

**ASSESSMENT OF INFIELD SPATIAL VARIABILITY OF NUTRIENTS IN
A UNIFORMLY MANAGED CORN (*ZEA MAYS L.*) FIELD**

by

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DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree, Master of Science in agriculture (Remote Sensing), has not previously been submitted by me for the 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.

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Ms. THABANG S. M



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Date

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DEDICATION

I would like to dedicate this publication to my mom (Helen Ranapo Thabang), her better half (Elias Tselamaoto Thabang), my younger two brothers, younger sister, my kids and husband (Mathibela Rousseau Mankge).

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ABSTRACT

The impact of agricultural chemicals on the environment has come under close scrutiny in the country of South Africa, for that reason, we are investigating alternative and appropriate methods for nutrients management. The objective of the study was to assess infield spatial variability of soil nutrients in a uniformly managed corn field, and (ii) to recommend method that can potentially help corn (*Zea mays* L.) producers in Limpopo Province to enhance grain yield with optimal utilization of resources. The study was conducted at Syferkuil agricultural experimental farm (23°50' S; 29 °40' E) of the University of Limpopo, in the northern semi-arid region of South Africa. Prior to planting of corn on this uniformly managed 7 ha portion of a 1 705 ha farm, the field was mapped with Ag132 Trimble differentially corrected global positioning system (DGPS) equipped with Field Rover II® GIS mapping software. Land suitability assessment for corn was conducted before planting and the field was classified for suitability as S1 based on FAO guidelines for irrigated agriculture and South African Binomial System of Soil classification. Soils and corn leaf sample parameters, including N were collected and measured from geo-referenced locations on a 40 x 40 m grid. Nutrient distribution spatial maps were produced with Surfer software 8.0. There was a significant variability ($P \leq 0.05$) of soil nutrients and pH across the corn field. Corn grain yield ranged from 2.7 to 6.3 Mg ha⁻¹. For a land suitability class of S1 under linear irrigation in a semi-arid environment, these grain yields were considered lower. This lower grain yields can be linked to variability of soil nutrients, and pH because the field was classified suitable according to FAO guidelines. This field, with its significant variability of nutrients and pH that resulted in lower grain yields, is potentially a good field for precision agriculture

methods of nutrient management such site-specific management zones for environmental quality and economic efficiency.

Keywords: Maize, Small-scale farming, Soil nutrient management, and Spatial variability

CHAPTER 1

INTRODUCTION

1.1 Background

The impact of agricultural chemicals on the environment has come under close scrutiny in recent years (Giasson et al., 2002), and the government of the country of South Africa has joined the scientific community in investigating alternative and appropriate methods for nutrients management. However, small scale, commercial, and commercializing farmers in the country are not well informed about best management practices for applying agricultural inputs, maximizing production, and protecting the environment. As researchers in South Africa, we understand that successful development of sustainable and innovative agricultural techniques and methodologies are as much reliant on farmers' involvement as it dependent on the scientific research. Different from agricultural practices in developed countries of North America and Europe, in South Africa, access to agricultural information and technology by small scale and commercializing farmers is slow to almost none. Understanding the importance of protecting the environment, there is a need for innovative, dynamic, and improved farming method that assures, (i) optimum productivity, (ii) nutrients management across spatially variable soils, (iii) environmental quality and, (iv) economic efficiency.

1.2 Aim

To understand and characterize the infield spatial variability of soil nutrients and recommendation of a method that can potentially help corn (*Zea mays* L.) production in Limpopo Province.

1.3 Objectives

- To assess infield spatial variability of soil nutrients in a uniformly managed corn field.
- To recommend method that can potentially help corn (*Zea mays* L.) production in Limpopo Province

1.4 Rationale and value of research

The impact of agricultural chemicals on the environment has come under close scrutiny in the country of South Africa, for that reason, this research will investigate alternative and appropriate methods for nutrients management.

CHAPTER 2

LITERATURE REVIEW

2.1. Background

Soils of the semi-arid northern regions in the country of South Africa are usually low on nitrogen (N). Nitrogen, a chief nutrient for corn (*Zea mays* L.) production is often a limiting factor, particularly in small-scale irrigated cropping systems. Different from other developing countries and some regions of the country of South Africa, small-scale farmers who are supported by the government, have access to inorganic fertilizers. Again, the northern region of the country of South Africa has irrigation schemes widely distributed across the country for small-scale farmers and water is readily available for irrigation of crops. Therefore, development of simple techniques that could be used by small-scale farmers for N fertilizer management became a primary focus of this project following the initial phase of data collection. It has been widely documented that because of inherent spatial variability of soils, not all areas of a field may require the same level of nutrient inputs (Moshia et al., 2008). Small-scale farmers and scientist in the region are unaware of spatial variability that may exist in agricultural fields; hence fertilizers are applied uniformly across farm fields (Moshia, 2006). Uniform application of inputs such as N fertilizers often results in various areas of the field receiving greater nutrient inputs than is necessary (Khosla et al., 2008). For that being the case, the concept of precision agriculture (PA), based on information technology, is becoming an attractive idea for managing N, and natural resources and realizing modern sustainable agricultural development (Maohua, 2001).

2.2. Precision Agriculture

Precision agriculture (PA) attempts to answer profoundly debated global issues of concern such as soil erosion, increasing demand for food due to increasing world population, unstable world economy, and the environment (Lal 1995; 2000). Practicing precision agriculture with a purpose of protecting the environment is a morally significant action. The concept of PA accepts that variability occurs within farm fields across a landscape (Tyler et al., 1997). According to Pierce and Nowak (1999) PA is defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality. In addition to improving crop performance and environmental quality, an ultimate goal of PA is to manage spatial variability associated with all aspects of agricultural production for optimum profitability, sustainability and protection of wildlife and the environment (Robert et al., 1995). The concept of PA is sometimes termed site-specific management, meaning that PA has the ability to apply the correct amount of agricultural inputs i.e. nitrogen (N), water, herbicides, etc. in the right place, right amount and at a right time (Khosla, 2008).

Precision agriculture assists growers in making precise management decisions for different cropping systems throughout the world (Koch and Khosla, 2003). With the ability to apply farming inputs on site-specific basis, precision agriculture helps growers to improve efficiency by matching inputs and practices to localized field conditions. In South Africa, precision agriculture appears to be an interesting agricultural and environmental business science. While its adoption, is as slow as in other developing

countries because of socio-economical barriers (McBratney et al., 2005). According to McBratney et al. (2005) there are researchers and practitioners who imagine that because of its technological demands, precision agriculture has little to no application in the developing world. In South Africa, Universities and government departments have sections, researchers and technicians who are well aware of the importance of precision agriculture and are working on social aspects of adoption and knowledge transfer to commercial and commercializing farmers. Agricultural researchers and academics are well aware that Precision agriculture may ultimately avert social and economic devastation and renew hope for the future in developing nations such as South Africa. This study was part of the multi-disciplinary research in precision agriculture, remote sensing, and land suitability assessment. This study report about soils collected in two years for one maize growing season as part of this multi-disciplinary research. After five years of intensive qualitative land suitability assessment on a 1 705 ha farm (Moshia et al., 2008), researchers at University of Limpopo started projects in precision agriculture that build on remote sensing data gathered since early 90's (Fouché and Booysen, 1994; Shaker and Fouché, 2004, 2006).

2.3. Nitrogen use in agriculture

Nitrogen is an essential nutrient for growth and reproduction of crops, except for legume crops and virgin soils with relatively high soil organic matter (SOM), soil N must usually be supplemented to sustain production. The challenge is that N is highly mobile in the soil and annually, there is 67% (\$15.9 billion) loss of N fertilizer (assuming fertilizer-soil equilibrium) in the form of soil denitrification, surface runoff, volatilization, and leaching

(Raun and Johnson, 1999). Whether the N source is animal manure or commercial N fertilizer, over application or ill-timed application of either source can provide too much plant-available N and increase the potential for NO₃ leaching (Hatfield and Cambardella, 2001). Although timing, method of N application, and accounting for mineralizable soil N are important for reducing potential NO₃ leaching. Power and Schepers (1989) reported that the most important factor was to apply the correct amount of N fertilizer. Bouma (1999) suggested that variable rate application practices could reduce the loss of agricultural chemicals such N into the environment, while Khosla (2009) emphasized correct time for application, place, rate, and amount.

Field studies on improved N use efficiency have emphasized the management of N inputs to reduce N losses and increase N uptake (Cassman et al., 1996). Some of the studies use the improved timing for N application (Shoji and Gandeza, 1992), and use of fertilizer amended with nitrification or urea as inhibitors (Chaiwanakupt et al., 1995). Apart from quantifying infield spatial variability through soil sampling, another question is whether the critical time for N application can be determined with a rapid, in-field methodology. One approach to improve N-use efficiency involves plant-based strategies that rely on monitoring the N status of crops (Peng et al., 1996). Turner and Jund (1991) demonstrated that the chlorophyll meter, which measures leaf greenness, can predict the need for N applications.

2.4. Precision nitrogen management

Growers, who adopt precision agriculture use site-specific techniques of applying nutrients to improve environmental management, maximize field production and increase profitability (Trimble navigation Ltd., Sunnyvale, CA, USA). Studies have emphasized the potential of variable rate application of N in protecting the environment because no N fertilizers would be applied to field areas with above optimum levels of N for crop production (Mulla, 1993; Franzen and Peck, 1995; Schepers et al., 2000). This strategy has the potential to improve profitability for the producer and to reduce threat of underground water contamination from agrochemicals such as Nitrate-N (Sudduth et al., 1997). While previous studies indicated that maximum net economic returns may not be achievable with uniform N application and management (Prato and Kang, 1998), in this thesis it was necessary to use uniform N application because the study aimed at establishing and quantifying the existence of infield spatial variability. In spite all other studies that discredit uniform N application based on grid sampling, Watkins et al. (1999) reported a \$43 ha⁻¹ lower economic return in potato (*Solanum tuberosum* L.) production under variable-rate N application compared with uniform N application. Therefore, there was a need to establish and quantify the type of infield spatial variability in a farm field for a better management and decision support system.

2.5. Plant N monitoring for in-season N fertilizer applications

Many studies have focused on identifying appropriate timing of N split applications at specified crop growth stages. The reason for these studies was that, failure to supplement correct amount of soil N at critical crop growth stages can potentially lead to

crop failure and consequently reduced grain yield. In recent years, there have been attempts to predict plant N by devices such as spectral reflectance data recording and laser induced chlorophyll fluorescence coupled with various prediction models (Shoji and Gandeza, 1992; Chaiwanakupt et al., 1995). While the approach of using these devices was reported to be efficient (Ladha et al., 1998), this method cannot be recommended for the farmers in rural South Africa because it involves sophisticated and expensive equipments and also demand expertise. Alternative non-destructive methods have been developed to monitor corn N status, and chlorophyll meter (SPAD) was proposed as an advantageous tool because it is economical and easy to use (Osborne et al., 2002). 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 is related to the condition of the plant, and thus can be used to determine when additional fertilizer is necessary. Even though chlorophyll meter requires time and labour for data collection, it has added advantages as compared to traditional methods of N monitoring. When using traditional methods, detection of early N deficiency of corn is often difficult because of the long process that involves destructive leaf sampling, drying, weighing and grinding of samples by either wet kjeldahl oxidation or dry oxidation automated analysis. Hence, a chlorophyll meter (SPAD Model 502, Minolta Inc. Ltd. Osaka, Japan) was used in this study.

2.6. Grid sampling

When the concept of precision agriculture was introduced, intensive grid soil sampling was used to develop application maps (Khosla, 2001). Grid sampling uses a systematic approach that divides a field into squares or rectangles of equal size, usually referred to as grid cells (Rehm et al. 2001). For management of nutrients such as N, grid sampling is labor intensive, time consuming, and must be performed every growing season in the field subject to variable-rate N fertilization (Khosla et al. 1999; Khosla et al. 2002). Hornung et al (2006) reported that aerial or satellite-based remote sensing is a promising alternative to intensive grid soil sampling and analysis for characterizing the spatial variability of soil properties for the purpose of variable-rate nutrient application. Precision agriculture soil sampling protocols must be sensitive to the fact that different objectives require different level of precision and accuracy, which include soil sampling techniques such as grid sampling. In this study, grid sampling was deemed necessary because this project was the first precision agriculture endeavor at Syferkuil experimental farm and intensive soil and crop information was required as a baseline.

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental sites

The study was conducted at Syferkuil agricultural experimental farm (23°50' S; 29 °40' E) of the University of Limpopo, in the Limpopo Province of South Africa. Limpopo province is the northern most province of the country of South Africa, and the study site is located in the proximity of Polokwane, the capital city of the Province. The climate of the area is classified as semi-arid. In the geographical area where the study site was located, rainfalls occur mostly in the summer months of October to March. In addition, it is interesting to note that about 80% of the annual rainfalls occur in these summer months. The maximum temperatures of 38.5 °C and annual average temperatures of 12.6 °C recorded during the crop growing season are normal temperatures in the geographical area of the study site. The soil of the field is classified as Hutton (Soil Classification Working Group, 1991).

For almost 35 years, Syferkuil agricultural experimental farm served as the main centre of university's research, on which both undergraduate and graduate student researches along with hands-on trainings are conducted. The farm is bordered by five populated rural small-scale farming communities. Syferkuil agricultural experimental farm has a total area of 1 705 ha and 80 ha of the farm is under automated linear move irrigation system. This study was conducted on a 7 ha portion of the 80 ha irrigated land (Fig. 1).

Field boundary map of study area

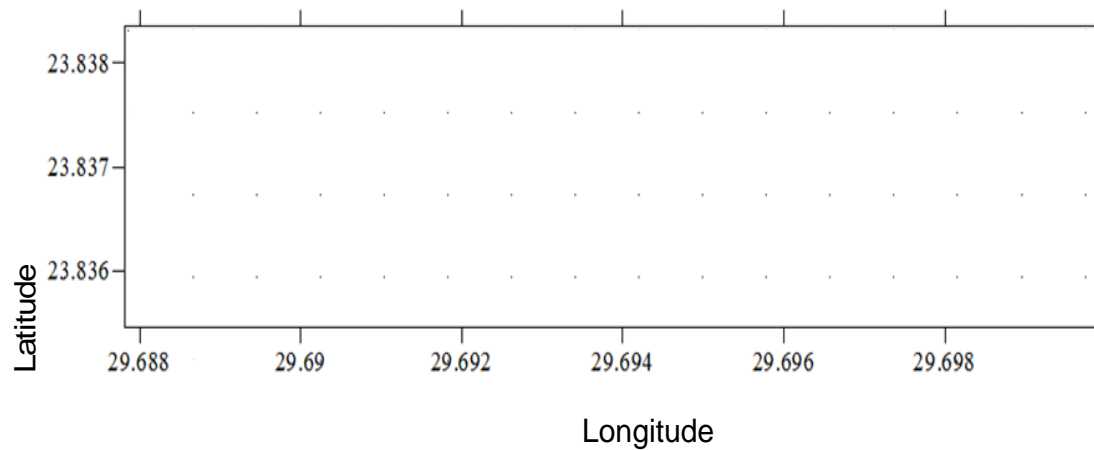


Fig. 1. Field boundary of the study area showing geo-referenced sampling locations on a full grid design.

3.2. Land suitability for corn (*Zea mays* L.)

Prior to planting, land suitability assessment for the crop of corn was conducted and then a section of the farm where this study was conducted was classified as suitable for corn (FAO, 1993; Moshia et al., 2008, b). The study was conducted by opening and classifying soil profiles, taking and analyzing soil samples, drawing soil maps and suitability maps for corn (*Zea mays* L.). According to the soil information from land suitability assessment, a soil on which the study was conducted was loamy sand and is characteristically deep with no stones or concretions. The soil has been classified under the South African soil classification system as belonging to the Hutton soil form (Soil Classification Working Group, 1991).

3.3. Soil sampling, preparation and analysis

The boundary of a 7 ha study field was mapped using Ag132 Trimble differentially corrected global positioning system (DGPS) and ArcView 3.2 GIS software. The Ag132 Trimble DGPS was equipped and operated for mapping with Field Rover II® GIS mapping software (SST). A normal full grid was used with a sampling density of 6.0 samples per hectare (40 m x 40 m) on the entire field. Soils were sampled using auger from a plough layer of 0-20 cm. Ag132 Trimble DGPS was used for navigating to the sampling points within each grid in the field. The DGPS coordinates were recorded at each sampling point for the purpose of plotting a spatial map of nutrients before and after the study. The following procedure entails how spatial maps were plotted: The GPS data (coordinates, table 4) were imported into Ms excel 2000 software as two columns. Column one represented the X coordinates (Easting) and column two, Y coordinates (Northing). The nutrients (PH, Phosphorus (P), Nitrogen and yield) determined were given a new column represented by Z and grid maps (Fig. 1-4) were then plotted using GIS Surfer version 8 software. Soil samples were collected prior to planting and after harvesting of the crop. Each geo-referenced soil sample consisted of three soil cores 20cm deep was composited into one sample within individual grids.

In the Soil, Plant and Water Analysis laboratory of University of Limpopo, Turfloop Campus, soil samples were air-dried and passed through a 2-mm sieve as part of soil preparation prior to analysis (Barnard et al., 1990). The Prepared samples were analyzed for pH using water solution method, NO₃-N using Kjeldahl method and phosphorus (P) using Bray1 method.

3.4. Corn planting and fertilization

The study was laid as a full grid (Maybury and Wahlster, 1998). According to field history reports, this field was not exposed to any manure or compost applications in the past 15 years. Prior to planting the crop of corn, the field was uniformly fertilized with Superphosphate based on recommendations from laboratory soil analysis results. The recommendation was to apply 300kg/ha of superphosphate on the study area. Uniform application of Superphosphate P fertilizer was based on an average number derived from the soil P results of forty-seven composite soil samples in a whole field. Maize (PANNAR 579) was planted in rows with row spacing of 80.0 cm. After the crop was planted, emerged, and had reached V6 six leaf growth stage, N was top-dressed as ammonium sulphate nitrate 26%N (ASN) based on laboratory soil analysis results. Nitrogen applications in this uniformly managed corn field was applied based on the average digit (3.4mg kg^{-1}) generated from 44 soil samples analyzed for N. Irrigation water was applied immediately after topdressing. Irrigation water was applied once every week with linear move irrigation system until the crop had reached physiological maturity.

3.5. Chlorophyll measurements, leaf sampling and analysis

Chlorophyll measurement and leaf sampling were done three times during corn growing season. The first collection of leaves and chlorophyll data was done at V6 (six leaf growth stage) 11-12 November 2003 prior to topdressing with N fertilizer, second collection was done when corn had reached V10 (ten leaf growth Stage) three weeks after nitrogen application, and final collection was performed at V14 (Final number of

leaf growth stage) three weeks after second collection. The very same leaf from which chlorophyll was measured was instantly collected immediately after chlorophyll measurement. The youngest fully expanded leaves of a plant were collected (Reseau Environmental Catalog, 2003). Four leaves were collected from four different maize plants of the same grid point.

Chlorophyll content was measured on corn leaves, and the leaves from which chlorophyll content was measured, were instantly removed from a crop and collected for laboratory analysis. The measurement of leaf chlorophyll content was performed on the youngest fully expanded leaves of a corn crop using Chlorophyll Meter (SPAD Model 502, Minolta Inc. Ltd. Osaka, Japan). Readings were taken on one side of the midrib of a leaf blade, midway between leaf base and tip (Vidal et al., 1999). Chlorophyll content measurements and leaf sampling were done on four sampling spots as replicates within each grid. The sampling spots where corn leaves were sampled were the geo-referenced locations from where soil samples were taken for analysis of nutrients at the beginning of the study.

On arrival in the laboratory, all leaf samples were washed with running water to remove unwanted material like dust. The cleaned, samples were placed in drying bags, and dried in the oven for 24 hours at 65°C. The dried leaves were ground and analyzed for N using Primacs N analyzer (Skalar, Inc., Norcross, GA).

3.6. Nutrient contour maps

The pre-planting and post harvesting laboratory soil analysis results were imported into Surfer software v8.0 with corresponding DGPS coordinates to produce nutrients spatial maps (Golden Software. 2002). Spatial maps for soil pH, N, P, and grain yield were produced (Fig. 3, 4, 5 and 6).

3.7. Data analysis

When the crop of corn had reached physiological maturity, corn was hand harvested from geo-referenced locations where leaf and soil samples were previously collected. The weight of the harvested grain was corrected to moisture content of 220 g kg^{-1} for determining grain yield. Grain yield for the area harvested was converted to Mg ha^{-1} . Geo-referenced pre-plant and post harvest soil and plant analysis data for N, P, pH, Leaf N, and Leaf Chlorophyll were subjected to t-test analysis in SAS (Littell et al., 2002). Descriptive statistics for soil, plant and grain yield data was performed with Statistix software (Tampa, FL) and Microsoft Excel (Redmond, WA).

CHAPTER 4

RESULTS AND DISCUSSION

A soil map of the study area (Fig.1) was produced with ArcView 3.2 GIS software (Environmental System Research Institute, CA). The gray-scale bare-soil imagery of the field exhibited spatial variability of soils based on color (Fig. 2). While the entire field was classified as one soil type (Table 1), it was unexpected that the bare soil reflectance would show variability in a field of such a small size of 7 ha. Mzuku et al. (2005) reported that the variability in bare soil reflectance is due, in part, to non-uniform distribution of certain soil organic matter, texture, and electrical conductivity that influence crop productivity. Fleming et al. (2000) and Khosla (2008) successfully used gray-scale bare-soil imagery on maize fields to delineate farmers' fields into management zones of different productivity levels. While this study was not about dividing the field into homogeneous yield limiting factors, the bare-soil imagery of this conventionally tilled field indicated a potential for zoning the field. Delineation of a field is part of best management practices in precision agriculture for optimal utilization of resources and maximization of productivity.

Although there was no practical conclusion related to crop performances that could be drawn based on variability shown on field image, pre-planting soil analysis results showed a significant ($P \leq 0.05$) variability in nutrients across the field (Table 2 on page 38). Using Stats SA, a common understanding among precision agriculture specialists and practitioners is that, when there is a significant variability of essential crop nutrients

in a farm, and nutrients are applied uniformly based on average values, there is a potential for grain yield variation across the field (Cahn et al., 1994; Moshia, 2006).

Bare soil imagery map of study area

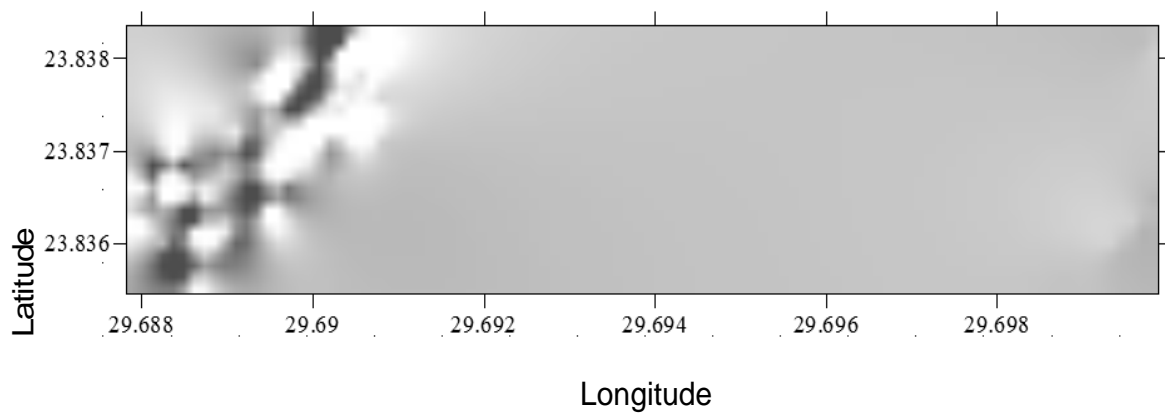


Fig. 2. Gray scale bare soil imagery of the study area.

4.1. Soil pH

Maize is reported to do well at soil pH between 5.8 and 7.0 (Miles and Zenz, 2000), however, in this study soil pH ranged from 5.0 to 8.6 (Fig. 3). While this study was about spatial variability and management of soil nutrients such as N, there was a need to assess soil pH levels across the field. The reason for soil pH assessment across the field was that, soil pH is known to affect the availability of nutrients in the soil (Grier et al., 1989). This wide range in soil pH (5.0 to 8.6) and significant variability across the field could be an indication that micronutrients, though not measured in this study, could be significantly variable in the field because soil pH has an effect on the quantity and available form of nutrients in the soils (Grier et al., 1989).

After harvesting of corn, there was a significant difference between pre-planting and post harvesting soil pH of soils sampled at geo-referenced location with differentially corrected GPS (Table 3). This indicated that agricultural inputs applied to the field had a significant impact on soil pH, and that uniform application of nutrients in a farm field based on average values did not correct nor account for spatial variability that existed in the field. Although we did not expect uniform application of fertilizers to correct variability of soil pH, the study suggest variable rate liming on site-specific basis to ensure that different parts of this agricultural field receive adequate amount of lime as required.

Soil pH contour maps

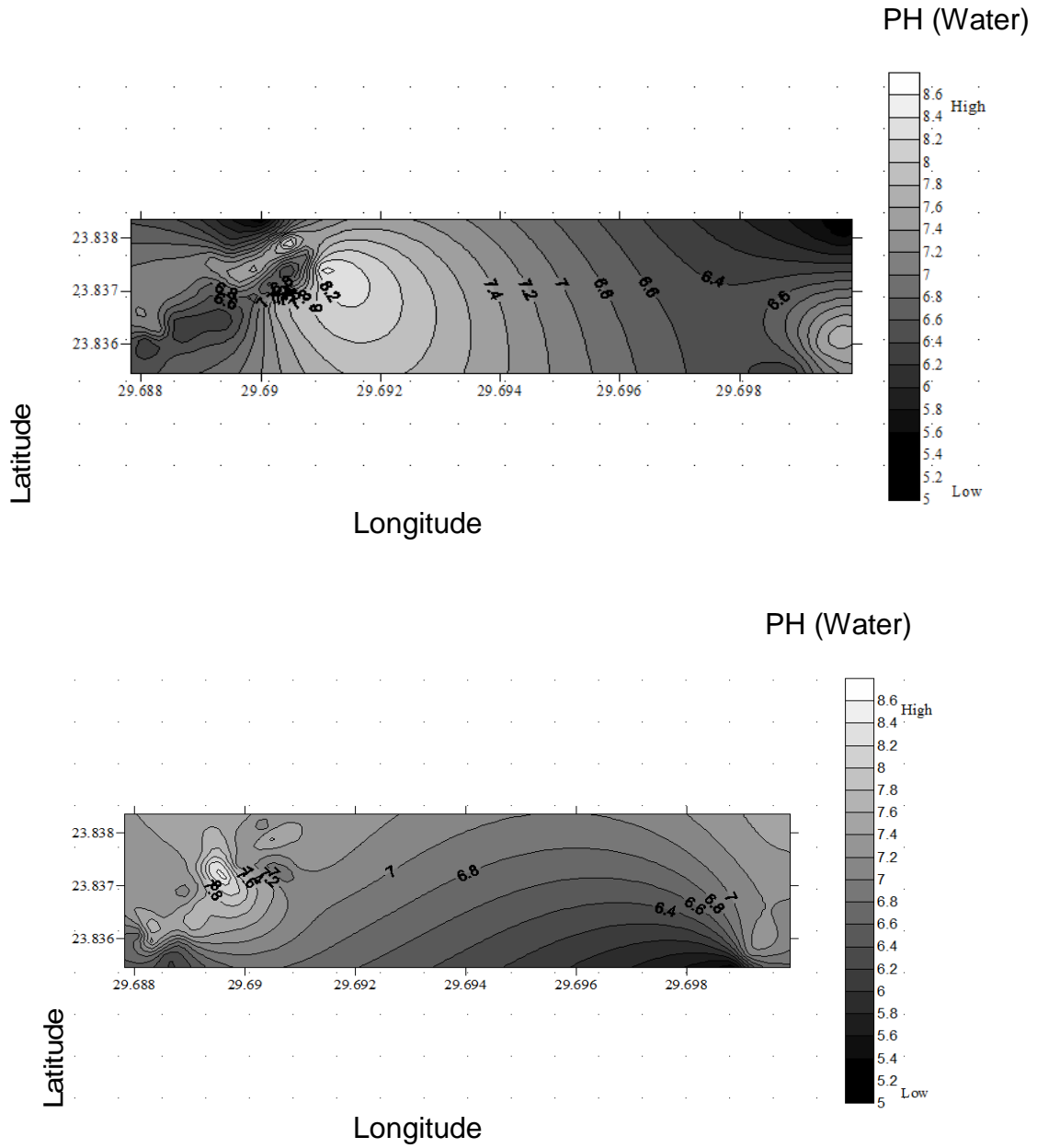


Fig. 3. Soil pH distribution in a uniformly managed corn field before planting (top) and after corn was harvested (bottom).

4.2. Soil nutrients

4.2.1. Soil nitrate-nitrogen

Despite the fact there was variability in soil N prior to planting of the crop of corn (Table 2). The variability of N and its potential impact on the crop was unknown. Quantification of the variability of N on spatially variable soils may require understanding of N budget and economics of corn production (Moshia, 2009; Watson and Atkinson, 1999). Consequently, Ammonium Sulphate Nitrate was applied uniformly in the field based on an average number (2.7 mg kg^{-1}) calculated from a sample size of 44 soil samples (Table 2). One disadvantage in small scale farming is that, even though the study highlighted variability of N in this field (Fig. 4), there are no high technology equipments (lack of technical instrument) and sensors to apply N on-the-go at variable rates. However, one simple method would be to delineate N management zones based on N variability in the field and soil color imagery of the field (Fig. 1). Variable application rate methods are the simple and low-cost methods that showed to be helpful to farmers in countries where precision agriculture is being applied (Fleming et al., 2000; Hornung et al., 2006). Even though N ranged from 2.20 to 3.40 mg kg^{-1} in the soil, N was lower for corn production (Table 2), the significant N variability across the field suggest that N should be applied based on site-specific methods to avoid over application and under application at various parts of the field.

Nitrate-nitrogen (NO₃-N) contour maps

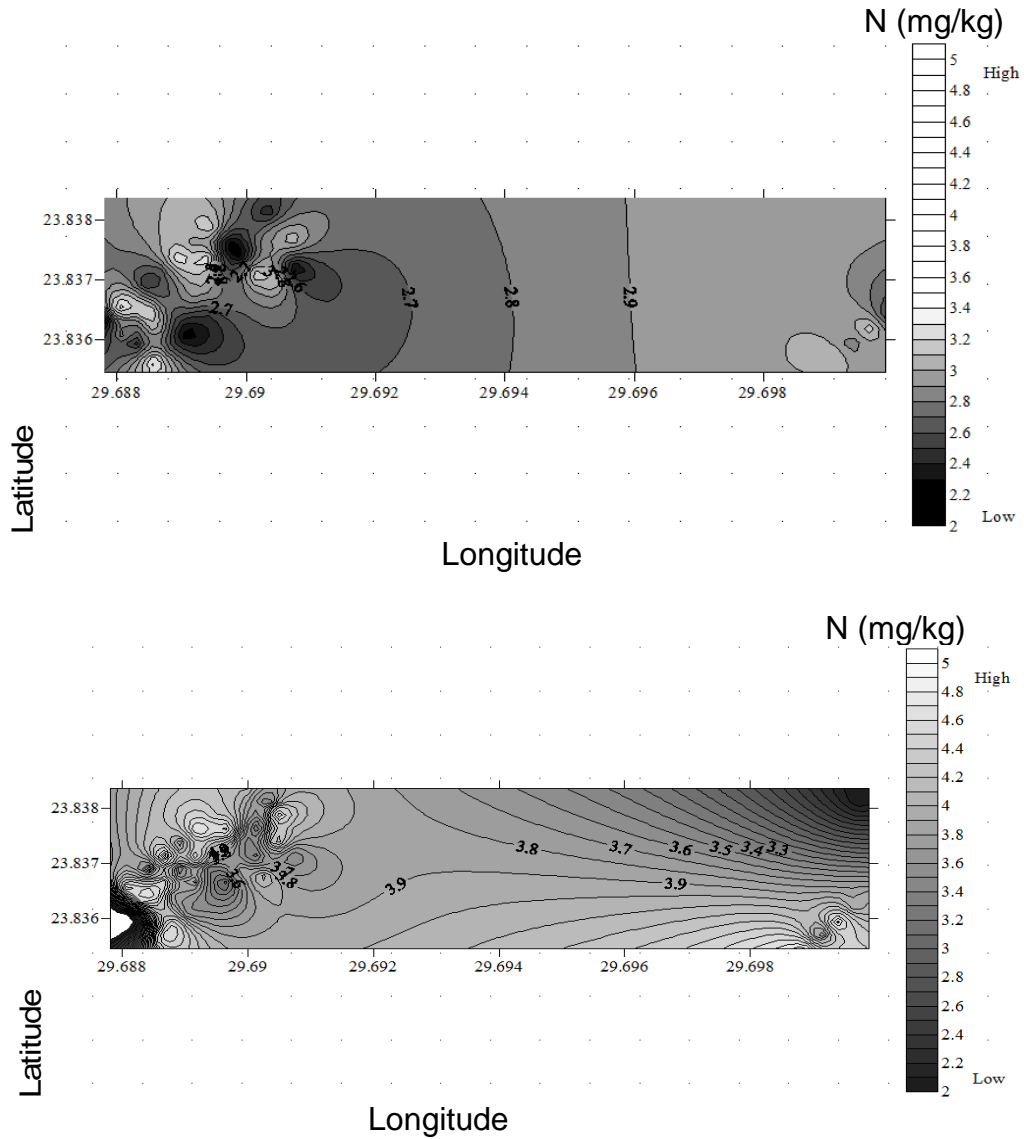


Fig. 4. Nitrate-nitrogen (NO₃-N) distribution in a uniformly managed corn field before planting (top) and after corn was harvested (bottom).

4.2.2. Soil phosphorus

The spatial distribution of soil P across the field before planting and uniform application of Superphosphate P, and after harvesting of corn is shown in Fig 5. The whitish spots in Fig. 5, indicate areas with higher P content while the darker areas designate areas with lower soil P. Some areas of the field appeared lighter in color after uniform P application and harvesting of corn than before P was uniformly applied, suggesting that P was increased in the soil. The lighter areas of a field were parts of the field where P was already higher before uniform application of superphosphate but less than corn required (Westfall and Davis, 2009). According to Westfall and Davis (2009), Bray1 P is classified as follows for corn production under irrigation, 0-6 low, 7-14 medium, 15-22 high and $>22 \text{ mg kg}^{-1}$ very high. In this study, before P fertilizer was applied in the form of Superphosphate, P ranged from 0.50 to 5.00 mg kg^{-1} , average 2.60 mg kg^{-1} (Table 2). The P level in field was lower than what is required for optimum corn production. In spite of low levels of P for corn production in the field, there was a significant increase in P after uniform application of superphosphate (Table 3). While this was not a surprise because P is relatively immobile in the soil, site-specific application of P can potentially ensure that there is no excess P left on topsoil after harvesting of a crop as the exact amount required crop in the specific area will be applied. Excess amount of P on topsoil can runoff to water bodies, consequently contaminating surface water and causing eutrophication (Sims et al., 1998).

Phosphorus (P) contour maps

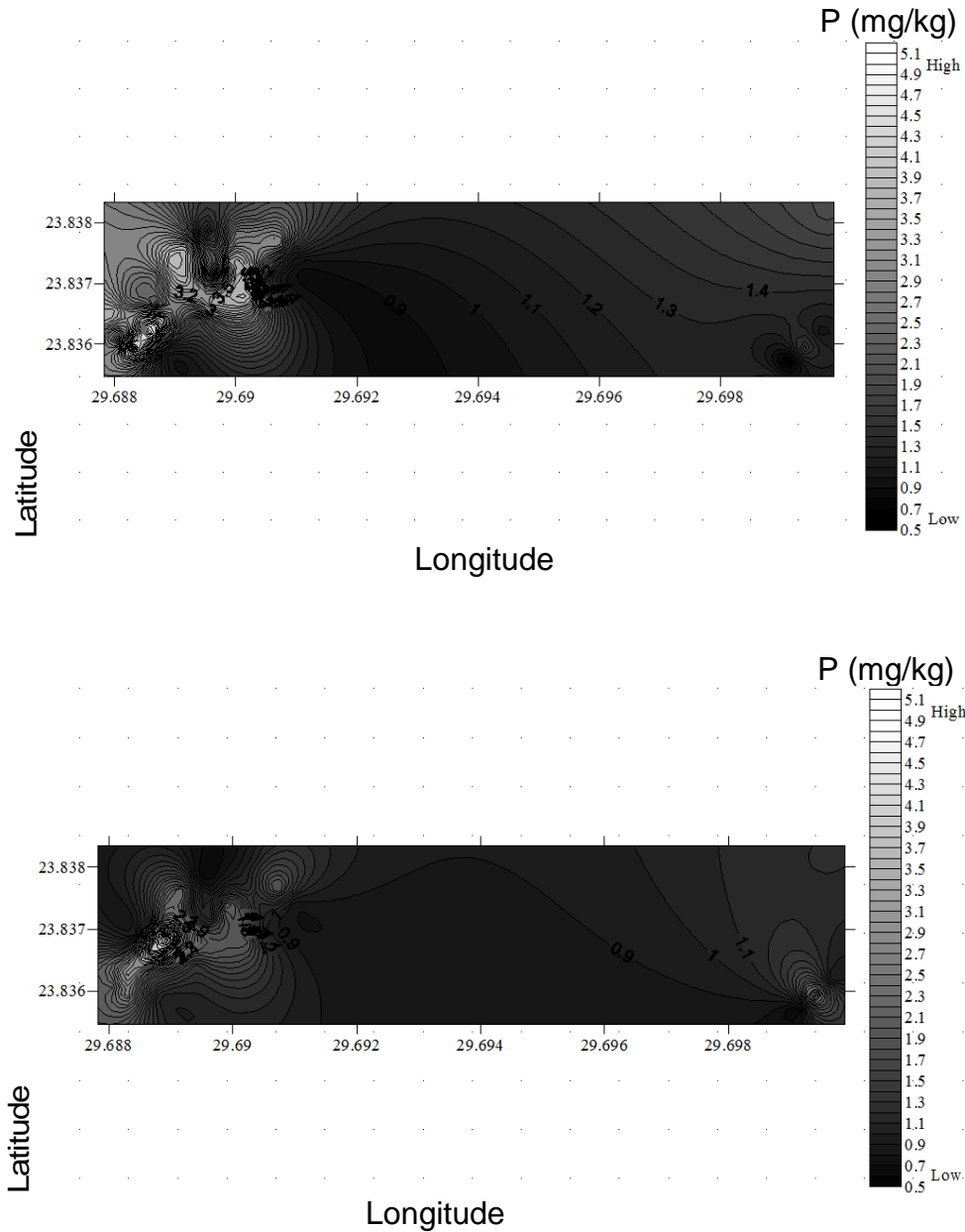


Fig. 5. Phosphorus (P) distribution in a uniformly managed corn field before planting (top) and after corn was harvested (bottom).

4.2.3. Maize grain yield

The average corn grain yield for the tradition and uniformly managed corn field under irrigation was 5.3 Mg ha⁻¹ (Fig. 6). Under normal circumstances like good irrigation scheduling, crop fertilization at agronomic rates, proper control of pest and diseases; an average corn grain yield under irrigation in a semi-arid environment for S1 classified soils should be above 6.5 Mg ha⁻¹ (Dang and Walker, 2001). The average yield in this experiment was 5.3 Mg ha⁻¹ (Table 4). While there was no control treatment for the corn grain, Whitbread and Ayisi (2004) conducted a study in the same experimental location, soil type, and irrigation method; the authors observed similar corn grain yield of 5.2 Mg ha⁻¹. The reason for no control for grain yield was because the objective was about assessment of infield spatial variability of soil nutrients in a uniformly managed corn field.

In precision agriculture, arithmetic average in an agricultural field can be a misleading number for any decision making process. Corn grain yield was reported on an average of 5.3 Mg ha⁻¹. Considering that precision agricultural practices aims at understanding, quantifying and managing in-field spatial variability of soil properties, every location in a field need to be treated as an individual not as an average. Therefore, grain yield for the crop of corn in this study ranged from 2.7 Mg ha⁻¹ for low producing areas to 6.3 Mg ha⁻¹ on highly productive areas across the uniformly managed irrigated corn field (Fig. 6). This lower grain yields under irrigation, which were significantly variable, can be linked to significantly different ($P \leq 0.05$) spatial variability of soil pH and essential plant nutrients in the field (Table 2). The reason for linking lower grain yields to in-field spatial

variability of nutrients is that, Rainfall records shows a normal pattern for the semi-arid environment (Fig. 7), and land suitability assessment was conducted on the field prior to planting of crops (Table 1). The land suitability class for this field was S1, meaning that the land was suitable for all agricultural crops with negligible limitations (Table 1.)

Maize grain yield contour map

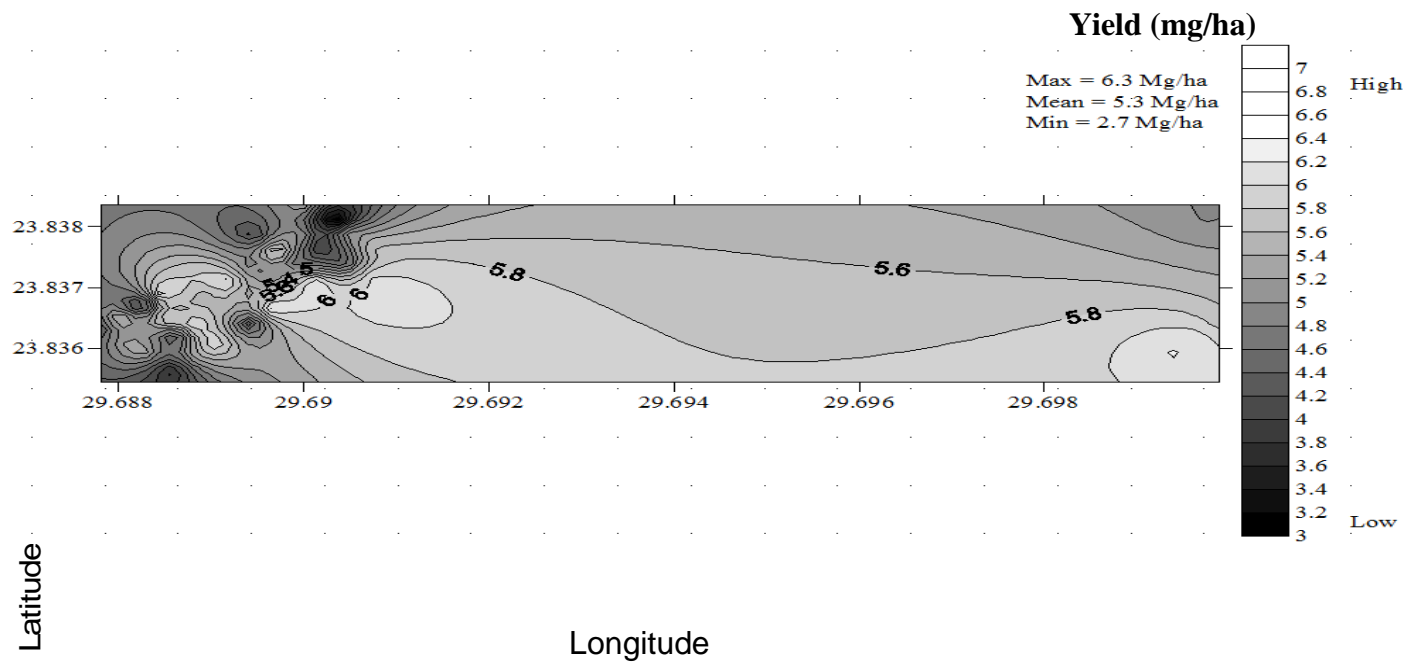


Fig. 6. Distribution of maize grain yield, with uniform application of nitrogen

Monthly recorded Rainfall map

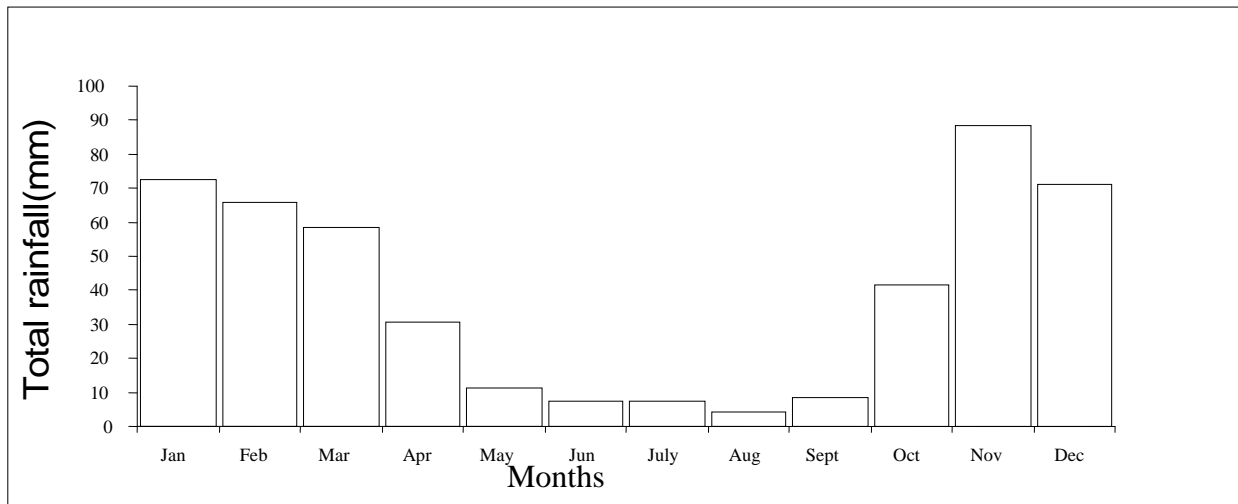


Fig. 7. Total rainfall (mm) recorded in the year corn was planted in the field. Maize was planted in October and harvested in April to May.

4.2.4. Chlorophyll and leaf sampling

The primary purpose for sampling corn leaf at various vegetative stages and taking chlorophyll reading was to check if in-season N fertilization could be determined from such data. However, considering that the field was under uniform management, meaning the entire field was treated as if there was homogeneity of soils; the data was initially averaged across the growing season. Leaf N analysis results from this study indicated that averaged N (3.40 mg kg^{-1}) across the field was significantly different from pre- and post- N fertilization (Table 3). There was a need to check if in-season N application can be recommended from chlorophyll and leaf N analysis data collected at different corn vegetative growth stages, the data was stored in an 3.5 floppy diskette could not be retrieved.

CHAPTER 5

CONCLUSION

Precision agricultural techniques discourage uniform application of inputs because of spatial variability that exist in agricultural fields. Soils exhibiting spatial variability are not supposed to be managed uniformly, but on site-specific. Nutrient distribution spatial maps which were produced with Surfer software version 8.0 showed a significant variability ($P \leq 0.05$) of soil nutrients and pH across the corn field. Corn grain yield ranged from 2.7 to 6.3 Mg ha⁻¹. For a land suitability class of S1 under linear irrigation in a semi-arid environment, these grain yields are considered low. This low grain yields can be linked to variability of soil nutrients and pH because the field was classified as suitable according to FAO guidelines

Site-specific soil management coupled with good crop management practices such as site-specific irrigation water management, and control of pest and diseases can help enhance corn grain yield, in this study it was discovered that the yield average is 5.3 mg ha⁻¹. The results of this study will assist producers and researchers in the Limpopo region of South Africa to gain knowledge of spatial variability, its effects on grain yield, and potentially opt for methods that apply inputs in site-specific basis or zoning fields according to productivity potential. The results of this study suggest a need for technologies to enhance fertilizer-use efficiency to protect the environment and enhance production in the Limpopo Province, where soils are generally low in productivity.

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CHAPTER 7: APPENDICES

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Soil classification and land suitability assessment results for the study area. Soils were classified according to South Africa Binomial System of Soil Classification.

Appendix 7.2

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Appendix 7.3

The mean difference \pm standard error difference and standard deviation of pre-fertilization and post-harvest/post-fertilization of soil pH, Soil NO₃-N, Bray1 P, K, Leaf Nitrogen and Leaf chlorophyll across uniformly managed corn field.

Appendix 7.4

X & Y co-ordinates versus pH, Phosphorus, Nitrogen in percentage and grain yield

Appendix 7.5

Soil and plant analysis methodology

Appendix 7.1

Tables showing statistical evaluation

Table 1. Soil classification and land suitability assessment results for the study area. Soils were classified according to South Africa Binomial System of Soil Classification.

Soil Form	Master Horizon	Soil depth	Diagnostic horizon	Structure Class	Textural	Colour	Consistency	Stones/ Concretions	Density	Bulk
Hutton	A	-mm- 255	Orthic	Apedal	Sandy loam	5YR 4/8	Hard	None		-g cm ⁻³ - 1.45
	B21	940	Red Apedal	Apedal	Sandy Clay	5YR 3/6	Friable	None		–
	B22	1590	Red Apedal	Apedal	Clay Loam	5YR 6/8	Friable	None		–
	B23	1590+			Loamy Clay	5YR 6/8	Friable	Concretions		–

-----Locality Characteristics-----

Climate: Semi-arid

Vegetation: Savanna Biome

Trees and Shrubs: *Acacia caffra*, *Dichrostachys cinerea*, *Lannea discolor*, *Sclerocaya birrea*,
and *Grewia species*

Grasses: *Digitaria eriantha*, *Schmidtia pappophoroides*, *Anthehora pubescens*, *Stipagrostis uniplumis*,
Panicum maximum and various *Aristida* and *Eragrostis* species.

Slope: 1 to 2 %

Table 2. Descriptive statistics of 44 composite soils sampled on a 40 x 40 m grid for 3 primary maize nutrients and pH. Soil samples were acquired at 0-20 cm depth prior to uniform fertilizer applications and maize planting.

Soil	Sampling	Soil Properties			
Properties	Depth	pH	NO ₃ -N	‡P	§K
	cm			mg kg ⁻¹	
Minimum	0-20	5.43	2.20	0.50	100
¶Mean ± SE	0-20	6.90±0.10	2.80±0.04	2.60±1.51	353±14.5
Maximum	0-20	8.50	3.40	5.00	544
SD		0.65	0.03	10.35	99.1
CV		9.39	11.7	42.50	28.1
Pr > t		<.0001	<.0001	<.0001	<.0001

†NO₃-N is nitrate-nitrogen in the soil

‡P is Bray 1 phosphorus

§K is soil potassium extracted with ammonium acetate

¶SE is the standard error of the mean

¶ Agronomic use efficiency (UAE) is calculated as observed yield/total available N.

Do one sample t-test to check if there was a significant variability in samples.

Table 3. The mean difference \pm standard error difference and standard deviation of pre-fertilization and post-harvest/post-fertilization of soil pH, Soil NO₃-N, Bray1 P, K, Leaf Nitrogen and Leaf chlorophyll across uniformly managed corn field.

Measured			
Parameter	†Mean diff. \pm SE diff.	Standard deviation	Pr > t
‡Soil pH	0.454* \pm 0.112	0.764	0.0002
‡Soil NO ₃ -N (mg kg ⁻¹)	0.105* \pm 0.010	0.071	< .0001
‡Bray 1 P (mg kg ⁻¹)	0.867* \pm 0.139	0.959	< .0001
Leaf Nitrogen (mg kg ⁻¹)	0.705* \pm 0.106	0.693	< .0001
Leaf Chlorophyll	1.895 ^{ns} \pm 1.687	11.06	0.2675

*Significant difference at $P \leq 0.05$,

ns = no significant difference at $P \leq 0.05$,

†Mean diff. \pm SE diff. is mean difference and standard error of the difference for measured soil and leaf parameters, and

‡Soil parameters measured from soils sampled before planting and fertilization, and soils sampled after harvesting of maize.

Appendix 7.4

Table 4: X & Y co-ordinates, pH, Phosphorus, Nitrogen in percentage and grain yield

Grid point	Coordinates		PH-1	PH-2	P-1	P-2	LN-1	LN-2	Yield
	Longitude(E)	Latitudes(S)							
1	29.690991	23.83743328	7.32	7.5	0.5	2.41	2.8	2.4	7.2
2	29.6907231	23.83719238	6.81	8.1	2.4	2.69	2.84	2.4	6.32
3	29.69048352	23.83697593	7.47	8.5	2.5	3.56	2.47	2.5	5.51
4	29.69024717	23.83676475	7.55	8.4	2.7	3.42	3.02	2.7	4.73
5	29.69988227	23.83641747	7.1	8.2	3.1	2.99	2.09	3.1	3.5
6	29.69965757	23.83620293	7.19	8.1	3.6	1.84	3.24	3.6	2.73
7	29.69936532	23.8359386	7.35	7.5	4.4	2.24	3.93	4.4	2.53
8	29.69912272	23.83571957	7.11	5.6	4.6	2.01	3.29	4.6	3.84
9	29.69885793	23.83545798	6.51	7.5	4.9	2.5	3.71	4.9	3.24
10	29.68857458	23.83565218	5.4	6.7	5.0	3.19	3.07	5.0	4.75
11	29.68882223	23.83588277	5.0	7.8	5.1	4.67	1.82	5.1	4.58
12	29.68906117	23.8360987	7.63	7.1	4.9	4.23	3.51	4.9	5.54
13	29.68941918	23.83641838	7.58	6.0	4.7	5.10	3	4.7	5.28
14	29.68964495	23.83663557	7.79	5.9	4.4	5.05	1.77	4.4	5.54
15	29.68987917	23.83687103	8.05	6.7	3.1	4.61	2.73	3.1	6.73
16	29.69012048	23.83710005	7.6	5.4	3.0	4.16	2.56	3.0	6.44
17	29.69043955	23.83740225	6.91	6.1	2.4	4.81	2.11	2.4	6.21
18	29.69071862	23.83766623	7.31	8.6	2.5	3.7	3.03	2.5	6.73
19	29.69045262	23.8379229	7.72	6.2	2.7	3.49	3.36	2.7	7.18
20	29.69017902	23.83767138	7.46	6.3	1.9	3.25	3.13	2.9	7.02
21	29.68991048	23.83741708	7.11	6.1	1.5	2.01	2.85	2.5	6.67
22	29.68964052	23.8371705	8.6	6.8	0.5	2.91	3.18	2.5	7.46
23	29.68937028	23.83690703	7.64	6.7	1.1	1.81	3.41	3.1	6.63
24	29.68913808	23.8366738	7.65	5.4	1.5	1.5	2.05	3.5	6.43
25	29.68881537	23.83638822	7.6	6.2	2.4	1.89	2.51	2.4	5.24
26	29.68860665	23.8362041	7.55	5.5	2.2	2.64	3.52	2.2	4.22
27	29.6882851	23.83592772	7.7	5.4	3.1	0.5	3.72	3.1	3.37
28	29.68808698	23.83608412	6.66	5.4	3.5	1.4	2.8	3.5	2.22
29	29.68826292	23.8362591	7.8	5.5	3.6	1.48	2.06	3.6	3.3
30	29.68850688	23.83647697	7.23	5.7	4.5	1.75	3.17	4.5	4.39
31	29.68869167	23.83664747	7.29	6.1	4.7	2.45	3.23	4.7	6.64
32	29.68893247	23.83686873	7.06	6.6	4.8	2.45	3.47	4.8	6.75
33	29.6891785	23.83709168	7.47	6.4	5.1	1.91	2.9	5.1	6.66
34	29.68943538	23.83734743	7.79	6.6	5.0	1.82	2.38	5.0	7.43
35	29.68970268	23.83759173	6.5	6.9	4.9	1.97	2.75	4.9	7.22
36	29.68997865	23.83785383	6.9	5.0	4.7	1.61	3.03	4.7	6.81
37	29.6903395	23.83810958	5.0	5.1	3.1	2.11	3.14	3.1	6.74
38	29.69002248	23.83835387	5.4	6.9	3.5	1.54	2.96	3.5	6.12
39	29.69974028	23.83810513	5.8	4.7	3.6	2.3	1.90	3.6	6.43

40	29.68946838	23.83785407	6.3	5.4	4.5	1.87	2.74	4.5	6.32
41	29.68920322	23.83759633	6.7	5.1	4.7	2.48	3.47	4.7	7.32
42	29.68891767	23.83734753	7.36	5.0	4.8	3.76	2.34	4.8	7.09
43	29.68867042	23.83712098	7.36	5.4	3.1	2.39	3.27	3.1	7.14
44	29.68843052	23.8368997	7.31	6.5	3.5	2.09	3.16	3.5	7.07

Abbreviations

LN-1: pH-1:pH before planting, pH-2: pH after harvest, p-1: phosphorus before planting, p-2: phosphorus after harvest, Leaf Nitrogen before nitrogen application, LN-2: Leaf Nitrogen after nitrogen application.

Appendix 7.5

Soil and plant analysis methodology

7.3.1 Soil analysis

PH (H₂O) (Barnard et al., 1990)

This procedure determines the pH of soil in a 1:2.5 soil: water ratio suspension

Apparatus

- Balance
- Beakers
- Stirring rod
- pH meter with glass-calomel electrode

Reagents

- Commercial buffer solution for pH 4 and 7
- De-ionized water

Procedure

PH meter is calibrated with the commercial buffer solution at a given temperature

Place 20g soil in a beaker

Add 50ml de-ionized water

Stir contents with glass rod; allow for ten minutes. Stir again and allow standing for ten minutes.

Determine pH with the electrode positioned in the supernatant solution

7.3.2 Extractable Phosphorus (Bray 1) (Black, 1965 and Barnard et al., 1990)

This procedure is used as an index of available phosphorus in soils by extracting easily acid-soluble forms of P.

Apparatus

- Balance
- Extracting bottles
- Whatman no.40 filter paper
- Spectrophotometer
- Spectrophotometer curvet
- Reciprocating shaker

Reagents

- Bray 1 extracting solution (NH₄F and HCL)
- Flocculant
- 1-amino-2-naphtol-4-sulphonic acid (ANSA)
- Ammonium molybdate
- Phosphorus standard solution

Procedure

- Place 6.67g soil in an extracting bottle
- Add 50ml Bray 1 solution
- Stopper bottle and shake contents on reciprocating shaker for 60 seconds

- Add 2 drops of flocculant
- Filter immediately through Whatman no. 40 filter paper
- Analysis
- Add 2ml ammonium molybdate and a few drops of the ANSA solution
- Allow color to develop for 10 minutes
- Transfer the solution to curvet and measure the percentage transmittance with spectrophotometer

7.3.3 Plant analysis

This method was used to determine the total percentage of Nitrogen in plant leaves

Apparatus

- Automatic balance machine
- Forceps
- Spatula
- Primacs^{Sn} Nitrogen Analyser V. 1.20
- Crucibles

Reagents

- EDTA (Ethylenediamine tetra acetic acid)

Procedure

- Place 0.2 g of samples into the crucibles

- Place 0.2g of EDTA for standards into two crucibles
- Put the crucibles with the samples and EDTA in the crucible tray
- Place the tray in the primancs nitrogen analyzer and run it.