Evaluation of Spatial Variability of Soil Physico-Chemical Characteristics on Rhodic Ferralsol at the Syferkuil Experimental Farm of University of Limpopo, South Africa

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Abstract

Spatial variability among selected soil physical and chemical properties in twelve profiles dug across the research block of the University of Limpopo experimental farm was investigated. The soils were moderately shallow to deep, contain variable textural classes and classified as Rhodic ferralsol. Over 90% of the samples were considered as slightly alkaline based on the water-measured pH values but decreased to marginally over 27% when measured in KCl. The electrical conductivity of the soils revealed a generally non-saline field. Bray P1, EC, exchangeable cations, extractable Zn and effective cation exchange capacity contents differed significantly (p < 0.05) with depth while K, Mg, Ca, Mn, organic carbon and ECEC differed significantly (p < 0.05) across profiles. Semi-variograms for the measured variables had low values indicating the existence of considerable level of spatial variability. Spatial dependence among top and subsoil pH, EC, organic carbon, sand, silt clay and bulk density ranged between weak and strong. Results revealed a significant spatial variability of the characterized parameters across the research block because to differences in tillage, cropping pattern and nutrient specific application over the years.

Keywords: spatial variability, soil physico-chemical properties, geostatistics, university research farm

1 Introduction

The provision of information about spatial variability of soil attributes is essential to achieve a better understanding of the complex relations between soil properties (Goovaerts, 1998), establish appropriate management practices for soil resources use (Bouma et al., 1999) and better management of spatially variable soils (Mohammadi, 2002). Spatial variability of soil physical and chemical properties within or among agricultural fields represents inherent attributes. However, the variability may either be attributed to geological and pedological soil forming factors or induced and exacerbated by tillage and soil management practices such as fertilizer use (Iqbal et al., 2005). Therefore, an ideal experimental field is one in which soil variability has been minimised for a specific crop or soil physical/chemical treatments (Cerri et al., 2004). Over the past 20 years, soils on the University of Limpopo experimental farm have continually being used for conducting various experiments ranging from cereal through legume crops production to horticultural crops. Cereal crops by their nature are heavy feeders requiring large amount of nutrients, particularly nitrogen, N (Nsanzabaganwa et al., 2014) while legumes are able to fix N into the soil. Many of the crop evaluation trials carried out on the field are often accompanied by variable fertiliser use that imposes a high degree of nutrient variability on the field. Thus, the farm is often subjected to various extensive tillage operations particularly during land preparation in each

planting season. Despite the long term history of intensive and continuous use and various management operations, the farm has no reliable detailed spatial variability information.

Many researchers have applied geostatistics to provide description and distribution of the spatial variability of soil physico-chemical properties (Mohammadi, 2002; Lin et al., 2005; Vaezi et al., 2010; Staugaitis & Sumskis, 2011; Akbas, 2014; Reza et al., 2015). Characterizing the spatial variation of soil variables can provide important implications on water and nutrient management as well as fertilizer use during agricultural production (Saglam et al., 2011). Agricultural sustainability depends to a large extent on improvements in soil physical and chemical properties that are largely controlled by several factors including mineral nutrition that has been largely described as the most important (Jat et al., 2006). Cerri et al. (2004) indicated that understanding the distribution and nature of soil properties in the field is essential in refining agricultural management practices while minimizing environmental damage. Information on the spatial variability of soil properties could therefore lead to better management decisions aimed at correcting problems, maintaining productivity, fertility and sustainability of the soils (Özgöz, 2009). Detailed soil characterization particularly on a research farm where high degree of accuracy and precision is required for prescribing recommendation will allow researchers to follow crop and soil management practices aligned with the soil conditions (Castrignanò et al., 2000). The study objectives of this paper therefore include, to: (i) evaluate the spatial distribution of soil physical and chemical characteristics in the research block, study the correlation between soil physical and chemical characteristics, and (ii) identify the trends in variability across the research block.

2 Method

2.1 Description of the Study Location

This study was conducted at the University of Limpopo Experimental Farm, Syferkuil (23°50'36.86"S; 29°40'54.99"E; 1324 meters above sea level), which is located in the Mankweng area within Capricorn District of Limpopo Province, South Africa. The area experiences hot summers with an annual rainfall of 350-500 mm. The research block is regularly used for agronomic and plant nutrition studies by students and researchers from various national and international institutions through research project collaboration by local researchers within the University. Soils at this farm are formed *in situ* on basalt, sandstone and biotic gneiss, possess inherent poor fertility status (FAO, 2009); and locally classified as Hutton according to South Africa classification system or Rhodic Ferralsol (WRB, 2006). The 1 650 ha farm size serves as the University's students' demonstration, agronomic and plant nutrition research as well as animal production studies. Currently on the farm, about 50 ha are allocated for rainfed crops, 80 ha for irrigated crops and 40 ha are used for rotation of winter and summer crops.

2.2 Sampling Points Selection and Digging of the Soil Profiles

Twelve soil profile pits were dug across the research block. The areas where the profile pits were dug were randomly selected for even distribution across the entire block. The coordinates of each profile pit were measured using a GPS device (Trimble Juno 3D) and the map showing the distribution of the pits across the study location and the total depth of each profile pit are shown in Figure 1.

2.3 Horizon Demarcation, Physical Parameters Characterization and Soil Sampling

All profile pit horizons were demarcated based on soil colour (moist and dry state) using the Munsell soil colour chart according to Schoeneberger et al. (1998). Soil structure was characterized based on the soil structure types while soil samples taken from each soil profile horizon were analysed for selected soil chemical and physical parameters using standard laboratory procedures. Some of the physical properties namely: depth, structure and consistency were documented in the field.

2.4 Analyses of Physical and Chemical Properties of Soil Samples

Soil samples collected were air-dried, ground to pass through a 2-mm sieve and used for the various determinations. Soil physical properties namely soil texture and bulk density (BD) were determined using the hydrometer method (Sheldrick & Hand Wang, 1993) and the cylindrical core method (Campbell & Henshall, 1991) respectively. Electrical conductivity (EC) was measured in a 1:5 ratio of soil/water suspension using a digital conductivity meter while pH was measured in water as well as in 1mol dm⁻³ potassium chloride (KCl) at a ratio of 1:2.5 using a digital electronic pH meter. Organic carbon (OC) was determined by Walkley-Black chromic acid wet oxidation method (Nelson & Sommers, 1996), available phosphorus (P) was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Okalebo et al., 2002) and exchangeable potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg) were extracted using 1M NH₄OAC, pH7 solution and concentration of each nutrient determined on atomic absorption spectrophotometer (Okalebo et al., 2002). Effective cation exchange

capacity (ECEC) was estimated by summation of exchangeable cations and exchangeable acidity (Okalebo et al., 2002). Extractable iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) in the soil samples were determined following Ambic-1 procedure (The Non-Affiliated Soil Analysis Work Committee, 1990).

2.5 Statistical analyses and creation of semi-variograms for the measured soil parameters

The collected data were subjected to classical statistical methods to obtain the minimum, maximum, mean, median, skewness (Shapiro & Wilk, 1965), and standard deviation for each horizon (n = 22). A one way analysis of variance was also performed using Statistix 8.1 to compare each variable across the soil profiles using LSD test at 5%. A Pearson-correlation analysis was performed to establish the significances of the linear relations between all measured variables. Semi-variograms of selected soil parameters were created using ArcMap10.2 software while the raw data were interpolated using Simple Kriging method (Santra et al., 2008).

3 Results

3.1 Distribution of Selected Soil Physical Parameters in the Research Block

Soil physical parameters measured revealed that the profiles were generally moderately shallow to deep (Table 1). Profiles 10 and 11 located on the eastern side of the field were the shallowest while profile 7 located at the central part of the field represented the deepest. The soil depth variability map revealed that the soils are deeper in the central part of the field towards the western part but shallowest in the eastern part of the field (Figure 1). The proportion of sand, silt and clay in all soil samples collected from the profiles ranged from 61-87%, 1-15% and 7-27%, respectively; broadly categorised as sandy loam, loamy sand and sandy clay loam. The BD values were generally relatively high and ranged from 1.20 g/cm³ to 1.80 g/cm³ with obvious variation across and within the profile pits. According to Lal (2006), normal bulk density for clay ranged from 0.90 to 1.40 g/cm³ while that for sand ranged from 1.40 to 1.90 g/cm³ with potential root restriction occurring at \geq 1.40 g/cm³ for clay and \geq 1.60 g/cm³ for sand. Other soil physical properties (colour, structure and consistency) and shown in Table 2. Soil colour (dry and moist) is highly variable and ranged from reddish brown to very dark greyish brown depending on the sampling depth while the predominant soil structural type was blocky. The consistencies of the soil samples determined dry were mainly firm and friable.

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Profile ID	Profile depth (cm)	% Sand	% Silt	% Clay	Texture class	BD (g/cm^3)
RBP1T	20	71	12	17	Sandy loam	1.48
RBP1S	80	74	12	14	Sandy loam	1.35
RBP2T	(0)	71	15	14	Sandy loam	1.47
RBP2S	60	84	9	7	Loamy sand	1.27
RBP3T	(1	67	9	24	Sandy clay loam	1.55
RBP3S	61	61	12	27	Sandy clay loam	1.58
RBP4T	70	81	2	17	Sandy loam	1.75
RBP4S	/9	67	9	24	Sandy clay loam	1.54
RBP5T	0.0	77	2	21	Sandy clay loam	1.74
RBP5S	80	84	9	7	Loamy sand	1.50
RBP6T	0.5	74	2	24	Sandy clay loam	1.56
RBP6S	85	80	9	11	Loamy sand	1.46
RBP7T	100	77	2	21	Sandy clay loam	1.78
RBP7S	100	74	9	17	Sandy loam	1.57
RBP8T	00	84	2	14	Sandy loam	1.69
RBP8S	98	68	7	25	Sandy clay loam	1.57
RBP9T		87	2	11	Loamy sand	1.65
RBP9S	45	84	2	14	Sandy loam	1.80
RBP10T	30	84	1	15	Loamy sand	1.78
RBP11T	28	87	2	11	Loamy sand	1.72
RBP12T	0.4	87	2	11	Loamy sand	1.72
RBP12S	94	74	2	24	Sandy clay loam	1.60
CV %	36	10	75	36		9

Table 1. Textural and bulk density varia	tions across the twelve soil profiles
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Note. RBP1T = Research block profile 1 topsoil; RBP1S = Research block profile 1 subsoil; BD = bulk density; CV = Coefficient of variation.



Total depth (cm)

Figure 1. Maps of the study location showing the twelve soil profiles and the total soil depths of each profile

Profile ID	Horizon thickness (cm)	Soil colour (dry)	Soil colour (moist)	Soil structure	Soil consistence (dry)
RBP1T	0-48	-5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP1S	48-80	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP2T	0-22	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Granular	Friable
RBP2S	22-60	7.5YR 6/8 (Reddish yellow)	7.5YR 4/6 (Strong brown)	Platy	Extremely firm
RBP3T	0-34	7.5YR 4/4 (Dark brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP3S	34-61	7.5YR 5/6 (Strong brown)	7.5YR 4/4 (Dark brown)	Blocky	Friable
RBP4T	0-37	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Friable
RBP4S	37-79	5YR 5/8 (Yellowish red)	5YR 4/4 (Reddish brown)	Blocky	Friable
RBP5T	0-24	10YR 3/2 (Very dark greyish brown)	10YR 2/2 (Very dark brown)	Blocky	Firm
RBP5S	24-80	10YR 5/2 (Greyish brown)	10YR 3/3 (Dark brown)	Blocky	Friable
RBP6T	0-32	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP6S	32-85	5YR 5/4 (Reddish brown)	5YR 4/4 (Reddish brown)	Blocky	Friable
RBP7T	0-46	5YR 4/3 (Reddish brown)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP7S	46-100	7.5YR 5/4 (Brown)	7.5YR 4/3 (Dark brown)	Blocky	Friable
RBP8T	0-30	7.5YR 4/4 (Dark brown)	7.5YR 3/3 (Dark brown)	Blocky	Friable
RBP8S	30-98	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Friable
RBP9T	0-20	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP9S	20-45	5YR 5/8 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP10T	0-30	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP11T	0-28	7.5YR 4/6 (Strong brown)	7.5YR 3/3 (Dark brown)	Blocky	Firm
RBP12T	0-30	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP12S	30-94	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Friable

	Table 2. Phy	vsical p	arameters o	of the two	elve soil	profiles	dug	across	the resear	ch bl	lock	within	the ex	perimental	l farm
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3.2 Distribution of Selected Soil Chemical Parameters in the Research Block

The measured chemical parameters for the soil samples are contained in Table 3. The pH value measured in water showed that over 90% of the samples were slightly alkaline while pH in 1 M potassium chloride solution revealed that about 73% of the soil samples were acidic. There was a significant (p < 0.05) variation in the measured pH values across and down the profiles. Soil pH values measured in both water and KCl had similar pattern of spatial variation; with generally lower values at the surface soil than subsurface depth. Virtually all the measured soil pH values in water were outside the desired pH range (6.5 to 7.2). The measured EC value of all soil samples was though high but generally non-saline; and revealed a non-significant variation both across and with the profiles. Organic carbon content in this field was low with marginal and non-significant variation across the field.

About 36% of the soil samples collected mainly from the topsoil were at or about the critical level of 10-16 mg kg⁻¹ for available Bray-1 P for grain crops and were more than nine times higher than in soil samples obtained from the subsoil depth. None of the exchangeable bases in the soil samples from this field was below the prescribed critical level. Bray-1 P, EC, exchangeable K, Ca, Mg and Na, extractable Zn and ECEC contents differed significantly (p < 0.05) with increasing soil depth while K, Ca, Mg, Mn, OC and ECEC differed significantly across soil profiles (data not shown). Based on Waskom et al. (2014) classification standard of EC level of > 2 dS/m or 2000 mS/cm for salt affected soils, the measured EC values are low and therefore the field has no incidence of salt or salinity problem despite the seeming high pH values. However, the coefficient of variation (CV) for the measured soil chemical parameters across the different profiles ranged from 5.8-45.8%. Among the soil chemical parameters, EC, P, K and Na recorded the most variable (CV > 35%) while measured pH, Cu and Mn values recorded the low variation (CV < 15%) on the field (Table 4). For all soil chemical parameters, the mean values are close to the median values. The distribution of pH, OC, available P, Fe, Cu and Zn as determined from the coefficient of skewness greater than 0.5.

3.3 Spatial Distribution of Selected Measured Soil Physical and Chemical Parameters

Spatial dependence of soil properties may be attributed to either intrinsic factors, extrinsic factors or both (Behera et al., 2011). Semi-variogram parameters (nugget, range, sill and nugget to sill ratio) measured in soil samples collected to describe the spatial distribution across the different profiles on the field are presented in Table 5. Large nugget values were obtained for topsoil and subsoil EC and clay and topsoil sand suggesting that additional soil samplings at shorter distances are needed to detect spatial dependence and more accurate maps (Mousaviard et al., 2012). According to Cambardella et al. (1994), spatial dependence was categorized using nugget/sill ratio with values $\geq 25\%$ implying strong, between 25 and 75% were considered as moderate while values > 75% were considered as weak. Hence, the spatial dependency of total depth, subsoil pH. EC and sand based on nugget/sill ratio was weak. However, the observed spatial dependence topsoil EC, OC, sand content and subsoil BD was strong while topsoil clay content and pH showed moderate dependence. The semi-variogram graphs of soil physical and chemical parameters (Figure 2) revealed considerable variability across the field while the spatial variability maps (Figure 3) revealed distinct textural (sand and clay) distribution pattern between the topsoil and subsoil horizons. Topsoil horizons with high sand content were found in the south eastern part of the field while high clay content found in the north and western parts. On the other hand, subsoil horizons with high sand content were found in the north, west and southern parts of the field while high clay content were found in the north and south eastern parts. Topsoil horizons containing high BD were found in the south eastern and north western part of the field while soils in the subsoil horizons with high BD were found in the southern part of the field. The maps revealed that the topsoil horizons were dominated with high BD while the subsoil horizons were characterized by low BD.

According to Wilding (1985), variability described in terms of the range of coefficient of variation can be grouped as least (< 15%), moderate (15-35%) and most (> 35%). Among the measured soil chemical parameters (Table 4), the content of EC, P, K and Na represented the most variable. On the other hand OC, Ca, Mg, Fe, Zn and ECEC were moderately variable while pH, Cu and Mn were the least variable. The values of range for pH, EC and OC measured from the semi-variogram for both topsoil and subsoil were low indicating a great amount of variability within the field. Majority of these chemical parameters were slightly skewed with a coefficient of skewness \geq 0.5 (Table 5). Variables that were normally distributed included pH, OC, P, Fe, Cu and Zn while EC, ECEC, K, Ca, Mg, Na and Mn were not normally distributed. High topsoil pH were found in the north, east and south eastern parts of the field whereas high pH levels appeared to be dominated in the subsoil horizons except in the north western and southern parts. The spatial distribution pH on the field showed highly varied topsoil that increased from west to the east but with partly uniform subsoil (Figure 3).

			FC	Bray_1 P	K	Ca	Μα	Na	Fe	Cu	Zn	Mn	FCFC	
Profile ID	pH_W	pH_{KCl}	mS/cm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	Cmol ₍₊₎ /kg	OC %
RBP1T	7.52	6.78	56	2	70	810	508	103	8.56	1.64	0.54	33	8.88	0.30
RBP1S	8.38	6.96	94	1	70	913	710	173	16	1.60	0.52	23	11.36	0.35
RBP2T	8.04	7.21	117	7	173	1068	668	88	14	1.84	1.08	39	11.69	0.38
RBP2S	8.49	7.25	139	1	60	1360	890	178	12	1.88	0.72	31	15.08	0.80
RBP3T	7.86	6.20	89	12	238	788	505	60	11	1.80	1.64	47	8.98	0.88
RBP3S	7.44	6.15	74	1	70	1055	683	115	17	1.84	0.52	32	11.60	0.83
RBP4T	7.23	6.39	66	14	228	718	433	40	23	1.76	1.80	42	7.93	0.49
RBP4S	7.99	6.10	80	1	98	958	708	128	18	1.56	0.48	26	11.45	0.35
RBP5T	6.92	6.23	70	9	150	1053	538	20	17	1.72	1.44	33	10.18	0.88
RBP5S	8.50	7.49	230	1	70	1910	920	138	13	1.56	0.76	27	17.93	0.75
RBP6T	7.08	5.95	44	15	298	805	420	23	15	1.80	0.72	23	8.36	0.71
RBP6S	8.18	7.22	88	3	150	1050	620	68	20	1.92	0.24	21	11.05	0.65
RBP7T	7.32	6.54	73	10	128	803	495	25	12	1.44	1.24	29	8.54	0.73
RBP7S	8.55	7.36	163	1	73	853	910	200	17	1.68	0.36	20	12.84	0.67
RBP8T	7.90	6.54	43	17	90	613	373	20	10	1.48	1.28	35	6.47	0.58
RBP8S	7.85	6.45	76	1	33	645	443	93	11	1.92	0.40	20	7.38	0.49
RBP9T	6.85	5.34	35	16	88	385	203	15	8.12	1.36	1.88	28	3.89	0.57
RBP9S	7.17	6.09	49	2	33	493	308	10	4.88	1.72	0.44	16	5.14	0.66
RBP10T	7.52	6.39	40	15	70	393	265	8	9.16	1.16	1.68	31	4.37	0.27
RBP11T	7.91	6.90	59	19	78	600	390	40	13	1.28	1.60	26	6.60	0.35
RBP12T	8.10	7.00	51	18	93	563	338	30	9.52	1.40	1.72	30	5.98	0.83
RBP12S	8.05	6.30	52	2	43	655	465	95	13	1.76	0.44	19	7.64	1.04

Table 3. Selected chemical parameters of the twelve soil profiles dug across the research block within the experimental farm

Note. RBP1T = Research block profile 1 topsoil; RBP1S = Research block profile 1 subsoi; EC = electrical conductivity; OC = organic carbon; ECEC = effective cation exchange capacity.

Parameter	Minimum	Maximum	Mean	Median	Skewness	CV%
pH _W	6.85	8.55	7.77	7.88	-0.213	5.8
pH _{KCl}	5.34	7.49	6.58	6.49	-0.145	6.4
EC (mS/cm)	34.57	229.67	81.35	71.75	1.946	45.6
OC%	0.27	1.04	0.62	0.65	-0.028	19.9
Bray-1 P (mg/kg)	1	19	8	5	0.395	41.7
Exch. K (mg/kg)	33	298	109	83	1.393	39.6
Exch. Ca (mg/kg)	385	1910	841	804	1.487	21.7
Exch. Mg (mg/kg)	203	920	536	500	0.497	15.4
Exch. Na (mg/kg)	8	200	76	64	0.677	45.8
Extr. Fe (mg/kg)	4.88	23	13.28	13	0.315	26.2
Extr. Cu (mg/kg)	1.16	1.92	1.64	1.7	-0.665	9.7
Extr. Zn (mg/kg)	0.24	1.88	0.98	0.74	0.339	33.6
Extr. Mn (mg/kg)	16	47	29	29	0.555	12.0
ECEC (Cmol/kg)	3.89	17.93	9.24	8.71	0.670	15.7

Table 4. Summary of statistical analysis of measured chemical parameters of soil samples (n = 22) across the twelve soil profiles

Table 5. Semi-variogram parameters of the measured soil variables

Soil properties	Nugget	Range	Partial sill	Nugget/Sill ratio
Total depth	0	0.002	761.524	0
Topsoil				
pН	0.14	0.01	0.21	0.68
EC	449.63	0.00	239.30	1.88
OC	0.05	0.01	0.02	2.71
Clay	16.31	0.01	32.05	0.51
Sand	38.81	0.01	30.97	1.25
BD	0.01	0.01	0	
Subsoil				
pН	0	0.00	0.27	
EC	491.32	0.01	6938.28	0.07
OC	0.05	0.01	0	0
Clay	57.33	0.01	0	0
Sand	0	0.00	70.86	0
BD	0.02	0.01	0.02	1.06

Note. EC = electrical conductivity, OC = organic carbon, BD = bulk density.





















Distance (Degree), h · 10³

0.288

0

- Model

0.408 0.817 1.225 1.633 2.042 2.45 2.859 3.267 3.675 4.084

Rimed + Averaged

Figure 2. Semi-variograms for selected top and subsoil physical and chemical parameters measured from the field

Note. A1 & A2 = top and subsoil pH; A3 & A4 = top and subsoil EC; B1& B2 = content of top and subsoil organic carbon; B3 & B4 = contents of topsoil and subsoil sand; C1 & C2 = top and subsoil clay; C3 = total soil depth.





Figure 3. Spatial variability maps of topsoil and subsoil sand, clay, bulk density and pH values measured from the field

3.4 Correlation between Measured Soil Parameters

Linear correlation between measured parameters on the field (Table 6) indicated a significant ($p \le 0.01$) positive relationship of EC with silt, pH, ECEC, Ca, Mg and Na content. BD had significant ($p \le 0.05$) negative relationship with Na (-0.78), ECEC (-0.69) as well as pH value measured in water (-0.61). The ECEC content had significant ($p \le 0.001$) positive correlation with Ca, Mg and Na but negative significant correlation with available P. There was significant positive correlation between pH and ECEC while a non-significant negative correlation was observed between clay content and ECEC. A significant negative correlation of BD was found with silt (-0.78) and poor non-significant correlation with organic carbon content (0.07).

Table 6. Pearson correlation matrix (r-va	lue) between measured so	il properties from the 12	2 profiles across different
sampling depths			

Parameters	Sand	Silt	Clay	BD	$\mathrm{pH}_{\mathrm{KCl}}$	pH_{W}	EC	OC	Bray P1	Κ	Ca	Mg	Na	ECEC	Fe	Mn	Cu	Zn
Sand	1																	
Silt	-0.60**	1																
Clay	-0.80***	0.01	1															
BD	0.33	-0.78***	0.17	1														
$pH_{\rm KCl}$	0.15	0.46*	-0.53	-0.45	1													
pH_W	-0.02	0.52	-0.36	-0.61*	0.81***	1												
EC	-0.06	0.55*	-0.33	-0.52	0.70**	0.66**	1											
OC	-0.04	-0.20*	0.20	0.04	-0.08	0.00	0.14	1										
Bray P1	0.51	-0.01	-0.15	0.58*	-0.30	-0.41	-0.52	-0.09	1									
Κ	-0.16	-0.07	0.25	0.04	-0.19	-0.33	-0.11	0.11	0.43	1								
Ca	-0.16	0.56*	-0.22	-0.59*	0.56*	0.47	0.85***	0.23	-0.53	0.04	1							
Mg	-0.34	0.71***	-0.11	-0.70**	0.65**	0.68**	0.87***	0.14	-0.00**	-0.10	0.85***	1						
Na	-0.39	0.74***	-0.06	-0.78***	0.56*	0.74***	0.71**	-0.01	0.75***	-0.27	0.59*	0.88***	1					
ECEC	-0.28	0.68**	-0.15	-0.69**	0.63*	0.60*	0.89***	0.19	-0.63*	0.00	0.95***	0.97***	0.78***	1				
Fe	-0.32	0.24	0.22	-0.21	0.20	0.15	0.26	0.02	-0.18	0.42	0.375	0.468	0.32	0.46	1			
Mn	-0.12	0.15	0.04	0.04	-0.05	-0.16	-0.02	-0.03	0.41	0.50	0.08	-0.05	-0.19	0.03	0.11	1		
Cu	-0.55	0.48*	0.33	-0.51	0.11	0.13	0.26	0.37	-0.58*	0.26	0.39	0.43	0.37	0.44	0.38	-0.02	1	
Zn	0.47	-0.52*	-0.21	0.54*	-0.28	-0.40	-0.33	-0.80	0.86***	0.33	-0.37	-0.55*	-0.62*	-0.48	-0.16	0.64*	-0.57	* 1

Note. CEC = effective cation exchange capacity; OC = organic carbon; BD = bulk density; * implies significant at P < 0.05; ** implies significant at P < 0.01; *** implies significant at P < 0.00-1.

4. Discussion

The observed spatial variations across the field have serious implications on soil volume, root growth, and crop management practices such as irrigation and fertilizer use. The textural types obtained on the field are well suited for crop production as they influence water holding capacity, CEC, soil workability, soil fertility and crop productivity (Heil & Schmidhalter, 2011). The observed high BD may be attributed to soil compaction following repeated use of tractor implements for tillage operations over the years. Soil compaction results in high bulk density (Afzalinia et al., 2011) causing restricted root growth, poor air and water movement within soil. The generally blocky structure of soils observed in the profiles might have resulted from the presence of high content of shrinking and swelling clay mineral types (Horn & Smucker, 2005). The observed soil colour variation could be related to the content of OC, soil texture, the presence of iron-containing minerals and the larger ecosystem processes (Viscarra-Rossel et al., 2006). Soils with firm and friable consistencies similar to those found in present study are reportedly favourable to workability and trafficability depending on their moisture content level (Huang et al., 2011).

The significant difference and high variability in most of the measured chemical parameters on the field may be related to land-use systems (Agoume & Birang, 2009). The slightly alkaline nature observed in this field could be related to the presence of high amount of exchangeable cations. Chik and Islam (2011) reported that soils containing high amounts of K, Ca, and Mg are likely to be alkaline while Kilic et al. (2012) attributed high soil pH in cultivated lands to high salt concentration of irrigation water. Frequent supplementary irrigation was performed on this field to support crop growth during winter and summer growing seasons. Balanced soil pH has an important influence on soil nutrient availability, solubility of toxic nutrient elements and CEC (Arain et al., 2000). Notwithstanding the high pH values on the field, the low EC values may be due to the low sodium levels in the soils, which were well below the critical level of 2000 mS/cm prescribed by Waskom et al. (2014). Soil variables that revealed normal distribution contributed to the observed results accuracy while the observed variation in soil OC level on the field may be due to differences in over the years cropping systems, diverse crop residues type and their decomposition rate (Tsui et al., 2004).

The significant distribution of micronutrients (Zn, Fe, Cu and Mn) observed across the profiles is in agreement with earlier findings (Verma et al., 2005). This may have been influenced by such characteristics as organic matter, clay and pH contents (Singh et al., 1989), and the cation activity ratios in soil solution on the field (Mayland &Wilkinson, 1989). The highly variable spatial dependence among measured variables may be attributed to soil intrinsic properties as influenced by the parent materials and extraneous factors like intensive and diverse cropping, soil erosion and fertilization (Alvares et al., 2011). The observed variation of the measured parameters over long distances on the field is probably due to increase of semivariance to points where the locations are considered independent of each other (Karl & Maurer, 2010).

In conclusion, the present study revealed the existence of fairly high level of spatial variability of soil physico-chemical properties across this intensively utilized research block associated with land use and management practices. Of all the measured parameters, electrical conductivity, Bray-1 P, exchangeable K, Ca and Na as well as extractable Fe and Zn showed a huge percent variation across the different depths and locations within the field. The correlation analyses indicated that there is negative and positive inverse or direct relationship among the measured soil physical and chemical properties. The findings explain the eventual anomalies/variabilities inherent in the results of current and similar research fields including soil that could be used for future experiments thus allowing researchers to implement management practices that are aligned with crop and soil requirements.

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