African Journal of Agricultural Research Vol. 7(31), pp. 4416-4426,14 August, 2012
Available online at http://www.academicjournals.org/AJAR
DOI:10.5897/AJAR12.615
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

The economic impact of infield spatial variability in a uniformly managed small-scale corn (*Zea mays* L.) field

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Accepted 18 June, 2012

The objective of the study was to assess spatial variability of soil nutrients in field, and their impact on grain yield and gross net returns in a uniformly managed 7 ha small-scale corn field. 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 corn planting, a land suitability assessment for corn was carried out following FAO guidelines. Soil sample parameters, which included N, were collected and/or measured from geo-referenced locations on a 40 m grid. Spatial maps of nutrient distribution were produced with the support of GIS. There was significant variability ($P \leq 0.05$) of soil nutrients and pH across the corn field. Corn grain yield varied significantly with a range from 2.7 to 6.3 Mg ha^{-1}. For an S1, highly productive Rhodic Ferralsol soil under linear irrigation in a semi-arid environment, these grain yields were considered low. The lower grain yields were associated with variability of soil nutrients, which negatively affected net returns. Spatial economic analysis revealed areas of loss that suggests that improvements in economic returns would be likely if small fields were managed site-specifically.

Key words: Precision agriculture, soil nutrient management, small-scale farming, spatial variability.

INTRODUCTION

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 Fleming et al. (2000a), Small-scale farmers, possibly due to lack of knowledge of soils 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 areas of a farm field receiving greater nutrient inputs than is necessary (Khosla et al., 2008). For that reason, the concept of precision agriculture (PA) based on information technology, is becoming an attractive idea for managing nutrients, and natural resources and realizing a modern sustainable agricultural development (Maohua, 2001).

Precision agriculture

Through the possibility of increased crop yields with fewer inputs, precision agriculture (PA) attempts to address important concerns such as the increasing demand for food due to increasing world population and unstable economies (Lal, 2000). In addition to improving crop performance, the ultimate goal of PA is to manage infield spatial variability associated with all aspects of agricultural production for optimum profitability, and sustainability (Robert et al., 1995). The concept of PA accepts that variability occurs within farm fields across a landscape (Tyler et al., 1997); however, the adoption of site-specific methods by small-scale farmers in South Africa is slow and similar to other developing countries because of socio-economical barriers (McBratney et al.,

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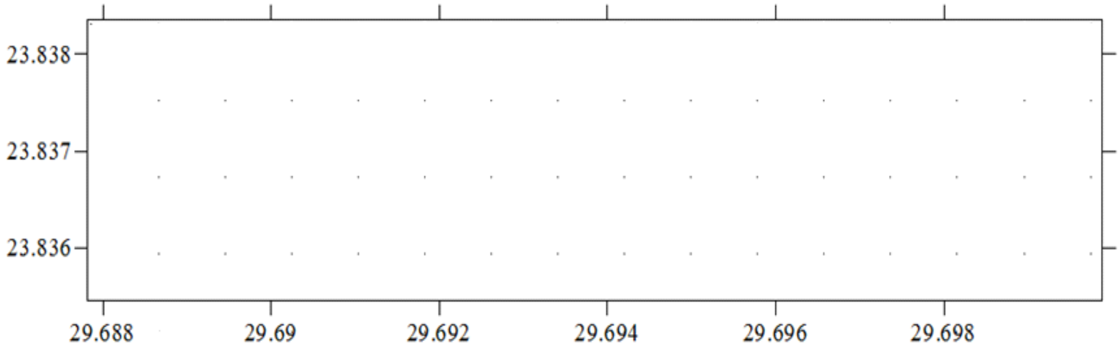

Figure 1. Field boundary of the study area showing geo-referenced sampling locations on a full grid design.

2005).

Nitrogen (N)

Increased N use efficiency is unlikely, unless a system-approach is implemented. A systems-approach may include the application of prescribed N rates in relation with the in-field variability using sensor-based systems within production fields, and low N rates applied at flowering (Raun and Johnson, 1999). Field studies on improved N use efficiency have emphasized the management of N inputs importance for reducing N losses and increase N uptake (Cassman et al., 1996). There has been some success through improved timing for N applications (Shoji and Gandeza, 1992), and fertilizer amendment with nitrification or urease inhibitors (Chaiwanakupt et al., 1995). One approach to improve N-use efficiency involves plant-based strategies that rely on monitoring the N status of crops (Peng et al., 1996), instead of more time-consuming soil sampling. Turner and Jund (1991) and Rostami et al. (2008) demonstrated that the chlorophyll meter, which measures leaf greenness, can predict the need for N applications.

Precision nutrient management

Growers who adopt precision agriculture use site-specific techniques to maximize field production and increase profitability (Trimble Navigation Ltd., Sunnyvale, CA, USA). There is also the potential for variable rate application of nutrients to protect the environment because no fertilizer would be applied to field areas with above optimum levels of nutrients for crop production (Schepers et al., 2000). This strategy has the potential to improve profitability for the producer while reducing environmental contamination threats from agrochemicals such as nitrate-N (NO_3-N) (Sudduth et al., 1997). Although, some comparisons on the economics of variable-rate fertilizer application support its use over uniform application (Prato and Kang, 1998) and uniform application of fertilizer is sometimes still most profitable (Watkins et al., 1999). Therefore, there is a need to establish and quantify the type of infield spatial variability in a farm field for a better management and decision support system. The objective of the study was to assess infield spatial variability of soil nutrients in a uniformly managed small-scale corn field, and the impact on grain yield and gross net returns.

MATERIALS AND METHODS

Experimental sites

The study was conducted at Syferkuil agricultural experimental farm (23°50’ S; 29°0’ E) of the University of Limpopo, in the Limpopo Province of South Africa. Limpopo Province is the northern 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. Rainfall occurs mostly in the summer months of October to March and the annual average rainfall for the area is between 401 to 500 mm. About 80% of the annual rainfall occurs in these summer months. The annual average maximum and minimum temperatures reported in the year of this study were 25 and 10°C (77 and 50°F), respectively. This study was conducted on a 7 ha portion of the 80 ha irrigated land (Figure 1). The soils in this farm developed from Granite parent material. The micro-topography of the 7 ha field consisted mainly of workable and friable to partially cloddy soils on a relatively flat surface at an elevation of 1 231±1 m.a.s.l. The field was conventionally tilled and continuously planted to corn for 4 consecutive years for research purposes under a linear irrigation system. In previous years, synthetic fertilizers on this corn field were uniformly applied based on soil analysis and the section of the field delineated for the purpose of this study had no history of manure application in the past 10 years.

Land suitability for crop

Prior to planting, corn land suitability assessment was conducted; a section of the farm was classified as suitable for corn based on FAO guidelines for land suitability assessment (FAO, 1993; Moshia et al., 2008). The soil profile was classified under the South African soil classification system as characteristically deep, loamy sand with no stones or concretions belonging to the Hutton soil form (Farmingham series; Rhodic Ferralsol, FAO) with a 1 to 2% slope.

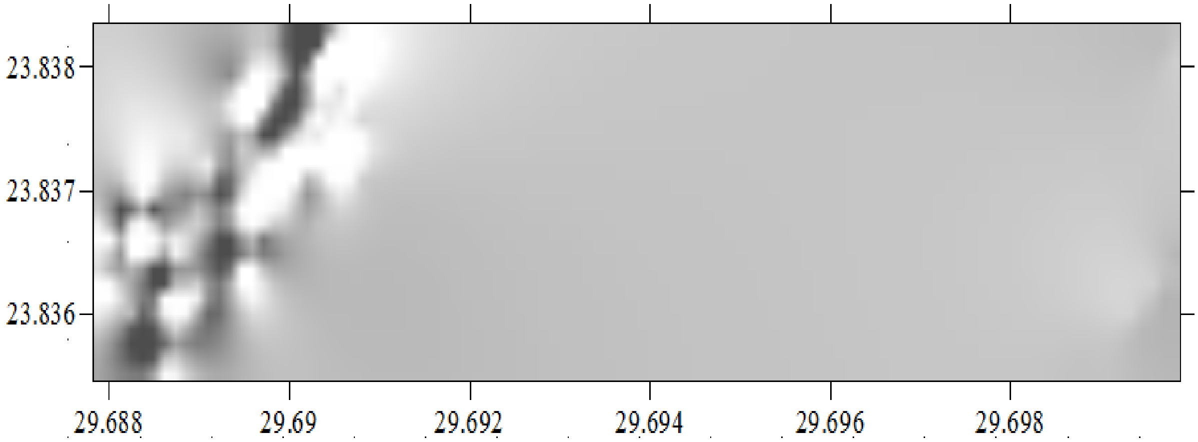

Figure 2. Gray scale bare soil imagery of the 7.0 ha study area.

Field mapping

A bare-soil Quickbird satellite imagery of a conventionally tilled 7.0 ha field as used in Hornung et al. (2006) was acquired, scanned into a computer, and converted to gray-scale (Figure 2) using image control settings in Microsoft Word 2003 (Redmond, WA; DigitalGlobe, 2010). The variability in bare soil reflectance is due, in part, to non-uniform distribution of certain soil properties that influence crop productivity (Figure 2). Traits such as regions of dark color are mostly areas of high organic matter, clay content, and low bulk density as compared to areas that are lighter in color (Mzuku et al., 2005). Details of this methodology are documented in the study of Fleming et al. (1999) and Hornung et al. (2006). The field boundary of a 7 ha study area was mapped using Ag132 Trimble differentially corrected global positioning system (DGPS) and ArcView 3.2 GIS software. This Ag132 Trimble DGPS was equipped and operated for mapping with Field Rover II® GIS mapping software (SST).

Soil sampling, preparations and analysis

A normal full grid was used for sampling, where samples where collected at a centre of a grid. In this normal full grid sampling, 6 soil samples were collected for every hectare based on the spatial data sampling recommendations (Saddler et al., 1998). Soil samples were obtained from the 0 to 20 cm depth. 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. Soil samples were collected prior to planting and after harvest. Each geo-referenced soil sample consisted of three soil cores that were composited into one sample with individual grids. Soil samples were passed through a 2 mm sieve as part of soil preparation prior to analysis at the Soil, Plant and Water Analysis laboratory of the University of Limpopo (Barnard et al., 1990). Prepared soil samples were analyzed for pH and electrical conductivity (EC) by saturated pasted extract (U.S. Salinity Laboratory Staff, 1954; Rhoades, 1982). Soil organic matter (OM) was determined using Modified-Walkey Black method (Nelson and Sommers, 1982), NO_3-N by Kjeldahl method (Bremner and Mulvaney, 1982), available phosphorus (P) was analyzed by Bray 1 (Bray and Kurtz, 1945), and exchangeable cations were extracted with 1 M ammonium acetate at pH 7 and Atomic Absorption Spectrophotometer (AAS) was used for the absorbance measurement (Chapman and Kelly, 1930).

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 10 years. Prior to corn planting, the field was uniformly fertilized with superphosphate (25 kg ha^{-1} of P) based on soil test recommendations. Uniform P was applied since pre-experiment soil samples (0 to 20 cm) averaged 2.6 ppm Bray 1 which is in the low category, and there were no sites with significantly different P requirements. Corn (PANNAR 579) was planted in rows with row spacing of 80.0 cm at of 36 000 seeds ha^{-1}. At planting, N was applied at a rate of 144.2 kg ha^{-1} of N. Again, after the crop was planted, germinated, and had reached V6 growth stage, N was top-dressed at a rate of 232.1 kg N ha^{-1} as ammonium sulphate nitrate (26% N) based on laboratory soil analysis results (FSSA, 2007). Nitrogen application in the uniformly managed corn field was applied based on the average value derived from the 44 soil samples analyzed for N. Irrigation water was applied immediately after topdressing. Irrigation water (0.73 mg NO_3-N per liter) was applied once every week with linear move irrigation system until the crop had reached physiological maturity.

Production of contour maps and data analysis

The pre-plant and post-harvest laboratory soil analysis results were imported into the software Surfer v8.0 with corresponding DGPS coordinates to produce distribution patterns of soil pH, nitrate-N, available P, crop yield, and financial gains and losses maps (Figures 3, 4, 5, 6 and 8; Golden Software, 2002). Soil maps of the study area were produced with ArcView 3.2 GIS software (Environmental System Research Institute, CA). Data was 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 to 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

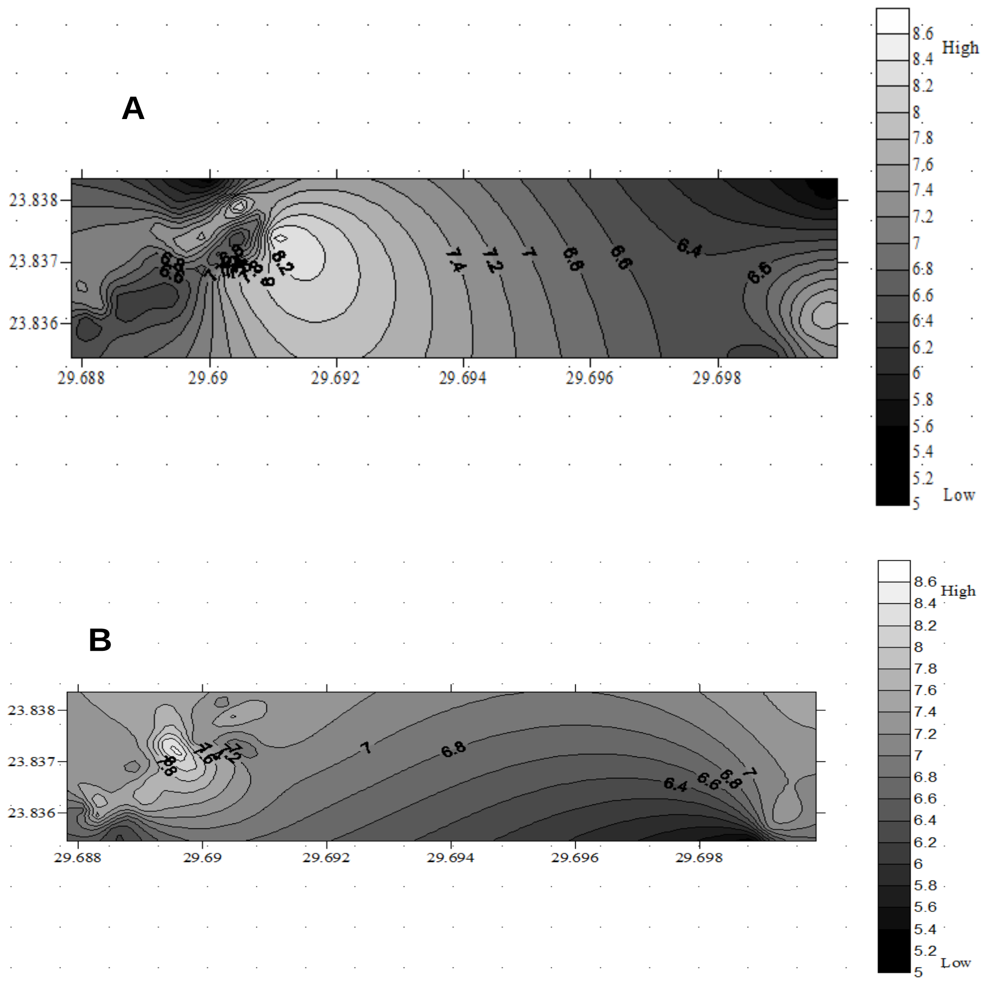

Figure 3. Soil pH distribution in a uniformly managed corn field before planting (top) and after corn was harvested (bottom).

and less by the more distant data points (Tobler, 1970). When the corn crop had reached physiological maturity, corn was hand harvested from geo-referenced locations on a 40 m grid. Corn was sampled at four sampling spots as replicates within each grid. Weight of the harvested grain was corrected to moisture content of 22.0% in the Limpopo Province for determining grain yield. Grain yield for the area harvested was converted to Mg ha^{-1}-and a grain yield map was produced (Figure 6). 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 using Statistix software (Tampa, FL) and Microsoft Excel (Redmond, WA).

RESULTS AND DISCUSSION

The gray-scale bare-soil imagery of the experimental field suggested that the soils were spatially variable (Figure 2). Because the entire field was classified as one soil type (Table 1) by the government soil survey (scale of 1: 10 000), it was unexpected that the bare soil reflectance would show such high variability in the 7 ha study field. Mzuku et al. (2005) reported that the variability in bare soil reflectance is due in part to non-uniform distribution of soil properties such as soil texture, organic carbon, and bulk density, which influence crop productivity. Fleming et al. (2000a) and Khosla (2008) successfully used gray-scale bare-soil imagery on maize fields to delineate farmers' fields into management zones of different productivity levels. The bare-soil imagery of this conventionally tilled field indicated a potential for zoning the field due to variability exhibited through soil color. Delineation of a field into zones is one of the best management practices in precision agriculture for optimal utilization of resources and maximization of productivity. Pre-plant soil analysis showed significant ($P \leq 0.05$) variability in nutrients across the field (Table 2). When there is a significant variability of essential crop nutrients in a farm field 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) and a potential for yield increases from variable-rate nutrient application.

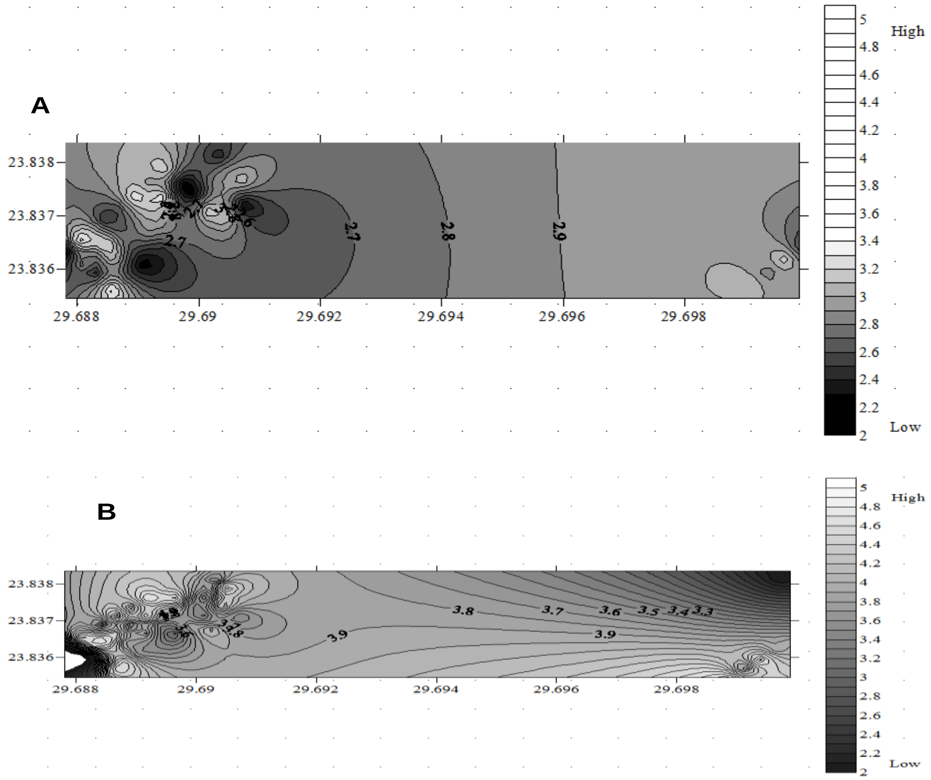

Figure 4. Nitrate-nitrogen (NO_3-N) distribution in a uniformly managed corn field before planting (top) and after corn was harvested (bottom).

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

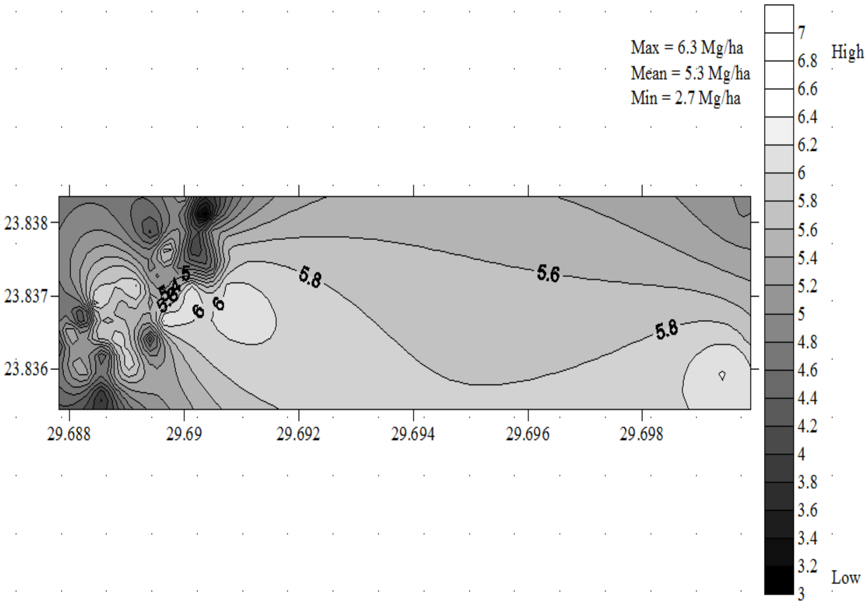

Figure 6. Maize grain yield distribution in a uniformly managed small-scale-field.

Soil pH

Soil pH affects the availability of nutrients in the soil (Grier et al., 1989). The lighter colors on Figure 2 of bare soil imagery portrayed lower soil pH levels (Figure 3 and Table 2), and soil pH increased significantly during the period of the study (Table 3). Maize yields are optimum between soil pH 5.8 and 7.0 (Miles and Zenz, 2000); however, in this study soil pH ranged from 5.4 to 8.5 (Table 2). The wide range in soil pH (5.4 to 8.5) and its significant variability across the field suggest that micronutrient availability could be examined in future studies, because soil pH has an effect on the availability of some micronutrients in soils (Grier et al., 1989). There was a significant difference between pre-plant and post-harvest soil pH (Table 3). This suggests that fertilizers may have had a significant impact on soil pH, and that uniform application of nutrients in a farm field that was based on neither average values did not correct nor account for infield spatial variability that existed. Although, we did not expect uniform application of fertilizers to correct variability of soil pH, the study suggests that variable rate liming might be useful to avoid areas already adequate or high in pH.

Soil nutrients

Soil nitrate-nitrogen

Although, variability in soil N prior to corn planting was recognized (Table 2), there was lack of quantification on the variability of N and its potential impact on the crop. 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, ANSUL N fertilizer was applied uniformly in the field based on an average number calculated from a sample size of 44 soil samples (Table 2). This uniform N application method at agronomic rates in the agricultural field is traditional to small scale, commercializing and commercial farmers in most parts of South Africa and predominantly in the semi-arid northern regions of South Africa.

One disadvantage in South African small-scale farming is that, even though the study highlighted statistical variability of N in this field (Figure 4), variable-rate equipment and sensors to apply N on-the-go are not common. However, one simple method to accomplish variable-rate N management would be to delineate N management zones based on N variability in the field and soil colour imagery of the field (Figure 1; Fleming et al. (2000b). Even though N ranged from 2.20 to 3.40 mg kg^{-1} NO_3-N in the soil, these N was considered to be low for corn production (Table 2; Westfall and Davis, 2009). The significantly variable N across the field suggests that N should be applied based on site-specific methods to avoid over application and under application at various parts of the field.

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 Figure 5. The whiter areas in Figure 5 indicate areas with higher P content while the darker areas designate areas with lower

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	Locality characteristics						Consistency	Stones/ concretions	Bulk density (g cm^{-3})
	Master horizon	Soil depth (mm)	Diagnostic horizon	Structure	Textural class	Colour			
Hutton	A	255	Orthic	Apedal	Sandy loam	5YR 4/8	Hard	None	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	–

Climate: Semi-arid; vegetation: savanna biome, trees and shrubs: *Acacia caffra*, *Dichrostachys cinerea*, *Lannea discolor*, *Sclerocaya birrea, and Grewia species*; grasses; *Digitiria eriantha*, *Schmidtia pappophoroides*, *Anthephora pubescens, Stipagrostis uniplumis, Panicum maximum* and various *Aristida* and *Eragrostis* species; slope: 1 to 2%.

soil P. Some areas of the P map appeared lighter in colour 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 the P map 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 Davis and Wesfall (2009), Bray1 P is classified as follows for corn production under irrigation: 0 to 6 mg kg^{-1} as low; 7 to 14 mg kg^{-1} as medium; 15 to 22 mg kg^{-1} as high; >22 mg kg^{-1} mg kg^{-1} as very high. In this study, before P fertilizer was applied in the form of Superphosphate, P ranged from 0.5 to 5.0 mg kg^{-1}, with a mean of 2.60 (Table 2), classifying the field as low in P. There was a significant increase in P after uniform application of superphosphate (Table 3). Site-specific application of P can potentially reduce excess P left on topsoil after harvesting of a crop. Over time, excess amount of P on topsoil can run off to surface water, consequently causing eutrophication (Sims et al., 1998).

Maize grain yield

The average corn grain yield for the uniformly managed corn field under irrigation was 5.3 Mg ha^{-1} (Figure 6). The post harvest soil analysis showed that soil pH, P and N changed significantly during the growing season after fertilizers were applied to meet crop nutrient requirements (Table 3). Under a normal semi-arid condition (Figure 7), good crop management including irrigation scheduling, crop fertilization at agronomic rates, and proper control of pest and diseases; average corn grain yield under irrigation in a semi-arid environment for S1 classified soils should be above 6.5 Mg ha^{-1} (Table 1; Dang and Walker, 2001). While there was no control treatment for the corn grain, Whitbread and Ayisi (2004) previously 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}. Grain yield for the corn ranged from 2.7 Mg ha^{-1} for low producing areas to 6.3 Mg ha^{-1} in highly productive areas (Figure 6). The lower grain yields under irrigation could be linked to significant ($P \leq 0.05$) spatial variability of soil pH, N and P (Table 2).

The impact on grain yield and gross net returns

The impact of applying fertilizers uniformly across spatially variable soils on a small-scale field was studied financially with costs of production for maize under the used irrigation scheme (Tables 4 and 5). The financial costs associated with maize production from land preparation, soil sampling and analysis, pest control, irrigation, fertilization to harvesting were calculated and it was found that variable cost of production per hectare were $838.7 (Table 4). When these variable costs of production were compared with the revenue from receipts of $932.8, total return on variable costs/contribution margin per hectare was$98.1 ha^{-1} (Table 5). While on average, the contribution margin was positive, showing a gain in production of irrigated small-scale maize, there were financial losses in parts of the field where maize grain yield was significantly lower. The contribution margin ranged from a negative value of -$364.1 to a positive gain of $264.2 ha^{-1} (Figure 8). The areas of economic loss suggest that profits might be realized if the field was managed site-specifically. Contrary to current thought, even small fields might benefit from low cost site-specific management (Swinton and Lowenberg-DeBoer, 1998; Koch et al., 2004).

Conclusions

In the continent of Africa and the country of South

Table 2. Descriptive statistics of 44 composite soils sampled on a 40 × 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 properties	**Sampling depth (cm)**	**Soil properties**						
		pH	**†NO_3**	**‡P**	**§K**	**#DUL**	**††CLL**	**‡‡PAWC**
			(mg kg^{-1})			**(mm)**		
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	137	85	52
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		<0.0001	<0.0001	<0.0001	<0.0001			

†NO_3-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; #DUL = drained upper limit; ††CLL = crop lower limit; ‡‡PAWC = plant available water capacity; §§DUL, CLL, and PAWC were measured by Whitbread and Ayisi (2004).

Table 3. The mean difference ± standard error difference and standard deviation of pre-fertilization and post-harvest/post-fertilization of soil pH, Soil NO_3-N, Bray1 P, K, Leaf Nitrogen and Leaf chlorophyll across uniformly managed corn field.

Measured parameter	**†Mean diff. ± SE diff.**	**Standard deviation**	**Pr > | t |**
‡Soil pH	0.454* ± 0.112	0.764	0.0002
‡Soil NO_3-N (mg kg^{-1})	0.105* ± 0.010	0.071	<0 .0001
‡Bray 1 P (mg kg^{-1})	0.867* ± 0.139	0.959	<0 .0001
Leaf nitrogen (mg kg^{-1})	0.705* ± 0.106	0.693	<0 .0001
Leaf chlorophyll	1.895^{ns} ± 1.687	11.06	0.2675

*Significant difference at $P \le 0.05$, ns = no significant difference at $P \le 0.05$, †Mean diff. ± 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.

Table 4. Direct costs of summary budget by operation.

Crop	Maize	
Year	2008	
Field	Syferkuil	
Field condition	Linear irrigation	
Month of harvest	May	
Yield	5.3 tons	
Units	ha	
Price of corn	\$176 ton^{-1}	
Gross receipts	\$932.8 ton^{-1}	
Operation type	**Name**	**†Total costs (\$ ha^{-1})**
Soils	Soil sample	4.94
Soils	Soil analysis results	208.2
Tillage	Plough	21.79
Planting	Plant corn	119.0
Pest control	Herbicide	60.4
Irrigation	Linear irrigate	89.4
Harvest	Harvest (labour)	97.12
Fertilization	Uniform N	275
Total cost of production per hectare		838.7

†Total costs include cost of application to land and taxes. Total net receipts per ha = Gross receipts – Total costs of production per ha (\$932.8 – 838.7 = \$94.1).

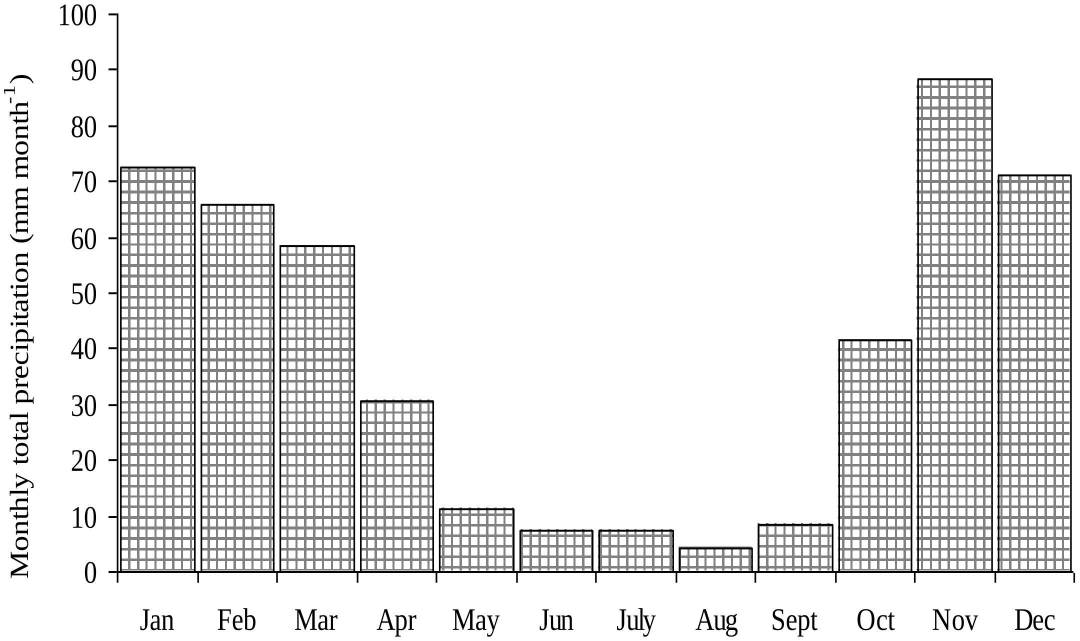

Figure 7. Monthly totals precipitation recorded in the year corn was planted in the field. This includes corn growing season from planting to harvesting.

Table 5. Net returns to land for uniform nutrient management on a small-scale maize field.

Activities	ANSUN applied (kg ha^{-1})	Price of ANSUN ($ kg^{-1})	Application cost ($ ha^{-1})	Total cost of production ($ ha^{-1})	Price of corn ($ ton^{-1})	Corn harvested (t ha^{-1})	Gross† income ($ ton^{-1})	Net ‡ returns ($ ha^{-1})
Costs	250	1.10	12.35	838.7	176	5.30	932.8	94.1

† Gross income ($ ha^{-1}) = Price of corn ($ ton^{-1}) * Corn harvested (tons ha^{-1}), ‡Net return ($ ha^{-1}) = Gross income ($ ha^{-1}) - Total Cost of production ($ ha^{-1}). Total cost of production = (total on summary budget of operation that include cost of application and taxes).

Africa in particular, precision agriculture is still considered a new technology. This study was the first in semi-arid northern region of South Africa to investigate spatial variability of N and other nutrients on a small-scale field. The study showed that generalization and averaging information in an agricultural field affect application of agricultural inputs such as N fertilizer and consequently grain yield. Precision agricultural techniques discourage such methods because of spatial variability that exist in agricultural fields. Soils exhibiting spatial variability should not be managed uniformly, but on site-specific basis. In South Africa, this study could potentially give a new direction to the provincial government department of agriculture in its agricultural input access policy that gives small-scale farmers access to agricultural inputs and in some cases

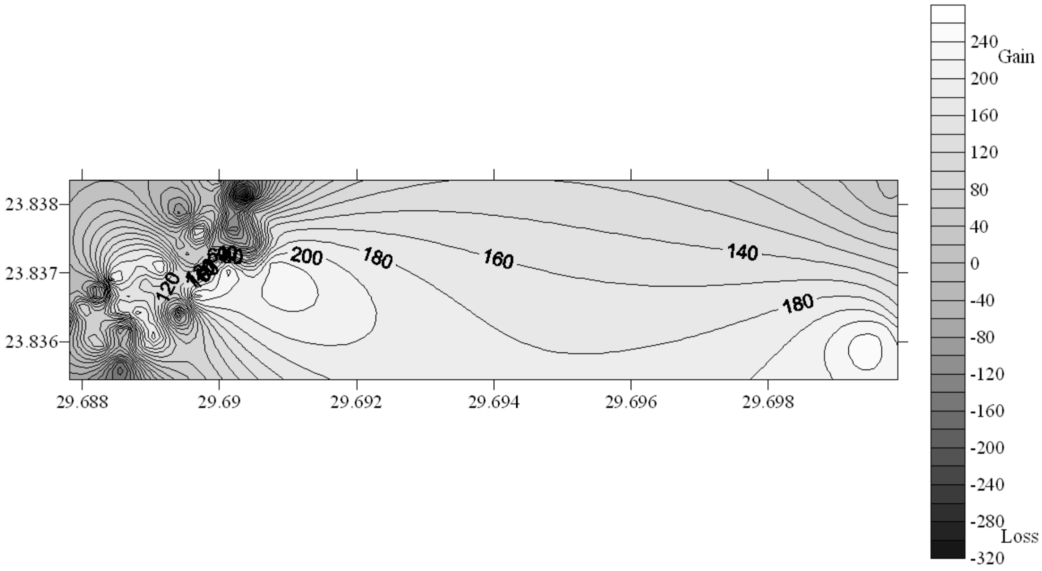

Figure 8. Distribution of financial gains and losses (\$ ton^{-1}) in a uniformly managed small-scale field.

soil management support. The study shows that infield spatial variability has a negative economic impact on production of irrigated maize, which is a stable food for the citizens. While there might be little logic in zoning a field of 7 ha with precision agriculture technology on large US fields, failure to conduct variable-rate fertilizer application in small fields in small-scale agriculture can potentially lead to continuous loss in yield, finances, and contamination of the environment due to uniform application of synthetic N fertilizers. Contrary to popular opinion that suggests that precision agriculture is a science of managing spatial variability of large commercial farms with expensive machines, this study showed the need to manage spatial variability on small-scale fields as yields resulted with an important variability even on a small-scale field, producing lower net returns than the potential returns.

ACKNOWLEDGEMENT

We acknowledge the National Research Foundation (NRF) for funding the study and providing a scholarship to masters' student who performed this study.

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