MAIZE GRAIN YIELD UNDER CONVENTIONAL AND SITE-SPECIFIC NUTRIENT MANAGEMENT IN A DRYLAND FARMNG SYSTEM: AGRONOMIC IMPLICATIONS

by

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MINI-DISSERTATION

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DECLARATION

I declare that the research work reported in this Masters titled “Maize grain yield under conventional and site-specific nutrient management in dryland farming system: agronomic implications” mini-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

____________________ ____________________

Mashego S (Ms) **Date**

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DEDICATION

I dedicate this mini-dissertation to my beloved parents, Mr. and Mrs. Mashego and my brothers and sisters.

ABSTRACT

Large amount of pre-plant nitrogen (N) fertilizer results in low nutrient-use-efficiency due to poor synchrony between soil N supply and maize demand, especially during N sensitive growth stages. Optimum maize production is dependent on adequate N availability to the crop during the critical vegetative and reproductive growth stages. High N fertilizer prices and maize yield decline are the main challenges faced by the Limpopo Province farmers. The objectives of this study were to compare growth and yield of maize under conventional and site-specific N management in a dryland farming system. The study was conducted in Leeukraal, Towoomba, Ga-Marishane and Radium in the Limpopo Province, South Africa. Experimental plots were laid out in a randomized complete block design, with four replications. Phosphorus was applied through band placement using a planter in all plots at a rate of 42 kg P/ha. Hybrid maize SNK 2147 was planted on a 20 by 20 m plot with Inter-row and Intra-row spacing of 0.9 and 0.35 m respectively. Treatments consisted of 3 N management strategies as follows, (i) No N application (N0), (ii) Site-specific N at a rate ranging between 18 and 33 kg N/ha (N1) and (iii) Conventional N application at 58 kg N/ha (N2). Treatment N2 was applied at a uniform rate during maize planting. Sufficiency index as an indication for N deficiency was determined using CCM-200 for treatment N1. The sufficiency index was determined during leaf stage V6, V10 and V14, and thereafter N was applied only when needed. Data were subjected to analysis of variance through Statistical Analysis System package. Mean separation tests were computed using Duncan’s Multiple Range Test. Maize grain yield at Leeukraal of 5.2 t/ha for N1 was higher than 3.2 and 4.0 t/ha of N0 and N2, respectively. There was no difference amongst the three N management approaches on the grain yield at Towoomba. The grain yield at Ga-Marishane for N1 of 2.2 t/ha was significantly higher than 1.7 t/ha of the N0. Conventional management approach, which is a traditional approach used by farmers in the Limpopo Province, had 2.6 t/ha grain yield that was significantly higher than the N0 and N1. The maize growth and yield under N2 and N1 was compared, N1 required between 43 and 69% lesser N fertilizer as compared to N2. Therefore site-specific nutrient management approach sustains and improves growth and yield of maize using minimal inputs of N compared to conventional approach. This therefore saves input costs and avoids unnecessary environmental consequences.

Key words: maize yield, nitrogen management, site-specific approach

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Maize (*Zea mays* L.) is a crop with a potential to contribute towards food security, particularly when properly managed. This chapter provides an introduction of the study, which includes background, problem statement, aim/ objective and the rationale for the study.

1.2 Background

The need to improve smallholder sustainable maize production is important in South Africa, Limpopo Province in particular, since maize is adaptable to a wide range of climatic conditions (IDP, 2002/2003). This study focused on nitrogen (N) management approaches that encompass the assessment of infield spatial variability and detection of the need for N fertilization at maize critical growth stages. The N fertilization at maize critical growth stages is in comparison with N management approach that disregards infield spatial variability and broadcast N at uniform rates. The study was designed to assess whether site-specific N management approach can enhance maize grain yield using minimum input costs as compared to conventional N management approach.

1.3 Problem statement

Limpopo Province of South Africa has a considerable amount of arable land, suitable for maize production and other agricultural crops despite its hot and dry climate (Thomas, 2003). However, low maize yield and low soil fertility are the current challenges that are being experienced by small-scale farmers in the area. Farmers take composite soil samples for routine nutrient analysis with the objective of obtaining the average nutrient status of their fields. As such, the soil analysis results becomes generic as field spatial variability is overlooked, and nutrients such as N are broadcasted at uniform rates throughout the field. The broadcasted N may results to over- and under-application of N in various parts of the field due to in-field spatial variability (Khosla *et al*., 1999; Thrikawala *et al*., 1999). Maize yield becomes low due to poor synchrony between N fertilization and the peak N sensitive maize stages. Nitrogen is the most limiting crop nutrient in maize production, for optimum maize grain yields, adequate N must be available for maize use during critical stages (Robertson and Vitousek, 2009).

1.4 Motivation of the study

Maize is a staple food for South Africans and is largely consumed across the Southern Africa region (Du Plessis, 2003). Maize has a wide range of utilization and is regarded as one of the potential crops in the contribution towards food security worldwide. Maize has a large and stable market (IDP, 2002/2003; Thomas, 2003) and provides quick cash to farmers when sold to the informal market as green maize. Small-scale farmers lack access to agricultural inputs such as fertilizers, pesticides, and irrigation water. Fertilizers are mostly a priority on the farming budget. Farmers with good agricultural land, however, have a challenge with access to fertilizers; hence there is a need for a better nutrient management strategy that will enhance maize grain yield.

The conventional farming practices that include uniform application of farming inputs such as fertilizer, disregard spatial variability that may exist in the farmers' field. This uniform application of farming inputs could result in over fertilization of environmentally sensitive N fertilizer in some areas of the field and under fertilization in other parts of the same field. Over fertilization of N contributes to challenges such as contamination of ground and surface water, human-induced climate change, and impairment of aquatic life (Nolan and Stoner, 2000). According to Khosla *et al*. (2002), uniform application of fertilizer across crop fields is not an efficient N management approach in terms of economic and environmental implications.

In contrast to conventional farming practices, site-specific nutrient management practices entail assessment and management of field spatial variability. Management of field spatial variability improves maize N use efficiency, grain yield crop quality that will promote better economic returns (Prato and Kang, 1998; Khosla *et al*., 2002; Koch *et al*., 2004). Small-scale farmers need assistance with effective nutrient management approach that will ensure optimum N use for maize production using minimum inputs without compromising grain yield. Raun *et al*. (2002) indicated that site-specific nutrient management increases N use efficiency by maize, which improves maize yields.

1.5 Purpose of the study

1.5.1 Aim

The aim of the study was to comparatively assess the growth response and yield of maize under conventional and site-specific nutrient management.

1.5.2 Objectives

a. To compare growth of maize production under conventional and site-specific nutrient management in a dryland farming system.

b. To compare yield of maize production under conventional and site-specific nutrient management in a dryland farming system.

1.5.3 Hypotheses

a. There is no difference in growth rate of maize under conventional and site-specific nutrient management in a dryland farming system.

b. There is no difference in yield of maize under conventional and site-specific nutrient management in a dryland farming system.

1.6 Summary

Maize is adaptable to wide range of climatic conditions and has a good market in South Africa; however decline in maize production and costly N fertilizers poses major challenges to small-scale farmers. The current N management approach that the farmers use have poor synchrony between N fertilization and the peak N sensitive maize stages that leads to low maize yields. Nitrogen fertilizer is banded at an average rate throughout the field disregarding in-field spatial variability. There is a need for effective N management approach that is economically and environmentally sound with regards to N use efficiency and maize yield. Site-specific N management has the potential to improve N use efficiency, hence this study was conducted to compare maize growth and yield under conventional and site-specific nutrient management approach.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the review of the current N management approaches on maize production with respect to nutrient use efficiency, N movements in the soil, factors contributing to the N movement. Challenges with the current conventional nutrient management approaches on field with spatial variability are outlined, as well as the potential of site-specific nutrient management approach for variable rate application.

2.2 Maize production and nitrogen fertilization

Republic of South Africa (RSA) is ranked between the ninth and fourteenth largest maize producers in the world on the international arena (FAO, 2009). Maize requires a substantial amount of nutrients, paticularly N, for chlorophyll synthesis and the ability to speed up growth (Sanchez, 2002; NSW Grains Report, 2004). Successful maize production depends on the optimal application of production inputs such as N fertilizers that will sustain grain yield and reduce the N movement on the environment (Du Plessis, 2003). Decline in soil fertility is significantly considered to be the dominant limitation on maize yields (Sangoi, 2000; FAO, 2001). Maize yield has also been reported to be affected by in-field spatial variability of soil and crop parameters (Johnson, 2003). Management of in-field spatial variability is essential in order to use the right amount of N fertilizer that has less effect on the environment (FAO, 2001).

2.3 Nitrogen movement

The primary mechanisms of N fertilizer loss from agricultural fields are nitrate leaching; surface runoff and erosion; gaseous losses from soil denitrification and ammonia volatilization (Raun and Johnson, 1999; Follet, 2001). Global evaluation of total N fertilizer losses indicated that leaching, erosion and runoff constitute about 46% of all losses (Power *et al*., 2001; Motavalli *et al*., 2008). The magnitude of N fertilizer loss processes is affected by factors such as, field spatial variability in terms of soil physical, chemical and biological properties. Other factors that affect N fertilizer loss include climatic variations; crop growth and management practices such as soil tillage method; N source, timing and method of N fertilization. Variation in soil water content and drainage due to either spatial differences in soil properties across agricultural fields or variation in precipitation during the crop growing season also affects N fertilizer losses (Power *et al*., 2001; Motavalli *et al*., 2008).

2.4 Environmental implications of excessive nitrogen

Poor N fertilizer management leads to environmental damage. Among the deleterious effects of excessive N on the environment is that, it contributes to an increased production of airborne particulate matter and acid rain. Nitrous oxide is responsible for 4.4% of greenhouse effects. The nitrous oxide is also the largest contributor to stratospheric ozone depletion and increased ozone-induced injury to crops (Galloway and Cowling, 2002). Sommer *et al*. (2004) reported that more than 50% of the N fertilizer can volatilize as NH_3 when the N fertilizer is applied at the soil surface. Banding of N fertilizer on the soil surface is also reported to cause soil acidification. Nitrogen fertilizer runoff that is encouraged by poor N fertilizer management integrates with other elements in the water system and causes algal bloom. Over fertilization of N promotes invasion and growth of weeds resulting in low nutrient use efficiency by the main crop (Raun and Johnson, 1999; Cassman *et al*., 2002; Galloway and Cowling, 2002).

2.5 Nitrogen use efficiency

Nitrogen use efficiency (NUE) is described as the ability of the crop to take up N from the soil, assimilate and remobilize the N for photosynthesis and grain formation (Good *et al*., 2004; Moose and Below, 2009). The major causes for low NUE on the current N management approaches is poor synchrony between soil N supply and maize demand particularly during the N sensitive growth stages (Cassman *et al*., 2002; Fageria and Baligar, 2005). The poor synchrony is a result of large N pre-plant fertilization that may be unavailable during the peak maize growing stages (Cassman *et al*., 2002). Low NUE is attributed to the way in which maize N fertilizer requirement is dependent on the targeted yield. Yield goal is set before maize is planted; the yield goal is then used to determine N fertilizer requirement (Meisinger and Randall, 1991), that assumes constant fertilizer NUE (Meisinger *et al*., 1992). Another factor contributing to low NUE is the uniform application rate of N fertilizer to a spatially variable field (Shahandeh *et al*., 2005; Hong *et al*., 2007). The focus of nutrient management received substantial attention over the past decades leading to development of sustainable nutrient management strategies that improve NUE (NSW Grains Report, 2004). Nutrient management strategies that have developed promoted a balance between N input and the crop uptake of N reducing the N losses (Grant, 2002).

2.6 Site-specific nutrient management

Site-specific nutrient management (SSNM) is defined as the management of nutrients on agricultural crops at spatial scales smaller than that of the whole field (Plant, 2001). Site-specific nutrient management focuses on improving agricultural sustainability through increased NUE so to increase the economic profit and to reduce losses of critical nutrients to the environment (Lark, 2001). The SSNM assess infield spatial variability as opposed to the conventional nutrient management strategies. Conventional management strategies relies on the premise that soil fertility and the production potential of a soil is homogenous throughout the field, hence leading to over application of nutrients to the soil. Site-specific nutrient management strategy is an approach that improve crop NUE, increase farm profits and greatly reduce the detrimental environmental effects associated with fertilizer loss (Khosla *et al*., 2002). Site-specific nutrient management or variable N fertilizer rate which aims at improving NUE (Khosla, 2002; Hornung *et al*., 2003) is reported to increase crop grain yield, crop quality and economic returns (Khosla *et al*., 2002; Koch *et al*., 2004). Optimum maize yield using lower N rate can be achieved using site-specific N management than the conventional N management approach (Paz *et al*., 1997).

2.7 In-field spatial variability and management zones

Soils vary across the field due to physical, chemical and biological properties of the soil within the field. Moshia *et al*. (2008) indicated that due to inherent spatial variability of soils, level of nutrient requirement may vary as a result of in-field variability. Field spatial variability is effectively managed through the deployment of site-specific management zones. Site-specific nutrient management is based on site specific management zone (MZ) that is regarded as sub-region of a field with homogenous yield-limiting factors (Doerge, 1999). Demarcated MZ is treated as homogenous unit, which receives similar production inputs and treatments (Doerge, 1999). Management zones are demarcated through technology aids such as global positioning systems (GPS), geographic information systems (GIS) and satellite or remotely sensed information (Ellison *et al*., 1995; Franzen *et al*., 2000; Nolan *et al*., 2000).

2.8 Chlorophyll meter use on N determination

Extensive laboratory method of determining N status in the soil for maize production is destructive to the crop and also time consuming and results become available after lengthy periods. Alternative non-destructive methods such as chlorophyll meters have been developed to monitor maize N status and improve NUE during the crop growing season (Peng *et al*., 1996). The chlorophyll meters are more effective with the presence of a reference strip. Reference strip is described as the strip of the crop that receives sufficient N throughout the crop growing season (Schepers *et al*., 1992). The chlorophyll meter provides a simple, quick and nondestructive method for estimating N concentration on a dry weight basis from crop leaves (Takebe *et al*., 1990). The amount of chlorophyll content of plant leaves are related to the condition of the plant, and thus can be used to determine additional fertilizer (Turner and Jund, 1991). Chlorophyll meters were indicated to be of an added advantage tool because of their ease to use and low economic implications (Prato and Kang, 1998; Osborne *et al*., 2002).

2.9 Efficacy of site-specific versus conventional approach

Small-scale farmers treat their agricultural fields as homogenous unit since they are not aware of the spatial variability that may exist in their fields and as such, fertilizers are applied uniformly across farm fields (Moshia, 2006) as conventional management approach. A two-year season study conducted by Lan *et al*. (2008), found that site-specific nutrient management approach had 11 and 33% more maize yield than conventional management approach. The amount of fertilizer was reduced by 32 and 29% for those consecutive seasons, which indicates that variable rate application or site-specific application approach is feasible on maize cultivation to produce optimum yields with minimum fertilizers (Lan *et al*., 2008). Koch *et al*. (2004)

assessed the economic feasibility of variable rate application and found that variable-rate N application was more economically feasible than conventional uniform N application.

2.10 Summary

Farmers apply uniform N rates across agricultural fields as they are unaware of spatial variability that may exist within the field. Uniform N application can result in over- and under fertilization in certain parts of the field that will have environmental and economic implications. This chapter demonstrated that uniform N application on field with spatial variability results to low NUE as N becomes unavailable to maize during critical growth stages. Poor synchrony between soil N and N demand by maize during critical stages under conventional management approaches also leads to low NUE that results to low maize yields. Site-specific nutrient management approaches have potential toward improving NUE and maize yields. Studies indicated that SSNM is more economically and environmentally feasible, that requires lower amounts of N and produced optimum maize yield when compared conventional management approach.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides the methodology and analytical procedures used in the study.

3.2 Description of the study site

The study was conducted at two locations in Sekhukhune and Waterberg districts in Limpopo Province of South Africa.

3.2.1 Site 1

Sekhukhune district the main experimental site consisted of two locations, Leeukraal (24.92723942 °S; 29.79986685 °E) and Ga-Marishane (24.65548609 °S; 29.74270873 °E). The long-term average annual rainfall for Sekhukhune district is 450 mm (Figure 3.1), while the average annual temperature is 20.7˚C (min average of 14.2˚C and max average of 29.6˚C) (Department of Agriculture, 2011). Leeukraal and Ga-Marishane have hornblende and biotite granites lithology with the Lebowa granite suite formation unit with soil parent material of acid, intermediate or alkaline intrusive rock type. The soil form at both locations is Hutton (Rhodic Ferralsols, FAO). Leeukraal is closer to a river as compared to Ga-Marishane (Figure 3.2). The Leeukraal, and Ga-Marishane sites were previously fallowed, and cultivated with vegetables, respectively.

3.2.2 Site 2

Two locations were selected for Waterberg district, Towoomba Agricultural Research Station (24.92723942 °S; 28.34573890 °E) and Radium (25.08956020 °S; 28.26244141 °E). The long term average annual rainfall for Waterberg district is 620 mm (Figure 3.1), with average annual temperature of 20.4˚C (min 12.7˚C and max 28.8˚C) (Department of Agriculture, 2011). Radium and Towoomba have basalt north-south trending dolerite dykes along Lebombo range lithology with the Letaba formation unit with soil parent material of mafic or basic lavas and the surrounding rivers (Figure 3.2). The soil form at both locations is Hutton (Rhodic Ferralsols, FAO). Radium and Towoomba were cultivated with sunflower and fallowed, respectively, for the previous growing season.

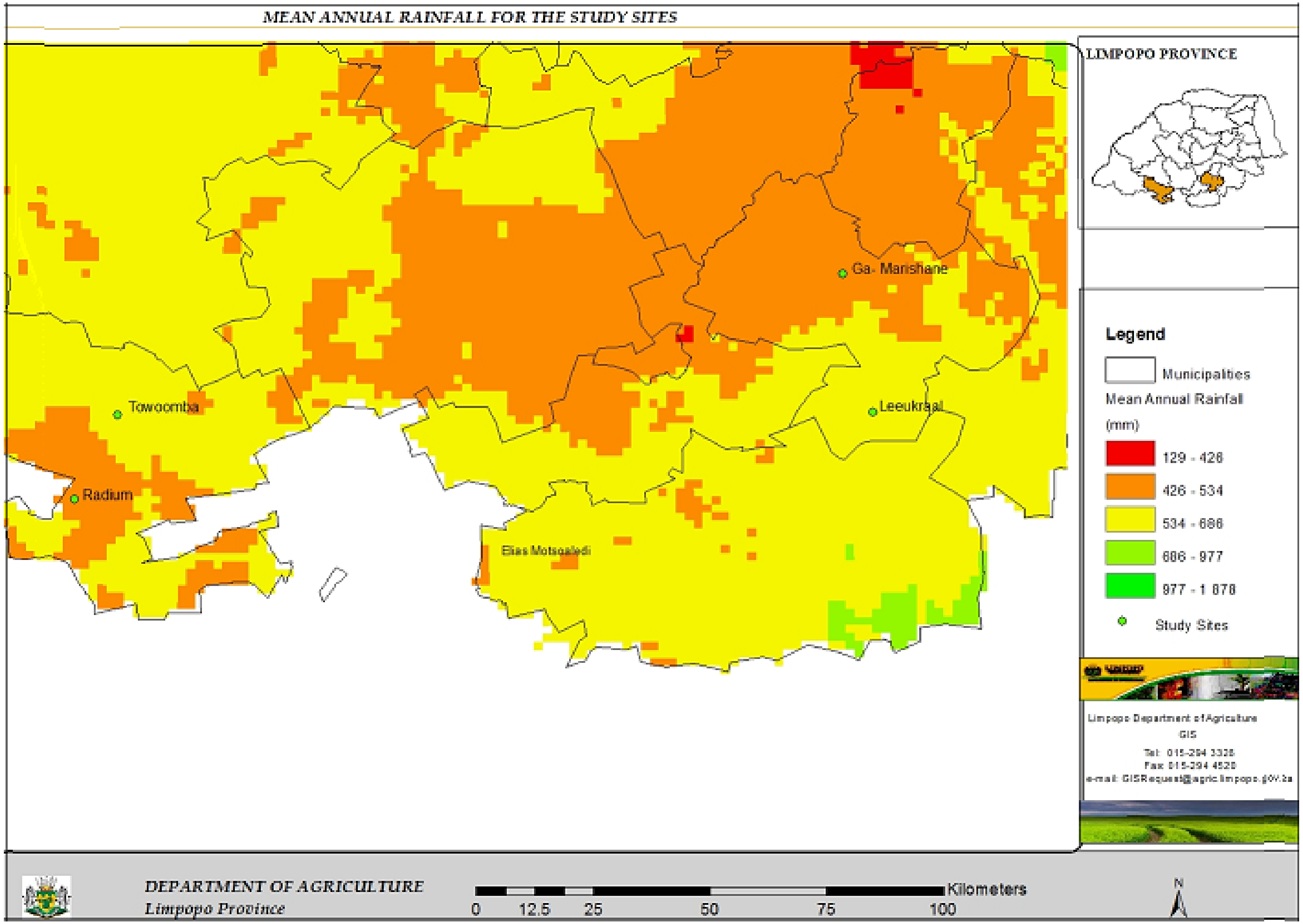

Figure 3.1. The mean annual rainfall for Sekhukhune and Waterberg districts showing the study sites

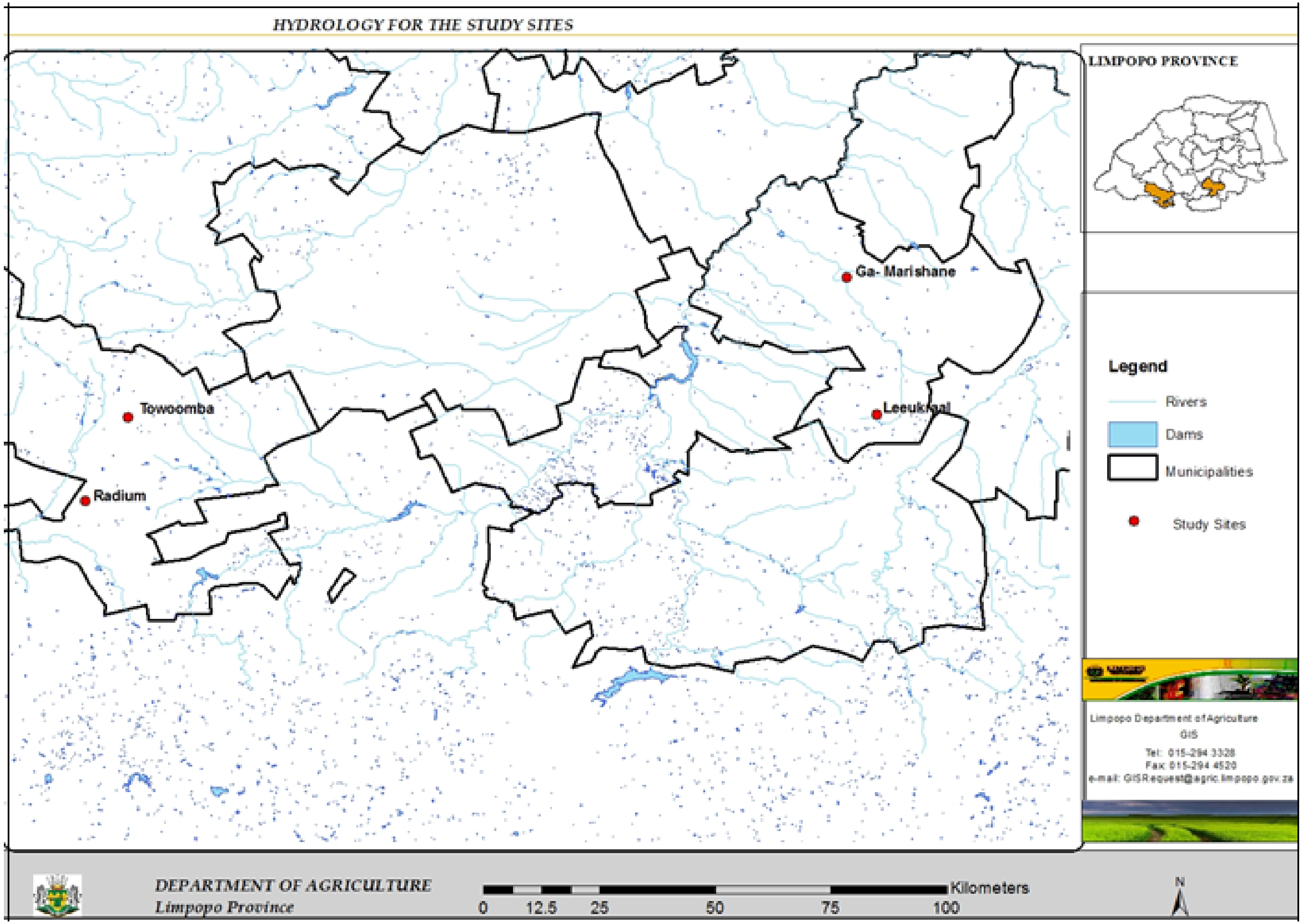

Figure 3.2. The hydrological systems for Sekhukhune and Waterberg districts showing the study sites

3.3 Soil sampling and analysis

A differential global positioning system (GPS) (Trimble, Handheld Juno Sc), with 5 m accuracy was used to demarcate the treatment plots and to obtain the geographical coordinates. Systemic soil sampling procedure was used to collect the soil samples. Soils were sampled at the soil depth of 0 to 20 cm topsoil and 30 to 60 cm, subsoil and GPS coordinates were recorded at each sampling point. Soil samples were analyzed for pH using soil: water solution method (McLean, 1982), total N digest total N was analysed using total N digest standard method; while, P was analysed using Bray1 method (Bray and Kurtz, 1945). Potassium, Ca, Mg and Na were analyzed using 1M ammonium acetate extraction, (McLean, 1982).

3.4 Land preparation and maize planting

The land was prepared using mouldboard plough and disked for fine seedbed. Phosphorus was applied through band placement using a planter in all plots at a rate of 42 kg P/ha, Single Super Phosphate (10.5% P). Hybrid maize (SNK 2147) was planted using a mechanical planter mounted to a tractor on a 20 by 20 m plot with Inter-row and Intra-row spacing of 0.9 and 0.35 m respectively. Plant population was 31 746 plants per hectare. The first season 2010, maize was planted at Leeukraal and Towoomba on 14 and 23 December 2010, respectively. During the 2011 season, maize was planted on the 22 December 2011 and 10 January 2012 at Radium and Ga-Marishane, respectively.

3.5 Treatment arrangement and N fertilization

The experimental plots were laid on as randomized complete block design, with four replications. Treatments for the study were three N management strategies, (i) No N application (N0), (ii) Site-specific N (N1) and (iii) Conventional N application (N2). Nitrogen treatment of N2 was applied at a uniform rate of 58 N kg/ha that the farmers use, determined from soil analytical results with the expected grain yield of 3 t/ha (FSSA, 2007). The N fertilizer was broadcasted at planting as blanket application to the N2 experimental plots. No N was applied to the N0, the control plots. The N1 treatment application rates varied across the study sites, that is 22, 18, 22, and 33 N kg /ha for Towoomba, Radium, Leeukraal and Ga-Marishane, respectively.

Nitrogen was topdressed in the maize rows as N1 treatment, based on CCM-200 (chlorophyll content meter) readings (Opti-Sciences, USA). Crop N deficiency was determined through non-destructive sensing of maize leaves during peak maize vegetative growth stages V6 (six leaf growth stage), V10 and V14. Measurements were taken from one side of the midrib of a leaf blade, midway between leaf base and the tip of the youngest fully expanded leaves (Reseau Environmental Catalog, 2003; Thabang *et al*., 2012). Sufficiency index, determined from the reference crop and the sensed crop using CCM-200 was used as an indication for the need of N application. Nitrogen was applied only when needed (Thabang *et al*., 2012). The CCM-200 requires an establishment of reference crop, which is the non-N limited crop that is treated similarly to the N2 crop except that it receives enough N throughout the season. This was planted in order to establish the sufficiency index (SI), Peterson *et al*. (1993) equation 1.

The field areas of N0, N1 and N2 plots were 400 m^2 i.e., 20 m long and 20 m wide. Two reference plots were established with an area of 100 m^2 i.e., 20 m long and 5 m.

$$SI = (VI\ \text{Sensed crop}/\ VI\ \text{Reference}) \times 100\% \qquad \text{(equation 1)}$$

Where SI is the sufficiency index

VI Sensed crop is the vegetation index (or measurement) of the sensed crop, and

VI Reference is the vegetation index (or measurement) of the non-N limited crop.

Peterson *et al*. (1993) specifies that SI ≤ 95 denotes N deficiency; hence topdressing of N fertilizer is necessary. The recommended N rate for 3t/ha grain yield is 58 kg N/ha. Nitrogen application rate for the site-specific management approach was based on the rate of SI and the percentage of the recommended N for 3t/ha grain yield. When SI was 0-23; 24-47; 48-71; 72-95 and >95, the following 100; 75; 50; 25; and 0% of the recommended rate were applied respectively.

Limestone Ammonium Nitrate (28% N) was used as source of N. Weeds were managed through manual weeding, which is the common method used by the farmers in these farming areas and the use of herbicide; and stalk borer pesticide was used to manage stalk and stem borer.

3.6 Data collection and analysis

Observations were recorded during maize growing stages. Agronomic data including plant height, number of leaves, leaf breadth and leaf length as well as leaf area were recorded. Maize plant height was measured from the soil surface to the tip of the maize plant. The number of leaves was recorded based on leaf count. Maize leaf lengths of fully opened leaf lamina were measured from the leaf base to the tip. Leaf breadth was measured at the widest point of the leaf lamina (Kaur *et al*., 2012). Leaf area was determined using the formula given by Montgomery (1911):

Leaf area = L x B x k (equation 2)

Where L = leaf length (cm), B = leaf breadth (cm), k = shape factor with value of 0.75 for maize (Montgomery, 1911).

Differential global positioning system co-ordinates were collected for the harvested maize, and yield component including field yield, grain yield, number of rows per cob, and 100 grain mass were also collected for the study. Maize was harvested after the crop had reached physiological maturity. Agronomic and yield component data were subjected to analysis of variance through Statistical Analysis System (SAS) package. Mean separation tests were computed using Duncan's Multiple Range Test at alpha level of 0.05 and 0.01(Littell *et al*., 2002).

3.7 Summary

White maize, SNK 2147 variety was planted at four different sites. Three N management practices namely, N0, N1 and N2 treatments were laid on a randomized complete design with four replications. No N was applied for the control, N0; site-specific N variable rate was only top dressed to the maize as per indication of the N sensor for the N1 treatment. Nitrogen was applied at a uniform rate as blanket application at maize planting for the N2 treatment. Growth parameters collected includes plant height, number of leaves per plant, leaf length and leaf area; these parameters serves as an important crop growth components as well as an indication of crop vigor. The growth parameters data were collected during vegetative growth stage V6, V10 and V14. The yield component variable measured includes the number of grain rows per cob, cob mass per plant, 100 grain mass and grain yield. Grain is an ultimate objective of all grain crops; as such the yield component data provides an indication of crop yield.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Soil analysis

Table 4.1 Soil analysis results of the study sites

Parameter		Towoomba	Leeukraal	Radium	Ga-Marishane
pH(H_2O)	Topsoil	6.1	5.7	6.1	6.8
	subsoil	6.2	5.7	6.0	7.1
Total N (%)	Topsoil	0.01	0.04	0.03	0.03
	subsoil	0.00	0.03	0.03	0.02
P (mg/kg)	Topsoil	1.4	1.8	8.6	13.3
	subsoil	0.4	0.5	1.8	2.6
K (mg/kg)	Topsoil	216	100	155	147
	subsoil	152	91	123	124
Ca (mg/kg)	Topsoil	1330	193	607	463
	subsoil	1444	154	588	474
Mg (mg/kg)	Topsoil	500	92	2161	79
	subsoil	662	110	207	89
Na (mg/kg)	Topsoil	2.94	0.06	9.20	8.40
	subsoil	11.20	1.01	8.60	9.90

Table 4.1 indicates soil analysis for pH and nutrient elements for the study sites. The soil pH for all the sites is within an acceptable pH range conducive for nutrient element availability such as N, P and K (FSSA, 2007). Soils with pH of about 5 or lower have lower N element availability than soils with approximate neutral soil pH. Maize is reported to grow and produce optimum yield at soil pH between 5.8 and 7.0 (Grier *et al*., 1989).

4.2 Plant height

Plant height is an important crop growth and yield component and it has a direct proportionality to 100 grain mass (Saidaiah *et al*., 2008). Plant height is positively correlated with grain yield (Tenaw, 2000); the higher the plant height, the better the crop yield. Figures 4.1 and 4.2 show maize plant height for Ga-Marishane and Radium sites, respectively.

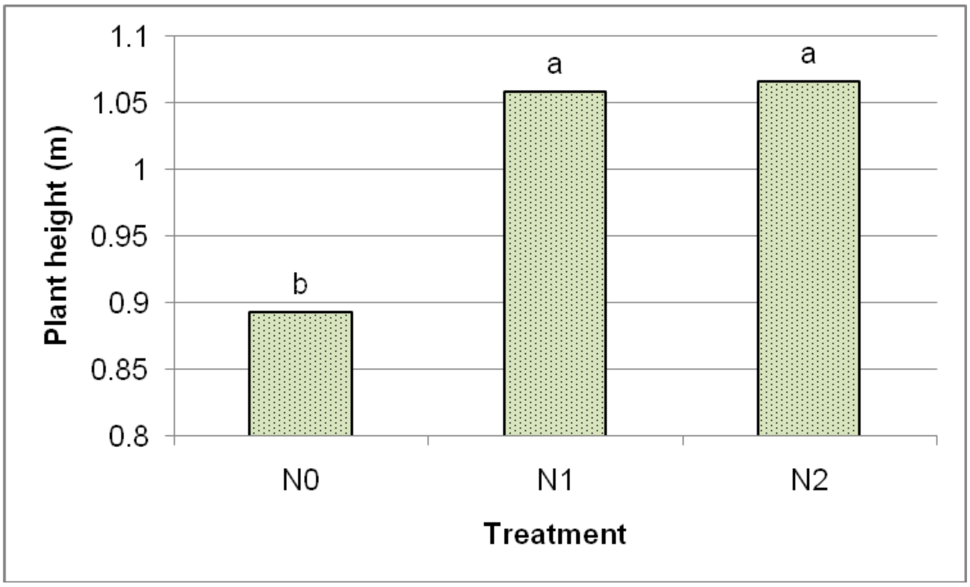

Figure 4.1 Plant height (m) during growth stage V10 at Ga-Marishane

Maize plant height of site-specific N management and conventional approaches of 1.059 and 1.066 m, respectively, were significantly higher ($P \leq 0.05$) than 0.893 m of the control during growth stage V10 (Figure 4.1). There was no significant difference on the plant height between conventional and site-specific N management approach during growth stage V10 Figure 4.1. It was observed that conventional N management approach required more N than the site-specific N management approach; however, site-specific N management approach had similar plant height as the conventional management approach.

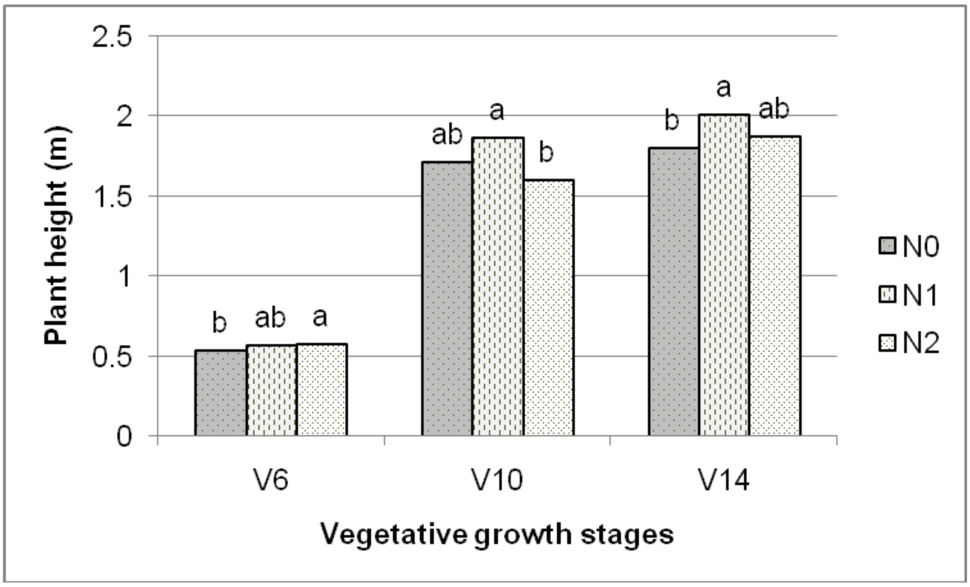

Figure 4.2 Plant height (m) during growth stage V6, V10 and V14 at Radium site

Figure 4.2 shows no significant difference on maize plant height between conventional and site-specific management approaches during growth stage V6. However, both approaches had significantly higher ($P \leq 0.05$) plant height than the control. Out of four experimental units of the site-specific approach, N fertilizer was applied to two experimental units that indicated N deficiency during growth stage V6. Hence, the highest ($P \leq 0.05$) plant height during growth stage V10 resulted from site-specific N management approach; with no significant difference between the control and conventional N management approach as indicated on Figure 4.2. During the maize growth stage V14, the plant height of site-specific N management approach was observed to be higher ($P \leq 0.05$) than that of the control. However, there was no significant difference on plant height between conventional and site-specific N management approaches (Figure 4.2) at Radium site. The results presented in Figure 4.1 and 4.2 indicate that optimum plant height can be reached through site-specific N management approach, which required lesser N than the conventional N management approach.

4.3 Number of leaves per plant

The number of leaves per plant is proportional to photosynthesis rate and grain production. The more the number of leaves per plant, the higher the photosynthetic rate, leading to positive crop growth. This therefore results in better crop yield. Figures 4.3 and 4.4 show the number of maize leaves per plant for Ga-Marishane and Radium respectively.

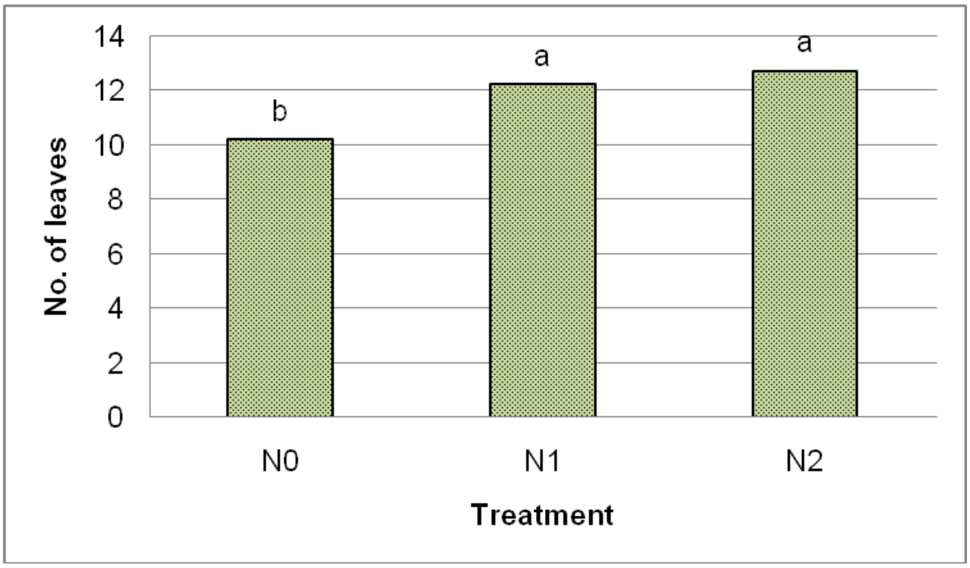

Figure 4.3 Number of leaves during growth stage V14 at Ga-Marishane site

The number of leaves under conventional and site-specific N management approaches was statistically similar. However, both approaches had higher ($P \leq 0.05$) number of leaves per plant than the control during growth stage V14 (Figure 4.3). The results presented in Figure 4.3 shows that there was significant increase in number of leaves per plant with conventional and site-specific N management approaches than the control during vegetative growth stage V14.

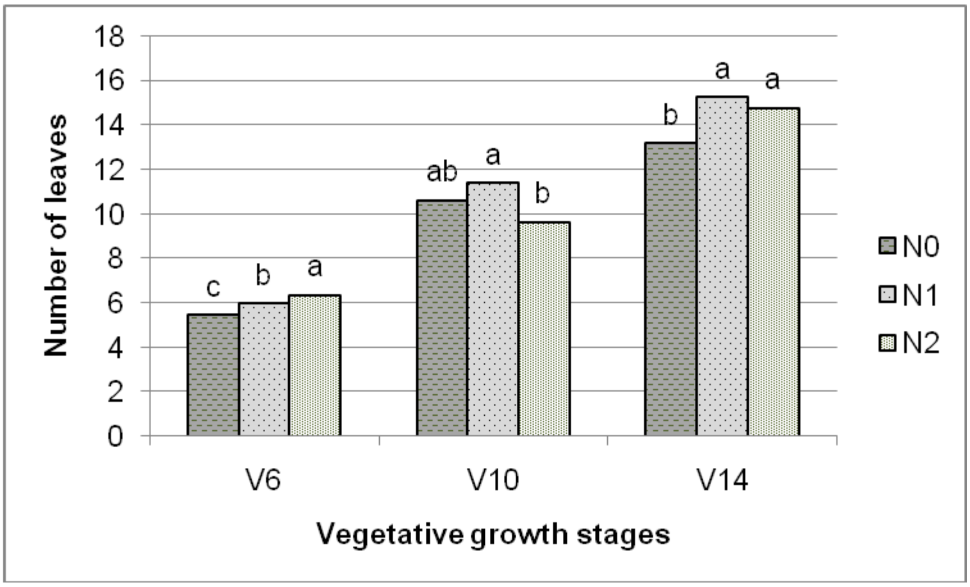

Figure 4.4 Number of leaves during growth stages V6, V10 and V14 at Radium site

Figure 4.4 shows the number of leaves per maize crop at various vegetative growth stages at Radium. Site specific approach had significantly higher ($P \leq 0.05$) number of leaves per plant than the control. However, conventional approach had the highest ($P \leq 0.01$) number of leaves than the two approaches during vegetative growth stage V6. The highest ($P \leq 0.05$) number of leaves per plant was recorded from site-specific N management approach during growth stage V10; conventional N management approach was statistically the same with the control. The number of leaves for site-specific approach was statistically similar with conventional approach and both approaches had higher ($P \leq 0.01$) number of leaves than the control during growth stage V14 (Figure 4.4). Nonetheless, site-specific N management approach required 69% lower N than the conventional approach. The high number of leaves on site-specific N management approach during growth stage V10 and V14 could be attributed to sufficient N that was available during the maize critical growth stage.

4.4 Leaf length

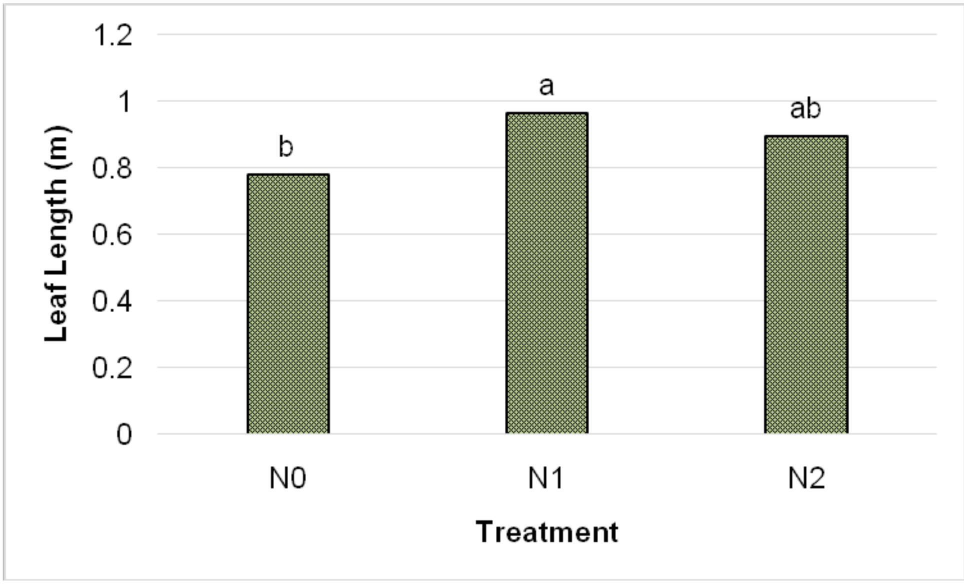

Figure 4.5 Leaf length (m) during growth stage V14 at Radium site

Figure 4.5 indicates the measured leaf length (m) at Radium. Maximum leaf length of 0.97 m was recorded from site-specific N management approach, which was not significantly different to 0.90 m of conventional management approach. The site-specific N management approach had significantly higher ($P \leq 0.05$) leaf length than 0.78 m of the control during growth stage V14 (Figure 4.5). Highest leaf length was achieved using 69% lesser N fertilizer under site-specific N management approach than the conventional approach. Attributing the synchrony between soil N supply and maize demand during the N sensitive growth stages was satisfied on the site-specific N management approach (Fageria and Baligar, 2005).

4.5 Leaf area

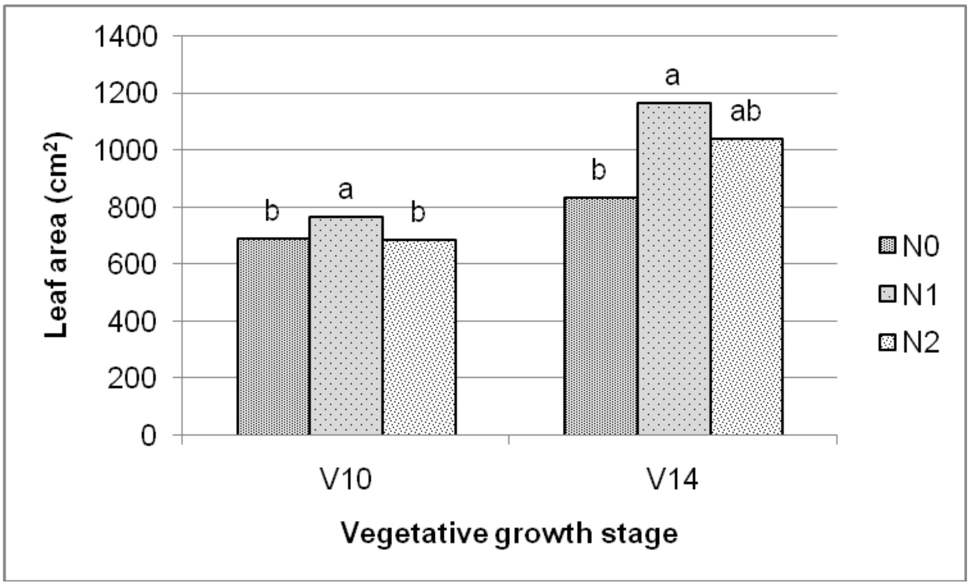

Figure 4.6 Leaf area (cm^2) during growth stages V10 and V14 at Radium site

Site-specific N management approach was observed to have the highest (*P*≤0.05) leaf area than the control and conventional management approach. The leaf area showed no significant difference between the control and conventional N management approach during vegetative growth stage V10 (Figure 4.6). During vegetative growth stage V14, the leaf area of site-specific N management approach was not significantly different with that of the conventional approach; but higher (*P*≤0.05) than that of the control. Nitrogen fertilizer was top-dressed during vegetative growth stage V6 as site-specific management approach. The high leaf area was observed on site-specific N management approach during maize growth stage V10 and V14. Nitrogen fertilizer has a significant effect on maize leaf area (Kaur *et al*., 2012). Increased NUE enhanced photosynthesis rate in the maize leaves and growth through increased leaf area.

4.6 Overview of main findings on crop growth

The observed maize plant height under conventional N management approach was statistically similar to that of site-specific N management approach, but significantly higher than the control during vegetative growth stage V6. The statistical similarity of the conventional and site-specific N management approaches on plant height may likely be due to the fact that maize N consumption is peak after vegetative growth stage V6. The maize under site-specific management approach showed no N deficiency, hence the two management approaches outperformed the control. Raun *et al*. (2002) recommended that the best time for in-season N fertilization is during vegetative growth stage V6. Maize N consumption is peak after the development of the 6^{th} maize leaf. Hence, the conventional approach had the highest number of leaves followed by site-specific management then the control during vegetative growth stage V6.

Number of leaves is a good indicator of crop response to N since the leaves hosts photosynthesis mechanisms. The N fertilization under conventional N management approach during maize planting could be attributed to the increased number of leaves per plant during vegetative growth stage V6. Nevertheless, the number of leaves of site-specific management N approach was later (vegetative growth stage V10) observed to be statistically similar to that of conventional N management approach. This could be due to the top-dressed N fertilizer on the site-specific N management treatment approach that made N available to the crop.

Nitrogen fertilizer was top-dressed during vegetative growth stage V6 of the site-specific N management treatment approach; while for the conventional N management approach, N fertilizer was applied during maize planting. Hence the plant height, number of leaves per plant and leaf area under site-specific management approach was significantly higher than that of conventional N management approach during growth vegetative stage V10. This could be due to the fact that N fertilizer of the conventional management approach was not applied in a same way to the site-specific N management approach during critical growth stages.

The observed significant performance of maize plant height, number of leaves per plant, leaf length and leaf area during vegetative growth stage V14 of site-specific N management approaches could be attributed to N availability in the soil. The soil pH for Ga-Marishane and Radium sites ranged between 6.0 and 7.1. Maize is reported to perform well at soil pH between 5.8 and 7.0. The availability of N in the soil is influenced by soil pH, the soil pH of Ga-Marishane and Radium sites were around the reported pH ranges. Good performance of significant growth parameters (e.g., plant height, number of leaves and leaf area) was achieved through site-specific N management approach that required lesser N than conventional N management approach. This is attributed to the availability of N to the growing maize during the crop critical growth stages (Robertson and Vitousek, 2009) that improved the crop N use efficiency. The available N may have promoted vigorous growth, improved meristematic and physiological activities in the crop that resulted to improved crop growth parameters.

4.7 Grain rows per cob

Table 4.2 Number of grain rows per cob under three N management approaches

Treatment	Towoomba	Leeukraal	Ga-Marishane
N0	12a	11b	14a
N1	11a	13a	13a
N2	11a	13a	14a
Significance	ns	**	ns
$LSD_{0.05}$	-	1.51	-
CV	9.39	5.31	5.09

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** significant at P≤0.01,* significant at P≤0.05. Means with same letter within the same column did not differ significantly from one another at $P<0.05$.

The number of maize grain rows per cob is an important yield component of maize crop. The more the number of grain rows per cob, the more will be the grain yield. Table 4.2 indicates number of grain rows per maize cob. The number of grain rows per cob of site-specific management approach was statistically at par with that of the conventional management approach, and both approaches had higher (P≤0.01) number of grain rows per cob than that of the control at Leeukraal site. The number of grain rows per maize cob (Table 4.2) showed no significant difference among the three N management approaches at Towoomba and Ga-Marishane sites.

4.8 Cob mass per plant

Table 4.3 Cob mass per plant (g) under three N management approaches

Treatment	Towoomba	Leeukraal	Ga-Marishane
N0	89b	195a	168b
N1	143a	234a	194b
N2	138a	204a	233a
Significance	**	ns	**
$LSD_{0.05}$	31.67		35.88
CV	11.35	15.96	10.45

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** significant at P≤0.01,* significant at P≤0.05. Means with same letter within the same column did not differ significantly from one another at *P<0.05.*

The results presented in Table 4.3 shows cob mass per plant. The cob mass per plant, 143 g for site-specific N management approach was statistically similar to 139 g for conventional N management approach. However, both N management approaches had higher (*P*≤0.01) cob mass per plant than that of the control (89 g) at Towoomba site. There was no significant difference on the cob mass per plant among the three N management approaches at Leeukraal site. The cob mass per plant of conventional management approach, 233 g was statistically higher (*P*≤0.01) than 168 and 194 g under control and site-specific N management approach, respectively, at Ga-Marishane site.

4.9 Maize 100 grain mass

The 100 grain mass is positively correlated with grain yield (Alvi *et al*., 2003; Bocanski *et al*., 2009), which makes the 100 grain mass an important yield component.

Table 4.4 Maize 100 grain mass (g) under three N management approaches

Treatment	Towoomba	Leeukraal	Ga-Marishane
N0	32b	34a	28b
N1	39a	37a	33a
N2	33b	36a	29b
Significance	*	ns	**
$LSD_{0.05}$	4.69	-	3.04
CV	5.99	3.38	5.93

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** significant at P≤0.01,* significant at P≤0.05. Means with same letter within the same column did not differ significantly from one another at *P<0.05.*

Table 4.4 indicates 100 grain mass results under three N management approaches. The 100 grain mass of site-specific N management approach was not significantly different with conventional N management approach, however, both N management approaches had significantly higher 100 grain mass than the control at Towoomba ($P\leq0.05$) and Ga-Marishane ($P\leq0.01$) sites. There was no significant difference on the 100 grain mass among the three management approaches for Leeukraal site.

4.10 Summary of yield components

The study was conducted to determine optimum maize yield through comparison of conventional and site-specific N management approaches. Site-specific N management approach was observed to be statistically at par with conventional N management approach, but significantly higher that the control on the grain rows per cob at Leeukraal; cob mass per plant at Towoomba. The findings implies that similar grain rows per maize cob and cob mass per plant may be achieved with lesser N through site-specific N management approach. Furthermore, site-specific N management approach was observed to have significant higher 100 grain mass than the control and conventional N management approach at Towoomba and Ga-Marishane. As small scale farmers broadcasts all N fertilizer at an average rate during maize planting, results presented from Table 4.2 to 4.4 justifies that optimum grain rows per cob; cob mass per plant and 100 grain mass can be achieved through the use of site-specific N management approach that takes spatial variability to consideration. The site-specific N management approach not only requires lesser N than conventional N management approach; but also improves crops N use efficiency that improves crop yields (Raun *et al*., 2002).

4.11 Maize grain yield

Grain yield is the ultimate objective of all the grain crops. Decline in soil fertility, particularly N, is significantly considered to be the dominant limitation on grain yields (Sangoi, 2000; FAO, 2001). In this study, the maximum grain yield of 5.2 t/ha was recorded under site-specific N management, and the minimum grain yield of 1.7 t/ha was recorded with the control i.e., no N application. Odhiambo (2011), conducted a two year study whereby one of the study objectives was to determine the effect of green manure and N fertilizer on maize, hybrid SNK 2147 in Limpopo Province. The author reported grain yield of about 4 and 6.7 t/ha with no N fertilization, 5 and 7.4 t/ha with N fertilizer application for the respective two seasons. Maize SNK 2147 is preferred by most of small scale farmers in the Province, hence it was used in this study.

Table 4.5 Maize grain yield (t/ha) under three N management approaches

Treatment	Towoomba	Leeukraal	Ga-Marishane
N0	4.0a	3.2b	1.7c
N1	4.6a	5.2a	2.2b
N2	4.7a	4.0ab	2.6a
Significance	ns	*	**
$LSD_{0.05}$	-	1.28	0.23
CV	15.38	13.67	6.43

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** significant at $P \leq 0.01$,* significant at $P \leq 0.05$. Means with same letter within the same column did not differ significantly from one another at $P<0.05$.

The grain yield results are presented in Table 4.5 under three N management approaches at Towoomba, Leeukraal and Ga-Marishane sites.

The site-specific N management approach at Leeukraal site had the highest grain yield of 5.2 t/ha than 4.0 t/ha of conventional N management approach and 3.2 t/ha of the control. The site-specific N management approach had statistically higher grain yield than the control. Although no statistical difference on grain yield was found between the conventional and site-specific N management approach, the site-specific N management approach outperformed conventional N management approach by 1.2 t/ha. Farmers consider the grain yield difference of 1.2 t/ha an improvement on grain yields given that site-specific N management approach required 63% lesser N than conventional N management approach. The grain yield results confirm findings of Raun *et al*. (2002) and Lan *et al*. (2008) that site-specific nutrient management approach improves crop N use efficiency, that promotes better maize grain yields. Precipitation followed immediately after N was top-dressed on the site-specific N management approach experimental units. It dissolved the top dressed N fertilizer, making N available to maize during N sensitive stages on the site-specific N approach. The grain yield (Table 4.5) at Leeukraal site suggests that site-specific N approach is a better N management approach than conventional approach. It is important that N fertilizer top-dressing be applied just before precipitation so that the N can be in a form that is available to the maize to achieve better yield for the site-specific N approach in a dryland farming system.

The maize grain yield at Towoomba site was not significantly different among the three N management approaches. Grain yield of 4.6 t/ha was recorded for site-specific management approach; 4.7 and 4.0 t/ha were recorded for the conventional N management approach and the control respectively (Table 4.5). The study encountered damages by warthogs which affected the results.

The grain yield at Ga-Marishane site for site-specific approach of 2.2 t/ha was significantly higher ($P \leq 0.01$) than 1.7 t/ha of the control. The results are in agreement with the findings of Sallah *et al*. (1998) that crop yield was reduced when N fertilizer was not applied. Conventional management approach had 2.6 t/ha grain yield that was significantly higher ($P \leq 0.01$) than the control and site-specific approach (Table 4.5).

Although conventional N management approach outperformed site-specific N management approach with grain yield of 0.4 t/ha; the site-specific N management approach required 43% lesser N than conventional N management approach. Uniform broadcast of N fertilizer across the farm during maize planting is not a good N management approach, as maize does not use N until growth stage V6. Any N fertilization before the 6th leaf development is likely to leach or volatilize depending on the weather conditions. Nitrogen fertilizer leaching is subject to the soil type; however, there is little leaching under dryland farming due to the erratic rainfall. The low grain yield under site-specific N management is attributed to the unavailability of N during peak maize growing stages (Cassman *et al*., 2002), as a result of low precipitation. Nitrogen uptake and distribution in crops is affected by soil moisture, which is influenced by rainfall in a dryland farming system (Ottman and Welch, 1988; Okalebo *et al.*, 1999). Although the study was based on dryland farming system, the soil moisture was low such that the N fertilizer that was top dressed as site-specific N management treatment approach at V6 was found still in granular forms during maize maturity stage. Inadequate moisture in the soil to dissolve the N fertilizer retards crop growth and development (Okalebo *et al.*, 1999) and is attributed to the lower grain yield of site-specific than conventional N management approach.

At Radium, the maize crops reached permanent wilting point before grain formation and as such, no harvest was made and no yield component data was available. This can be attributed to increased rainfall variability in light of the changing climate which affects timing and distribution of rainfall.

Site-specific N management approach is observed to have similar and or higher growth and some yield components than the conventional N management approach. The site-specific N management approach required lesser N fertilizer than the conventional N management approach of 63, 63, 69 and 43% at Towoomba, Leeukraal, Radium and Ga-Marishane respectively.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The difference between conventional and site-specific management approach on maize growth and yield was determined at four study sites in a dryland farming system. Site-specific N management approach required between 43 and 69% lesser N fertilizer as compared to conventional N management approach, and resulted in statistically similar and or higher plant height, number of leaves per plant, leaf length and leaf area than that of the conventional N management approach. The use of site-specific N management approach has potential towards improving maize grain yield; as 5.2 t/ha of grain yield was achieved through site-specific N management approach at Leeukraal and was found to be the highest amongst the N management treatments at all the study sites.

5.2 Recommendation

Site-specific N management approach under dryland has potential towards optimum maize production with less N input as compared to conventional N management approaches for the achievement of the same yield. However, it is recommended that N fertilizer top-dressing coincide with precipitation for better crop growth and yield. Therefore farmers should regularly observe rainfall forecasts through the local radio station and/or collect seasonal risk and disaster advisory from Agriculture service centers. Farmers are encouraged to monitor the maize growth particularly during vegetative growth stages so that N deficiency can be corrected in time.

Further studies may focus on the application of satellite derived indices for variable rate technology recommendation of N management on other crops.

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APPENDICES

Summary of Analysis of Variance (ANOVA) tables

Appendix 1 Plant height during V10 at Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	0.00356	0.00119		
Treatment	2	0.07650	0.03825	5.54	0.0434
Error	6	0.04143	0.00691		
Total	11	0.12150			

Appendix 2. Plant height at during V6 at Radium site

Source	DF	SS	MS	F	P
Block	3	0.00873	0.00291		
Treatment	2	0.00315	0.00158	4.71	0.0589
Error	6	0.00201	0.00033		
Total	11	0.01389			

Appendix 3. Plant height during V10 at Radium site

Source	DF	SS	MS	F	P
Block	3	0.01176	0.00392		
Treatment	2	0.14662	0.07331	7.70	0.0220
Error	6	0.05712	0.00952		
Total	11	0.21549			

Appendix 4. Plant height during V14 at Radium site

Source	DF	SS	MS	F	P
Block	3	0.05796	0.01932		
Treatment	2	0.08645	0.04322	5.10	0.0507
Error	6	0.05082	0.00847		
Total	11	0.19523			

Appendix 5. Number of leaves during V14 at Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	4.9167	1.63889		
Treatment	2	14.0000	7.00000	7.88	0.0210
Error	6	5.3333	0.88889		
Total	11	24.2500			

Appendix 6. Number of leaves during V6 at Radium site

Source	DF	SS	MS	F	P
Block	3	5.04883	1.68294		
Treatment	2	1.57892	0.78946	32.67	0.0006
Error	6	0.14497	0.02416		
Total	11	6.77272			

Appendix 7. Number of leaves during V10 at Radium site

Source	DF	SS	MS	F	P
Block	3	1.9833	0.66111		
Treatment	2	6.1517	3.07583	7.95	0.0206
Error	6	2.3217	0.38694		
Total	11	10.4567			

Appendix 8. Number of leaves during V14 at Radium site

Source	DF	SS	MS	F	P
Block	3	2.5000	0.83333		
Treatment	2	10.0317	5.01583	23.98	0.0014
Error	6	1.2550	0.20917		
Total	11	13.7867			

Appendix 9. Leaf length during V14 at Radium site

Source	DF	SS	MS	F	P
Block	3	0.09093	0.03031		
Treatment	2	0.06905	0.03452	7.50	0.0234
Error	6	0.02763	0.00461		
Total	11	0.18762			

Appendix 10. Leaf area during V10 at Radium site

Source	DF	SS	MS	F	P
Block	3	47869.9	15956.6		
Treatment	2	15584.3	7792.2	5.87	0.0387
Error	6	7961.9	1327.0		
Total	11	71416.1			

Appendix 11. Leaf area during V14 at Radium site

Source	DF	SS	MS	F	P
Block	3	172167	57389		
Treatment	2	222047	111023	7.59	0.0228
Error	6	87802	14634		
Total	11	482016			

Appendix 12. Number of grain rows per cob at Towoomba site

Source	DF	SS	MS	F	P
Block	2	0.22222	0.11111		
Treatment	2	2.88889	1.44444	1.30	0.3673
Error	4	4.44444	1.11111		
Total	8	7.55556			

Appendix 13. Number of grain rows per cob at Leeukraal site

Source	DF	SS	MS	F	P
Block	2	1.5556	0.77778		
Treatment	2	10.8889	5.44444	12.25	0.0197
Error	4	1.7778	0.44444		
Total	8	14.2222			

Appendix 14. Number of grain rows per cob a Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	1.66667	0.55556		
Treatment	2	0.50000	0.25000	0.53	0.6141
Error	6	2.83333	0.47222		
Total	11	5.00000			

Appendix 15. Cob mass per plant at Towoomba site

Source	DF	SS	MS	F	P
Block	2	2710.75	1355.38		
Treatment	2	5404.09	2702.04	13.84	0.0159
Error	4	780.83	195.21		
Total	8	8895.66			

Appendix 16. Cob mass per plant at Leeukraal site

Source	DF	SS	MS	F	P
Block	2	1818.38	909.19		
Treatment	2	2458.79	1229.39	1.09	0.4201
Error	4	4529.52	1132.38		
Total	8	8806.69			

Appendix 17. Cob mass per plant at Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	1997.9	665.97		
Treatment	2	8349.4	4174.71	9.71	0.0131
Error	6	2579.4	429.91		
Total	11	12926.8			

Appendix 18. 100 grain mass at Towoomba site

Source	DF	SS	MS	F	P
Block	2	10.889	5.4444		
Treatment	2	76.222	38.1111	8.91	0.0336
Error	4	17.111	4.2778		
Total	8	104.222			

Appendix 19. 100 grain mass at Leeukraal site

Source	DF	SS	MS	F	P
Block	2	6.2222	3.11111		
Treatment	2	8.2222	4.11111	2.85	0.1703
Error	4	5.7778	1.44444		
Total	8	20.2222			

Appendix 20. 100 grain mass at Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	1.7942	0.5981		
Treatment	2	50.8220	25.4110	8.23	0.0191
Error	6	18.5263	3.0877		
Total	11	71.1425			

Appendix 21. Grain yield at Towoomba site

Source	DF	SS	MS	F	P
Block	2	0.73232	0.36616		
Treatment	2	1.07206	0.53603	1.15	0.4020
Error	4	1.85710	0.46427		
Total	8	3.66147			

Appendix 22. Grain yield at Leeukraal site

Source	DF	SS	MS	F	P
Block	2	0.02204	0.01102		
Treatment	2	5.64687	2.82344	8.81	0.0342
Error	4	1.28136	0.32034		
Total	8	6.95027			

Appendix 23. Grain yield at Ga-Marishane site

Source	DF	SS	MS	F	P
Block	3	0.05034	0.01678		
Treatment	2	1.69172	0.84586	44.65	0.0002
Error	6	0.11368	0.01895		
Total	11	1.85574			