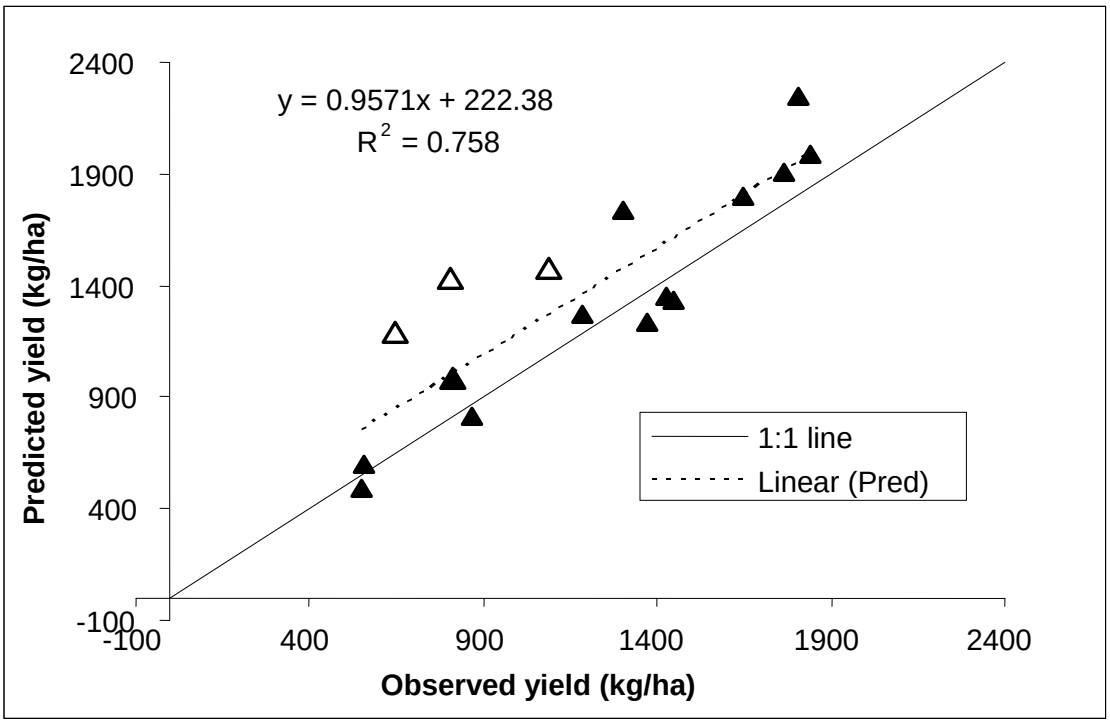

Fig. 5.2 The relationship between observed and predicted grain yields for different nitrogen application rates over four sites.

5.3.2 Total biomass yields

Seasonal effects on TBM (RSMD = 648) production were simulated relatively well for the four trial sites with different rainfall patterns. In general, the model predicted an increase in TBM with an increase in N rates (Fig. 5.3). The model has predicted the TBM yields well at all sites at 0, 14 and 28 kg N ha^{-1} levels. Like in the case of grain yield, once more, the model has over predicted high rates of N, and for TBM at all four sites (the four blank points are all the 56 kg N ha^{-1}). This shows that the model has a tendency to over predict the N response, especially at high levels, across sites, but the overall r^2 = 0.865 is higher.

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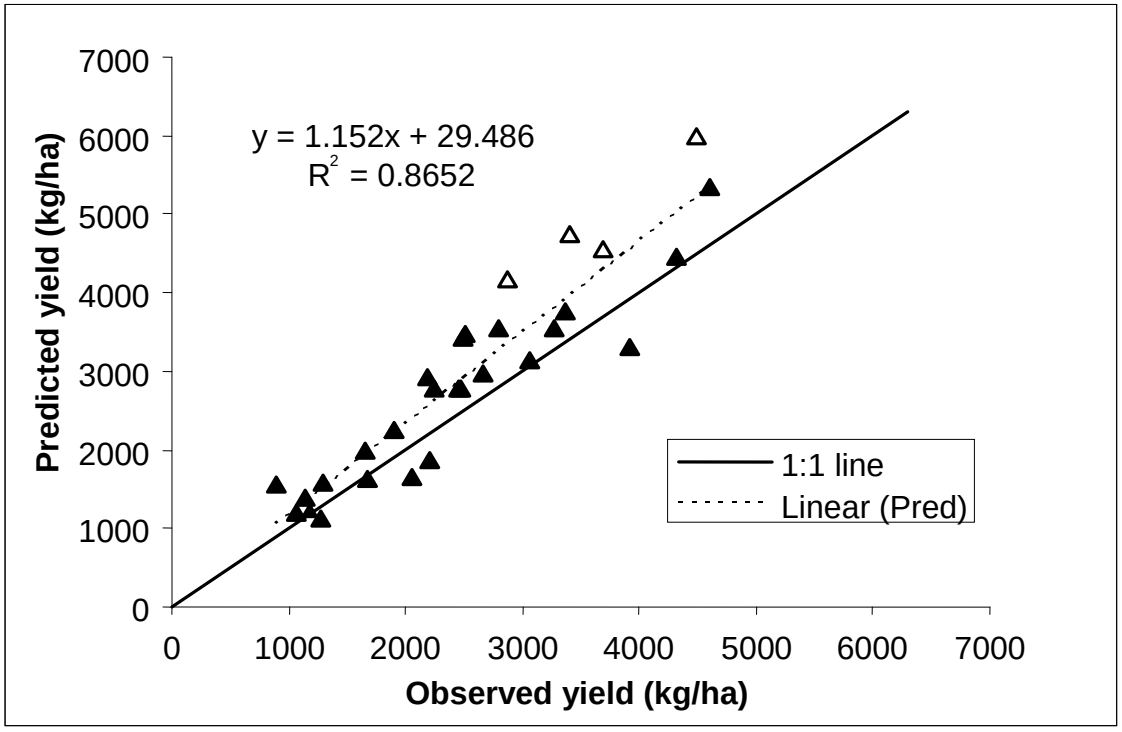

Fig. 5.3 The relationship between observed and predicted total biomass yields for different nitrogen application rates over four sites.

5.3.3 Long term simulated performance of maize production at Mafarana and Perskebult

The simulation of grain production without N inputs under dry land conditions both at Mafarana and Perskebult, using the weather data for the period 1975 to 2005 indicates extremely poor mean maize grain yields especially on sandy soil (Fig. 5.4). A mean yield of less than 500 kg ha^{-1} was realised both at Mafarana and Perskebult with zero kg N ha^{-1} on sandy soils. However, when simulations were done with the same zero N treatment on clay loam soils, mean grain yield improved, but was still below 1000 kg ha^{-1}. With the application of 14 kg N ha^{-1}, mean grain yields increased to 1500 kg ha^{-1} depending on the soil type (Fig 5.6). The model predicted the highest mean grain yield of 2000 kg ha^{-1} at 56 kg N ha^{-1} for both Mafarana clay loam soil and Perskebult clay loam soil. Soil type (clay loam) influenced grain yield positively than the climate.

The long term simulated yield at Mafarana and Perskebult from clay loam and sandy soil, respectively, is show in figures 5.5 and 5.6. There are some years where there are no yield differences at both sites regardless of the N level. Similarly there are years when there are no yield differences between applied N rates, but the difference exist between the zero rate and applied rates. With no fertilizer inputs, simulated yields reflect the current low levels obtained by farmers, while the addition of only 14 kg N ha^{-1} is sufficient to double yields in most seasons. Application of the recommended fertilizer rate (56 kg N ha^{-1}) can substantially further increase yield in some seasons, but the additional response is very uncertain compared to that for the lower application rate.

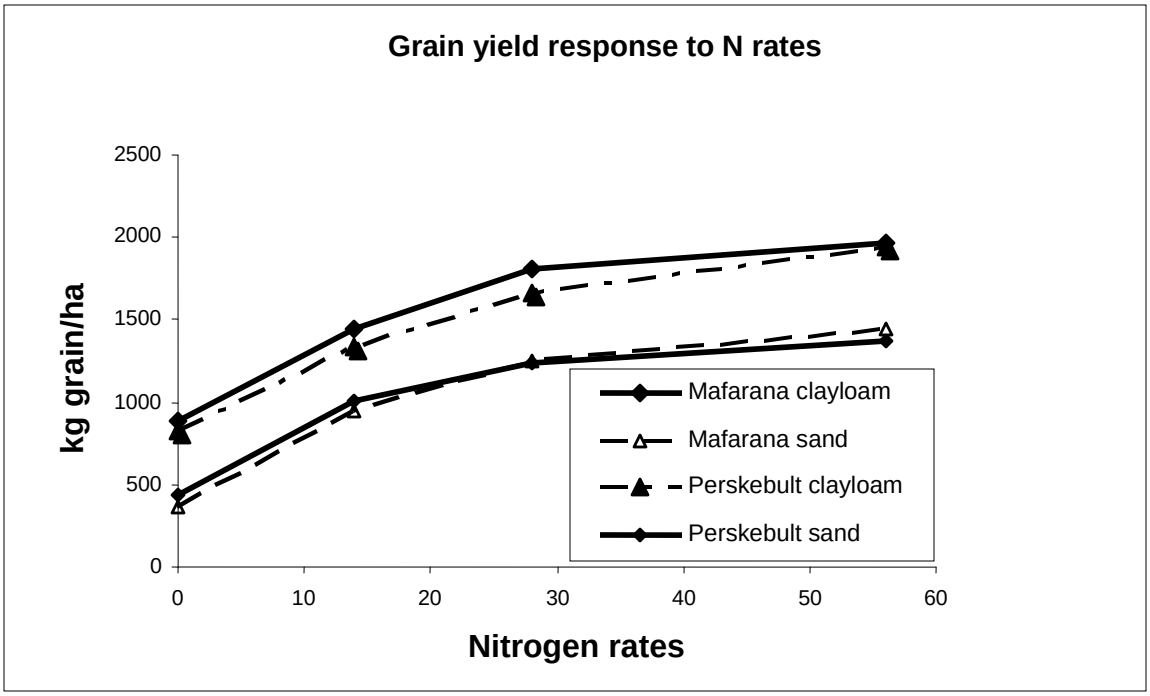

Fig. 5.4. Long term expected mean simulated grain yield response to different nitrogen rates (0, 14, 28 and 56 kg N ha^{-1}) in the clay loam and sandy soils for Mafarana and Perskebult sites

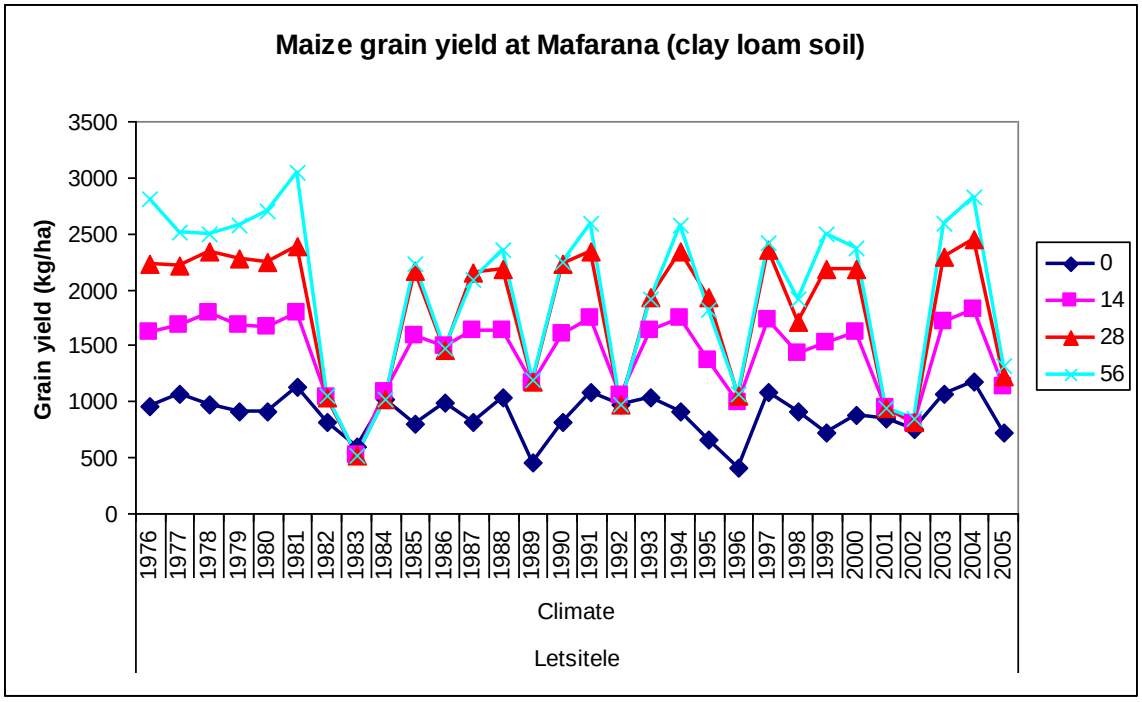

Figure 5.5. Long term simulated maize yield on a clay loam at Mafarana for climate records 1975 to 2005 and N inputs of 0, 14, 28 and 56 kg N ha^{-1}.

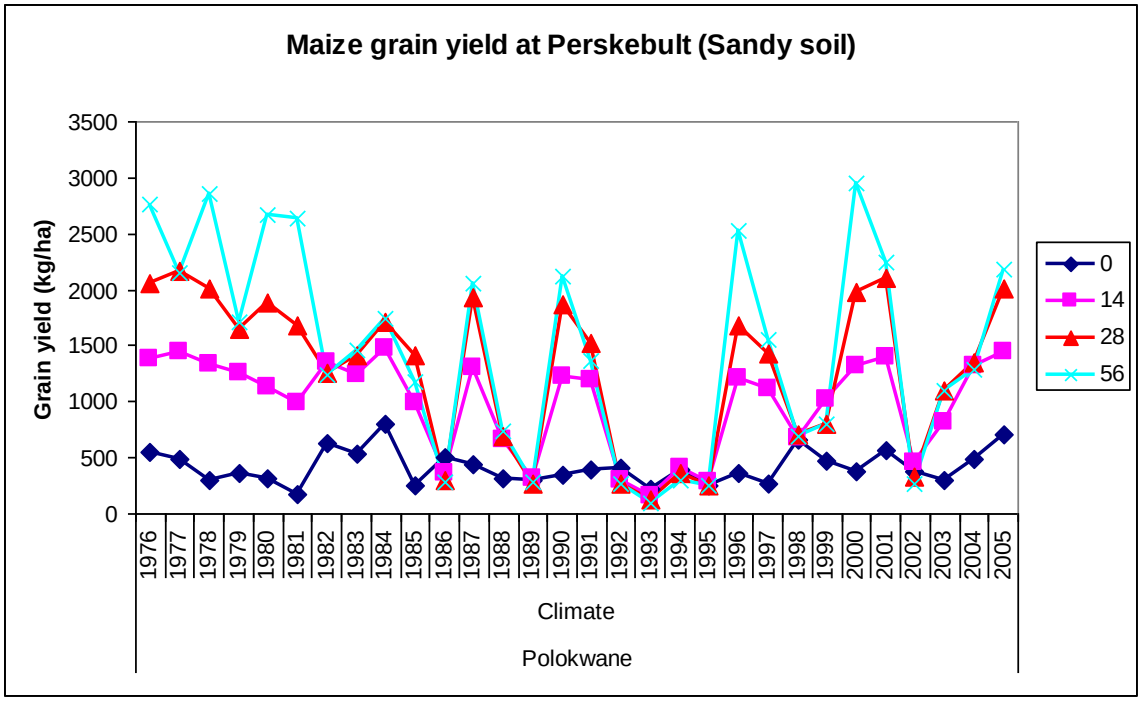

Figure 5.6. Long term simulated maize yield on sandy soil at Perskebult for climate records 1975 to 2005 and N inputs of 0, 14, 28 and 56 kg N ha^{-1}.

5.4. Discussion

5.4.1 Maize grain and TBM yield

APSIM has shown some capabilities in simulating maize response to N application rates. Simulation of maize yields was generally good over the four sites that were simulated; r^2 values were 0.758 and 0.865 for grain and total biomass yields, respectively (Fig 5.2 and 5.3). At Mafarana, the model predicted the maize response to N at all rates with high degree of precision. However, the model tended to over-estimate N rates in some instances, especially for the high rates of N in Bokgaga, Perskebult and Mothiba. It is not clear why this occurred, but this could be attributed to the presence of weeds at Bokgaga and Perskebult and the rainfall data from the University of Limpopo weather station seemed not to have been reliable for Mothiba site. The correct rainfall is probably somewhere between the farmer recorded and the weather station rainfalls. The patterns could also be partly due to the effect of soil characteristics

The time series with days after planting on the x axis clearly shows that the higher temperature affected the duration differences of the crop at the Bokgaga and Mafarana sites compared to Mothiba and Perskebult (Fig. 5.1). Perskebult site was also affected by late planting.

5.4.2 Long term performance of maize production

The field experiments described in this study were able to measure the response of maize yields to N rates in two seasons at four sites, the simulation was able to extend this to many different climatic conditions encountered between 1975 to 2005. The predicted grain yield suggests that the use of 14 kg N ha^{-1}, especially in the clay loam soils both at Perskebult and Mafarana is a good start for improving productivity in the maize dominated semi-arid cropping systems of Limpopo province. These results confirm earlier results conducted in the semi-arid areas of Zimbabwe, which are similar to the ones in Limpopo Province (Rusike et al., 2006; Mupangwa, 2008; Dimes et al., 2003) that the addition of one bag of ammonium nitrate (17 kg N ha^{-1}) was able to double yield in most

seasons. The clay loam soils have better prospects of giving yield than the sandy soils regardless of N levels. These results provide illustrative rationale for researchers and extension agents to re-align fertilizer recommendations for drier regions lower down the nitrogen response curve (Fig 2.4) in order to match farmers' investment capacity and risk aversion

5.5 Conclusions and recommendations

The results of this study show that APSIM maize model is able to predict the observed crop yields and give a long term impact of the N fertilizer application rates on maize yield. The model was able to simulate grain yield at Mafarana for all four N rates with a high degree of precision. For other three experimental sites, there were reasonable agreements between observed and predicted maize yield data sets with the exception of the highest N rate (56 kg Nha^{-1}) across sites. The observed maize yields at Bokgaga, Mothiba and Perskebult were affected by the presence of weed competition that was not simulated.

Long term simulations showed that maize productivity at both Mafarana and Perskebult under semi-arid conditions can be improved significantly through addition of N. However, the significant improvement was more evident on the clay loam soil. Low doses of N improved maize production in more than 80 % of seasons and improves yield by about 60 %, whereas recommended amount increases yield by about 76% of seasons. Low dose gives a low risk investment compared to the recommended rates. The soil properties that were used in this study are common in most areas occupied by the SH farmers in the Limpopo province. By using the characterization information presented in this study and modifying it to match other sites will hasten the model application in the Province.

APSIM is a tool currently underutilized in Limpopo province. Its use must be adopted to enhance extension recommendation and overall crop productivity in the province. Research institutes when conducting agronomic field experiments in the province should have the following minimum data set for APSIM to be applied (Appendix 4). These field experiments should also put more resources into monitoring and evaluating soil behaviour.

6. EVALUATION OF ECONOMIC RETURNS OF DIFFERENT FERTILIZER APPLICATION RATES ON MAIZE USING VALUE COST RATIO

6.1 Introduction

The value cost ratio or VCR is a measurement that researchers use to assess the viability of technology adoption (ICRISAT, 2008). It is calculated from the value of extra grain produced relative to the control and the cost of the additional inputs. If the VCR is more than 2:1, in other words, if the value of the extra grain produced is double the cost of the fertilizer needed to boost the yields, the technology is more likely to be adopted. According to Dimes (2007) in ICRISAT (2008) the VCR for small doses of fertilizer in on-farm trials conducted in Limpopo Province easily exceeded the 2:1 threshold in all three seasons from 2004 to 2006. In comparison, the VCR for the blanket recommended rates only reached 2:1 in the better rainfall seasons.

According to a study conducted by Dimes *et a*l (2003), there are several reasons why adoption of improved fertility management methods has been poor in Africa. Firstly, SH farmers have largely ignored official recommendations promoting near-optimal inputs of fertilizer application and few use the recommended levels of application. Typically, recommendations fail to consider rainfall risks; capital and resource constraints or marketing costs faced by SH farmers. Consequently, the suggested application rates are too high, and therefore too expensive and too risky, especially in more drought-prone regions. They also do not account for the variability of farming objectives that typifies SH farming systems, especially the focus on food security with limited resources and minimal risk, and the relative returns of other investment options available to the farmer compared to that for fertility investments. Moreover, inorganic fertilizer is rarely available in local markets (Manyong *et al*. 2002) or only a limited range is available. As a result, adoption rates are low, grain yields and per capita food production are declining, and food security is worsening, particularly in Africa's extensive semi-arid areas (FAO 2001).

The objective of this study was to evaluate economic returns of different nitrogen fertilizer application rates on maize yields using VCR. This objective is based on the hypothesis that the VCR of fertilizer investments for maize production in drier regions is much more favourable for low doses of N fertilizer compared to current recommended doses.

6.2 Materials and Methods

Trial sites, experiment layout and treatments were similar to what is reported in the common materials and methods of chapter 3. The VCR was derived from actual grain yields obtained from trial site. The price of nitrogen was based on the current prices (2006/07) of R 250.00 for LAN (28) (R/kg N =R17.86) fertilizer while the maize price was based on the current price (2006/07) of R1500.00/ton. The VCR was calculated as follows:

$$VCR = \frac{((\text{Grain yield} - \text{control grain yield}) * (\text{maize price}/1000))}{(\text{Amount of N applied} * \text{N price})}$$

Grain yield and amount of N are expressed in kg ha^{-1}, maize price and N price in rand per ton and rand per kg N respectively.

6.3 Results

6.3.1 Experiment

The VCR of maize grain yield response to fertilizer investments in on-farm trials at four sites is shown in Fig. 6.1. Recommended rate (56 kg N ha^{-1}) gave highest VCR at Bokgaga in a poor growing season and where site variability was such that differences in grain yields between treatments was only significant at the highest level. Lower rate (14 kg N ha^{-1}) resulted in the highest VCR at other three sites in 2007/08 season and approached or exceeded the theoretical adoption threshold of 2:1. There is a general trend across sites of a decreasing VCR as input investment increases. Hence, investment in 14 kg N ha^{-1} returned the highest average VCR's of about 2.36:1 R/R. An exception to decreasing VCR as input investment increased was observed at Bokgaga where the trend was relatively flat.

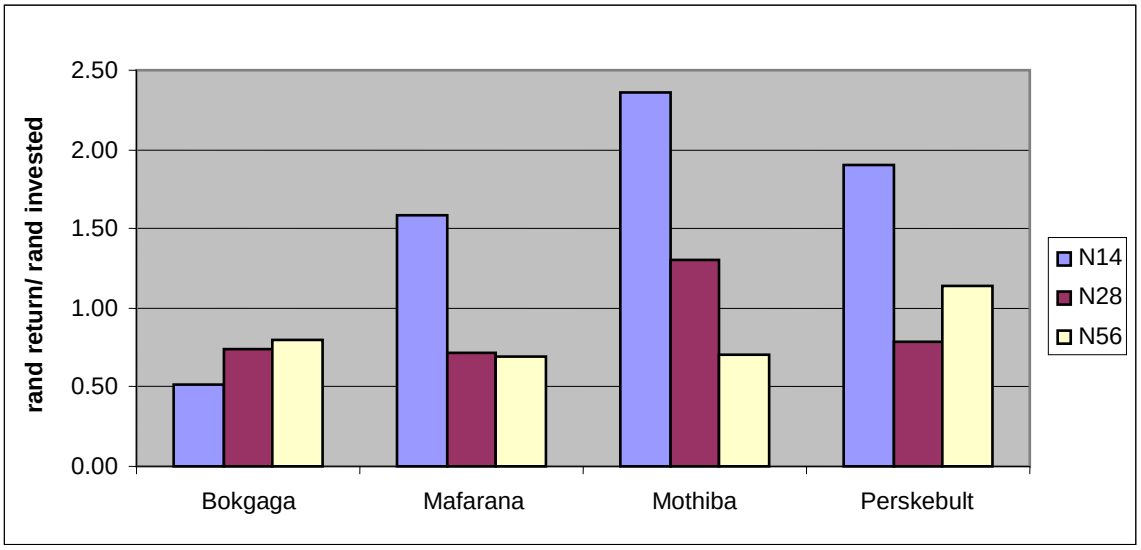

Fig. 6.1 The value-cost ratio of maize grain yield response to fertilizer investments in on-farm trials at Bokgaga in 2006/07 season and Mafarana, Mothiba and Perskebult in 2007/08 season.

6.3.2 Simulation

6.3.2.1 Mafarana

Probability of getting value cost ratio at Mafarana with three rates of N over a 30 year period on sandy and clay soils under semi arid conditions are shown in Figure 6.2. For Mafarana, 10 -15 % of seasons will give a negative return on N investment (all the negative values have been transformed to zero). With a VCR benchmark of 2:1, the 14 and 28 kg N ha^{-1} exceeded the benchmark in 80 % and 70 % of years, respectively, with little difference between sand and clay soil. While the 56 kg N $ha^{-1}$and on clay soil and sandy soil exceeded the benchmark in 48 % and 42% of years respectively.

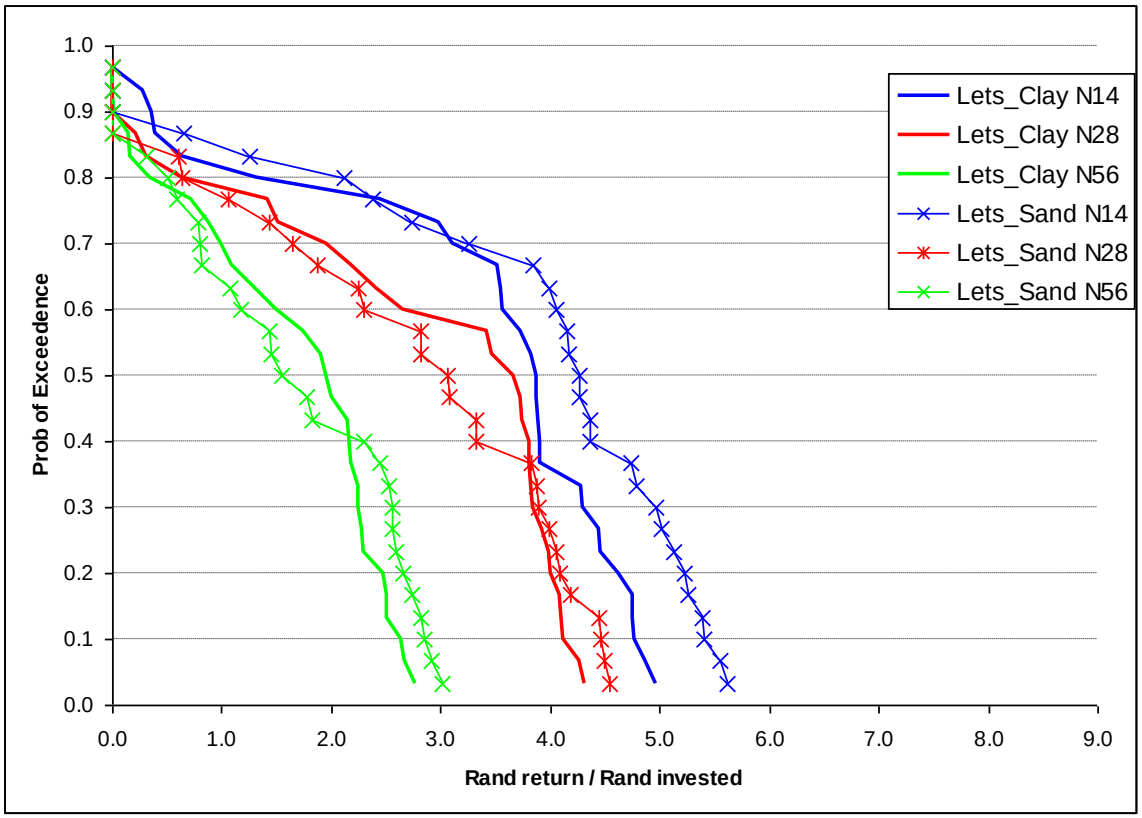

Fig 6.2 Probability of getting value cost ratio at Mafarana with three rates of N over a 30 year period on sandy and clay soils under semi arid conditions

6.3.2.2 Perskebult

Probability of getting value cost ratio at Perskebult with three rates of N over a 30 year period on sandy and clay soils under semi arid conditions are shown in Figure 6.3. For Perskebult, 20 -25 % of seasons will give a negative return on N investment (all negative values have been transformed to zero), irrespective of soil type. With a VCR benchmark of 2:1, the 14 kg N ha^{-1} exceeded the benchmark in 70 % of years for sandy soil and in 74 % of years for clay soil. While the 28 kg N $ha^{-1}$and on sandy soil and clay soil exceeded the benchmark in 63 % and 68% of years respectively. The highest rate had the lowest probability (< 50 % of years) of exceeding the benchmark for both soil textures.

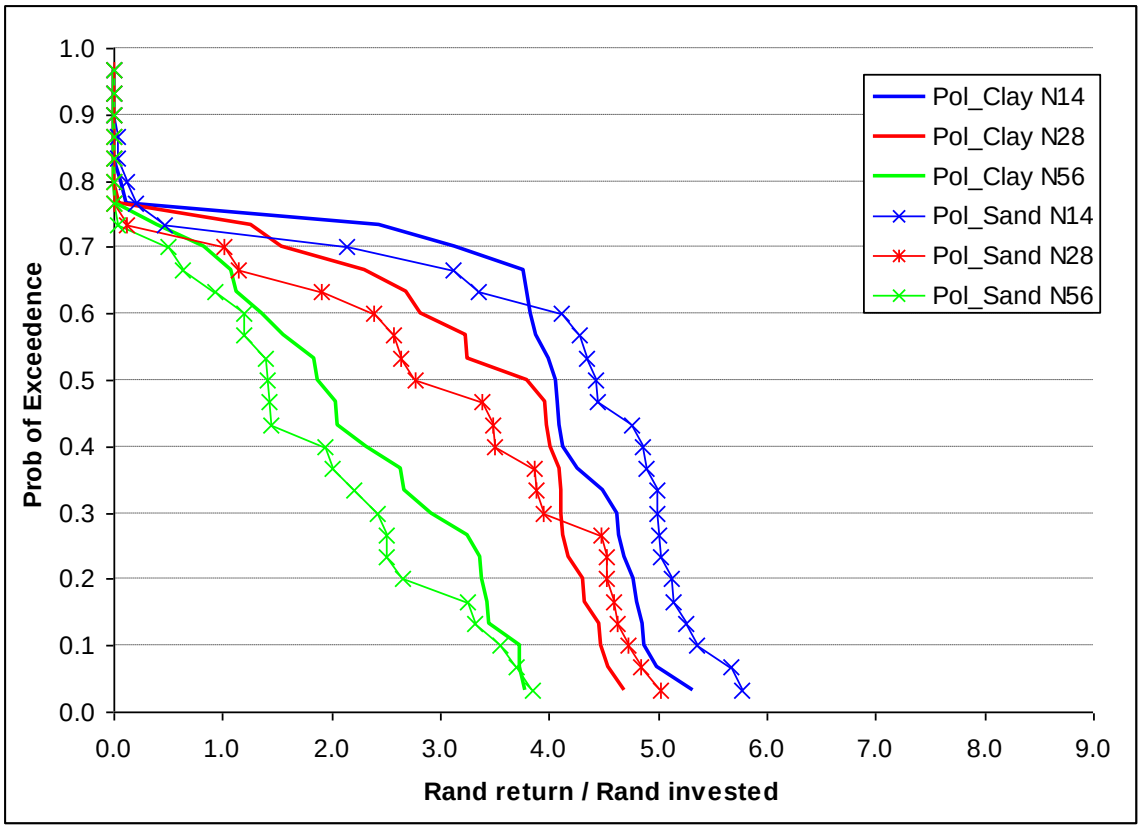

Fig. 6.3 Probability of getting value cost ratio at Perskebult with three rates of N over a 30 year period on sandy and clay soils under semi arid conditions

4 Discussions

The high VCR for 14 kg N ha^{-1} at Mothiba can be attributed to semi-dry conditions that prevailed during the 2007/08 season. There was no yield advantage in applying 28 and 56 kg N ha^{-1}. Recommended rate (56 kg N ha^{-1}) gave highest VCR at Bokgaga in a poor growing season and where site variability was such that differences in grain yields between treatments was only significant at the highest level.

The fact that, 20 -25 % of seasons at Perskebult gave a negative return on N investment, irrespective of soil type, demonstrates the higher rainfall risk of the Perskebult site compared to the Mafarana site above. The predicted VCR suggests that the probability of getting higher VCR is at 14 kg N ha^{-1} at both sites and soil types (Fig 6.2 and 6.3). There is a probability of getting a VCR of up to 6:1 at Perskebult on a sandy soil (Fig 6.3). The consistently higher VCR for the sandy soil in the better growing seasons reflects the stronger fertility constraint on this soil type compared to the clay soil.

6.5 Conclusion

The results of these trials in drier regions of Limpopo province have confirmed the profitability of low rates of N fertilizer in the SH sector. However, this trend is complicated by soil variability factors at each site, and the fact that the previous seasons were relatively dry, and residual N levels in the soil may have limited the N treatment response in some areas. These trials conducted over two seasons at four sites, clearly showed little increase in crop response to N fertilizer top dressing beyond 50 kg of Limestone Ammonium Nitrate (LAN 28) per ha, the equivalent of only 14 kg N ha^{-1} (Fig 4.4). The return on investment at this level for these farmer-managed trials was as high as R2.36:R1. Both grain yield and VCR data for this season generally shows a slightly higher response to investment in top-dress N fertilizer. Nevertheless the trends in these seasons again show that resource-poor farmers can expect a higher return to low levels of N fertilizer (and therefore less risk) compared to the current higher recommended rates.

7. GENERAL DISCUSSION AND RECOMMENDATIONS

7. 1 Low rates of nitrogen and phosphorus fertilizer

Application of inorganic fertilizer can improve maize yield even in the semi-arid areas. But in this study, there was no yield response to P applications despite low levels of P in the soil. Yield response to maize only occurred when application of inorganic N rates was done. Inorganic N fertilizer application influenced maize yield even though the effect differed with site. However, the response of maize yield to N fertilizer application rate was influenced by available moisture. In the semi-dry season, the application of 14 kg N ha^{-1} was more economical than the 28 and 56 kg N ha^{-1}. These semi-dry conditions prevail in about 80 % of South African areas (FAO, 2005).

The highest N rate was expected to perform better than lower rates at Mafarana. This is because Mafarana is under high rainfall conditions associated with high organic carbon (high soil fertility). Contrary to the expectation, there was no yield advantage in applying 14, 28 and 56 kg N ha^{-1} over 0 kg N ha^{-1}. This shows the importance of having soil analysis done in order to determine the amount and type of fertilizer to be applied for a specific agro-ecological zone.

Rainfall use efficiency (RUE) was higher at sites which received low rainfall i.e. Perskebult and Mothiba and lower at sites which received relatively high rain fall i.e. Bokgaga and Mafarana (Fig. 4.3). RUE was improved by the application of nitrogen fertilizer across all sites.

7. 2 Agricultural production system simulator (APSIM) to simulate response to low inputs of nitrogen and phosphorus

This modeling exercise has shown that response of maize to fertilizer was also influenced by the availability of soil moisture during different seasons. The model helped in explaining that the application of different N rates produced higher maize yields than zero application. The Limpopo province experienced a dry

season in 2006/07 and at the end of the season most farmers had a grain shortage. In 2007/08 normal rainfall occurred and grain production was adequate except in the poorly-resourced and marginal farms (i.e. Phaudi) where a grain deficit still occurred. This shows that, potentially, all farmers are faced with a constant threat of poor rainfall seasons and household food insecurity. Long term average rainfall figures confirm this (Table 3.1). By using simulation model, farmers can be provided with a means by which the observed technology from field experimentations responses can be extrapolated across soils, seasons and crop management options.

Long term simulations showed that maize productivity under semi-arid conditions can be improved significantly through addition of N. However, the significant improvement was more evident on the clay loam soil. Low doses of N improved maize production in more than 80 % of seasons and improves yield by about 60 %, whereas recommended amount increases yield by about 76% of seasons. Low dose gives a low risk investment compared to the recommended rates. The soil properties that were used in this study are common in most areas occupied by the SH farmers in the Limpopo province. By using the characterization information presented in this study and modifying it to match other sites will hasten the model application in the Province. The model results suggest that the productivity of maize can be enhanced by the application of low rate of N in the infertile soils of the semi-arid areas of Limpopo province.

7.3 Economic returns of different fertilizer application rates using value cost ratio (VCR)

The response to N fertilizer varies from season to season depending on the rainfall characteristics of seasons. In years with below average rainfall there are no responses to N fertilizer while significant yield improvements are realized from N when rainfall is not a constraint. It is less risky to use 14 kg N ha^{-1} than 28 and 56 kg N ha^{-1}. The 14 kg N ha^{-1} will give exceed the VCR benchmark 2:1 in more than 70 % of years irrespective of the soil type.

A concern is the sustainability of such low levels of fertilizer, especially when only a single nutrient is being promoted (and adopted) as having the highest payoff for farmers with severely limited investment capacity. But this concern must be counterbalanced by the reality that existing low levels of fertility investment by smallholder farmers is even more damaging to the sustainability of the soil resource, and in turn, farmer livelihoods. However, further research needs to be done on the response of low levels of P so as to balance the nutrient status of the soils in these cropping systems.

Very limited research had been carried out to address soil fertility problems in the province and limited research are fragmented and had not been coordinated to mitigate fertility problem.

7.4 Recommendations for future work

1. Study should be conducted to establish what caused no response to P fertilization across all sites with varying rainfall gradient and soil types
2 Future work should cover P absorption isotherm curves for the test soils
3. Subsequent studies should focus on demonstration trials on farmers' fields where large blocks of maize, fertilized at 14 Kg N ha^{-1} are compared with unfertilized controls under semi arid condition.
4. Research institutes when conducting agronomic field experiments in the province should have the following minimum data set for APSIM to be applied (Appendix 4). These field experiments should also put more resources into monitoring and evaluating soil behaviour.

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APPENDICES

Appendix 1. Indications of approximate optimum soil analysis values for maize crop

Fertility Recommendation...

Indication of approximate optimum soil analysis values for maize crop

Crop	pH (H_20)	P (Bray1)	K	Ca	Mg
		_____mg kg^{-1} _____			
Maize	5.5 – 7.5	15 - 30	80 - 160	300-2000	80 – 300

Source: Fertilizer Society of South Africa, 2003

Appendix 2. Lime needs according to caly % and pH (KCl)

LIME NEEDS ACCORDING TO CLAY % AND pH (KCl)

CLAY %	Ph (KCl) VALUE				
	3.7 – 3.8	3.9 – 4.0	4.1 – 4.2	4.3 – 4.4	4.5-4.6
0 – 6	3.0	2.0	1.5	1.0	0.5
7 – 15	4.0	2.5	2.0	1.5	1.0
16 – 36	5.0	3.0	2.5	2.0	1.0
37 – 55	6.0	4.0	3.0	2.5	1.5
> 55	7.0	5.0	3.5	3.0	1.5

Source: Fertilizer Society of South Africa, 2003

Appendix 3. N, P and K fertilization guidelines for maize

N FERTILISATION GUIDELINES

PLANNED YIELD	N-FERTILISATION (KG N/HA)
2	20
3	45
4	70
5	95
6	120
7	145
8	170
9	195
10	220

Source: Fertilizer Society of South Africa, 2003

PHOSPHORUS GUIDELINES

- ARE BASED ON THE SOIL STATUS OF P, AS WELL AS THE PLANNED YIELD

Soil P (mg/kg)	**P recommendation for yield potential (t/ha)**								
Bray 1	2	3	4	5	6	7	8	9	10
0-4	20	42	65	88	109	130	130	130	130
5-7	17	31	47	63	67	90	93	95	97
8-14	13	19	30	42	50	59	64	67	68
15-20	10	13	21	29	36	42	47	50	53
21-27	**7**	**10**	**15**	**19**	**26**	**31**	**34**	**38**	**41**
28-34	6	9	12	15	18	22	24	27	30

Source: Fertilizer Society of South Africa, 2003

POTASSIUM GUIDELINES

- MAIZE REACT WELL TO K FERTILISATION, PARTICULARLY WHERE SOIL STATUS IS LOW

Soil K (mg/kg)	K recommendation for yield potential (t/ha)								
NH_4OA_C	2	3	4	5	6	7	8	9	10
< 20	10	18	27	35	45	54	64	73	82
20	4	11	20	29	39	47	56	64	74
40	0	5	13	21	31	39	47	56	64
60	0	0	8	15	25	33	41	48	56
80	0	0	0	11	21	29	35	42	50
100	0	0	0	9	18	25	31	38	45
120	0	0	0	7	15	22	28	34	41

Source: Fertilizer Society of South Africa, 2003

Appendix 4. Minimum data set for APSIM to be applied

1) Rainfall
2) Temperature (Max and Min)
3) Radiation
4) Soil N ($NH4^+$ and $NO3^-$)
5) Soil Phosphorus (PO4)
6) Soil pH
7) Soil Organic Carbon
8) Gravimetric Moisture
9) Bulk Density
10) Phenological development
11) Total Biomass
12) Grain Yield