SITE-SPECIFIC SOIL pH MANAGEMENT ACROSS SPATIALLY VARIABLE SOILS

by

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DECLARATION

I hereby declare that this mini-dissertation submitted to the University of Limpopo for the degree, Master of Science in Agriculture (Soil Science), has not been previously submitted by me for a degree at this or any other University, and that it is my work in design and in execution, and all material contained therein has been duly acknowledged.

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P.M. KANYANE Date

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My brother Moeti, thank you for investing in me through education. My little sisters, Shatadi and Hunadi, my brother, Lentsu, and my husband Moketla Kgopa, thank you guys for standing by me. I know it’s been a rocky road but I made it because of your love and support.

Above all, let me thank my Father in heaven, God the Almighty. Thank you Lord for preparing this road, and setting goals for me. Amen.

DEDICATION

I dedicate this work to my late father, Ramolangoana Piet Kanyane, my loving mother, Nthakwedi Fancy Kanyane, and my two babies, Mokgethi and Thuto.

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ABSTRACT

Knowledge and management of soil pH, particularly soil acidity across spatially variable soils is important, although this is greatly ignored by farmers in the Limpopo Province of South Africa. The significance of understanding spatial variability of soil acidity is the implementation of best and site-specific management strategies because when soil acidity is poorly managed, toxicity and nutrient deficiency problems in the soil are inevitable. The objective of the study was to evaluate in-field spatial variability of soil pH, and compare the efficiency of managing soil pH through site-specific method vs. uniform lime application. The study was conducted in 3 site years (23^{o}50' S; 29 ^{o}40' E and 23^{o}59' S and 28^{o}52' E) with site year I, and II adjacent to each other in the semi-arid regions of the Limpopo Province, South Africa. Soil samples were taken in four replicates within a 1 m radius from geo-referenced locations in 3 study sites to sampling depths of 0-20 cm on a regular grid of 30m using differential Global Positioning System (DGPS). Soils were analyzed for pH, and SMP buffer pH for lime recommendations. Lime requirement to achieve a soil pH of 6.5 for a 20 cm plough layer per hectare was calculated using Calcium Carbonate equivalent, efficiency factor (fineness factor), and neutralizing index of the liming materials. The spatial maps for SMP buffer pH and lime requirement maps were produced with surfer version 8.0 (Surfer Version 8, Golden Software, Golden, CO). The soil pH datasets from systematic unaligned randomly sampled soils on a 30-m grid were interpolated using inverse distance weighing (IDW) in Surfer software version 8.0 (Surfer Version 8, Golden Software, Golden, CO). Soil pH varied from strongly acidic to slightly acidic with minimum values of 4.22, 3.93, and 4.74 and maximum values of 6.11, 7.00, and 6.82 in site I, II, and II respectively. In Site I, II, and III, the areas of the field that had soil pH values of less than 6.0 were 99.43, 82.61, and 62.89% of the field. When lime was recommended for application using a conventional method of uniform lime application based on an average value derived from samples collected in the whole field, the results of the study showed a waste of lime in excess of lime recommended for individual grids. An excess amount of lime as high as 10, 30, and 7 tons/ha recommended on sites I, II and III respectively under uniform application. These recommendations were in excess on field areas that needed little or no lime applications. Again, the fields showed under applications of lime as much as 30, 35, and 13 tons/ha in site I, II, and III respectively for uniform liming applications. This under- and over recommendations of lime based on average soil pH values suggests that uniform soil acidity management strategy is not an appropriate strategy to be adopted in these fields. Again, in both of these sites as shown in the maps, the areas that required high amount of lime and those that require little or no lime are clearly defined, such that the fields can be divided into lime application zones. When a field is divided into lime application zones, management of soil acidity becomes easier because instead of applying variable rates of lime for every grid, lime rates are applied per zone. These zones could be areas in a field that require, (i) high rates of lime, (ii) low rates of lime, and (iii) areas that requires no lime at all. Agricultural fields that exhibit spatial variability of soil acidity must not be managed or treated as uniform when lime is applied in the field.

Keywords: Lime requirement, Site specific management and Soil pH.

CHAPTER 1

INTRODUCTION

1.1 Background

Traditionally, soil pH management is performed through random sampling with a "representative" sample analyzed. Irrespective of field size, this traditional soil pH management system uses an average value derived from a large number of soil samples from the whole field (Adamchuk and Mullinek, 2005). While this study was based on site-specific soil pH management, a great emphasis was put on low pH soils of Mapela and the University of Limpopo experimental Farm. Based on the average value for soil pH, farmers in the Limpopo Province apply lime uniformly in the whole field (Nethononda et al., 2012). When lime is applied uniformly in a field that exhibit spatial variability of soil pH, other parts of a field received more/less lime than it is necessary. This method is financial inefficient and pose an environmental threat to the fragile ecosystem. Therefore, there is a need for an efficient and environmentally friendly method of managing soil pH on spatially variable soils.

1.2 Aim

To study soil pH management across spatially variable soils and produce lime application maps for variable rate vs. uniform lime applications.

1.3 Objectives

I. To evaluate in-field spatial variability of soil pH.

II. To compare the effectiveness of managing soil pH through site-specific application method vs. uniform lime application.

1.4 Hypotheses

I. There is no in-field spatial variability of soil pH.

II. Managing in-field spatial variability of soil pH is effective with uniform lime application than site-specific application method.

1.5 Motivation of the study

Precision agriculture methods have a potential to manage infield spatial variability by applying agricultural inputs on site-specific basis (Santra et al., 2008). Small scale and commercial farmers in South Africa are accustomed to traditional and uniform whole-field method of inputs application across farm fields. There is a need for site-specific soil pH management to apply lime cost effectively across spatially variable acidic soils, and potentially reduce pollution. The site-specific farm management is known to provide accurate farm records and environmentally sound recommendations.

CHAPTER 2

LITERATURE REVIEW

Site-specific management (SSM) is the management of agricultural fields at a spatial scale smaller than that of the whole field (Jin and Jiang, 2002; Plant, 2001). Site-specific management of soil pH is one agricultural practice that may potentially benefit farmers for efficient crop production (Adamchuk et al*.,* 1999). Previous studies reported that natural variation in field landscape and past or present management practices can cause significant variation in soil pH, lime requirement, and soil properties (Adamchuk et al*.*, 1999; Jin and Jiang, 2002; Pierce and Warncke, 2000). Spatial variability within an agricultural field has become a focus of many studies in precision agriculture (PA). One of PA goals is to manage agricultural inputs according to changing local field conditions in order to increase profitability and reduce environmental waste of agricultural inputs (Li et al*.*, 2008; Pierce and Warncke, 2000). Spatial variability occurs when a parameter that is measured at different spatial locations exhibits values that differ significantly across the locations in a single field. At present, the use of site-specific management zones (MZs), rather than the traditional whole field management approach, is a popular approach for farm managers to manage field variability on a site-specific basis (Li et al*.*, 2008).

2.1 Site-specific management zones

Site-specific management zones are defined as sub-regions of a field that has a relatively homogeneous combination of yield-limiting factors, for which a single rate of a specific crop input is appropriate to attain maximum efficiency of farm inputs (Vrindts et al., 2005). A field study conducted at West Virginia State in the United States indicated that MZs could be used as an alternative to grid soil sampling and to develop nutrient maps for variable rate fertilizer application (Khosla and Alley, 1999). Thus, the delineation of MZs is simply a way of classifying the spatial variability within an agricultural field. There have been several different techniques of MZs delineation proposed in the literature by Fleming et al. (1999). However, one commonality in all MZs delineation techniques described is that, MZs are minimally intrusive, do not rely strictly on soil sampling, and therefore have potential to be more economically feasible than grid soil-sample-based variable rate application (VRA) map.

There are several geographic information system (GIS) layers that can be used to delineate MZs. Such GIS layers include topography data, apparent soil electrical conductivity (ECa), and previous years' grain yield data or farmers' field management experiences (Fleming et al., 1999). These GIS data can be used to delineate and identify MZs because of their ability to reflect different soil properties, noninvasiveness, and may be of low cost (Schepers et al., 2000). Fleming et al. (1999), evaluated farmer-developed MZs maps and concluded that soil color from aerial photographs and satellite imagery, topography, as well as the farmer's past management experience are effective in developing VRA maps.

Management Zone sampling are a new recommendation to reduce a number of samples and sampling costs while maintaining acceptable information about nutrient variation within fields (Franzen et al., 2000). Khosla (2009), emphasized that MZs are a new cost effective approach of mapping in-field soil variability for crop management as compared to labour intensive and time consuming traditional random sampling.

2.2 Spatial variability

Almost all soil properties exhibit variability as a result of the dynamic interactions between natural environmental factors, i.e., climate, parent material, vegetation, and topography (Jenny, 1941). Significant differences in the soil nutrients from areas with uniform geology are known to be related to landscape position (Jenny, 1941; Rezaei and Gilkers, 2005). Soil properties, and consequently plant growth, are significantly controlled by variation in landscape attributes including slope, aspect, and elevation. These landscape attributes influence the distribution of energy, plant nutrients and vegetation by affecting organic activity, runoff and run-on processes, condition of natural drainage, and exposure of soil to wind and precipitation (Rezaei and Gilkers, 2005). Describing the spatial variability across a field has been difficult until new geospatial information technology tools such as GPS, GIS and remote sensing were introduced (Robert et al., 1995; Mulla and Schepers, 1997). These geospatial information technology tools allow fields and soil sample locations to be mapped accurately and also allow complex spatial relationships between soil fertility factors to be computed. This in turn increased interest and use of soil-sampling techniques that attempt to describe the variability in soil fertility factors within agricultural fields (Flowers et al., 2005). Soil variability also occurs across soil series and soil units and may be large or small depending on different soil forming factors. The spatial variability in physical or chemical soil properties of soil formed on the same parent material may be small but exist within the same soil unit (Falatah et al., 1997).

Spatial variability of soils was reported and studied for nearly a century (Waynick and Sharp, 1919). The spatial variability in soil pH has mostly been measured using samples collected in the field and analysed in the laboratory (Hoskinson et al., 1999). Soils are characterized by high degree of spatial variability due to combined effects of physical, chemical or biological processes that operate with different scales (Goovaerts, 1998). Reports have shown that there is large variability in soil, crop, disease, weed and yield; not only in large-sized fields, but also in small-sized fields (Santra et al., 2008). In site-specific management, the concept of MZs was adapted in response to this large variability with the main purpose being efficient utilization of agricultural inputs with respect to spatial variation (Godwin and Miller, 2003). Santra et al. (2008), studied spatial variability of soil properties and its application in predicting surface map of hydraulic parameters India, and found variations on all properties including bulk density. Furthermore, Mahinakbarzadeh et al. (1991) investigated the spatial variability of soil organic matter along several transects located within soil map unit. The authors found that organic matter in the soil unit showed variable weaker trends. Spatial variability can also be influenced by depth of a soil in the units, as studied by Huang et al. (2004). Huang et al. (2004) further reported that soil pH of a continuously cropped land of Zeith, Central Kansas to be higher in the upper depth than in the lower depth; however these had greater variations, particularly in the upper depths.

2.3 Importance of soil pH and liming

Soil pH is an important soil parameter impacting on crop nutrient availability and soil microbial activities (Hill, 2002). Therefore, careful monitoring of soil pH may predict crop productivity. Hill (2002) also reported that every crop has an optimum soil pH range for effective growth and potential maximum yields. When pH of a soil solution is increased above 5.5, essential crop nutrients are made available to crops (Mc Lean, 1982). For example, Nitrogen (N), a chief nutrient for most agronomic crops is made available to crops in the form of nitrate-N at a specific soil pH (Spector, 2001). Ketterings et al. (2003) indicated that Phosphorus (P) on the other hand, is available to crops when soil pH is between 6.0 and 7.2. These show that different essential crop nutrients are available to crops at different soil pH while within an agricultural field there can be significant soil pH variability that may potentially affect soil fertility for specific crop production.

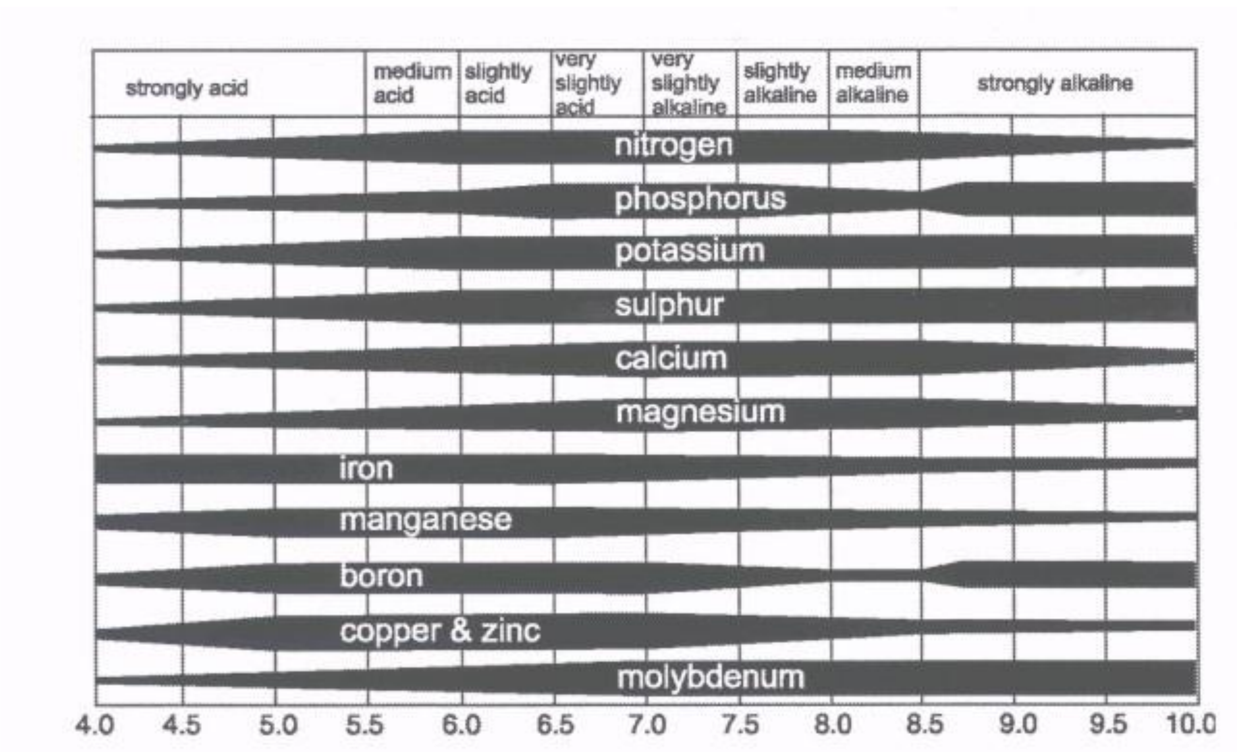


Fig. 1. Effect of soil pH on plant nutrient availability (Brady, and Weil, 2007)

Certain bacteria help crops obtain N by converting organic N into inorganic N, a form of N that crops can use (Kowalenko, 2004). These bacteria live in root nodules of legumes such as alfalfa (*Medicago sativa* L.) and soybeans (*Glycine max* L.), and function best when soil pH is within a range of 6.4 to 7.2 (Spector, 2001). For example, alfalfa grows best in soils with a pH range of 6.2 to 7.8, while soybean grows best in soils with a pH ranged from 6.0 to 7.0. Peanuts *(Arachis hypogaea*) on the other hand grow best in soils with a pH range of 5.3 and 6.6 (Hill, 2002). Many other crops, such as vegetables, flowers and shrubs, fruit trees and weeds, and fruits are pH dependent and rely on the soil solution to obtain nutrients (Hill, 2002). When the soil solution is acidic, crops cannot utilize essential nutrients required for effective crop growth and development. In acidic soils, crops are more likely to take up toxic metals and some crops eventually die of toxicity (Hill, 2002; Spector, 2001). Crops vary in their response to soil pH, will respond to lime application only when soil pH levels limit crop performance (Black, 1993). McLean and Brown (1994) reported that corn (*Zea mays*) frequently did not respond to soil pH in the range of 5.0 to 6.0, while alfalfa was strongly affected by this pH range, but soybean showed intermediate response.

While soil pH varies continuously within farm fields, traditional and uniform farm management techniques lack the ability to manage this soil pH variability. Again, these spatial variability of soil pH within farm fields cannot be measured everywhere in the field due to cost implications associated with soil sampling and analysis (Al-Omran et al., 2004). Al-Omran et al. (2004) further stated that the understanding of spatial variability of soil properties will allow better management of soil nutrient status and crop in the field. Spatial variation in soil pH is often observed in grid sampling soil tests indicating a potential for site-specific lime applications in agricultural soils (Franzen and Peck, 1995; Tevis et al., 1991). Peck and Melsted (1973) sampled soils from two 16.2 ha fields in Illinois State in the US in 1961 on a systematic grid spacing of 25.2 m and found that soil pH averaged 6.6 and 6.2 for the two fields but ranged from 5.5 to 8.0.

2.4 Lime quality, application and cost

Two factors determining the effectiveness (ECCE) of liming materials are neutralizing value or purity, also referred to as calcium carbonate equivalent (CCE); and particle size or fineness of the liming material (Mamo et al., 2003; Agri-Briefs, 2006). The neutralizing value, or CCE, is the amount of acid on a weight basis that a given quantity of lime will neutralize when dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate or calcite. There are major factors that affect the successful neutralization of soil acidity by agricultural limestone. They are lime rate, lime purity, lime particle size distribution or fineness of grind and degree of incorporation or mixing with the soil (Mamo et al., 2003). Agri-Briefs (2006) indicated that most soil testing laboratories usually assume that agricultural lime has a CCE of at least 80 to 90 percent and an excellent fineness of grind (i.e. large majority of particles passing a 50 to 60-mesh sieve Particle fineness is also important for lime effectiveness as the neutralization effect is greater with small particles because of increased total surface area exposed to the soil acidity (Comfort and Frank, 2000).

Purer and more finely ground materials, having more surface area, will react faster compared to impure or coarser materials. It is generally recommended that lime be thoroughly incorporated by tillage to optimize neutralization throughout the plowlayer (Mamo et al., 2003).

The cost of liming soil to a depth of 20 to 30cm should be considered an investment of five to ten years. This is illustrated with an example from Washington County in a disk-tilled system where the initial soil pH was 5.5 and the cost of liming with agricultural lime of 66 percent ECCE was R352/ha (Peterson and Hilgenkamp, 2002). Over eight years, there was yield increase of 63kg/ha for soybeans and 504kg/ha for corn.

2.5 Lime management for site specific or variable rate application

Lime recommendations are usually made to reach a target soil pH in the top horizon of a cultivated soil, which is about 20 cm (Comfort and Frank, 2000). If the soil is tilled to a depth greater than 20 cm, then proportionately more lime is required to reach the same target soil pH according to lime requirements. Lime requirements vary within fields and can be mapped using grid soil sampling or, alternatively, by sampling zones within fields (Pagani, 2011). Variations in lime requirement may occur, depending on past practices in the field, such as land use and cropping system, manure application; nitrogen fertilizer use; and irrigation (Mamo et al., 2003).

Research concerning site-specific lime management has increased in recent years. Borgelt et al. (1994) showed that 9 to 12% of an 8.8-ha field would have been over limed and 37 to 41% of the field under limed with a uniform application, with the range in percentages corresponding with different methods of lime determination used in their study. Bongiovanni and Lowenberg-DeBoer (2000) simulated corn and soybean yields using soil pH response functions from small-plot data and predicted larger annual returns with site-specific pH management. Pierce and Warncke (2000) applied five lime treatments for corn and soybean to small field plots (4.5 by 30.5 m) located according to interpolated surfaces from soil samples collected from 0.5-, 61-, and 91.5-m cells and found no corn response to lime but a critical pH value of approximately 6.0 below which soybean response to lime was observed.

2.6 **Crop response to liming**

Crops vary in their response to soil pH, responding to lime applications only if pH levels limit crop performance (Black, 1993). Farmers may or may not experience yield changes from liming depending on the accuracy of their soil tests, spatial variability in pH, and the sensitivity of each crop in their rotation to pH. Yields may not decline from over liming, as liming soils of high pH may or may not have detrimental effects on the crop but on the bi-product of that crop. Negative effects of over liming are usually tied to pH-induced nutrient deficiencies or toxicities at high pH (Adams, 1984). However, Christensen et al., (1998) reported that applications of sugar beet (*Beta vulgaris* L.) lime, a bi-product of beet processing, to the high pH (7.2–7.8) lake-bed soils of the Thumb region of Michigan; increased soil pH by 0.3 to 0.5 pH units but had no detrimental effects on crop yield while improving sucrose content in sugar beets during the first 2 years of their 5 year study.

2.7 **Related work done in South Africa and other African countries**

There is little information on site specific soil pH management in South Africa and other African countries; however soil scientists investigated other soil properties using precision agricultural management. Spatial variability of soil pH, extractable P, K, Ca and Mg under resource-poor farming conditions at Rambuda irrigation scheme, in Vhembe District, South Africa was studied by Nethononda et al., (2012). Their recommendation was that geostatistics presents spatial distribution of nutrients elements in the form of simple spatial maps that may be simple to understand by resource-poor farmers and thus, making it easy for the resource-poor farmers to identify areas that require more fertilizers more than others, hence preventing over-application or under-application for fertilizer inputs into the soil. Obi and Uto (2011) worked on identification of soil management factors from spatially variable soil properties of coastal plain sands in South Eastern Nigeria and concluded that water and nutrient management could be improved as their variability and spatial structure could be predicted for utilization at the planning stage of crop production process.

CHAPTER 3

MATERIALS AND METHODS

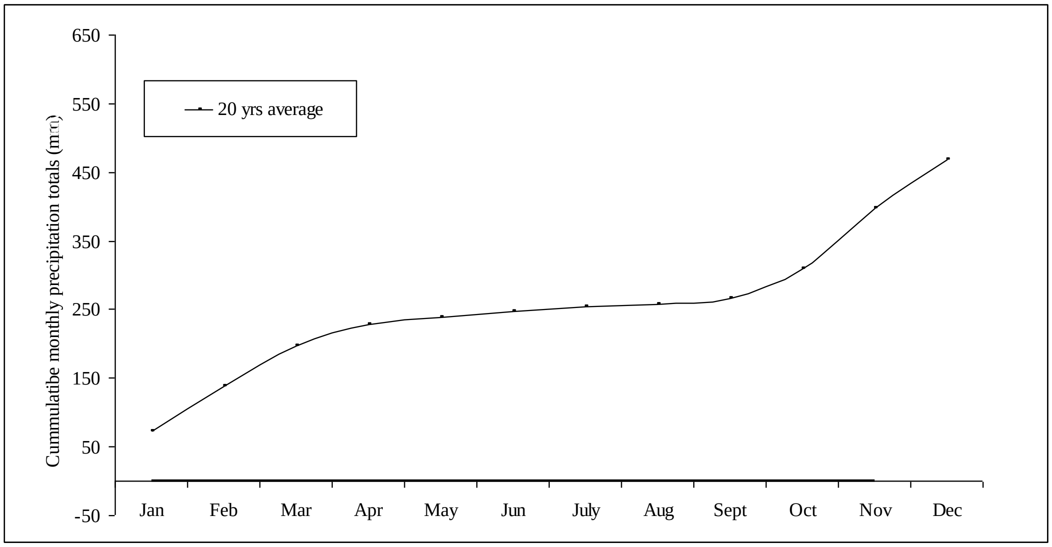
3.1 Study site description

This study was conducted over 3 site years in the Limpopo Province of South Africa. The 2 agricultural fields, sites I and II at Syferkuil Experimental Farm (23^{o}50' S; 29 ^{o}40' E) were small-scale experimental fields under automated linear move irrigation system demarcated from 80 ha of irrigated field crops section in the experimental farm, and another field, site III at Mapela Irrigation Scheme (23^{o}59'04.61''S and 28^{o}52'29.43'E) is under floppy irrigation system. The study sites at Syferkuil experimental farm were 7 and 10 ha portions of the irrigated 70.8 ha while at Mapela irrigation scheme, only 24.4 ha of a communal 70.8 ha field was used for the study. The two fields at Syferkuil Experimental Farm were under continuous maize (Zea mays L.) production for research, and Mapela irrigation scheme is operated with private agricultural strategic partners. Previously, this 70.8 ha of Mapela irrigation scheme comprised on small-scale fields of equal sizes managed by individual farmers in the community. The small-scale fields at Mapela irrigation scheme were planted to various crops of farmers' desire ranging from vegetable, to various agronomic crops.

The climate of all these study sites is classified as semi-arid with sites I and II receiving 495 mm of annual rainfall while site III receives approximately 609 mm. Approximately 80 to 87% of the annual rainfalls in all these sites occur mostly in the summer months of October to March. The long term minimum temperatures for sites I and II ranged between 2.2 and 6.0°C from May to August, and 9.0 and 16.7°C from September to

August. The maximum temperature ranged between 20.2 and 23.04°C from May to August, and between 26.7 and 29.6°C from September to April. Soils of these locations are mainly deep red, sandy clay loam soils classified under South African Binomial Soil Classification System as Hutton soil form (Rhodic Ferralsol, FAO). At site III, temperatures vary from an average daily maximum and minimum of 29.6 and 18.8^{o}C for January to 20.9 and 5.7^{o}C for June respectively (Nel et al., 2006).

Soils were sampled on two soil profiles spatially distributed across the farm field within the same study site. The first soil profile consisted of dark reddish brown to reddish brown, structureless sandy loam to sandy clay loam topsoil overlying a dark red to dark reddish brown, structureless sandy clay loam subsoil. This soil profile was also classified under South African Binomial Soil Classification System as Hutton soil form (Rhodic Ferralsol, FAO). The second soil profile exhibited dark brown, structureless, sandy loam topsoil overlying a dark yellowish brown to dark brown, structureless, sandy clay loam subsoil. A mottled bottom layer of soil had undergone localised accumulation of iron and manganese oxides under conditions of a fluctuating water table with clear red-brown, yellow-brown or black strains in more than 10% of the horizon (Soil Classification Working Group, 1991). The soil profile was classified as Avalon soil form (Plinthic Ferrasol, FAO).



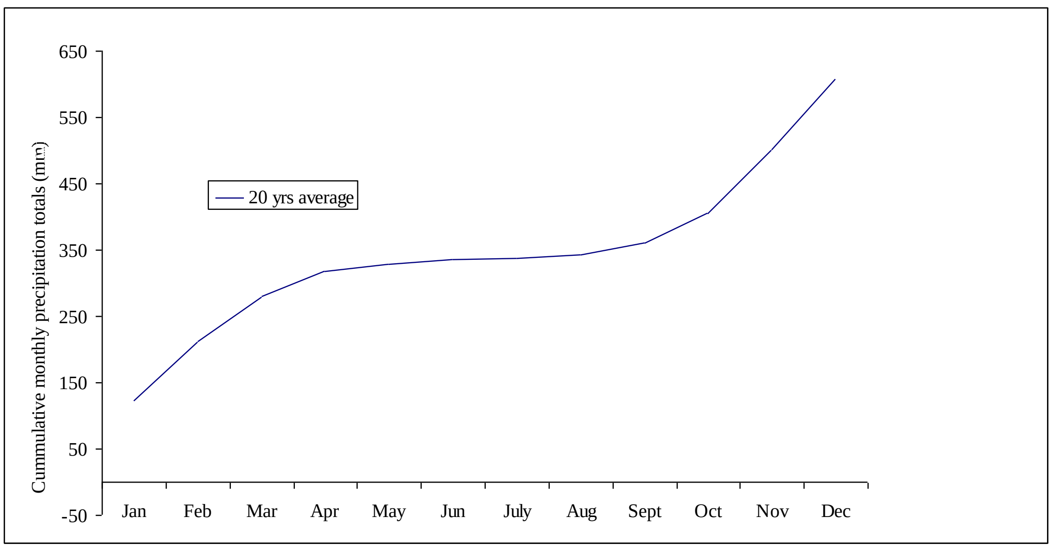


Fig. 2. Long-term monthly total precipitation recorded in site I, and II (top) and III (below)

3.2 Field boundary mapping

The field boundaries of sites I and II were mapped using Ag132 Trimble differentially corrected global positioning system (DGPS). This Ag132 Trimble DGPS was equipped and operated for mapping with Field Rover II® GIS mapping software (SST). The field boundary at site III was mapped using GPS-based digital mapping utilizing a handheld Trimble GeoXM GPS receiver with 2 to 5 meter accuracy (Trimble Corp., Sunnyvale, CA), and a high resolution Quickbird satellite imagery of the field (DigitalGlobe, 2010). The Quickbird satellite images were used to correct the coordinates collected with Trimble GeoXM GPS receiver. Trimble® TerraSync™ software was used for attribute data collection and ESRI GPS Pathfinder® Office software for post-processing (ESRI, Redlands, CA; Trimble, 2003). The Trimble GeoXM field computer has a small color screens measuring about 6 cm by 8cm (2 by 3 In).

3.3 Soil sampling, preparations and analysis

A special combination of grid and random sampling techniques, known as systematic unaligned sampling, was used for soil sampling in all study sites (Wolcott and Church, 1991). The GPS coordinates were recorded for each sampling point in the field. Soil samples were collected from geo-referenced locations on a 30-m grid to a sampling depths of 0-20 cm. Four replicates of soil samples within each grid were collected with a steel handheld drill auger, mixed in a polyethylene bucket, and packaged in labeled sampling bags and transported to the laboratory for analysis. In the laboratory, soil samples were prepared by air drying, hand crushing and mixing, and sieving through a 2-mm sieve (Tan, 1996). Soils were analyzed for pH (appendix 7.1), and SMP buffer pH for lime recommendations (Shoemaker et al., 1961).

3.4 Interpolation and spatial maps

Lime requirement to achieve a soil pH of 6.5 for a 20 cm plough layer per hectare was calculated using Calcium Carbonate equivalent, efficiency factor (fineness factor), and neutralizing index of the liming materials. The spatial maps for SMP buffer pH and lime requirement maps were produced with surfer version 8.0 (Surfer Version 8, Golden Software, Golden, CO). The soil pH datasets from systematic unaligned randomly sampled soils on a 30-m grid were interpolated using inverse distance weighing (IDW) in Surfer software version 8.0 (Surfer Version 8, Golden Software, Golden, CO). The interpolating surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases (Cliff and Ord, 1981; Cressie, 1993). The IDW, which is a technique of determining values between data points, applies Tobler's first law of geography on the principle that the interpolating surface should be influenced mostly by the nearby soil data points and less by the more distant data points (Tobler, 1970).

Table 1. Characteristics of liming materials recommended for Maize at Site year I, II, and III.

†Liming material	Efficiency factor ‡ENV	Fineness	¶CCE
Calcite ($CaCO_3$)	1	0.01	100
Calcitic limestome ($CaCO_3$)	0.9	0.01	90
Dolomitic limestone $CaMg(CO_3)_2$	1.09	0.01	109
Hydrated lime $Ca(OH)_2$	1.156	0.85	136

†Assume 100% pure material of these liming materials.

‡ENV = Effective Neutralizing Value, is the fraction of the material's CCE that will react with soil acidity in the first year of application. The ENV is calculated by multiplying a liming material's CCE and its fineness.

§Fineness. The rate of reaction of a liming material is determined by the particle sizes of the material; 100% of lime particles passing a 100-mesh screen will react within the 1st year.

¶CCE = Calcium Carbonate Equivalent. This standard compares the liming material to pure calcium carbonate ($CaCO_3$). Some materials such as hydrated lime will have a CCE higher than 100%. Pure magnesium carbonate ($MgCO_3$) as in the table above will neutralize about 1.2 times more acidity than $CaCO_3$ so dolomitic limestone will have a higher CCE than calcitic lime.

CHAPTER 4

RESULTS AND DISCUSSIONS

Descriptive statistics for soil pH and recommended liming materials in three study sites were presented in Tables 2, 3, and 4. The mean soil pH values were 4.48, 5.37, and 5.80, while the minimum values were 4.22, 3.93, and 4.74 for the three study locations respectively. These minimum soil pH values were strongly acidic. This level of acidity in the 3 study sites has potential to affect soil microbial activities, cause potential toxicity problems, and deficiency of some essential plants nutrients (Adamchuk, and Mullike, 2005; Fig. 1). The consequences of this level of acidity that has a potential to cause toxicity and nutrient deficiency problems in the soil is limitations of Maize growth and reduced grain yield. While the mean and minimum soil pH values were categorized as strongly acidic based on soil pH scale (Fig. 1), maize is known to grow better in the soil pH ranging from very slightly acidic to very slight alkaline soil pH values of 6.5 to 7.2 (Fig. 1).

All these study locations were in semi-arid areas, and it is unlikely that this acidity could be as a result of high rainfalls leaching salts (Fig. 2-climatic data). The lower pH values in fields 1 and 2 could be attributed to applications for acid-forming fertilizers, removing bases with harvested crops. The reason for this attribution is that, Thabang et al., 2012, reported average soil pH values of 6.97, and 7.51 in the same fields in 2002, and 2003 respectively. Thabang et al. (2012), there were other several students who conducted N management strategy studies on this field. This included a project completed by a student who did not write thesis on her variable rate N management strategy that included annual application of higher N rates such 180 kg N ha^{-1} on a monoculture irrigated Maize. Most of these N management strategies were on Randomized Complete Block Design (RCBD).

Study sites I and II were sampled in the month of September, consistent with previous soil sampling in these fields. The beginning of the month of September in South Africa is few weeks before the start of summer rainfalls, which occurs between a month of October and March. At site III, soil acidity could be as a result of different management practices for various horticultural and agronomic crops, and a fluctuating water table, which was reported in soil survey reports of the field (Nell et al., 2006).

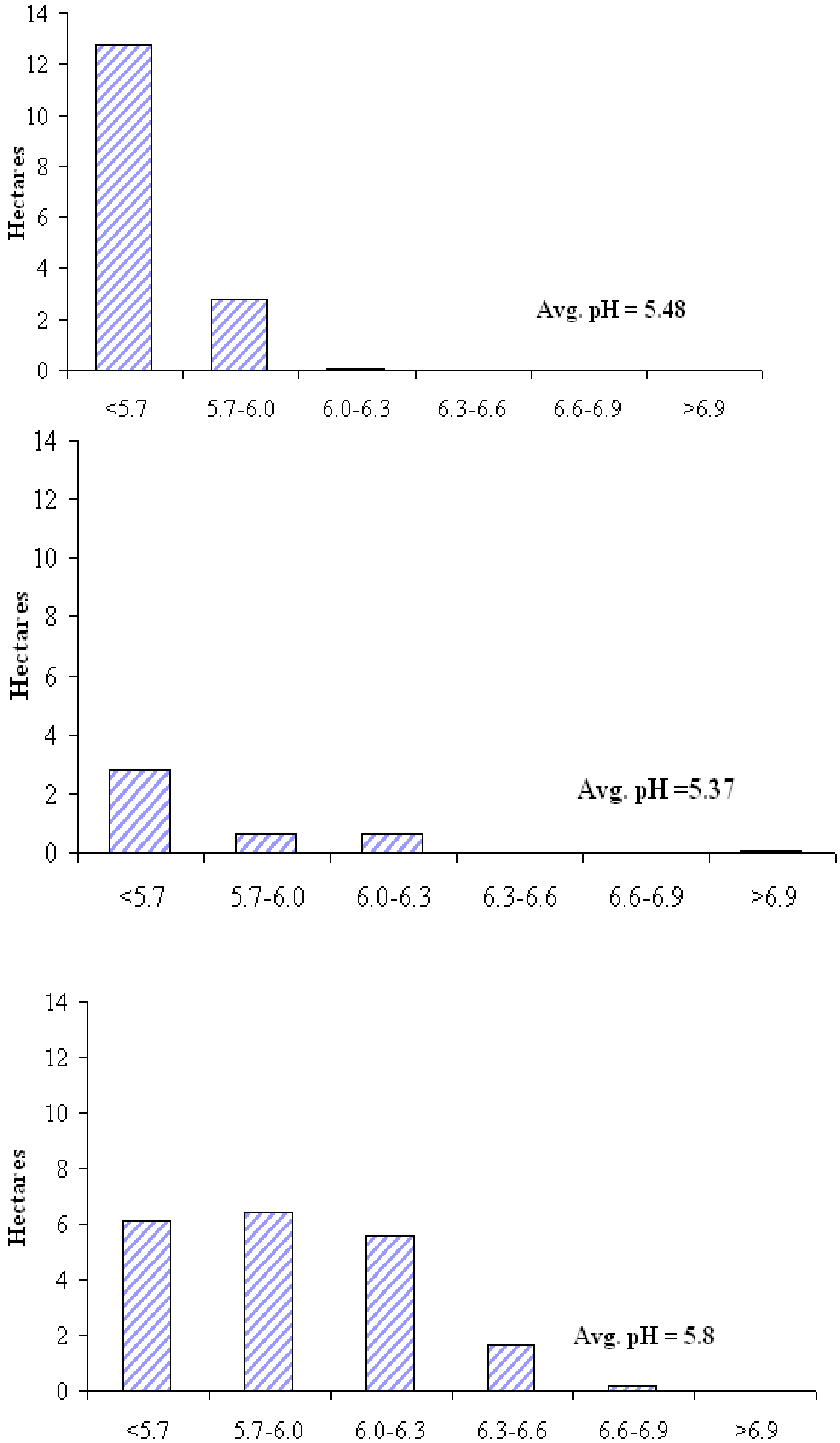


Fig. 3. Distribution of Soil pH in study sites I, II, and III, average soil pH values, and frequency distribution for the soil pH.

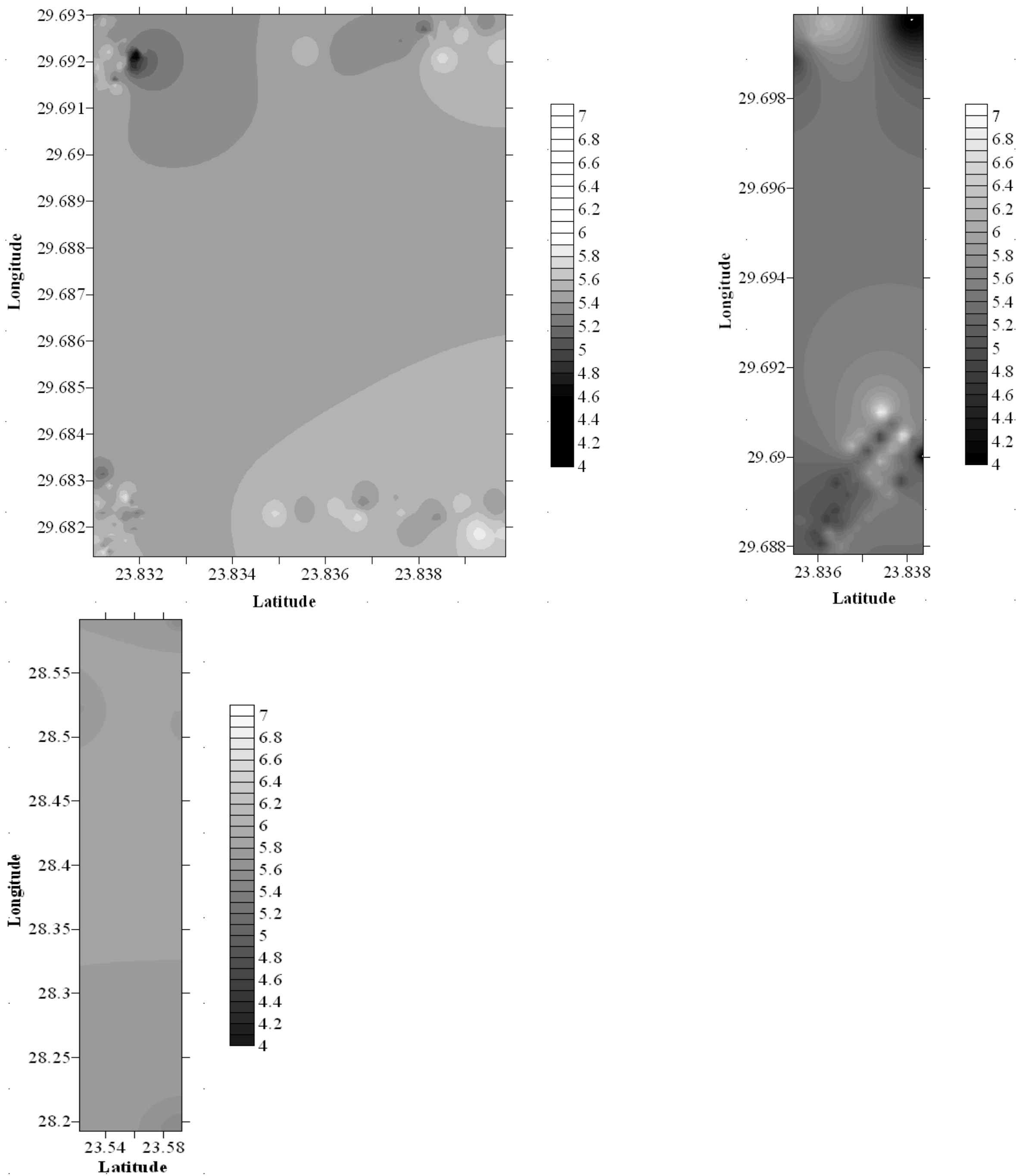


Fig. 4. Soil pH spatial distribution in study sites I (top left), II (top right), and III (below).

4.1 Soil pH spatial variability

Measures of central tendency and histograms of the data indicated that the soil pH data was normally distributed with the mean, mode, and median values almost identical (Fig. 3). For site I and II, the mean, mode and median soil pH values were strongly acidic, while for site III the values were medium acidic (Tables 2, 3 and 4). Again, the standard deviation and standard error of the mean as presented in Tables 2, 3, and 4 indicated that soil pH values measured in these 3 sites were not different from the mean; however, there was a difference in terms of the level of acidity. These are shown in the table 1 through lime requirement calculations that included both the minimum and maximum SMP soil pH values and the entire data of each individual field. The soil pH spatial distribution for the study locations is presented in Fig. 4, where a decrease in the level of darkness on the map indicates an increase in SMP soil pH, or a decrease in level of acidity.

4.2 Lime requirement

Interpolated maps of variable rate application of liming materials in site I, II, and III are presented in Fig. 5, 6, and 7. In both of these sites, the areas that require high amount of lime and those that require little or no lime application are clearly defined by different colours, such that the fields can be divided into lime application zones (Hurtado et al., 2009). When a field is divided into lime application zones, management of soil acidity becomes easier because instead of applying variable rates of lime for every grid, lime rates are applied per zone. These zones could be areas in a field that require, (i) high rates of lime, (ii) low rates of lime, and (iii) areas that requires no lime at all. For example, on Fig. 5, 6, and 7, areas that are black in colour require no lime application while areas that are light in colour require high amount of lime to be applied. There are also areas in the middle between dark and light, which do not require heavy lime applications.

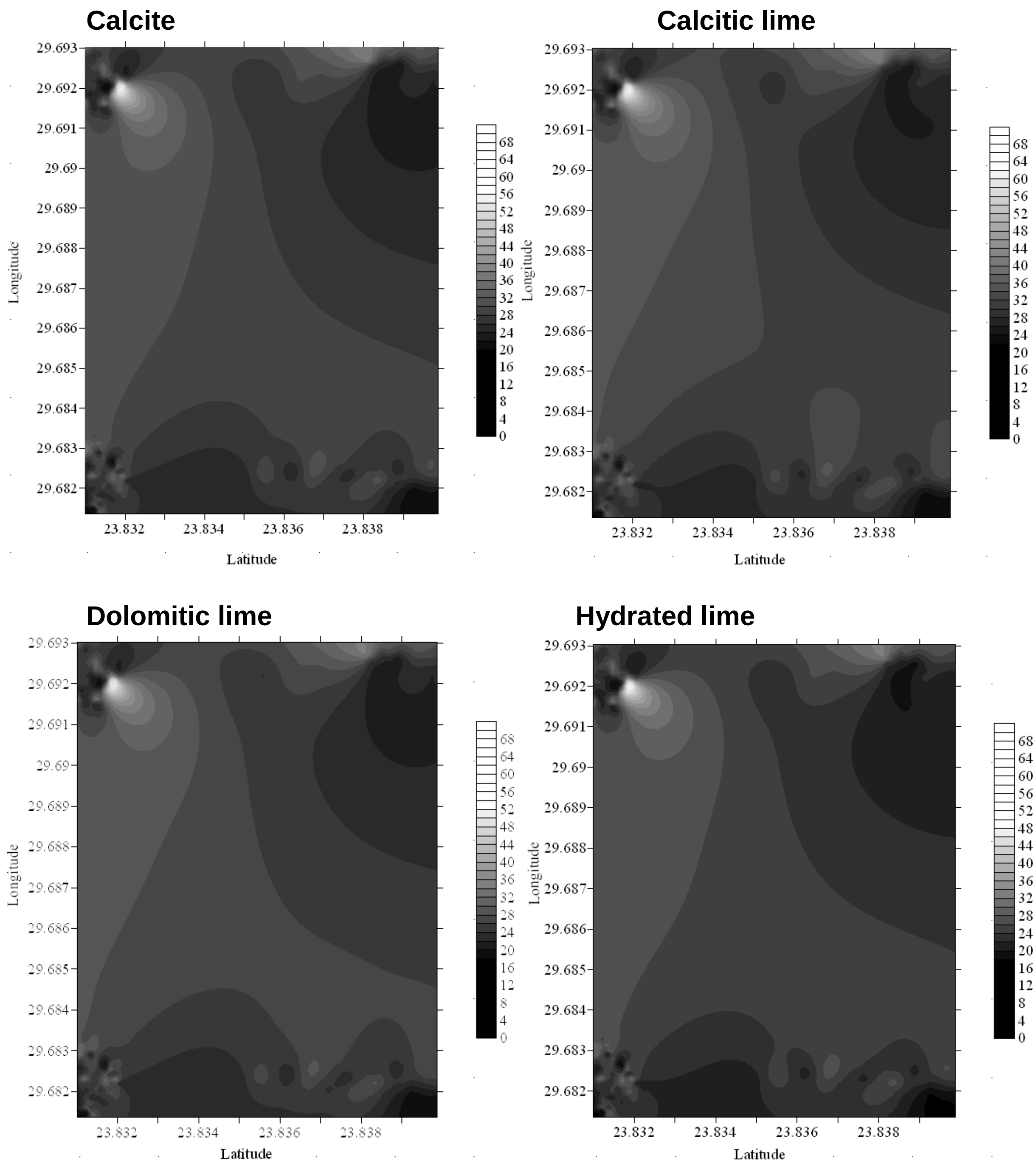


Fig. 5. Interpolated maps of variable rate application of recommended liming materials for Site I.

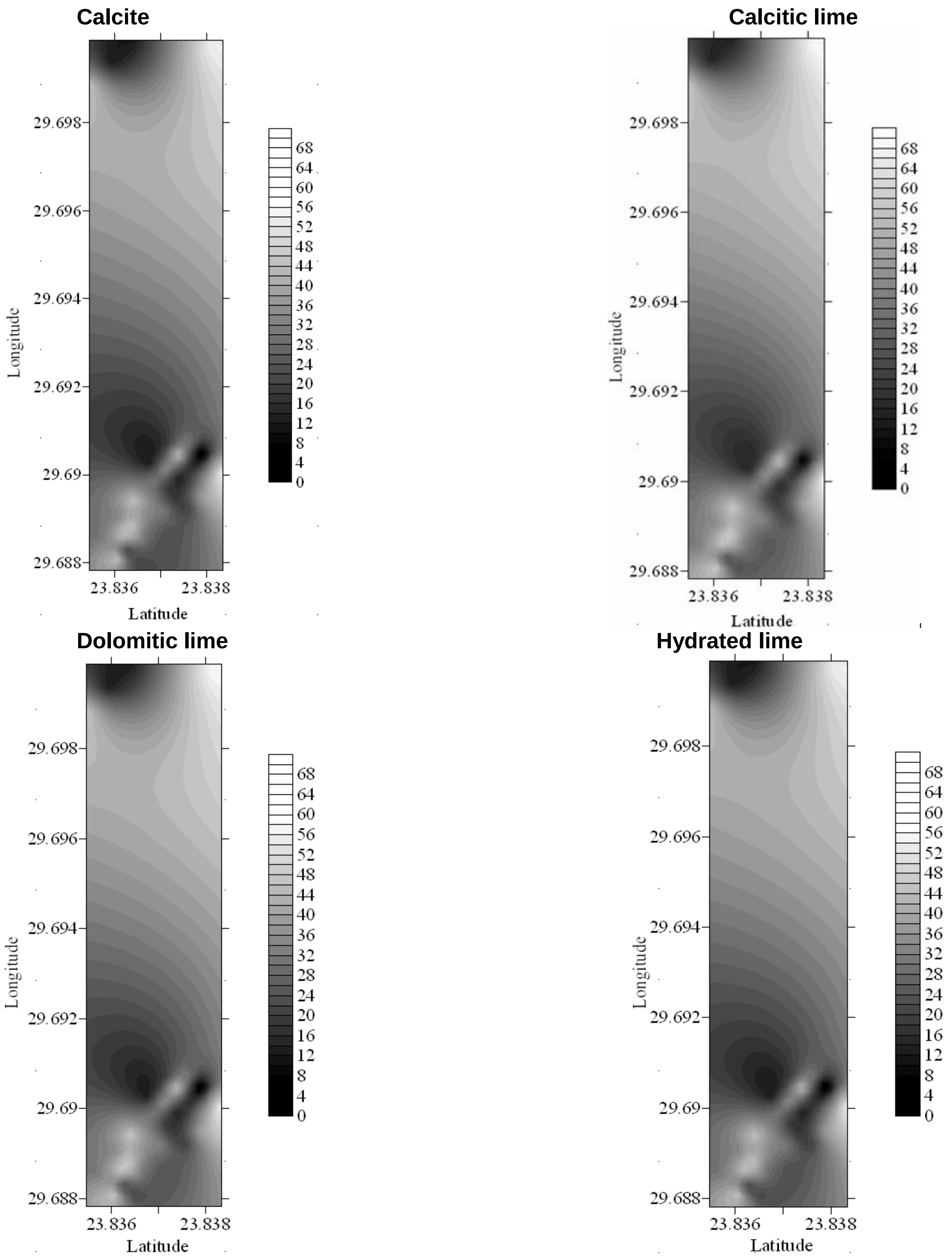


Fig. 6. Interpolated maps of variable rate application of recommended liming materials for Site II.

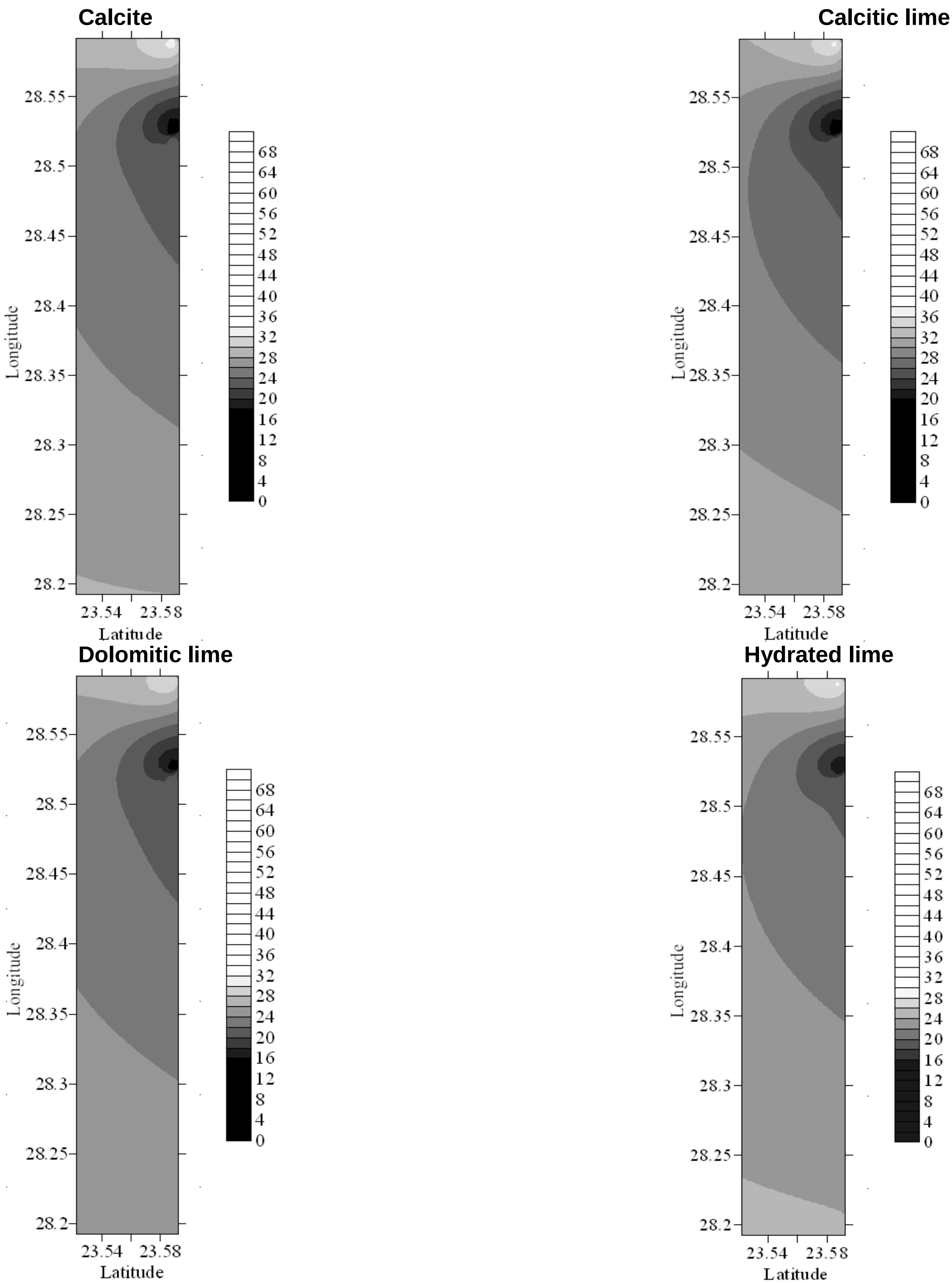


Fig. 7. Interpolated maps of variable rate application of recommended liming materials for Site III

Table 2. Soil pH, recommended liming materials, and descriptive statistics for Site I.

Variable	Mean	Min	Median	Max	†SD	‡SEM	95% §CI
pH	5.478	4.22	5.51	6.11	0.252	0.019	5.4408 – 5.5160
Calcite	28.53	16.1	28.0	60.7	5.697	0.432	27.676–29.381
Calcitic lime	31.70	17.9	31.1	67.4	6.347	0.481	30.750–32.649
Dolomitic lime	26.16	14.8	25.7	55.7	5.249	0.398	25.370–26.941
Hydrated lime	24.68	14.0	24.2	52.5	4.948	0.375	23.938–25.419

The % field size in 10.0 ha field with specific soil pH ranges

pH range	<5.7	5.7-6.0	6.0-6.3	6.3-6.6	6.6-6.9	>6.9
	(81.61%)	(17.82%)	(0.57%)	(0.0%)	(0.0%)	(0.0%)

†SD = Standard deviation,

‡SEM = Standard error of the mean,

§CI = Confidence interval.

Table 3. Soil pH, recommended liming materials, and descriptive statistics for Site year II.

Variable	Mean	Min	Median	Max	SD	SEM	95% CI
pH	5.3670	3.93	5.25	7.00	0.6095	0.0899	5.186 – 5.548
Calcite	28.030	0.0	29.3	54.1	12.009	1.771	24.464–31.597
Calcitic lime	36.191	0.0	37.6	69.4	15.401	2.271	31.618–40.765
Dolomitic lime	29.880	0.0	31.0	57.3	12.719	1.875	26.103–33.657
Hydrated lime	28.178	0.0	29.3	54.1	12.003	1.770	24.614–31.743

The % field size in 7.0 ha field with specific soil pH ranges

pH range	<5.7	5.7-6.0	6.0-6.3	6.3-6.6	6.6-6.9	>6.9
	(67.39%)	(15.22%)	(15.22%)	(0.0%)	(0.0%)	(2.17%)

†SD = Standard deviation,

‡SEM = Standard error of the mean,

§CI = Confidence interval.

Table 4. Soil pH, recommended liming materials, and descriptive statistics for Site year III.

Variable	Mean	Min	Median	Max	SD	SEM	95% CI
pH	5.8007	4.74	5.86	6.82	0.417	0.0281	5.74 – 5.86
Calcite	22.014	2.7	20.2	51.7	8.359	0.562	
Calcitic lime	24.463	3.0	22.4	57.5	9.275	0.624	23.233–25.693
Dolomitic lime	20.194	2.5	18.5	47.5	7.652	0.515	
Hydrated lime	19.047	2.3	17.4	44.8	7.212	0.485	

The % field size in 24.4 ha field with specific soil pH ranges

pH range	<5.7	5.7-6.0	6.0-6.3	6.3-6.6	6.6-6.9	>6.9
	(30.76%)	(32.13%)	(28.05%)	(8.1447%)	(0.9%)	(0.0%)

†SD = Standard deviation,

‡SEM = Standard error of the mean,

§CI=Confidence interval.

4.3 Variable rate vs. uniform liming

When SMP soil pH results were recorded, an average SMP soil pH value from soil analysis results was used to calculate lime applications in the field using uniform lime application method. The results as presented in Fig. 8, 9, and 10 showed a potential waste of lime with an excess amount of lime as high as 10, 30, and 7 tons/ha recommended on sites I, II, and III respectively. These recommendations were in excess on field areas that needed little or no lime applications. Again, the fields showed under applications of lime as much as 30, 35, and 13 tons/ha in sites I, II, and III respectively. When lime is under applied, soil pH remains acidic, and plant nutrients that are deficient in acid soils can potentially affect growth and yield of Maize crop. What is important to a farmer is to learn that crop yield may be restricted in under-fertilized areas (Cahn et al., 1994). Similarly, in areas where lime was over-recommended, soil pH can potentially increase to the level where other essential plant nutrients can be deficient or in excess. This excess amount of lime is the result of recommending uniform lime application based on a single average number derived from many samples collected from an agricultural land used for farming.

Agricultural fields that exhibit spatial variability of soil acidity must not be managed or treated as uniform when lime is applied in the field. This study showed that soil acidity variability is different from soil nutrient variability, and therefore the management must be different. For example, in site 3, there were areas of the field that had a soil pH of 4.74 and others 5.74. The difference between these two areas in the same field is 1 unit increase in SMP soil pH. For example, areas of the field that had a soil pH of 4.74, required lime application of 51.7 tons/ha while the areas that had a soil pH of 5.74 required 24.0 tons/ha. Uniform soil acidity management that recommends uniform lime application showed a need for an average application of 22.04 tons/ha. When lime is applied uniformly in this field instead of variable rate applications, this study showed that areas of the field that had a soil pH of 4.74 and 5.74 will receive less liming material than it is required to increase soil pH to 6.0 or 6.5, a level required for Maize production. This means that there will be a need for supplemental lime of 29.73 and 1.95 tons/ha on areas that had 4.74, and 5.74 soil pH respectively. This is one scenario, which is apparent in other fields also. Most importantly, it is known from (Bongiovanni and Lowenberg-Deboer, 2000) that site-specific management with the economic decision result in increased annual return more than uniform management strategy.

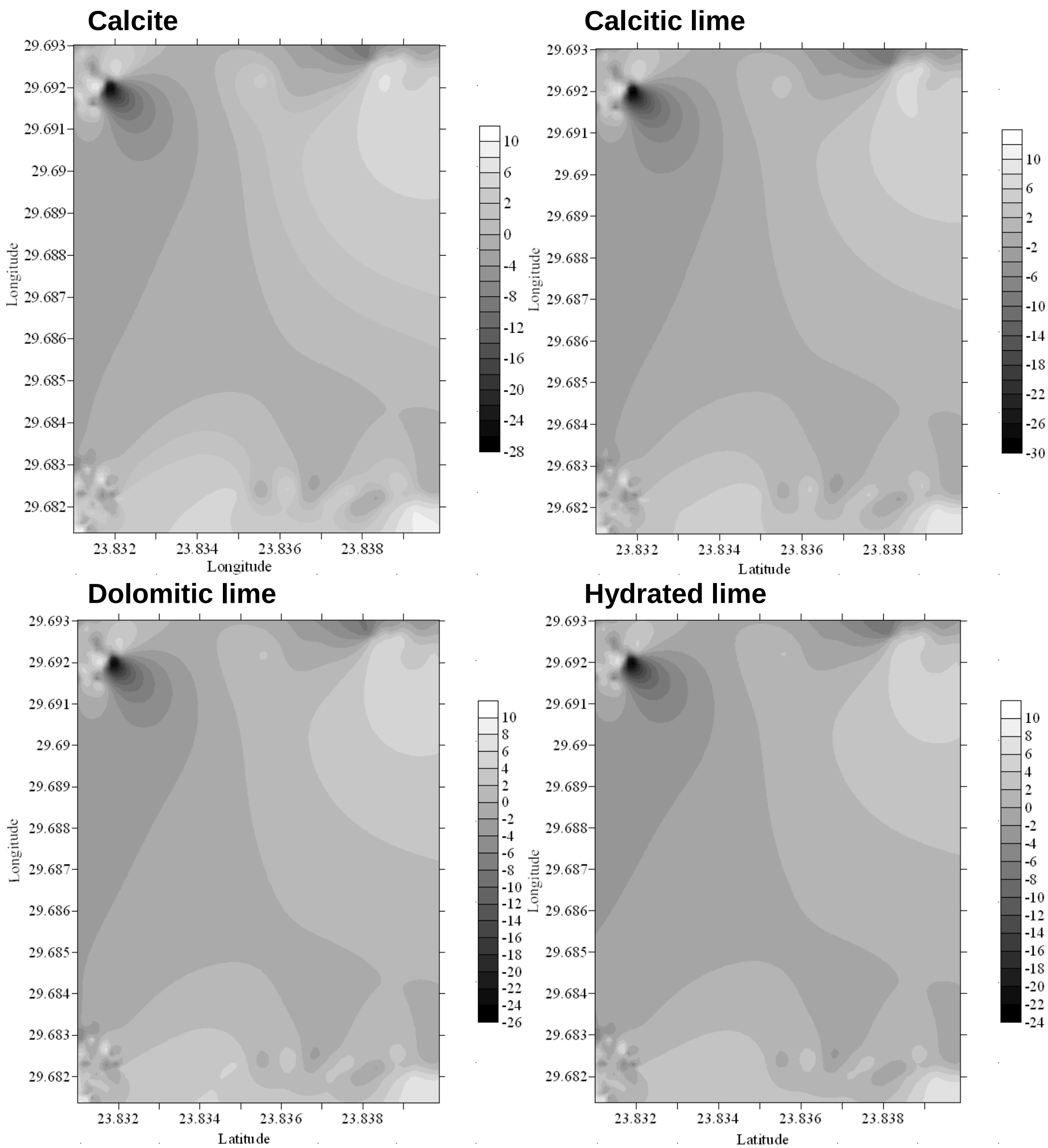


Fig. 8. Over and under-limed areas of site I as a result of uniform applications of recommended liming materials

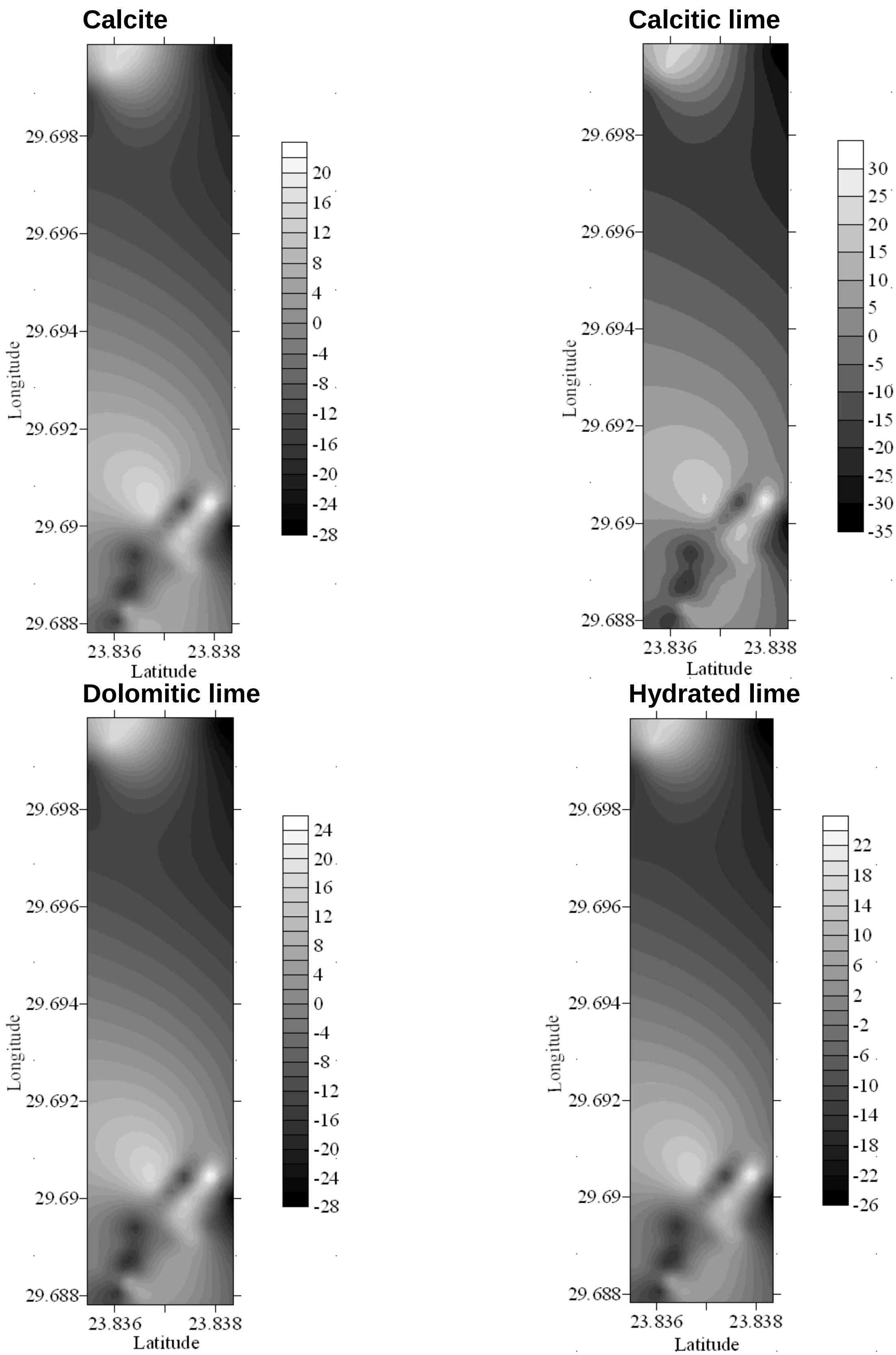


Fig. 9. Over and under-limed areas of site II as a result of uniform applications of recommended liming materials.

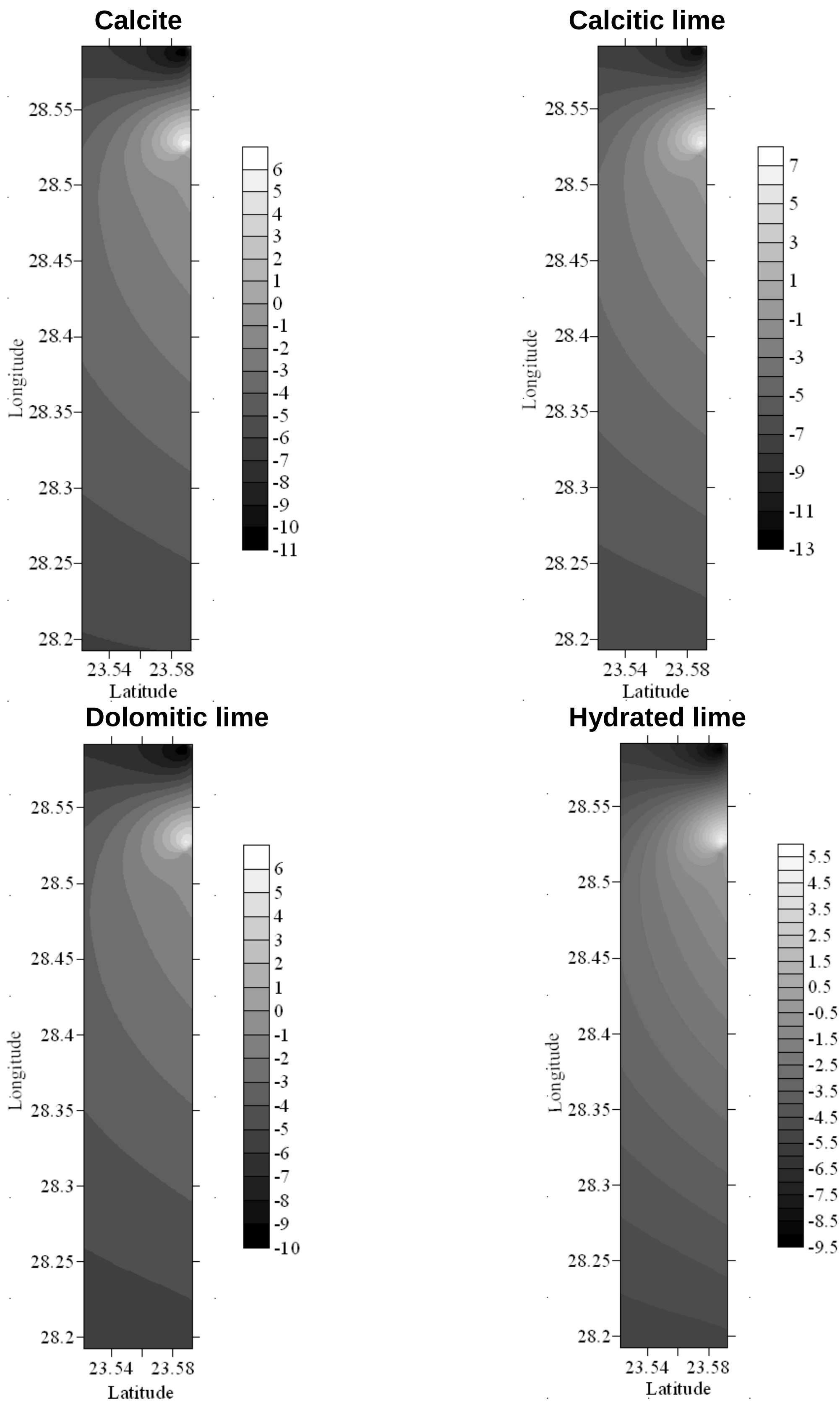


Fig. 10. Over and under-limed areas of site III as a result of uniform applications of recommended liming materials.

4.4 **Lime application and management**

While variable rate application of liming material is recommended in the fields based on grid sampling data, there is also a possibility of zoning the fields into three areas of lime applications. The zoned areas will be high rates, low rates, and no lime applications as an advanced procedure of soil acidity management with potential economic benefits. The concept of management zones was proved efficient by several studies on agricultural fields (Clay et al., 1998; Swinton and Lowenberg-DeBoer 1998; Koch et al., 2004), hence this study find it easy to recommend zoning the fields for soil acidity management.

The study sites I, II, and III, had no history of variable rate lime applications or application of lime based on precision agriculture recommendations despite the variability that exists in the field. Thabang (2010) reported significant spatial variability of soil nutrients in study site II, and the corresponding economic implications on Maize grain yield.

Figures 7, 8, and 9 indicate areas that can be over and under-limed in I, II, and III as a result of uniform applications of recommended liming materials. It is apparent that some areas of the field do not need lime since the SMP soil pH is 6.5 or above for Maize production, however, there are areas within the field with a soil pH of 6.5 and lower that needs soil acidity correction. As shown on the soil pH, and lime application maps in Fig. 5, 6, and 7, it is also clear on Fig. 8, 9, and 10 that acidity distribution followed a definable spatial pattern in the field, as opposed to random occurrence of soil acidity at certain parts of the field. This makes management of soil acidity easier even for variable rate lime applications.

CHAPTER 5

CONCLUSION

Site specific management of soil pH discourages the random soil sampling that leads to uniform application of liming material. The three sampled study sites showed spatial variability resulting from the grid sampling which was done in sizes of 30 m. Soil pH varied from slightly acidic to strongly acidic. This observation would not be easily noted, if the traditional methods of soil pH management were followed. When lime was recommended using the traditional methods of uniform application, based on average value derived from the samples collected from the whole field, the results showed a potential waste of lime in excess and under application in fields I, II and III. These over and under applications of liming material indicate that the uniform application is not appropriate for soil pH managements.

The site specific pH management can be improved further by following the management zone sampling which leads to application zones method. When fields are divided into lime application zones, management of soil acidity becomes easier because instead of applying variable rates of lime for every grid, lime rates are applied per zone. These zones could be areas in a field that require high rates of lime, low rates of lime and no lime at all.

Farmers of Limpopo province of South Africa are used to the random sampling and uniform soil acidity management. They ignore the site-specific management because there is a general thinking that it is very expensive. This study will assist these farmers with the difference in application and how the site specific management can save costs. To produce good yields, optimum application of liming material is needed and that way good money will be generated. Under and over applications will be minimized, and high productivity will be enhanced.

CHAPTER 6

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APPENDICES

Appendix 7.2

Soil pH analysis methodology

Appendix 7.1

Producing Maps with Surfer (Step-by-step example)

Appendix 7.1

Soil pH determination in H_2O

This procedure determines pH of a soil in a 1:2, 5 soil/water ratio suspensions on a mass basis. By definition pH is the logarithm to base 10 of the H+ ion activity. Due to the possible presence of soluble cations with greater affinity for adsorption on exchange sites on the soil, adsorbed H+ ions will be displaced from such sites, leading to a lowering of pH.

Apparatus

- balance, accurate to 0,1g
- Beakers,
- 100cm3 capacity
- measuring cylinders or automatic dispenser, 25cm-3
- glass rods
- pH meter readings reproducible to 0,05 pH units
- a combined glass-calomel electrode system

Reagents

- Buffer solutions: use commercially available buffer solutions, pH=40 and 7.0

Procedure

- the pH meter is calibrated at a given constant temperature with commercially available standard buffer solutions
- Re-calibrate hourly to compensate for drift
- Place 10g dried soil (≤2mm) in a glass beaker
- Add 25cm^3 de-ionised H_2O solution (1mol dm^{-3})
- Stir the contents rapidly for 5 seconds using a glass rod
- Stir again after 50 minutes and allow to stand for 10 minutes

- Determine pH with a calibrated pH meter with the electrodes positioned in the supernatant and record as pH H_2O

<u>Reference</u>

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Appendix 7. 2

Producing Maps with Surfer (Step-by-step example)

Install Surfer software on your computer and follow this procedure to produce maps and surfaces, and do the exercise.

Optional Exercise. Complete any or all of the Surfer Tutorials… <u>Lesson 1</u> – Creating an XYZ Data File, <u>Lesson 2</u> – Creating a Grid File, <u>Lesson 3</u> – Creating a Contour Map, <u>Lesson 4</u> – Creating a Wireframe, <u>Lesson 5</u> – Posting Data Points and Working with Overlays, <u>Lesson 6</u> – Introducing Surfaces.

<u>Generating 2-D Contour Display</u>

Access the Surfer demo system pressing **Start→ Programs→ Golden Software Surfer 8→ Surfer 8 Demo**.

Investigating the Data…

The **Demogrid.dat** data set was used to generate the interpolated surface you will be displaying. You can view a listing of the data by selecting **File→ Open…→ Demogrid.dat** from the main menu. In the table, click and drag the values in the "Elevation" column then select **Data→ Statistics** note the statistics that can be calculated and generate the statistics by pressing OK. Close the *Data View* window.

In the main menu in the *Plot View* window select **Map→ Post Map→ New Post Map…** and then select **Demogrid.dat**.

Click on the **Labels Tab** and insure that the **Column C: Elevation** is set as the "Worksheet Column for Labels" and that **0.30in** is set for the "3D label Lines Length."

Note the spatial pattern of the point sample values.

Generating Contour Plots…

From the main menu click **MAP → Contour → New Contour map** then specify the **Demogrid.grd** and click **OK** to generate a default contour map.

Double-click on the contour plot to access the *Contour* dialog box…

…check the "**Fill Contours**" box and press **OK**.

Screen grab this plot for later use.

Double-click on the plot to re-access the *Contour* dialog box, then click on the **Levels Tab** get the following specifications table.

Levels Tab

Change the contour interval by clicking on the **Level Button** and entering a different value (e.g. change from 5 to 10).

Click **OK → OK** to redisplay the map. Screen grab the 10-interval contour plot for later use.

Extended graphical displays

Double-click on the 5-interval plot to pop-up the *Contour* dialog box, switch to the **Levels** tab, then double-click on the "Fill" button to pop-up the *Fill* dialog box.

Click on the **Foreground Color** button to pop-up the *Color Spectrum* dialog box.

Click on the **left arrow** just above the color spectrum and assign green as the color. Click on the **right arrow** and assign red. **Ctrl/click** in the middle of the spectrum and assign yellow. Click **OK**, **OK** and **OK** to generate the color filled contour plot. Click on the plot then **resize** and **reposition** it to the top of the workspace.

Generating 3-D Wireframe Plots

From the main menu click **Map → Wireframe**, then select the **Demogrid.grd** file and press **Open** to generate a default wireframe plot of the same data. Click, drag and resize the *Wireframe Map* to the bottom of the workspace.

Double-click on the wireframe plot to access the **Wireframe Properties** dialog box.

General Tab. Click to "check" the boxes for **X**, **Y**, **Z** then click **OK**. Repeat the procedure (3 times) specifying only **X**, only **Y** and only **Z** to see the differences various line patterns make (choose your favorite line pattern for the last display). Note that the **Z Levels Tab** and **Color Zones Tab** allow you to change the "colors and fills" of the Z line (stacked contours).

You can graphically superimpose the geo-registered displays. **Shift-click** on each of the three displays (Post map, Contour map, Wireframe 3D plot; "green handle" boxes will surround all three) and then select from the main menu **Map→ Overlay Maps**.

Click the **View** tab to access the **View** dialog box.

View Dialog Box. The schematic grid in the window represents the base of the surface (note the "typical" settings of Tilt= 30, Rotation= 45 and FOV= 45). Moving the sliding bars and clicking **OK** will cause the 3D plot to **Tilt**, **Rotate** and change the **Eye Distance**.

There are two 3D projection types— Orthographic and Perspective. **Orthographic** projection displays the X, Y lines as projected onto a plane resulting in parallel lines. **Perspective** projection, on the other hand, creates a visual effect with lines converging as distance is increased. The **Eye Distance** slider only operates in the Perspective projection mode.

Reset the 3D View factors to the default ones identified in the View tab shown above. From the main menu, click **Map → Scale** to pop-up the **Scale** dialog box.

Scale Dialog Box

The horizontal scaling (X and Y) must be the same for both axes when plotting geographic data. This is assured by checking the **Proportional XY Scaling** box. The **Z Scale** determines the degree of vertical exaggeration and is independent of the X and Y scaling. Change the automatically assigned **Z Scale factor** to about one-half its value (to 25) and click **OK**. Repeat the procedure to change the **Z Scale Factor** to about twice its automatically assigned value (to 100).

Just for fun, shift/click on the contour map and the wireframe map (default Z-scale factor) to select both of them ("handles" around both will appear), then select **Map→ Overlay Maps**. Embed a screen grab of the results below…

Double-click on the composite map and use the **Background** tab to set the background fill to a **solid light gray** and the background line to solid **black**.

Generating Interpolation Surfaces

From the main menu click **Grid → Data…**, then select the **SAMPLE3.dat** file in the \Samples folder and press **Open** to access a set of point sampled data. Click on the **View Data** button to view the individual data values

Note that each row represents a sample point (100 samples) with the first two columns identifying the relative position of the points (X, Y) followed by a time series of data (six sample periods).

In the **Z field** in the **Data Columns** portion of the dialog box, specify the column that matches your team number (e.g., Team 1= **Column C** for Z1 period data; Team 2= **Column D** for Z2 period data; etc.

Note: the remainder of these instructions will show processing for Team 1 (Column C, Z1 data). You need to substitute changes that are appropriate to the data your team is processing.

Click the **Statistics** button to review the summary of the point data that will be used in the interpolation.

Screen grab the **Data Counts** and **Univariate Statistics** information for later use.

Step 1. Set the **Gridding Method** to "Inverse Distance to a Power."

Step 2. Set the **Output Grid File** name to **…\Sample3_Z1_IDW.grd** *(be sure to change Z1 to your team's data column number)*.

Note for later use the default settings for the fields in the **Grid Line Geometry** portion of the dialog box.

Step 3. Screen grab the completed dialog box and then press the **OK** button to create the interpolated surface. Briefly checkout the *Gridding Report* and then close its window.

Step4a. From the main menu, select **Map→ Contour Map→ New Contour Map** and specify the **…\Sample3_Z1_IDW.grd** file you just created *(or Z2, Z3, etc.)* to generate a contour plot of the interpolated surface.

Step4b. From the main menu, select **Map→ Surface** and specify the **…\Sample3_Z1_IDW.grd** file you just created *(or Z2, Z3, etc.)* to generate a surface plot of the interpolated surface.

Step 4c. Click on one of the plots, and then Shift/Click on the other to select both plots (green handle symbols will surround both plots). From the main menu, select **Map→ Overlay Maps** to superimpose the two plots. Move the combined plot to the top of the canvas.

Combined Plot with IDW surface on top.

Repeat the processing (*Steps 1-4*) to generate a similar analysis for the **Kriging** griding method using the same data *(Z1 or Z2, Z3, etc.)*. Screen grab the same set of intermediate results and the final combined plot with both interpolated surfaces (IDW on top and Kriging below).

Double-click on both of the plots to insure that their display settings are the same so the visual comparison is valid. Screen grab the **Combined Plot** with the IDW surface on top and the Kriging surface on the bottom for later use.

Before you exit Surfer be sure to save your IDW and Krig interpolated surfaces in export format so we can bring them into MapCalc for further analysis. From the main menu select **Grid→ Convert…→** open **Sample3_Z*x*_IDW.grd** (stored in default binary format)→ change the "save as type" to **GS ASCII (*.grd)**→ name the output file to **Sample3_Z*x*_IDW_ASCII.grd** and press the Save button.

Email both the **Sample3_Z*x*_IDW_ASCII.grd** and the **Sample3_Z*x*_Krig_ASCII.grd** files *(Z1 or Z2, Z3, etc.)* to Tracy and Joe …the surfaces will be used for next week's exercise for map-*ematically* evaluating and comparing interpolation results.

REFERENCE

BERRY, J.K., and KENSINGER, J. 2001. Educational Materials for Instruction in Grid-

Based Map Analysis. Proc. 15th Annual Conference on Geographic Information Systems.

February 19-22. Vancouver, British Columbia, Canada.

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