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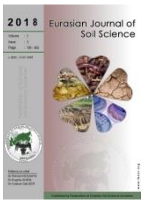

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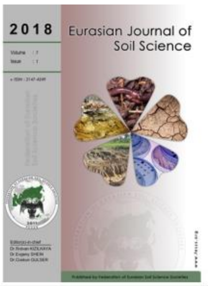

Imaging soil pore characteristics using computed tomography as influenced by agroecosystems

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Abstract

Soil pore parameters are important for water infiltration into the soil and transport within the soil. The aim of this study was to compare influences of agroecosystems on soil pore characteristics (number of pores, macropores, coarse mesopores, porosity, macroporosity, coarse mesoporosity, pore circularity) using computed tomography (CT). This experiment was carried out four different agroecosystem field [Tucker Prairie (TP): native prairie, Prairie Fork (PF): restored prairie, Conservation Reserve Program (CRP), and row crop (RC): corn/soybean rotation] in Missouri state of United States during the year of 2017. Undisturbed soil samples were collected at four soil depths (0-10, 10-20, 20-30, and 30-40 cm) from each treatment with three replications. Five scan images from each sample were acquired using a X-ray CT scanner with 0.19 by 0.19 mm pixel resolution with 0.5 mm slice thickness and analyzed with *Image-J*. TP, PF, CRP, and RC treatments had 195, 88, 112, and 49 pores on a 2500 mm^2 area, respectively across all the depths. Soil under TP and CRP treatment had significantly higher porosity (0.046 m^3 m^{-3}, 0.046 m^3 m^{-3}), and macroporosity (0.036 m^3 m^{-3}, 0.041 m^3 m^{-3}) values than other treatments. The CT-measured number of macropores (>1000 μm diam.) were 5 times higher for TP when compared with RC treatment. The CT-measured pore circularity values were lower for CRP and RC treatments. CT-measured number of coarse mesopores, and mesoporosity were significantly greater under TP treatment. Results show that native prairie can improve soil pore parameters.

Keywords: Agroecosystems, computed tomograpy, *Image-J*, soil pore.

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Introduction

Soil porosity is very important for transport and storage of water and nutrients in the soil. Hence, it is essential to understand soil pore characteristics. Water transmission and storage depend on the geometry and size distribution of soil pores (Eynard et al., 2004). Moreover, better water retention is also important to improve plant growth. Pasture, grass buffers, and agroforestry buffers as perennial vegetation increases soil porosity compared to row crop area (Seobi et al., 2005). Macropores (diam. >1000 μm; Zaibon et al., 2016) are pores with diameters larger than 0.3 to 0.5 mm and form from earthworm burrows decaying plant roots, swelling-shrinkage cracks, or interaggregate voids (Jarvis, 2007). The impact of macropores on soil transfer properties is directly related to their geometrical and topological characteristics, among which continuity and pore size distribution are of prime importance. Many investigators have shown that macropore characteristics such as shape, size, orientation, and size distribution affect the rate, flow, and retention of water (Scott et al., 1998; Udawatta et al., 2006).

Porosity determined by traditional methods often lacks detailed information on pore characteristics and sometimes porosity is estimated by indirect procedures (Udawatta et al., 2006). These procedures do not provide information on the spatial distribution of pores (Gantzer and Anderson, 2002).

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X-ray computed tomography (CT) provides a direct procedure to quantify the geometrical attributes of soil pore space in three dimensions (Wildenschild and Sheppard, 2013). It has been used effectively for measuring pore size, shape, distribution and arrangement of soil pores, surface area and pore connectivity (Udawatta and Anderson, 2008; Kumar et al., 2010; Rab et al., 2014). The connected and unconnected pores could easily be visualised and quantified using the X-ray CT method (Munkholm et al., 2012; Tracy et al., 2012) while this is not possible using the soil-water retention method.

Objectives of the study were to compare differences in CT-measured soil pore characteristics (number of pores, macropores, coarse mesopores, porosity, macroporosity, coarse mesoporosity, pore circularity) as influenced by Tucker Prairie, Prairie Fork, Conservation Reserve Program, and row crop (corn/soybean rotation).

Material and Methods

Study site

This study was conducted in four different agroecosystem fields: Tucker Prairie (TP: native prairie), Prairie Fork (PF: restored prairie), Conservation Reserve Program (CRP), and row crop (RC; corn/soybean rotation) in central Missouri during the year of 2017. The undisturbed TP area has been under native prairie vegetation and includes big blue stem (*Andropogon gerardi* Vitman.), little blue stem (*Schizachyrium scoparium* Nash.), prairie dropseed (*Sporobolus heterolepis* [A. Gray] A. Gray), and Indian grass (*Sorghastrum nutans* [L.J. Nash]) (Buyanovsky et al., 1987). The PF area was under row crop management for approximately 100 years and was restored in 1993 with native grasses and legumes. The study site vegetation consisted of little blue stem, side-oats gamma (*Bouteloua curtipendula var. curtipendula*), and Indian grass. CRP and RC sampling plots are located within the USDA-ARS Agricultural Systems for Environmental Quality site near Centralia, MO which had originally been under cultivation for approximately 100 years. The CRP sampling sites had been in CRP since 1991 with present vegetation consisting of 95% tall fescue, some orchardgrass, and red clover. The RC sampling areas were managed with mulch tillage since 1991 with 0.19 t ha^{-1} N during corn years and lime, P and K applied based on soil analysis for a grain yield of 1 t ha^{-1} for corn and 2.5 t ha^{-1} for soybean. These areas were in corn in 2005. Soils at these sites (TP, PF, CRP and RC) are Mexico silt loam (Fine, smectitic, mesic Vertic Epiaqualfs). The Mexico series are composed of very deep and poorly drained soils with an argillic horizon at varying depths on 0 to 4% slopes. The potential for runoff is high to very high and permeability is very slow. The native vegetation consists of warm-season grasses and forbs. Most areas are used to grow corn, soybeans, hay, pasture, and small grains.

Soil sampling and preparation

Undisturbed soil samples were removed from four soil depths (0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm) with three replications using a Uhland sampler with Plexiglas cylinders (76.2 mm x 76.2 mm) during spring 2017. Two plastic caps and masking tape were used on each end of the sample to secure soil inside the cylinders. The soil samples were trimmed, labeled, and sealed in plastic bags and then transported to the laboratory. Samples were stored in a refrigerator at 4°C until measurements were taken. Selected soil properties for the sites are given in Table 1.

Table 1. Some physical and chemical properties of the treatments.

Treatments	Sand (%)	Clay (%)	Silt (%)	pH	Total Org. C (g kg^{-1})	CEC (c mol kg^{-1})
TP	6.28	27.26	66.46	4.98	15.40	19.54
PF	5.67	36.43	57.90	5.86	11.66	25.66
CRP	4.11	39.47	56.42	5.47	10.75	28.35
RC	4.03	38.90	57.07	5.77	9.25	28.67

TP: Tucker Prairie, PF: Prairie Fork, CRP: Conservation Reserve Program, RC: Row Crop (corn/soybean rotation), CEC: Cation Exchange Capacity, Org.C: Organic Carbon.

The bottom end of the cores was covered with two layers of fine nylon mesh to secure soil within the cylinder. The soil cores were slowly saturated from the bottom with distilled water using a Mariotte system. After 24 hours saturation, wet weights were recorded and samples were placed on a -3.5 kPa glass-bead tension table for 24 hours for draining. This procedure removed water from macropores and coarse mesopores to enhance the image contrast. Samples were re-weighed and two plastic end caps were secured with masking tape, and refrigirated until the scanning process.

Soil samples were taken out from refrigerator and re-weighed and prepared (put into the wooden boxes container) for transport to the University of Missouri Veterinary Medicine Hospital for computed tomography (CT) measurement. Two phantoms; a distilled water in an aluminum tube (outside and inside diam. 2.32 and 1.60 mm) and a solid copper wire (outside diam. 0.55 mm) were attached to the long axis of the Plexiglas cylinder for a standard comparison of values through scans.

Scanning and imaging procedure

The X-ray CT scanner used in this study was a Toshiba Aquilion 64 set at a peak voltage of 120 keV and a current of 100 mA to acquire CT scan images. Soil samples were placed horizontally on the scanner bench so that the X-ray beam was perpendicular to the longitudinal axis. The scanning produced images with a slice thickness of 0.5 mm with a pixel size of 0.19 by 0.19 mm. Five scan slices per sample were taken. The scanned images were analyzed using the *Image-J* version 1.50i software (Rasband, 2013) to determine macropore (>1000µm diam.) and coarse mesopore (200-1000µm diam.) characteristics of the soils. The Threshold tool was used to characterize pores from solids after converting the image into an 8-bit grayscale image. A value of 40 was chosen as the threshold value to analyze all images. The values lower than the threshold value (40) were identified as the air-filled pores and values greater than the threshold value (40) were identified as non-pore (Figure 1). Statistics of individiual pores were estimated under the Analyze Particles Tool. The following CT-measured pore parameters were used in the analysis: CT-measured number of total pore area, macropore area, and coarse mesapore area of an image. These values were divided by the 2500 mm^2 scan area to calculate total porosity (macroporosity+coarse mesoporosity), macroporosity and coarse mesoporosity, respectively. Additionally, the circularity of pores was determined by dividing the pore area by 4 π multiplied by the pore perimeter squared (Tracy et al., 2015).

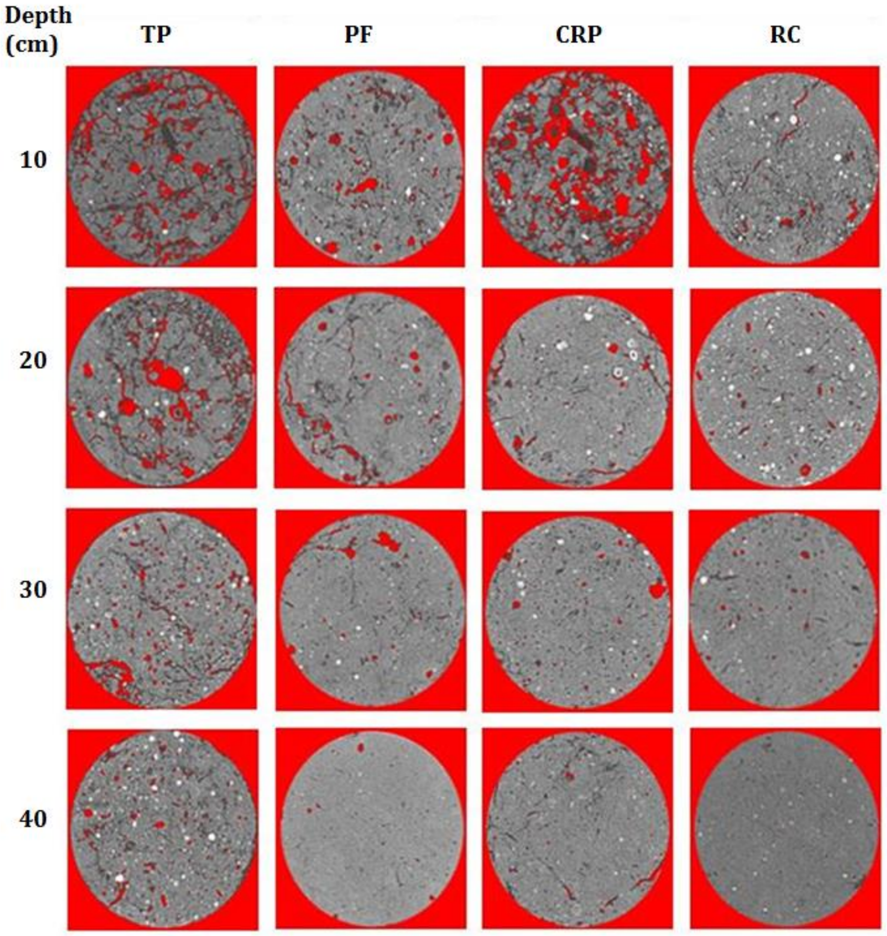

Figure 1. Selected some scan images of TP (Tucker Prairie), PF (Prairie Fork), CRP (Conservation Reserve Program), RC (Row Crop: corn/soybean rotation) treatments at four scan depths. Air-filled pores are in red, solid areas in gray and manganase in white colour.

Statistical analysis

Analysis of variance (ANOVA) was performed with SAS 9.4 using the GLM procedure. Means and differences among means for the measured parameters were determined with PROC MEANS. Statistical differences were declared significant at the α=0.05 level. Contrasts among treatments were analyzed to find significant differences among management practices.

Results

Computed tomography-measured number of pores, macropores and coarse mesopores

Two terms (depth zone and scan depth) were used to distinguish between the four depth zones or soil core depths (0–10, 10–20, 20–30, and 30–40 cm) and the 20 scan depths (five scans per depth zone), respectively, to examine CT-measured pore parameters. Number of pores refers to CT-measured pores, which indicate the lower limit of resolution on detecting pores and is directly related to the scanner resolution. The distribution of CT-measured pore sizes varied among the treatments and depth zones and significant (*P*<0.05) differences were observed between the treatments and depth zones and some interactions (Table 2). The average CT-measured number of pores were greater (195) in TP (Tucker Prairie) treatment as compared to the PF (Prairie Fork), CRP (Conservation Reserve Program), and RC (row crop) treatment (Table 2, *P*<0.05). The number of pores were higher in TP treatment in first soil depth zone compared to RC; values decreased from 310 at the 10 cm soil depth zone to 120 at the 40 cm soil depth zone for the TP treatment (Figure 2A) Also, this parameter was significantly higher in first soil depth zone compared to the other soil depth zones, values decreased from 221 at the 10 cm depth zone to 45 at the 40 cm depth zone (Table 2, *P*<0.05).

Averaged across the four depth zones, TP, PF, CRP, and RC treatments had 42, 22, 27, and 8 macropores on a 2500 mm^2 scan area, respectively (Table 2). No significant differences (*P*<0.05) were observed between the PF and CRP treatments. Soil under TP treatment had significantly more macropores than the other treatments (*P*<0.05). CRP treatment showed higher number of macropores (86) at the 10 cm soil depth zone when compared with the other treatments (Figure 2B).

TP, PF, CRP, and RC treatments had an average of 84, 38, 44, and 21 coarse mesopores across all scan depths on a 2500 mm^2 scan area, respectively (Table 2). The number of coarse mesopores was significantly different among the treatments and depths. The TP treatment area had the highest number of coarse mesopores when compared with the other treatments (*P*<0.05). TP treatment was also higher (120) in first depth zone than other treatments (Figure 2C).

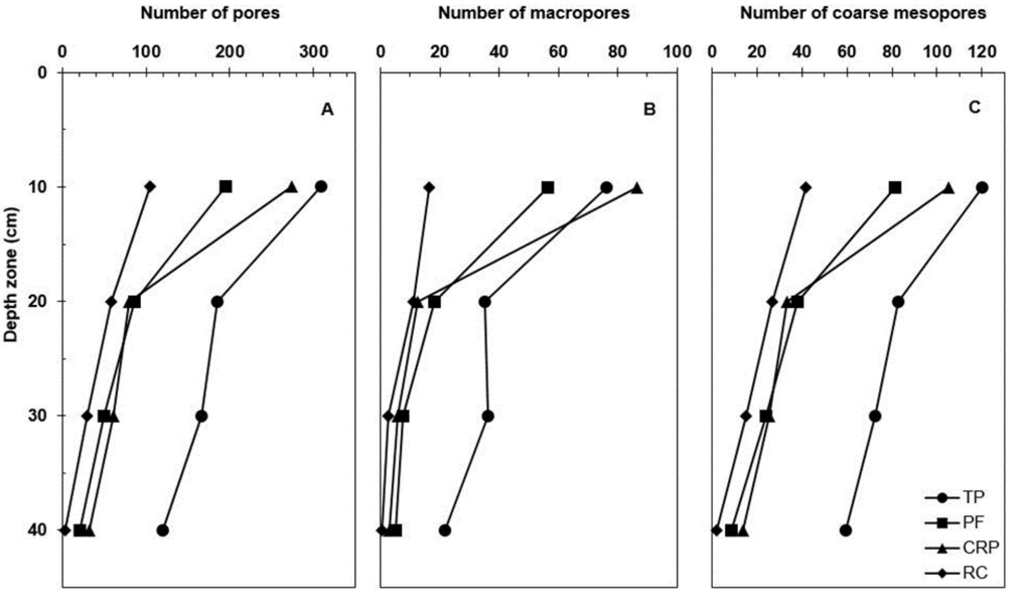

Figure 2. Computed tomography-measured (A) number of pores, (B) number of macropores, (C) number of coarse mesopores for tucker prairie (TP), prairie fork (PF), conservation reserve program (CRP), and row crop (RC) treatments by depth.

Computed tomography-measured porosity, macroporosity and coarse mesoporosity

The CT-measured porosity, macroporosity (diam.>1000 μm) and coarse mesoporosity (diam.200-1000 μm) were significantly affected by all the treatments, depth zones and some interactions (Table 2, *P*<0.05). TP and CRP treatments had greater porosity (0.046 m^3 m^{-3}) than PF (0.027 m^3 m^{-3}) and RC (0.011 m^3 m^{-3}) treatments. The CT-measured porosity, on average, significantly decreased with depth zone for all the treatments (Table 2). The higher CT-measured porosity was determined by CRP treatment as 0.158 m^3 m^{-3} at the first soil depth zone (Figure 3A). Similar to CT-measured porosity results, CT-measured macroporosity and coarse mesoporosity values decreased with increasing depth zones for all the treatments.

Table 2. Computed tomography-measured number of pores-macropores-coarse mesopores, porosity, macroporosity, coarse mesoporosity, and pore circularity as affected by depth and treatment and the ANOVA.

	Number			**Porosity (m^3 m^{-3})**			
	Pores	**Macropores**	**Coarse mesopores**	**Porosity**	**Macroporosity**	**Coarse mesoporosity**	**Pore circularity**
Treatment means							
TP	195 a	42 a	84 a	0.046 a	0.036 a	0.009 a	0.432 a
PF	88 b	22 ab	38 b	0.027 ab	0.022 ab	0.004 b	0.434 a
CRP	112 b	27 ab	44 b	0.046 a	0.041 a	0.005 b	0.348 b
RC	49 b	8 b	21 b	0.011 b	0.008 b	0.003 b	0.350 b
Depth zone means							
0-10 cm	221 a	59 a	87 a	0.084 a	0.073 a	0.009 a	0.437 a
10-20 cm	102 b	19 b	45 b	0.023 b	0.017 b	0.005 b	0.408 ab
20-30 cm	77 bc	13 b	34 bc	0.017 b	0.012 b	0.004 bc	0.367 bc
30-40 cm	45 c	8 b	21 c	0.007 b	0.004 b	0.002 c	0.352 c
Analysis of variance *p*>F							
Treatment	0.007	0.025	0.006	0.014	0.014	0.007	0.002
RC vs. Others	0.009	0.013	0.011	0.005	0.006	0.011	0.008
TP vs. PF&CRP	0.006	0.044	0.004	0.280	0.534	0.005	0.038
PF vs. CRP	0.451	0.583	0.623	0.065	0.046	0.741	0.002
Scan depth	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Treatment x scan depth	0.266	0.043	0.321	<0.001	<0.001	0.124	<0.001

The ANOVA table presents significance levels among treatments and by depth for the measured parameters. (TP: Tucker Prairie; PF: Prairie Fork; CRP: Conservation Reserve Program; RC: Row Crop). (Treatment x scan depth= Treatment by scan depth interaction.) Mean comparisons were only made when *P* values for the main effects were ≤0.05. Means with different letters for a pore parameter are significantly different at the 0.05 probability level.

Macroporosity values averaged across all scan depths were 0.036, 0.022, 0.041, and 0.008 m^3 m^{-3} for TP, PF, CRP and RC treatments, respectively (Table 2). TP and CRP treatments had same significant level and also higher than the other two treatments ($P<0.05$, Table 2). CRP treatment had greater macroporosity values (0.143 m^3 m^{-3}) than the other treatments in first depth zone (Figure 3B). The greater CT-measured averaged coarse mesoporosity (diam. 200-1000 µm) values were found within the TP (0.009 m^3 m^{-3}) treatment ($P<0.05$, Table 2). TP treatment had about 3 times higher coarse mesoporosity than the RC treatment (0.003 m^3 m^{-3}). There were not observed any significant differences ($P<0.05$) between the PF, CRP and RC treatments. In addition, there were not found any coarse mesoporosity values in RC treatment at the fourth depth zone (Figure 3C).

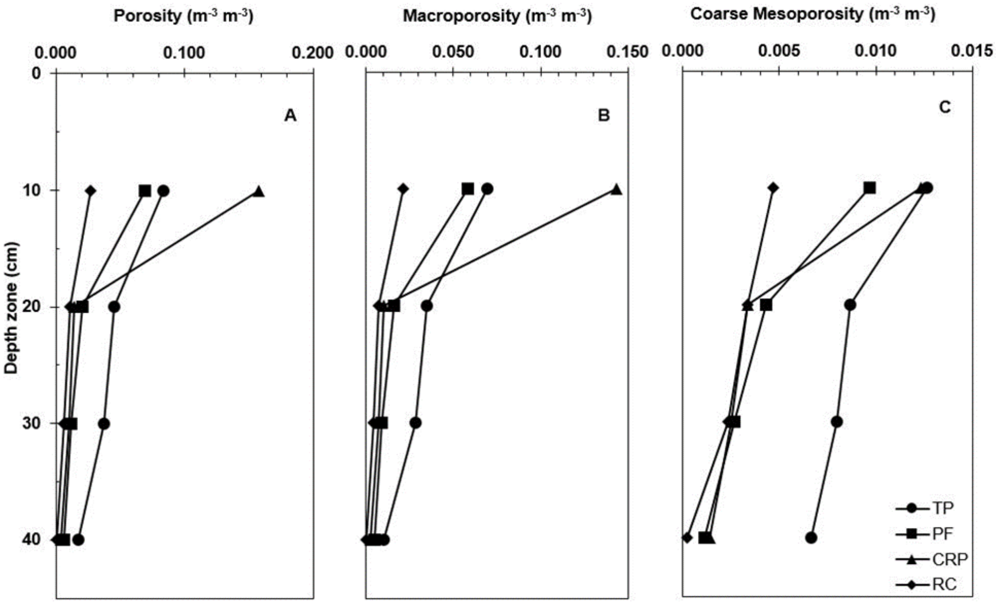

Figure 3. Computed tomography-measured (A) porosity, (B) macroporosity, (C) coarse mesoporosity for tucker prairie (TP), prairie fork (PF), conservation reserve program (CRP), and row crop (RC) treatments by depth.

Computed tomography-measured pore circularity

The CT-measured averaged circularity values were sifnificantly larger (about 25%) for the TP (0.432) and PF (0.434) treatments compared to CRP (0.349) and RC (0.350) treatments ($P<0.05$, Table 2). However, CRP treatment showed greater pore circularity value (0.493) than the other treatments at the first depth zone (Figure 4). Moreover, all the treatments showed significant differences averaged over scan depth.

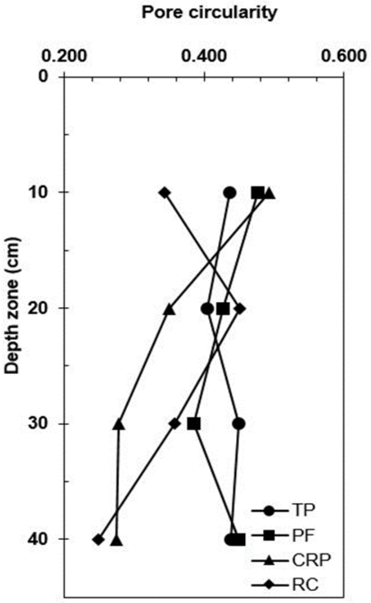

Figure 4. Computed tomography-measured pore circularity for tucker prairie (TP), prairie fork (PF), conservation reserve program (CRP), and row crop (RC) treatments by depth.

Discussion

This project evaluated the differences in CT-measured soil pore parameters under TP, PF, CRP, and RC managements at four depth zones. Differences were significantly higher for all pore parameters at the first depth zone (0-10 cm) compared with deeper depth zones. CT-measured number of pores, macropores, coarse mesopores, total porosity, macroporosity, coarse mesoporosity, and pore circularity were found to be significantly different among the treatments, depth zones and some interactions. Results showed that soil pore parameters were improved by tucker prairie and conservation reserve program treatments. The tucker prairie treatment had significantly greater pore parameters than the other treatments. Similar to tucker prairie, the conservation reserve program managements were also showed greater porosity, and macroporosity values with same significance level. Distribution of pores and macropores affect the ability to transport water and thereby influence nutrients in runoff (Pachepsky et al., 2000; Cadisch et al., 2004). Pachepsky et al. (1996) reported that management practices mostly effect the number and area of large elongated pores. Similarly, Rachman et al. (2005), observed significantly larger number of pores in soils under grass as compared with crop areas.

Some researchers found that permanent vegetation improves soil porosity compared with row crop land under till or no-till management (Bharati et al., 2002; Seobi et al., 2005). Rachman et al. (2005) and Udawatta et al. (2006) reported some differences in computed tomography measured macroporosity and mesoporosity under grass and trees compared with row crop areas. They found these differences due to roots, organic matter, agricultural activities, and duration of the vegetation period.

Pore circularity is one of the parameters that are often adopted to characterize pore shape. If the circularity approaches 1.0, the pore approaches a round shape. If the area of the pore is fixed, the more irregular its circumference is, the smaller its circularity will be (Zhao et al., 2010). CT-measured pore circularity was the highest in soil under the prairies and the smallest under row crop management. Prairie fork and tucker prairie treatments showed the highest CT-measured pore circularity with same significance level. Native and restored praires had increased more elongated larger pores in soils when compared with conservation reserve program and row crop treatments. Udawatta and Anderson (2008) demonstrated that prairie restoration improves CT-measured pore parameters, morphological characteristics and porosity. Results of this current study indicate that pore shape or form was highly related to vegetation treatment.

These findings show that native prairie (also known tucker prairie) and conservation reserve program soils improved pore parameters when compared to other treatments. Increased macroporosity in tucker prairie and conservation reserve areas will probably increase soil water infiltration, increase gas exchange and reduce runoff and nonpoint-source pollution. In addition, these management practices might help prevent surface runoff and serve as a sediment trap and they may enhance the groundwater recharge. This study also show that the usefulness of CT-scanning techniques combined with image analysis for quantifying pore parameters. These nondestructive techniques will prove useful for similar experiments in the future and will further expand the knowledge of soil pore systems.

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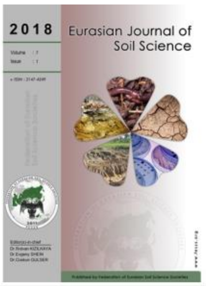

Assessment of soil fertility index for potato production using integrated Fuzzy and AHP approaches, Northeast of Iran

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Abstract

Considering the important role of soil fertility and nutrient management in the modern agriculture seems to be a key step in appropriate site-specific fertilizers management for crop production. The present study was conducted to prepare a soil fertility zonation map based on soil nutrient elements including total nitrogen, available potassium and phosphorus, magnesium, manganese and iron and soil chemical parameters comprising cation exchange capacity, organic carbon, salinity and pH by integrated Fuzzy and AHP approaches for potato production in Rokh plain, northeast of Iran. In this regard the most important soil chemical parameters and nutrient elements in 0-30 cm depth of the soil was analyzed and mapped. The S-shaped fuzzy membership function was subsequently defined for each factor to fuzzify soil fertility parameters. The soil fertility map was prepared by weighing factor layers by the AHP approach and summation of factor layers by IDW interpolation function in GIS. The values of the soil fertility index in the scale of 0 to 1 ranged from 0.104 to 0.574, classified the study area in very low (922.90 km^2), low (566.10 km^2) and moderate fertility (14.86 km^2) classes which comprises 61.37%, 37.64% and 0.99% of the surface area, respectively. A regression between soil fertility values and potato yield in the study area revealed a high correlation ($R^2 = 0.91$) between the observed results which validate the zonation of the fertility classes in the region.

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Introduction

The rapid growth of population demands higher land use efficiency to ensure food security. The most appropriate way to reach this goal is to increase yield per unit area rather than by expansion of cultivated areas. In this regard, evaluating soil fertility and productivity is of great importance in plant production. Determining the degree of soil fertility was done based on soil chemical parameters including cation exchange capacity (CEC) and Organic carbon (OC) as key indicators of soil quality, soil salinity (EC_e) and pH, as well as macro nutrient elements including nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) due to high rate of consumption and their great effect on crop yield and its quality, and micro nutrient elements comprising, manganese (Mn) and iron (Fe) because of their important role in conducting physiological processes in plant nutrition (Westermann, 2005). Nutrition of the potato (*Solanum tuberosum L.*) crop is characterized by its shallow rooting habit and rapid growth rate. Therefore, high yields necessitate an adequate supply of nutrients throughout the growth period. Nitrogen application promotes early development of the foliage and therefore, of the photosynthetic capacity during the growth period. However, excess N may delay tuber initiation and so reduce yield. The N requirement depends on many

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factors including soil type and cropping system. A preceding legume or another crop with high residual effects, or an application of organic manure, can reduce fertilizer N requirements by 40–50 kg.ha^{-1}. Potatoes utilize both ammonium and nitrate N, but show a preference for ammonium, especially in the early stages of growth. Usually, the entire N is applied to the seedbed. However, in high rainfall conditions, a split application may reduce leaching losses. N applications after the start of tuber development may delay crop maturity. Potatoes need a good supply of readily available Phosphorous because their root system is not extensive and does not readily utilize less available P forms. Water-soluble P is the most efficient source for potatoes. Potassium plays a major role in starch production by the potato crop. Potato plants well supplied with K are found to withstand frost better than low K plants. Fertilizer K requirement depends on soil type and organic manure application. Irrigation can improve the availability of soil K, and there can be varietal differences in susceptibility to K deficiency. Magnesium is the central part of the chlorophyll molecule, where photosynthesis occurs. It also helps the plant metabolize energy and form protein. Magnesium deficiency can occur on leached, sandy soils with low cation exchange capacities and may be intensified by large K fertilizer applications. It can be controlled by Mg applied in amendments such as dolomite or by Mg-containing fertilizer materials. Manganese (Mn) is involved in chlorophyll formation, nitrate assimilation, enzyme systems, and iron metabolism. Manganese deficiency is generally caused by a high soil pH, whereas Mn toxicities occur at low soil pH. Iron (Fe) is used in chlorophyll and protein formation, enzyme systems, respiration, photosynthesis, and energy transfer. Iron deficiency is believed to be caused by an imbalance of metallic ions, such as Cu and Mn; excessive amounts of P; and a combination of high pH, high lime, cool temperatures and high levels of carbonate in the root zone. Soil application or foliar sprays are the widely used methods for supplying micro-nutrients. The micro-nutrient needs of potato can also be met simply by soaking the seed tubers in nutrient solutions. The non-dormant seed tubers are soaked in 0.05% micro-nutrient salt solutions for three hours. The deficiencies of Mn and Fe are controllable by soil or foliar application. Potato cultivars can differ markedly with regard to their sensitivity to micronutrient deficiencies.

Fuzzy model is one of the most flexible models used to provide different kinds of soil maps (Cassel-Gintz et al., 1997). The model comprises high accuracy for preparing the soil attribute maps (Kremenová, 2004). Fuzzy set theory and concept of a linguistic variable is derived values of variables and made its use for expanded application area. Fuzzy logic makes conversion of imprecise information to precise one, consists of capability to design rational decisions containing imperfect information. Uncertainty, imprecision, incompleteness, risk management, partial true and vice versa is an attribute of information in Fuzzy systems. The fuzzy logic design is the best approach to get precise, accurate result and conclusions. Fuzzy set theory has been used in environmental sciences including land suitability evaluation, soil fertility classification, soil geo-statistics and soil quality indices (Burrough, 1989; McBratney and Odeh, 1997; McBratney et al., 2003; Zhang et al., 2004; Lagacherie, 2005). The development of fuzzy logic-based soil fertility mapping techniques is due to its ability to represent the continuous nature of soil spatial variation (Zhu et al., 2001; Yang et al., 2007). Fuzzy set theory has been widely used in soil fertility classification, mapping and land evaluation (McBratney et al., 2003; Zhang et al., 2004; Lagacherie, 2005; Sanchez Moreno, 2007). The analytical hierarchy process (AHP) developed by Saaty (1980) is a multi-criteria evaluation approach, used to enhance with fuzzy factor standardization. The AHP plays an important role in selecting alternatives (Dey and Ramcharan, 2008), (Vahidnia et al., 2009). AHP has become one of the most widely used methods for the practical solution of multi criteria decision making issues (Chan et al., 2000; Chang et al., 2007). AHP uses understanding and informed knowledge without the need of specific data (Bottero et al., 2011). But the main shortage of AHP is that it deals with people's expert judgment as a crisp number between 1and 9 and their Eigen values, this doesn't handle the uncertainty associating to these judgments. In order to overcome that incompetence, Fuzzy set integrated with AHP technique to determine the best alternative (Levary and Wan, 1998), (Chang et al., 2007). The combination of fuzzy set and AHP leads to more flexibility in judgment and decision making. The AHP reflects human thinking as it uses approximate information and uncertainty to generate decision in addition to inheritance of the advantages of AHP, ease of handling qualitative and quantitative data, use of hierarchical structure, pairwise comparison, reduce inconsistency, and generates priority vectors (Vahidnia et al., 2009). The main hypothesis behind our research is that there is a logical relationship between the soil chemical properties, soil fertility index and crop yield which can be defined as a modeling by integrating Fuzzy and AHP approaches. The aim of the present study is to evaluate soil fertility and classification for potato production in Rokh plain, northeast of Iran. In this regard integration between Fuzzy and AHP approaches and GIS was used to produce and classify soil fertility zonation map for the study area.

Material and Methods

General characteristics of the study area

The present study was conducted in Rokh plain, Khorasan-e-Razavi Province, Northeast Iran (Figure 1). The study area is located between latitude 35°28′51"N to 35°47′45"N and longitude 58°34′49"E to 59°35′39"E including lands less than 2933 m asl. The general physiographic trend of the plain extends in a west-east direction with a maximum length of 92 km. The total surface of the study area comprises 1503.86 km^2. The elevation values of the study area vary between 1386 m and 1901 m asl, with an average of 1643.5 m asl. The main land use practice in the study area is irrigated farming. The climate of the study area is semi-arid with mean annual precipitation of 267.7 mm and means annual temperature of 14.3°C (Figure 1).

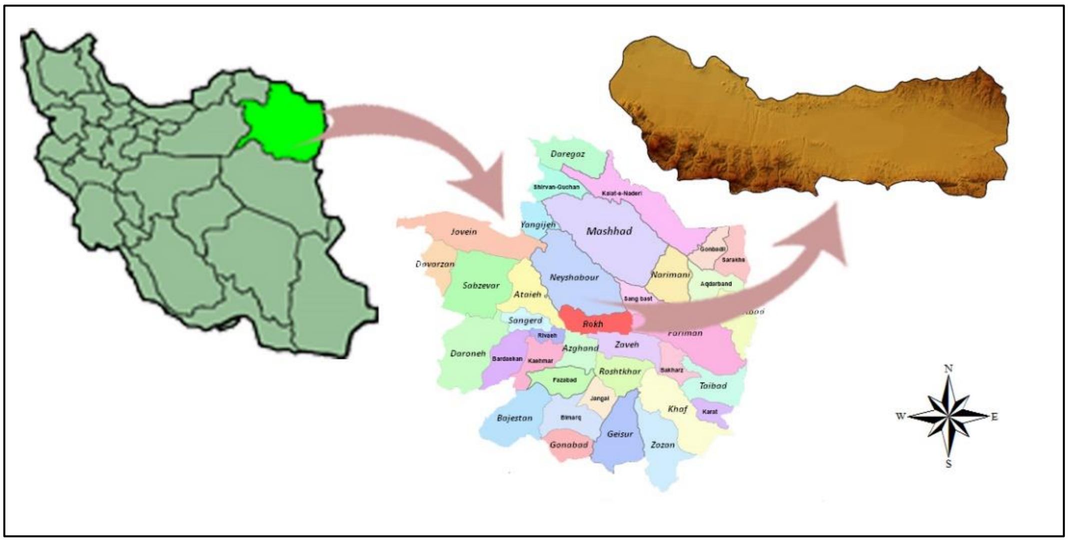


Figure1. the Geographical location of the study area

Soil analysis

Some 300 soil samples in depth of 0-30 cm were collected from current potato fields all over the study area. The values of Cation Exchange Capacity (CEC), Electro Conductivity of soil saturated extract (EC$_e$) and soil pH were determined by Ammonium Acetate method, Electro Conduct-meter and standard pH meter, respectively. The Soil organic carbon was measured using the Walkley Black method (Walkley and Black, 1934). The total N (%) was determined using the electro ultra-filtration (EUF) apparatus with an auto-analyzer, the available P was determined using the blue color method of Murphy and Riley (1962) and the absorbance measured on spectronic-20 equipment. The available K was determined by flame photometer approach and the Mg values were analyzed by spectrophotometer through CFA method. The atomic absorption spectrophotometer (AAS) was used for measuring manganese and iron. The cumulative quantities of the nutrients desorbed after 10, 30 and 35 min were subsequently calculated.

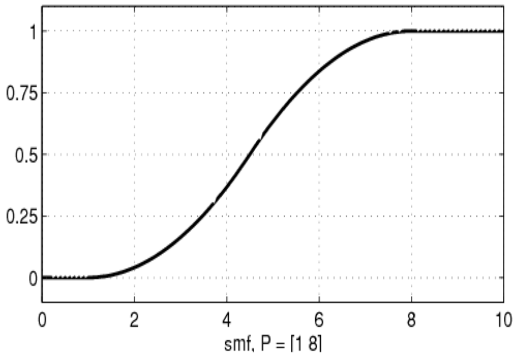
Fuzzy set theory

The fuzzy set theory originated by Zadeh (1965). Fuzzy set theory is a mathematical method used in data and functional relationships to characterize uncertainty and imprecision. To characterize uncertainty using standard statistical measures using a fuzzy set is useful (e.g., Mean, standard deviation, and distribution type). The fuzzy set theory includes fuzzy mathematics, fuzzy measures, fuzzy integrals, etc. One of the aspect of the field of fuzzy mathematics is fuzzy logic. In classical set theory, the membership of a set is defined as true or false, 1 or 0. Membership of a fuzzy set, however, is expressed on a continuous scale from 1 to 0 that $\mu A = 0$ means that the value of x does not belong to A and $\mu A = 1$ means that it belongs completely to A. A fuzzy set A, defined in the total space X, is a function defined in X which assumes values in the range [0, 1]. A fuzzy set (A) may be defined as follows (Burrough et al., 1992):

$$\text{For each } A = \{x, \mu A(x)\}\ x \in X \qquad \text{(Eq. 1)}$$

Where, $X = \{x\}$ is a finite set of points and $\mu A(x)$ is a membership function of x in A.

The membership function describes the variable's membership assigned to A and, therefore, it may quantify the influence of the variable x on the predicted phenomenon, as it is grasped by the developer (Burrough et al., 2015). There are several fuzzy membership function that in the paper was used Linear membership function. The Fuzzy Linear transformation function applies a linear function between the user-specified minimum and maximum values. Any value below the minimum will be assigned as 0 (definitely not a member) and any value above the maximum as 1 (definitely a member) (Sys et al., 1993; Sanchez Moreno, 2007). Fuzzy membership functions have been linear for the majority of soil factors, hence the S-shaped built-in membership function was defined as Equation 1 (Oberthur et al., 2000). This spline-based curve is a mapping on the vector x, and is named because of its S-shape. The parameters a and b locate the extremes of the sloped portion of the curve, as given by: y = smf(x,[a b]) (Figure 2).



$$f(x;a,b)=\begin{cases} 0, & x\le a \\ 2\left(\dfrac{x-a}{b-a}\right)^2, & a\le x\le \dfrac{a+b}{2} \\ 1-2\left(\dfrac{x-b}{b-a}\right)^2, & \dfrac{a+b}{2}\le x\le b \\ 1, & x\ge b \end{cases}$$

Figure 2. The S-Shaped membership function and its equation

The applied function is asymmetrical linear where *a* and *b* are the critical and adequacy value limits used for each of the ten factors (Table 1).

Table 1. Soil fertility factors and the critical values (mangle and adequacy limits) in the fuzzy membership function (the values of *a* and *b* are calculated based on 40 t.ha^{-1} potato production).

Fertility factors	units	*a*	*b*
CEC	meq/100g	7	18
OC	%	0.86	1.29
EC_e	dS m^{-1}	1.7	6
N_{total}	%	0.05	0.2
K	mg kg^{-1}	40	110
pH	-	5.2	8.2
P	mg kg^{-1}	6	15
Mg	mg kg^{-1}	10	20
Mn	mg kg^{-1}	3	6
Fe	mg kg^{-1}	2	4

Analytical Hierarchy process (AHP)

The AHP developed by Saaty (1990) considers a one-level weighting system through a pair wise comparison matrix between the parameters as described by Saaty (1990, 1994) and Saaty and Vargas (2001). The method employs an underlying nine-point recording scale to rate the relative preference on a one-to-one basis of each criteria (Malczewski, 1999). For better map presentation purposes, the scale assigns a linguistic expression to each corresponding numerical value (Table 2).

Table 2. The Saaty scale (2003) was used for generation of pairwise comparison matrix.

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Equally preferred
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong
9	Extreme importance

The weights of factors are calculated from the pair-wise comparison matrix undertaking specific values and vectors calculation. It has been demonstrated that the specific vector corresponding to the largest specific value of the matrix provides the relative priorities of the factors, i.e., if one factor has preference; its specific vector component is larger than that of the other. The components of the specific vector sum to unity. Thus, a vector of weights is obtained, which reflects the relative importance of the various factors from the matrix of paired comparisons. The complete pair-wise comparison matrix contains many multiple paths by which the relative importance of factors can be assessed; therefore, it is also possible to determine the degree of consistency that has been used in developing the judgments. In the construction of the matrix of paired comparisons, the consistency of the judgments should be revealed because this matrix is a consistent matrix. The results of the pair-wise comparison matrix and the factor weights are shown in Table 3.

Table 3. Pair-wise comparison matrix for calculating factor weights

Parameters	CEC	OC	EC_e	N	K	pH	P	Mn	Zn	Fe	Weight
CEC	1.00										0.282
OC	0.33	1.00									0.199
EC_e	0.33	0.50	1.00								0.154
N	0.33	0.33	0.50	1.00							0.122
K	0.20	0.33	0.33	0.33	1.00						0.076
pH	0.20	0.20	0.33	0.33	0.50	1.00					0.063
P	0.20	0.20	0.25	0.33	0.50	0.50	1.00				0.050
Mg	0.13	0.14	0.14	0.17	0.20	0.20	0.25	1.00			0.023
Mn	0.11	0.13	0.13	0.14	0.20	0.20	0.25	0.50	1.00		0.018
Fe	0.11	0.13	0.13	0.13	0.17	0.17	0.20	0.33	0.50	1.00	0.014

In AHP method, an index of consistency, known as the consistency ratio (CR), is a ratio between the matrix's consistency index and random index. CR is used to indicate the probability that the matrix judgments were randomly generated (Malczewski, 1999).

$$CR = \frac{CI}{RI} \qquad \text{(Eq. 2)}$$

where RI is the average of the resulting consistency index depending on the order of the matrix given by Malczewski (1999) and CI is the consistency index and can be expressed as

$$CI = \frac{\lambda \max - n}{n-1} \qquad \text{(Eq. 3)}$$

Where, λmax is the largest or principal specific value of the matrix and can be easily calculated from the matrix, and n is the order of the matrix. CR ranges from 0 to 1. A CR close to 1 indicates the probability that the matrix's rating was randomly generated. A CR of 0.10 or less is a reasonable level of consistency (Malczewski, 1999). A CR above 0.1 requires revision of the judgments in the matrix. The calculated value of Cr in our study was 0.056. Once a satisfactory CR is obtained, the resultant weights are applied. The weights should add up to a sum of 1.0, as the linear weighted combination calculation requires. It was shown that the most important factor affecting soil fertility was cation exchange capacity (CEC) with the weight of 0.282 and the least important factor was defined as Iron with the weight of 0.014. Finally, in order to finalize soil fertility map the values obtained by AHP with the fuzzy values of each affecting parameters. In this procedure the values obtained by fuzzification of each parameter is multiplied in the factor weight of that parameter and the summations of the resultant values is used to produce the final soil fertility map as shown in the following equation (Kremenová, 2004):

$$\mu_A = w_i \mu_{A1} + \cdots + w_k \mu_{A1}$$

$$\mu_A = \sum_{j=1}^{k} w_j \, \mu_{Aj(\mathrm{x})} \qquad \mathrm{x} \in \mathrm{X} \qquad \text{(Eq. 4)}$$

$$\sum_{j=1}^{k} W_j = 1 \qquad \mathrm{W_j} > 0$$

Where; μ is the membership function related to each of the parameters and W is the specific weight given to each of the parameters. The analytical procedures in this study including interpolation, fuzzy mapping and final soil fertility map calculations have been done using Arc map (Version 10.5) software. The flowchart of the fuzzy AHP procedure used for soil fertility zonation in our study has been shown in Figure 3.

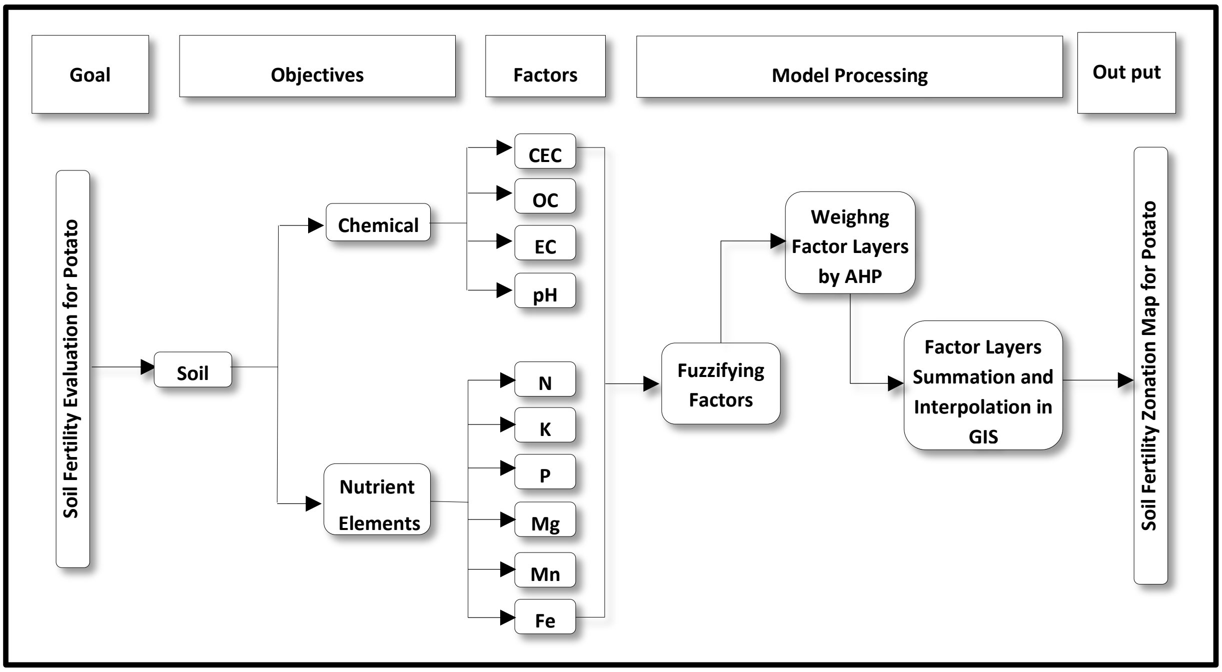


Figure 3. Schematic diagram of the Fuzzy-AHP Model for preparing soil fertility zonation

Results

Spatial distribution of factors affecting soil fertility

Soil chemical parameters including cation exchange capacity (CEC), organic carbon (OC), soil salinity (EC_e), pH and six nutrient elements including total Nitrogen (N), Potassium (K), Phosphorous (P), Magnesium (Mg), Manganese (Mn) and Iron (Fe) were analyzed and their spatial distribution in the upper 30 cm of the soil was mapped (Figure 4, 5).

The zonation of soil chemical parameters in the study area

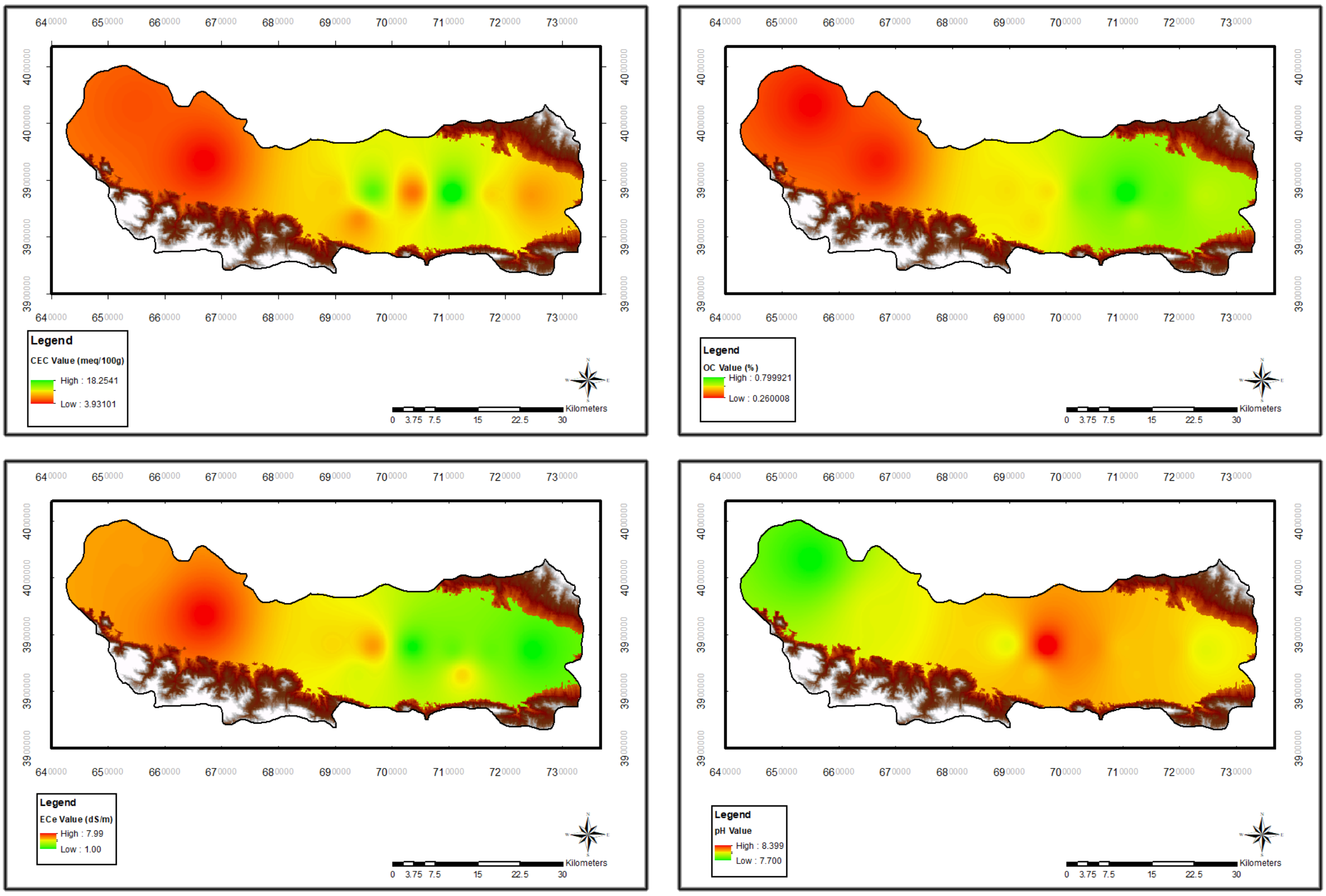


Figure 4. The zonation of soil chemical parameters in the study area

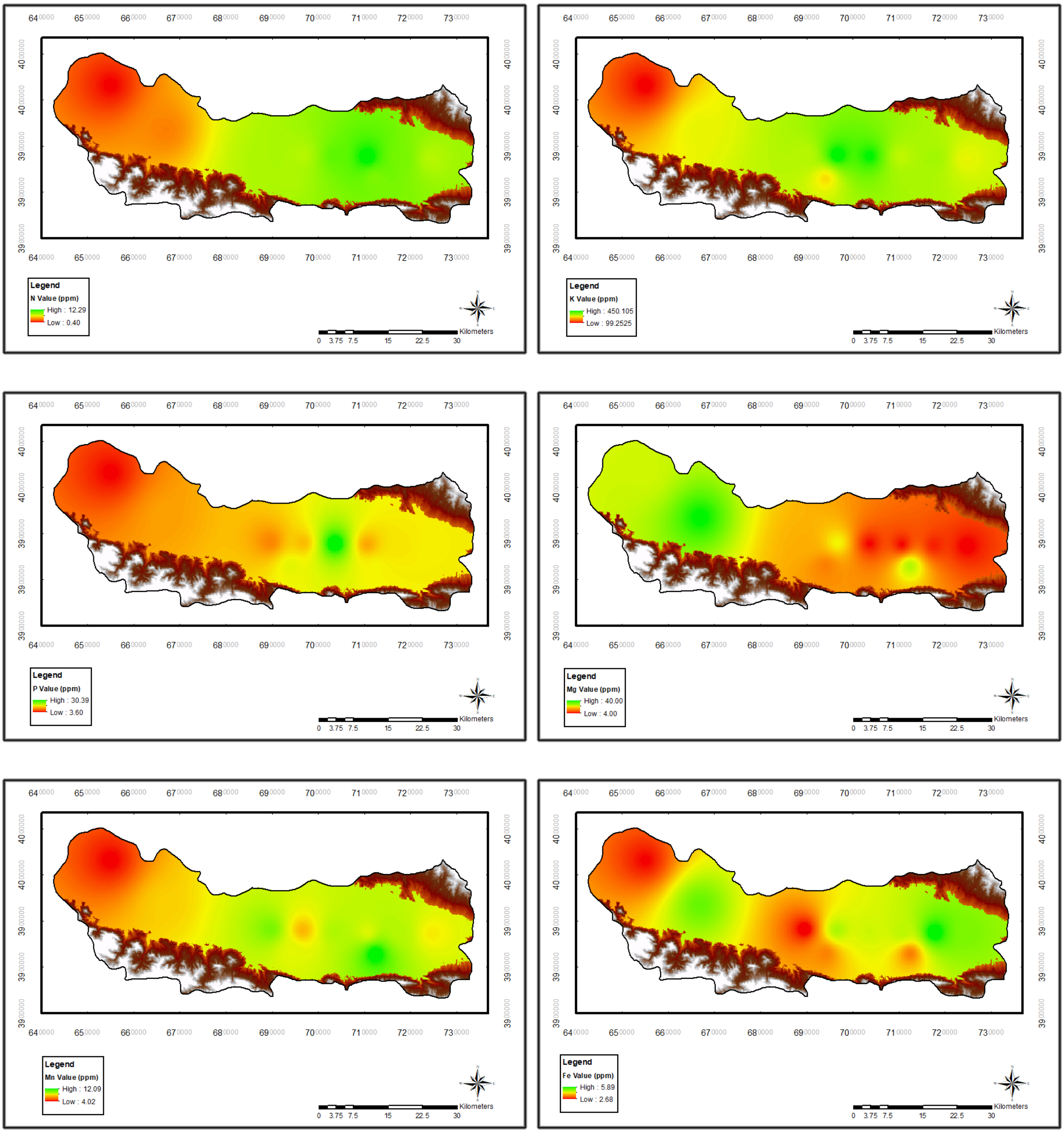


Figure 5. The zonation of soil nutrient elements in the study area

The main physiological functions of the selected nutrient elements in potato have been shown in Table 4. The values of cation exchange capacity in the study area varied between 6.23 and 13.8 meq/100g. The higher values of CEC were found mainly in west, while in east parts of the study area due to lower values of soil organic carbon and light texture of the soil the values of CEC were found as very low. The values of organic carbon in the study area ranged from 0.26 to 0.80%. The spatial distribution of soil organic carbon was followed the same pattern as CEC. The upper values of OC were observed in north and west, while the lower values were found mainly in the middle and south parts of the study area. The EC_e values ranged from 1 dS m^{-1} in some areas in the west to 8 ds m^{-1} in the north of the study area. It was revealed that the values of EC_e in west of the study area were in tolerance threshold for potato production; however to compensate the negative effects of high soil salinity and alkalinity on potato production a distinct amount of granulated sulfur were applied to soil before planting. The values of pH varied between 7.7 in west to 8.4 mainly in the middle of the study area. Potato grows best on slightly to moderately acid soils although it grows successfully in soils with a wide pH range, but in base soil reaction of our study area its negative effects on the availability of phosphorous and micronutrients such as manganese and iron cannot be ignored. It was revealed that the values of mineral nitrogen at the study area were very low, ranged from 0.4 to 12.3 mg.kg^{-1}. The upper values of total N (%) were found in east and the lower values were distributed mainly in west of the study area. The values of available phosphorous in the study area ranged from 3.6 to 25.2 mg.kg^{-1}. The lower values of available P were observed in the west and the higher values were found mainly in east parts of the study area. The values of available potassium varied between 99.24 and 450.15 mg.kg^{-1}. The lower values of available K were found in the west and the higher values were observed in the middle and east of the plain. The values of magnesium varied between 4.0 and 28.0 mg.kg^{-1}. The lower values of Mg were observed in the east and the higher values were found in west of the study area. The values of manganese ranged from 4.02 to 12.10 mg.kg^{-1}. The upper values of Mn were observed in the middle and east, while the lower values were found in west of the study area. The values of Iron ranged from 2.68 to 5.90 mg.kg^{-1}. The lower values of Fe were found in west and some parts in the middle of the plain and the upper values were observed mainly in east of the study area.

Table 4. The main functions of nutrients elements in Potato

Nutrient	Function
Nitrogen (N)	Synthesis of proteins (growth and yield).
Phosphorus (P)	Cellular division and formation of energetic structures.
Potassium (K)	Transport of sugars, stomata control, cofactor of many enzymes, reduces susceptibility to plant diseases.
Magnesium (Mg)	Central part of chlorophyll molecule.
Manganese (Mn)	Necessary in the photosynthesis process.
Iron (Fe)	Chlorophyll synthesis.

Soil fertility index zonation

The soil fertility factors including chemical and nutrient elements were fuzzified by S-shaped membership function (Figure 2). To determine the degree of membership for each factor the critical and adequacy values *a* and *b* were defined based on 40 t.ha^{-1} potato production. The pairwise comparison matrix was used by AHP approach to give the appropriate weight to each factor layer (Table 3). To determine the final soil fertility zonation for potato production the summation operator was used in GIS to combine the weighted layers in a final soil fertility map (Figure 6). The values of soil fertility index in the scale of 0 to 1 ranged from 0.104 to 0.574 which classified as very low to moderate fertility (Table 5). Based on our results the soil fertility classes were categorized in very low (922.90 km^2), low (566.10 km^2) and moderate fertility (14.86 km^2) which comprises 61.37%, 37.64% and 0.99% of the surface area, respectively. A linear regression between soil fertility values and the potato yield at each point study revealed a high correlation ($R^2=0.91$) between the observed results which verify the zonation of the fertility classes in the region.

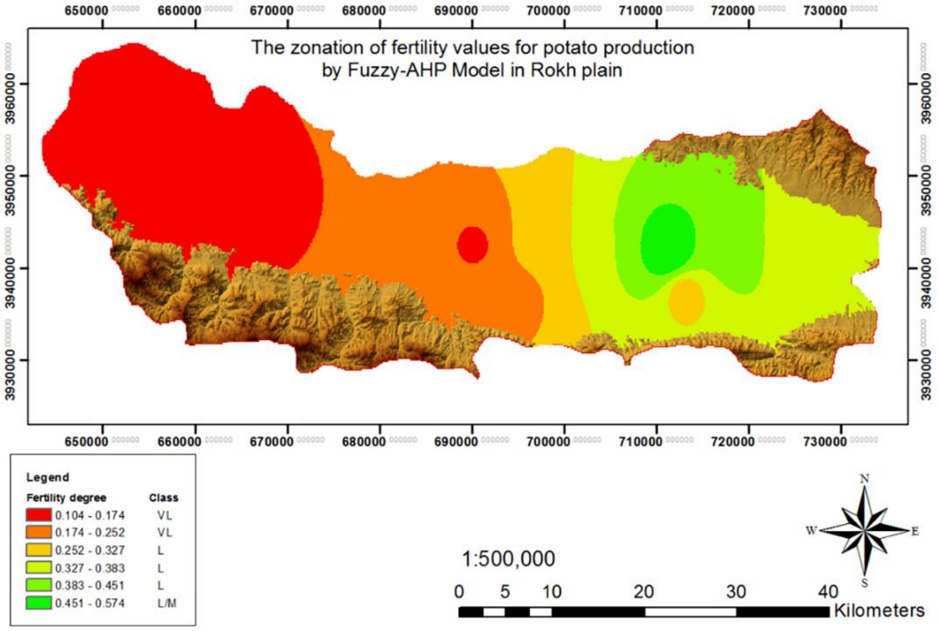


Figure 6. The zonation of soil fertility values for Potato production by Fuzzy-AHP approach in Rokh plain

Table 5. The values of soil fertility and the corresponding fertility classes

Fertility Value	Fertility Class
0.00 – 0.25	Very Low (VL)
0.25 – 0.50	Low (L)
0.50 – 0.75	Moderate (M)
0.75 – 0.90	High (H)
0.90 – 1.00	Very High (VH)

Discussion

To determine the soil fertility index and preparing a soil fertility zonation map for potato cultivation in Rokh plain, northeast of Iran, we applied an integrated Fuzzy and AHP approach. On this basis the most important soil chemical parameters and nutrient elements in 0-30 cm depth of the soil were analyzed and mapped. For fuzzifying each soil fertility parameter, a S-shaped fuzzy membership function was defined. The soil fertility map was prepared by weighing factor layers by the AHP approach and summation them by IDW interpolation function in ArcGIS. The values of the soil fertility index in the scale of 0 to 1 ranged from 0.104 to 0.574, which classified the study area in very low (922.90 km^2), low (566.10 km^2) and moderate fertility (14.86 km^2) classes which comprises 61.37%, 37.64% and 0.99% of the surface area, respectively. The spatial distribution of classes shows two areas in northwest and southeast as very low fertility zones, while great parts in north to east and some areas in west was demonstrated as low fertility zones for potato production. The poor values of soil fertility in the study area contributed mainly to very low amounts of soil organic carbon and mineral nitrogen which reduces potato yield to 35 t.ha^{-1} in the study area. Hence, to provide a desirable production of beet the consumption of nitrogen fertilizers as well as organic manures is inevitable. The results of the proposed model agreed with current conditions of potato production in the study area. The zonation of soil fertility for Potato production by integrating Fuzzy and AHP approach in the study area could be helpful in the potato production management decisions. It is proposed that exact fertilization program have to be done according to the specific crop needs, soil and water conditions and the farmers experiences. Our results revealed that the disaggregation of soil fertility variables allows direct evaluation of the contribution that individual components of soil fertility can make to potato yield. Worldwide, many studies have considered the impacts of environmental hazards such as climate change on future agricultural land use through scenario modelling and their consequent policy impacts (e.g. Ewert et al., 2005), but there is limited literature on the impacts of soil fertility rate on the crop production, a key factor influencing a region's ability to adapt agricultural practices to real conditions. But such analyses can play a critical role in formulating future land policies given the multi-functional role of agriculture and its importance for ecosystem services (Winter, 2009). The present study emphasized the importance of developing regional agricultural policy approaches that allow the transfer of indigenous knowledge to farmers, where they do not carry out routine soil nutrients analyses for potato production.

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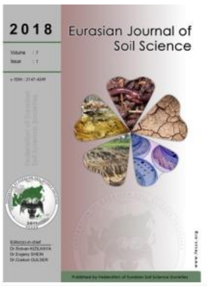

Applications of geographic information systems in studying changes in groundwater quality and soil salinity in Sohag Governorate

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Abstract

Sohag governorate is a narrow long strip of a cultivated valley located in upper Egypt. Groundwater and soil samples were collected along the Nile river, starting form the southern border to the northern border of Sohag governorate to assess the groundwater quality and soil salinity between 1991 and 2006. The obtained data reveal that the electrical conductivity of well waters (EC_w) was classified to four classes (250-750, 750-2250, 2250-5000 and greater than 5000 μS/cm). The results showed an increase in the groundwater salinity within 15 years, especially in the first class where it increased from 9% in 1991 to 14% in 2006 but it raised from 17% in 1991 to 37% in 2006 for the third class. The surface and subsurface soil layers showed an increase trend in the soil salinity from 1991 to 2006. The soil salinity increased with depth from 1991 to 2006. The groundwater pH values changed due to the changes in their salt content from 1991 to 2006. The pH values of the surface and subsurface soil samples also changed from 1991 to 2006 that may be due to the changes in salt content of well waters. Cations and anions of the groundwater increased from 1991 to 2006. The groundwater SAR decreased for the first class (0-10) from 89 % in 1991 to 83 % in 2006 but increased for the second class (>10) from 11% in 1991 to 17% in 2006. The groundwater RSC for the first and third classes changed from 91 and 3 %, respectively, in 1991 to 83 and 11%, respectively, in 2006. The increase in the high class of RSC may limit the use of these waters in irrigation. Thus, the irrigation with such water might affect the permeability of soil and cause infiltration problems.

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Introduction

Egypt lies in the arid region. Most of agricultural expansion areas are sandy soils which have poor physical and chemical properties, especially low water retention. One of the ways to overcome the increase of population in Egypt is to cultivate these soils. The expansion in the new areas needs more enough water to irrigate these soils. Saline soils are mostly located in arid and semi-arid regions. One of the conditions for the presence or formation of saline soils is the high evaporation, which greatly exceeds the precipitation. Soil salinity caused by natural or human-induced processes is a major environmental hazard. Crop growth reduction due to soil salinity is generally related to the soil solution osmotic potential of the root zone. As the soil salinity level increases, the plant must spend more energy to take up water from the same soil water content (Al-Khaier 2003; Bakeer 2008; Sayed, 2013). Salinization is of a great danger for arid and semi-arid irrigated agriculture. Without taking care, the salinity will have a negative impact on soil productivity and crop yields and lead to ecological degradation of land and water resources (Hillel, 2000).

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Groundwater is considered the second major source of irrigation water in upper Egypt after the Nile water. The newly cultivated desert areas depend mainly up on the groundwater for irrigation. The groundwater in some cases has a poor quality and contains enough salts to significantly alter the physical and chemical properties of soils and even to make growing crops rather difficult.

Use of poor-quality groundwater has become inevitable for irrigation to compensate the rapid increase of water demands in many arid and semiarid regions. Salinity and sodicity are the principal soil and water quality concerns in such areas. Many saline–sodic and sodic soils have saline or saline–sodic subsurface drainage waters (Qadir et. al., 2001)

Monitoring the groundwater quality, soil salinity and the efficiency of remedial efforts is very much needed in upper Egypt. Geographic information system (GIS), as a new technique, is widely used nowadays as a rapid method for delineating soil boundaries and characterization of soil units. GIS is used an important tool in monitoring and mapping of water quality and land evaluation (Yunus et al., 2003; Bakeer, 2008; Albaji et al., 2010 Ismail and Yacoub, 2012). The combination between remote sensing and GIS creates possible monitoring the soil salinity and waterlogging (Ghabour and Daels, 1993).

This study aims to evaluate the changes in the groundwater quality and soil salinity of Sohag governorate between 1991 and 2006, to help building the future strategic plans of agriculture in upper Egypt. GIS is used an important tool in monitoring and mapping these concerns.

Material and Methods

Sohag governorate lies in Upper Egypt. It is a narrow long strip of a cultivated valley and the total maximum length is about 96 Km, with a maximum width of about 25 km. It is located between 26°, 10', & 26º, 50' N and 31º, 15' & 32º, 50' E and consists of 11 counties. Groundwater and soil surface and subsurface samples were collected from transects along the Nile river, starting form the southern border to the northern border of Sohag governorate, covering a distance of about 96 km to identify the changes in the groundwater quality and soil salinity between 1991 (the results reported by Ghallab, 1995) and 2006 (the results of this study). It is very important to reassess the groundwater and surrounding soils quality after 15 years. One water sample was taken from each well water and two soil samples were collected from the surface (0-25cm) and the subsurface layers (25-50 cm) from the area that the well covered. Groundwater and soil samples were collected from 35 locations in this governorate (Figure 1). Table 1 shows the particle size distribution of these soils. The collected groundwater and soil samples were analyzed for the major constituents using the standard methods of Jackson (1967, 1969), McLean (1982), Nelson (1982), Rhoades (1982), and Page et. al. (1986). This study is exploiting GIS for monitoring and mapping groundwater and salinity soils of Sohag governorate using Arcview, 9.1. The percentage of each class of soil or groundwater property in each figure was calculated based on the total number of groundwater or soil samples and was present in the key of each figure.

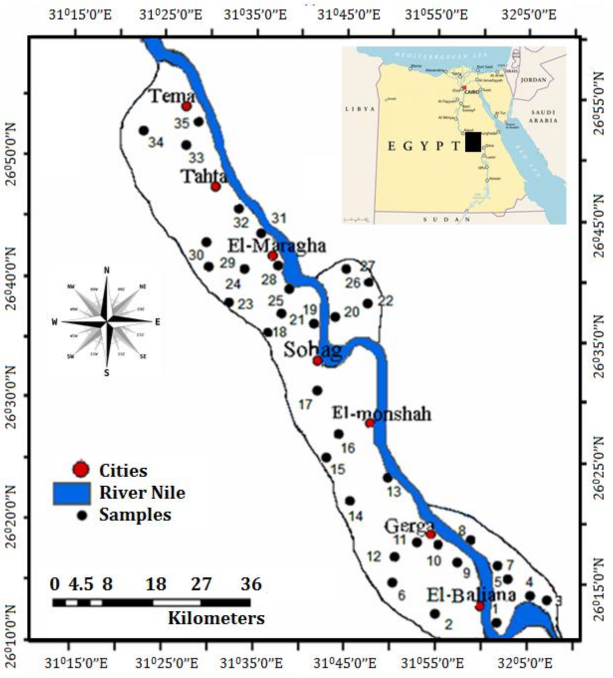

Figure 1. Locations of the colleted groundwater and soil samples.

Table 1. Particle size distribution of the studied soils in the areas irrigated by groundwater

No	Location	Surface (0 - 25 cm)				Subsurface (25- 50 cm)			
		Sand, %	Silt, %	Clay, %	Class	Sand, %	Silt, %	Clay, %	Class
1	El -Balabesh Gobly	55.088	24.386	20.526	SCL	55.088	24.386	20.526	SCL
2	El-Ghabat	76.140	17.018	6.842	SL	73.333	18.456	8.211	SL
3	Awlad Salam Bahre	55.088	35.333	9.579	SL	49.818	39.235	10.947	L
4	Naknk	60.702	37.930	1.368	SL	64.913	30.982	4.105	SL
5	Gazert Naknk	74.737	21.158	4.105	SL	71.930	17.123	10.947	SL
6	Beat Alam	77.544	18.351	4.105	LS	76.736	15.053	8.211	SL
7	El-Nosirat	51.877	40.912	7.211	SL	53.685	35.368	10.947	SL
8	Nego Mazen Shark	39.649	48.035	12.316	L	50.877	36.807	12.316	L
9	Gazert Bardes	53.684	39.474	6.842	SL	56.491	33.930	9.579	SL
10	Gazert Bardes	46.667	39.649	13.684	L	48.070	35.509	16.421	L
11	Gerga	31.228	41.404	27.368	L	35.438	33.088	31.474	CL
12	El-Rakakna	48.877	31.965	19.158	L	52.281	27.193	20.526	SCL
13	Awlad Hamza	51.158	42.737	24.632	L	24.210	32.631	24.632	SiL
14	Awlad Salama	60.386	20.772	18.842	SL	53.684	21.684	24.632	SCL
15	El-Zara	42.053	32.947	25.000	L	46.667	30.070	23.263	L
16	Awlad Harwon	45.263	41.053	13.684	L	34.035	46.807	19.158	L
17	Rwafe Eyswaia	59.298	32.491	8.211	SL	48.666	36.702	14.632	L
18	Awlad Azaz	86.717	8.860	4.423	LS	85.860	8.719	5.421	LS
19	Kelfao	57.895	29.789	12.316	SL	52.281	31.298	16.421	SL
20	Arab El Atawla	57.895	21.579	20.526	SCL	59.299	29.754	10.947	SL
21	Gezert Shandawil	43.860	32.877	23.263	L	55.087	20.281	24.632	SCL
22	Bahta	43.859	34.246	21.895	L	55.088	21.649	23.263	SCL
23	El-Ghrizat	56.491	33.930	9.579	SL	52.281	31.298	16.421	SL
24	El-Ghrizat	85.965	10.298	3.737	LS	84.562	8.596	6.842	LS
25	Tunise	55.088	28.491	16.421	SL	56.491	21.614	21.895	SCL
26	Neida	83.158	11.368	5.474	LS	83.158	12.737	4.105	LS
27	Gehina El Sarkia	55.087	36.702	8.211	SL	56.491	31.193	12.316	SL
28	El-Swamia Shark	50.877	43.649	5.474	SL	55.087	23.018	21.895	SCL
29	Neg Hermas	78.948	19.684	1.368	LS	76.141	19.754	4.105	SL
30	El-Sheik Shibl	49.473	38.211	12.316	L	39.649	39.825	20.526	L
31	Nazlt Aly	85.965	12.667	1.368	S	88.772	8.491	2.737	S
32	El-Swamea Gharb	57.894	36.632	5.474	SL	71.930	21.228	6.842	SL
33	Nazlt Imara	46.088	8.526	4.105	LS	81.754	10.035	8.211	LS
34	Bin Harb	57.895	35.263	6.842	SL	59.298	31.123	9.579	SL
35	Um Dona	57.299	33.754	8.947	SL	56.895	30.947	12.158	SL

SL: Sandy loam, LS: Loamy sand, CL: Clay loam, SCL: Sandy clay loam SL: Silty Loam, L: Loamy

Results and Discussion

Studying the changes in the groundwater quality and soil salinity due to the use of this water in irrigation between 1991 (Ghallab, 1995) and 2006 (this study) is very important to reassess the groundwater and surrounding soil quality after 15 years. This comparative study will include the changes in most groundwater properties as well as soil salinity and soil pH.

Groundwater

- Salinity (EC_w)

The results of the groundwater salinity, expressed as electrical conductivity values (EC_w) are present in Table 2. Figure 2 shows the changes in the groundwater Salinity (EC_w) in Sohag governorate between 1995 and 2006. The groundwater salinity was classified to four classes (< 750, 750-2250, 2250-5000 and > 5000 µS/cm) according to the American soil salinity lab (Richards, 1954). The maps of the groundwater salinity in 1991 and 2006 show increase in the EC_w. The first class of groundwater salinity (< 750 µS cm^{-1}) increased from 9% in 1991 to 14% in 2006. However, the second class (750-2250 µS cm^{-1}) decreased from 71% in 1991 to 46% in 2006. The 25% difference of this groundwater salinity class went to the upper salinity class. Therefore, the third class of groundwater salinity (2250-5000 µS cm^{-1}) increased from 17% in 1991 to 37% in 2006. Moreover, the last groundwater salinity class (>5000 µS cm^{-1}) has the same level as in 1991. These results ensure increases in the groundwater salinity within these 15 years. . These results agree with those obtained by Bakeer (2008).

Table **2**. Analysis of the groundwater samples of the areas understudy between 1991 and 2006

No	**Location**	**EC_w , µS cm^{-1}**		**pH_w**		**SAR**		**RSC**	
		1991	**2006**	**1991**	**2006**	**1991**	**2006**	**1991**	**2006**
1	El -Balabesh Gobly	0.84	2.84	8.44	8.22	2.08	8.45	0.84	0.00
2	El-Ghabat	1.04	1.30	7.53	8.11	2.13	0.98	0.00	0.00
3	Awlad Salam Bahre	1.33	1.20	7.85	8.54	2.88	3.27	0.00	0.20
4	Naknk	0.94	1.23	8.05	7.93	1.15	3.55	0.00	0.00
5	Gazert Naknk	0.79	1.19	8.24	7.38	0.96	1.16	0.00	0.00
6	Beat Alam	7.04	8.02	7.84	8.40	13.31	13.97	0.00	0.00
7	El-Nosirat	0.94	1.13	8.10	7.92	3.31	3.12	1.92	0.00
8	Nego Mazen Shark	3.37	4.04	8.39	8.59	17.28	18.52	2.94	0.00
9	Gazert Bardes	0.90	1.55	7.92	8.42	1.43	0.77	0.00	0.20
10	Gazert Bardes	1.02	1.58	8.06	8.50	1.72	1.00	0.00	1.00
11	Gerga	1.14	0.70	8.31	8.24	2.85	3.35	0.71	3.97
12	El-Rakakna	1.97	3.20	7.93	8.42	5.39	5.84	0.00	0.00
13	Awlad Hamza	1.49	0.89	8.22	8.76	7.32	7.45	2.28	5.83
14	Awlad Salama	0.68	1.01	7.97	8.83	2.43	1.07	0.00	0.00
15	El-Zara	1.11	0.97	8..47	8.49	2.37	3.77	0.00	0.03
16	Awlad Harwon	2.05	2.94	7.45	8.08	6.51	8.54	0.00	0.00
17	Rwafe Eyswaia	0.89	0.60	8.46	8.34	1.29	1.60	0.77	2.30
18	Awlad Azaz	1.87	0.92	7.88	8.27	5.48	5.17	0.00	4.03
19	Kelfao	0.91	0.62	7.99	8.56	2.08	3.83	0.43	0.97
20	Arab El Atawla	0.84	0.57	8.17	8.23	1.01	0.91	0.00	0.03
21	Gezert Shandawil	1.09	0.95	7.81	8.06	1.49	1.65	0.00	0.23
22	Bahta	1.28	3.19	7.83	8.25	1.53	7.91	0.00	0.10
23	El-Ghrizat	3.16	3.24	7.87	7.96	8.74	13.38	0.00	0.00
24	El-Ghrizat	4.91	4.41	7.97	8.16	10.82	14.32	0.00	0.00
25	Tunise	1.04	0.91	8.34	7.96	2.70	7.90	0.91	5.30
26	Neida	0.94	0.73	8.05	7.48	1.33	1.48	0.00	2.50
27	Gehina El Sarkia	1.18	1.19	7.82	8.63	2.12	0.45	0.00	0.00
28	El-Swamia Shark	2.58	3.20	7.71	8.28	6.31	14.48	0.00	0.00
29	Neg Hermas	3.47	4.12	7.66	8.29	9.63	6.05	0.00	0.00
30	El-Sheik Shibl	2.01	2.50	8.05	8.02	5.69	4.80	0.00	0.00
31	Nazlt Aly	1.77	4.20	8.37	7.85	12.68	3.46	0.15	0.00
32	El-Swamea Gharb	0.73	0.98	8.36	8.10	1.63	0.43	0.02	0.00
33	Nazlt Imara	3.18	4.30	7.27	8.17	7.25	13.12	0.00	0.00
34	Bin Harb	0.87	1.30	8.25	8.36	2.25	1.76	0.00	0.20
35	Um Dona	0.70	2.72	8.08	7.98	1.09	2.57	0.00	0.00

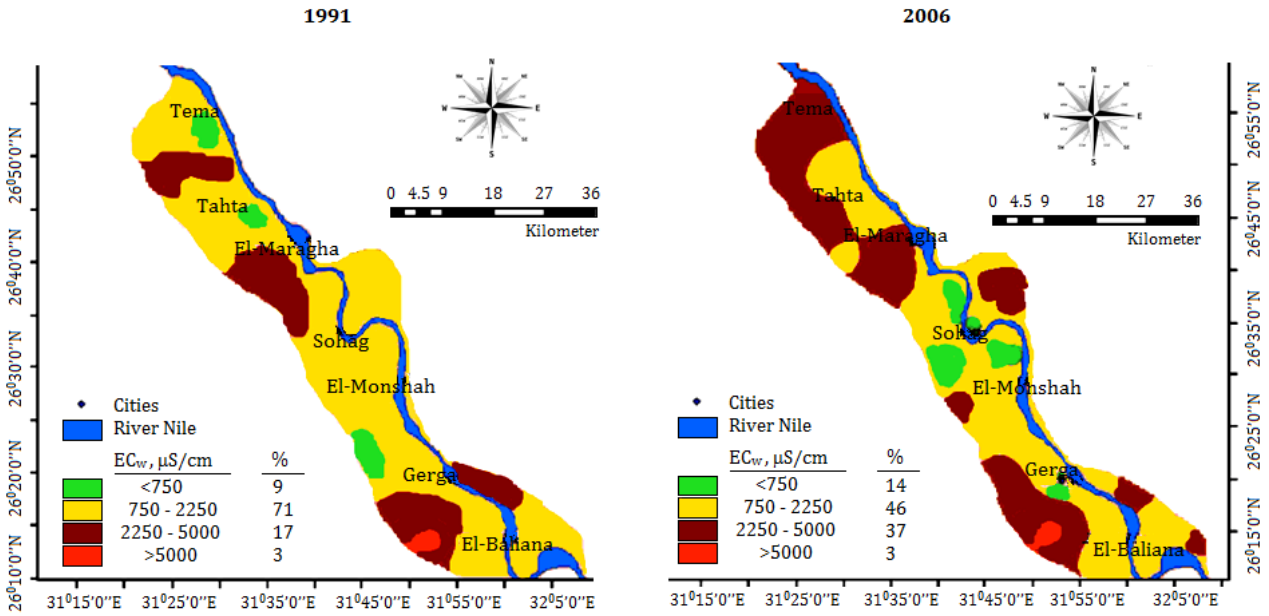

Figure 2. The changes in the electrical conductivity (EC_w) of the groundwater between 1991and 2006.

- pH$_w$

The data in Table 2 and pH$_w$ map of the groundwater (Figure 3) reveal that groundwater pH has three classes, namely, less than 7.5, 7.5-8.0, and greater than 8.0. The pH of the first groundwater class has the same level (6%) as in 1991 but the pH of the second class (7.5-8.0) decreased from 43% in 1991 to 17 % in 2006. Also, the third class pH (>8.0) increased from 51% in 1991 to 77 % in 2006. These changes in the pH classes may be attributed to the changes in the groundwater salt content which is negatively correlated to the pH (El-Dardiry, 2007).

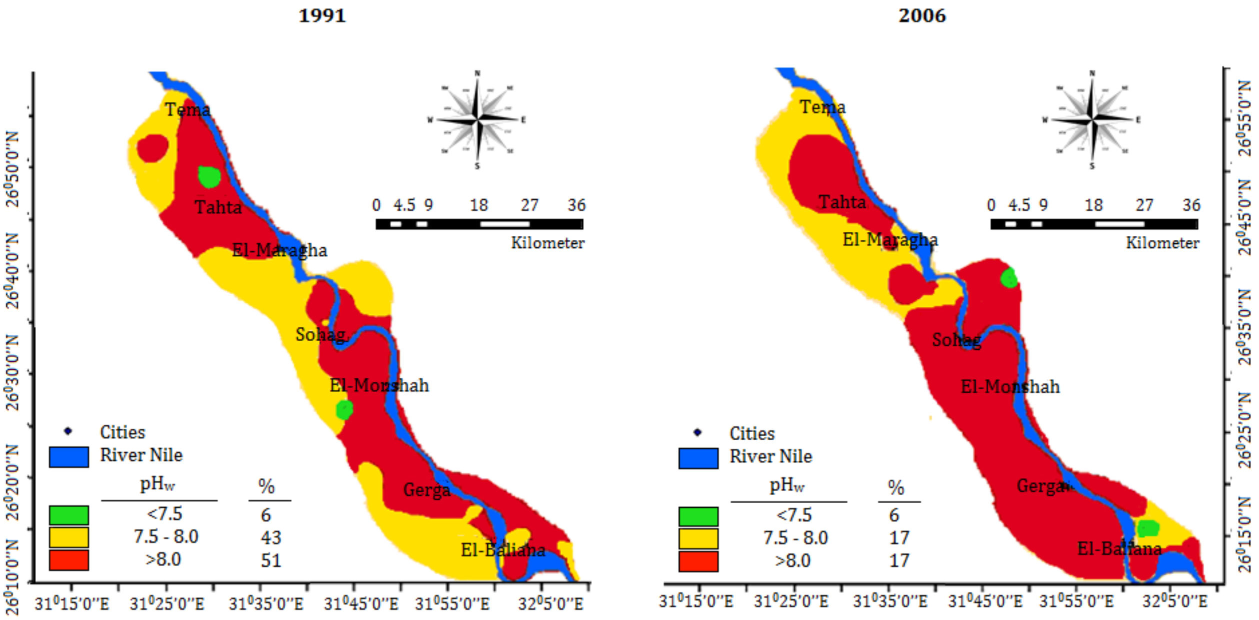

Figure 3. The changes in the groundwater pH between 1991 and 2006.

- Sodium Adsorption Ratio (SAR$_w$)

Groundwater SAR of the studied area were classified into two classes namely, 0 to10 and > 10 (Table 2 and Figure 4). The groundwater SAR of the first class (0-10) decreased from 89 % in 1991 to 83 % in 2006 but it's the second class (> 10) increased from 11% in 1991 to 17% in 2006 (Labeeb, 2002).

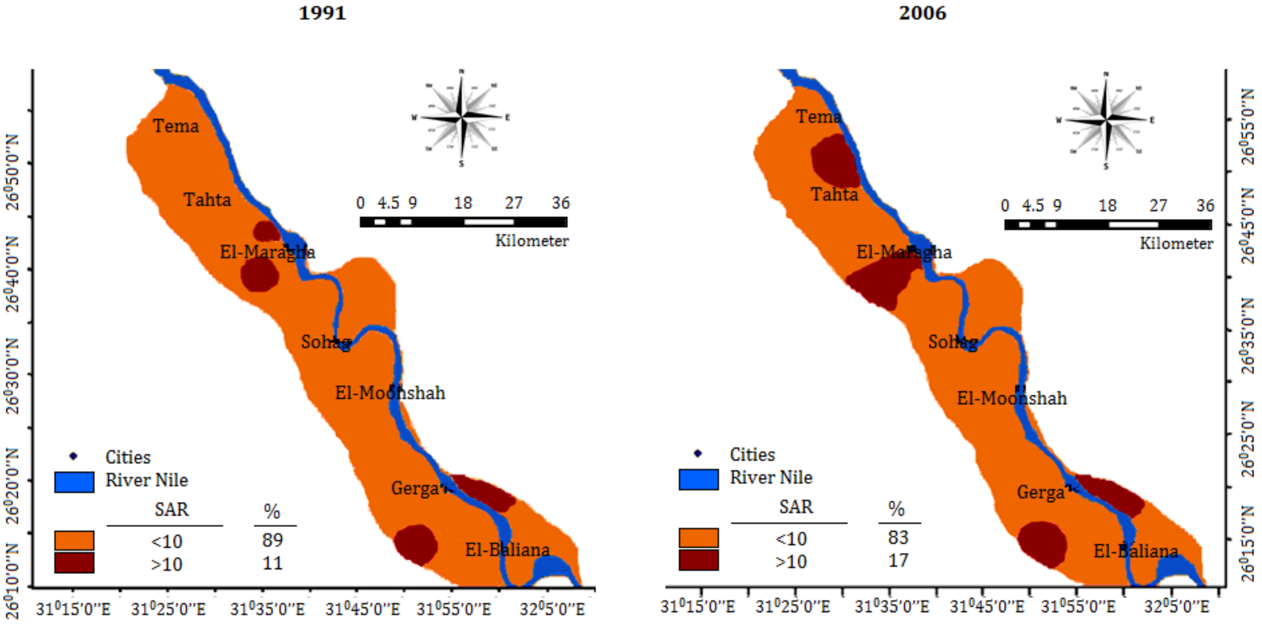

Figure 4. The changes in the sodium adsorption ratio (SAR) of the groundwater between 1991 and 2006.

- Residual Sodium Carbonate (RSC$_w$)

RSC of groundwater samples were classified into three classes, namely, less than 1.25, 1.25 to 2.50, and greater than 2.50 meq/l (Table 2 and Figure 5). The maps showed that the first and third classes of RSC$_w$ changed from 91 and 3 %, respectively, in 1991 to 83 and 11%, respectively, in 2006. The second class (1.25

-2.5 meq/l) showed the same level of 6 %in 1991 and 2006. The increase in the high groundwater class of RSC may limit the use of this water in irrigation. If the RSC is greater than 2.5 meq/l, the water will not be appropriate for irrigation. High sodium ions in water affect the permeability of soil and cause infiltration problems. This is because the exchangeable sodium on soil clays can replace the adsorbed calcium and magnesium on these clays and cause the dispersion of soil particles. The increase in the RSC of irrigation water is attributed to the increases in salinity (EC_e) and SAR of the soil.

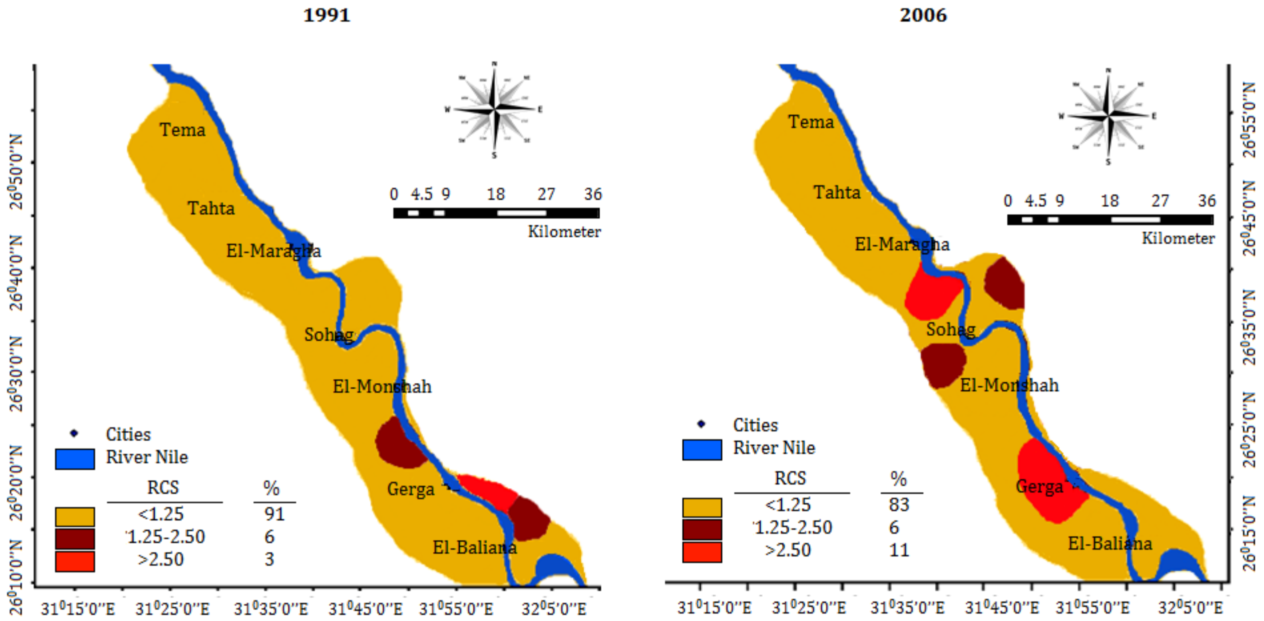

Figure 5. The changes in the residual sodium carbonate (RSC) of the groundwater between 1991 and 2006.

- Soluble Cation Changes

Table 3 reveals that the major ions in groundwater samples are sodium, calcium and magnesium. The mean value of the sodium in the groundwater increased from 8.18 meq/l in 1991 to 11.95 meq/l in 2006. The increase in sodium concentration matches the changes in the EC_w. The mean calcium ions in the groundwater increased from 1.57 meq/l in 1991 to 4.65 in 2006. The mean groundwater magnesium also increased from 4.41 meq/l in 1991 to 4.74 meq/l in 2006.

- Soluble Anion Changes

Chloride, sulfate, carbonate and bicarbonate ions are the main anions in groundwater (Table 3). The average groundwater chloride generally increased from 6.59 meq/l in 1991 to 7.23 meq/l in 2006. The increase in the groundwater chloride was consistent with that of the EC_w and Na. The mean sulphate ions in the groundwater were doubled from 3.94 meq/l in 1991 to 7.07 meq/l in 2006. However, average concentrations of $CO_3^=$ + HCO_3^- ions in the groundwater increased from 3.69 meq/l in 1991 to 6.12 meq/l in 2006.

Soils

- Soil Salinity

Various analyses in Table 4 indicate that the soil salinity increased from 1991 to 2006. The salinity maps of surface and subsurface soils (Figures 6 and 7, respectively) show an increase trend in the soil salinity from 1991 to 2006. The salinity class of < 0.05% for the surface soils increased from 69 % in 1991 to 77 % in 2006. However, the salinity class of 0.05-0.10 % salts approximately appears to have the same level (17 %) in 1991 and 2006. Also, the class of 0.10- 0.15% salts decreased from 11% in 1991 to 3% in 2006. The worse soil salinity class of > 0.15% has been the same percentage (3 %) in 1991 and 2006. The results reveal that the salinity of the surface soils decreased from 1991 to 2006 in some classes. This may indicate that the salts were leached from surface layer to subsurface one. The percentage of the 0.05-0.10% salinity class of subsurface layers decreased from 37 % in 1991 to 28 % in 2006. Also, the class containing 0.10 -0.15% salts decreased from 23 % in 1991 to 15 % in 2006. However, the class of 0.15 -0.20 % salts increased from 11 % in 1991 to 14 % in 2006. The worse soil salinity class of > 0.20 salts ascended from 29 % in 1991 to 43 % in 2006. These results reveal that the soil salinity increased with depth from 1991 to 2006. This may be due to the leaching processes.

Table 3. Some chemical properties of the groundwater of the studied areas between 1991 and 2006

No	Location	Na^+		Ca^{2+}		Mg^{2+}		Cl^-		SO_4^{2-}		$CO_3^{2-} + HCO_3^-$	
		(meq/l)											
		1991	**2006**	**1991**	**2006**	**1991**	**2006**	**1991**	**2006**	**1991**	**2006**	**1991**	**2006**
1	El -Balabesh Gobly	2.83	28.14	0.82	8.00	2.88	14.20	1.79	22.00	2.08	8.36	4.54	4.20
2	El-Ghabat	3.36	2.00	1.03	4.20	3.91	4.20	3.58	5.00	3.02	4.77	3.31	6.80
3	Awlad Salam Bahre	4.34	5.26	0.82	3.60	3.71	1.60	3.23	2.00	6.25	4.21	4.27	5.40
4	Naknk	1.85	10.69	1.24	8.20	3.91	10.00	1.79	4.20	1.77	5.14	2.75	7.40
5	Gazert Naknk	1.51	3.29	0.62	8.00	4.33	8.20	2.33	4.20	1.15	5.87	2.26	8.20
6	Beat Alam	26.05	28.50	6.39	7.00	1.27	1.40	29.03	3.20	13.54	6.20	1.24	5.20
7	El-Nosirat	3.99	6.53	0.62	6.20	2.28	2.60	2.50	2.40	4.06	6.04	4.82	4.40
8	Nego Mazen Shark	24.29	41.66	0.32	3.00	3.63	7.20	17.56	30.00	7.40	14.82	6.89	6.80
9	Gazert Bardes	2.19	1.41	0.82	3.60	3.90	3.00	1.97	3.60	1.04	2.98	3.86	6.80
10	Gazert Bardes	2.78	1.58	2.68	2.80	2.57	2.20	2.69	3.00	1.88	2.69	4.54	6.00
11	Gerga	4.09	4.42	0.82	1.07	3.29	2.43	2.51	1.87	2.19	4.52	4.82	7.47
12	El-Rakakna	10.54	11.50	2.88	3.40	4.74	4.40	9.68	1.40	5.10	3.67	2.75	5.20
13	Awlad Hamza	10.24	7.98	0.41	1.28	3.50	1.02	3.40	1.87	4.17	4.89	6.19	8.13
14	Awlad Salama	2.59	3.13	1.03	6.20	2.06	10.80	1.79	3.60	1.25	8.81	3.03	6.20
15	El-Zara	3.80	6.34	0.82	3.42	4.33	2.28	2.69	6.94	3.96	4.93	4.41	5.73
16	Awlad Harwon	12.88	23.91	1.85	6.21	5.97	9.49	9.14	20.23	4.90	11.78	3.30	5.53
17	Rwafe Eyswaia	2.92	2.29	0.41	1.93	4.33	2.17	1.43	1.02	2.08	2.53	5.51	6.40
18	Awlad Azaz	9.95	7.90	0.82	2.14	5.77	2.56	3.76	1.53	4.48	1.61	3.72	8.73
19	Kelfao	2.83	4.45	0.82	1.93	2.88	0.77	1.79	1.19	1.04	1.34	4.54	3.67
20	Arab El Atawla	1.66	1.51	0.82	2.57	4.53	2.93	1.79	1.02	1.04	8.36	4.13	5.53
21	Gezert Shandawil	2.29	2.77	0.62	2.57	4.12	3.13	2.15	1.36	1.04	3.95	4.41	5.93
22	Bahta	3.61	14.47	1.24	2.57	9.89	4.13	2.23	3.06	2.81	7.09	2.75	6.80
23	El-Ghrizat	19.02	32.24	2.68	7.28	6.79	4.42	21.86	18.87	5.21	28.03	2.07	3.93
24	El-Ghrizat	31.92	43.11	4.94	10.49	12.45	8.81	26.52	30.94	9.38	7.09	1.93	2.93
25	Tunise	3.67	8.45	1.65	1.28	2.67	1.02	1.79	1.53	1.56	6.73	5.23	7.60
26	Neida	1.95	2.22	0.82	3.21	3.50	1.29	1.43	1.36	1.04	3.23	3.72	7.00
27	Gehina El Sarkia	2.97	0.98	0.82	4.20	3.09	5.40	1.79	6.40	4.06	2.42	3.72	5.80
28	El-Swamia Shark	14.31	29.25	4.12	4.80	6.18	3.40	13.98	11.60	6.98	10.89	2.62	7.80
29	Neg Hermas	20.49	14.65	4.12	6.20	4.94	5.60	22.67	11.80	5.73	9.89	2.07	4.20
30	El-Sheik Shibl	11.41	10.56	1.65	3.21	6.37	6.50	7.53	4.93	6.25	7.30	4.68	7.47
31	Nazlt Aly	15.22	9.51	0.82	7.80	2.06	7.40	3.94	4.40	6.35	11.74	3.03	4.40
32	El-Swamea Gharb	2.34	0.95	0.82	5.60	3.29	4.20	1.08	3.20	1.35	3.99	4.13	4.20
33	Nazlt Imara	17.56	33.33	3.09	5.60	8.65	7.40	15.41	17.40	10.42	13.69	2.34	7.40
34	Bin Harb	3.31	3.56	0.82	5.00	3.50	3.20	1.97	3.80	1.56	3.33	3.59	8.40
35	Um Dona	1.61	6.99	1.24	8.20	3.09	6.60	1.97	12.20	1.88	14.59	2.07	6.60
	Mean	8.18	11.87	1.58	4.65	4.41	4.74	6.59	7.23	3.94	7.07	3.69	6.12

Table **4.** Analysis of the soil samples of the area understudy between 1991 and 2006

No	Location	Salts, %				pH$_e$			
		1991		2006		1991		2006	
		Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
1	El -Balabesh Gobly	0.04	0.08	0.03	0.31	7.69	8.21	7.95	8.60
2	El-Ghabat	0.04	0.06	0.03	0.06	7.96	8.70	7.85	8.75
3	Awlad Salam Bahre	0.04	0.07	0.04	0.09	7.94	8.60	7.84	8.50
4	Naknk	0.03	0.18	0.02	0.27	7.75	8.15	7.75	8.35
5	Gazert Naknk	0.06	0.27	0.04	0.32	7.94	8.18	7.72	8.10
6	Beat Alam	0.04	0.07	0.03	0.08	8.20	8.60	8.50	8.30
7	El-Nosirat	0.06	0.07	0.03	0.13	7.74	7.82	7.95	8.26
8	Nego Mazen Shark	0.12	0.29	0.08	0.31	7.90	8.60	8.15	8.60
9	Gazert Bardes	0.02	0.10	0.03	0.09	7.80	8.50	7.74	8.45
10	Gazert Bardes	0.02	0.07	0.02	0.09	7.75	8.44	7.84	8.30
11	Gerga	0.04	0.10	0.03	0.71	8.10	8.70	8.00	8.00
12	El-Rakakna	0.04	0.12	0.03	0.17	7.83	8.71	7.75	8.50
13	Awlad Hamza	0.11	0.14	0.13	0.14	7.95	9.30	8.16	9.60
14	Awlad Salama	0.03	0.09	0.02	0.09	7.95	8.86	7.77	8.71
15	El-Zara	0.04	0.14	0.04	0.37	8.05	8.90	8.00	8.20
16	Awlad Harwon	0.04	0.60	0.05	0.16	7.90	8.44	7.75	9.20
17	Rwafe Eyswaia	0.04	0.66	0.02	0.45	7.74	8.20	7.82	8.10
18	Awlad Azaz	0.15	0.08	0.27	0.21	8.01	8.99	8.95	9.25
19	Kelfao	0.02	0.19	0.02	0.20	8.06	8.35	7.75	8.30
20	Arab El Atawla	0.02	0.15	0.02	0.22	7.85	9.50	7.69	9.10
21	Gezert Shandawil	0.02	0.25	0.02	0.50	7.75	8.16	7.70	7.98
22	Bahta	0.05	0.34	0.06	0.40	7.95	8.20	7.91	8.25
23	El-Ghrizat	0.03	0.12	0.04	0.16	7.82	8.52	8.06	8.75
24	El-Ghrizat	0.02	0.05	0.01	0.12	8.50	8.55	8.50	8.72
25	Tunise	0.02	0.25	0.02	0.45	7.65	8.22	8.10	7.95
26	Neida	0.02	0.10	0.02	0.10	7.91	8.33	8.15	8.50
27	Gehina El Sarkia	0.03	0.09	0.04	0.07	7.80	8.41	8.54	8.70
28	El-Swamia Shark	0.03	0.09	0.02	0.09	7.74	8.38	8.00	8.35
29	Neg Hermas	0.16	0.14	0.07	0.13	7.75	8.75	7.90	8.82
30	El-Sheik Shibl	0.05	0.21	0.07	0.27	7.65	8.10	7.75	8.19
31	Nazlt Aly	0.05	0.30	0.04	0.36	8.10	8.05	8.30	8.00
32	El-Swamea Gharb	0.02	0.08	0.06	0.07	7.82	8.45	7.63	8.35
33	Nazlt Imara	0.02	0.30	0.02	0.07	8.12	8.10	8.35	8.10
34	Bin Harb	0.05	0.08	0.04	0.23	7.82	8.58	7.90	8.19
35	Um Dona	0.14	0.19	0.04	0.17	7.78	8.64	7.78	8.16

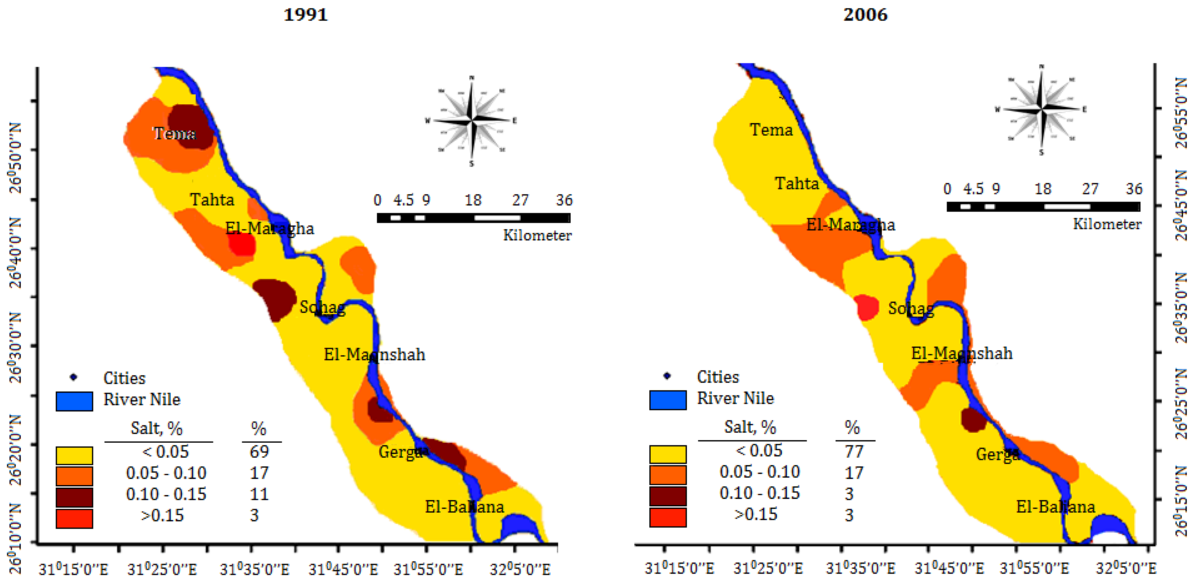

Figure 6. The changes in salt concentration of surface soil samples (0-25cm) irrigated by groundwater between 1991 and 2006.

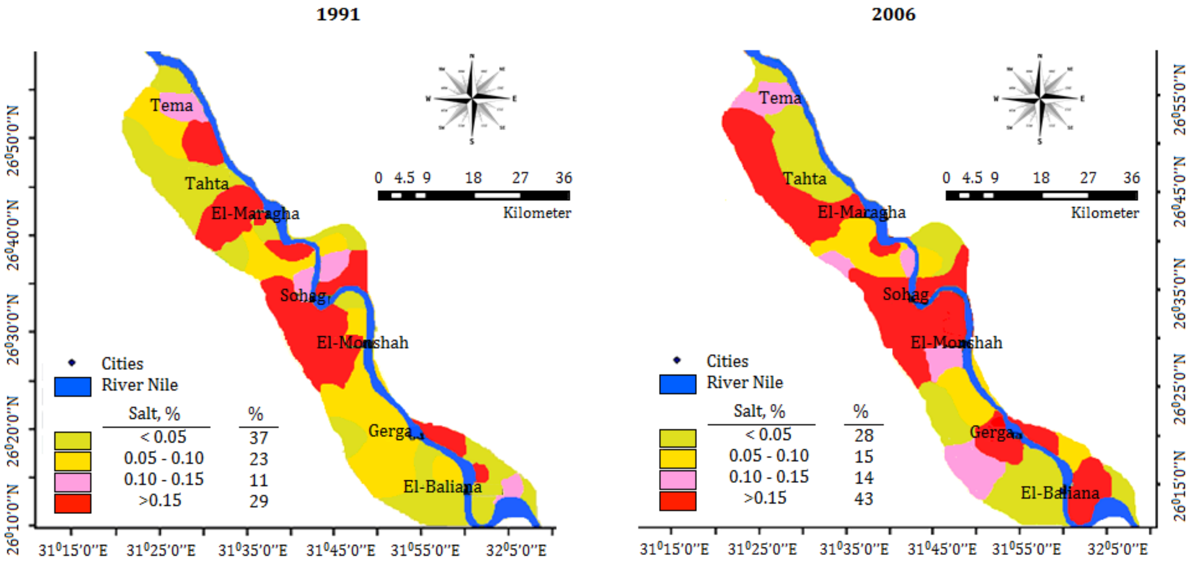

Figure 7. The changes in salt concentration of subsurface soil samples (25-50 cm) irrigated by groundwater between1991 and 2006.

It is clear that the future of Sohag soils irrigated with groundwater is of a great danger at most measures. The overall view of the salinity indicates a shift toward the salinization of the groundwater and soils irrigated with these waters. The excess of salt content is one of the major concerns with water used for irrigation. A high salt concentration in the water and soil negatively affects the crop yields, degrade the land and pollute the groundwater. These results agree with those obtained by Ghallab and Ali (2000).

- **Soil pH**

The pH of the soil samples (Table 4, Figures 8, 9) was classified into two classes, namely less than 8.0 and greater than 8.0 according to Ghallab (1995). The percentage of surface soil samples of the first class (pH < 8.0) decreased from 77 % in 1991 to 60 % in 2006. However, the second pH class (> 8) increased from 23 % in 1991 to 40 % in 2006. The first pH class (< 8) of the subsurface layers increased from 3 % in 1991 to 6 % in 2006. However, the percentage of subsurface soil samples having pH range between 8.0 and 8.5 increased from 51 % in 1991 to 60 % in 2006. However, subsurface soil pH having > 8 decreased from 46 % in 1991 to 34 % in 2006. These changes in the soil pH may be related to the changes in the salt content.

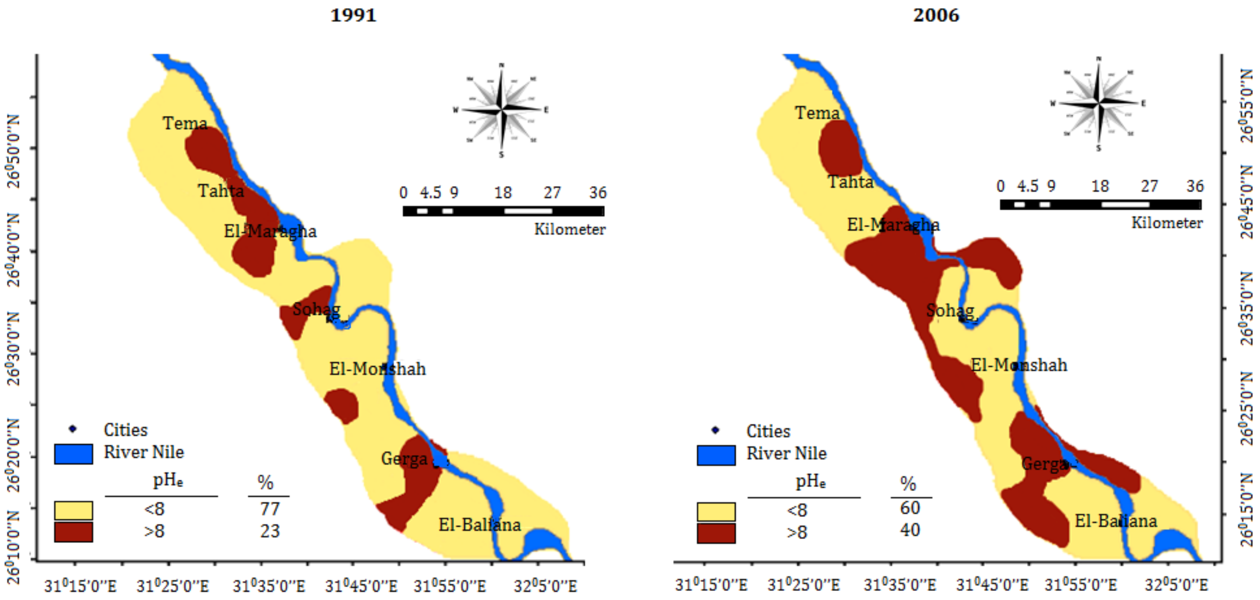

Figure 8. The changes in the pH of surface soil samples (0-25 cm) irrigated by groundwater between 1991 and 2006.

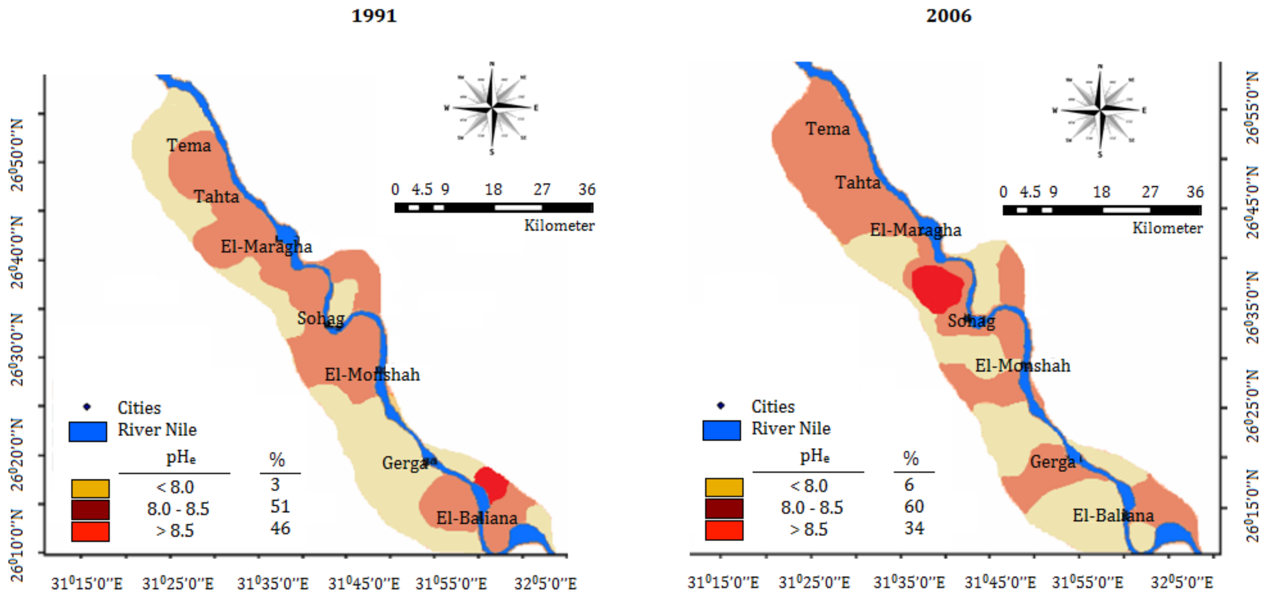

Figure 9. The changes in the pH of subsurface soil samples (25-50 cm) irrigated by groundwater between 1991 and 2006.

Conclusion

The increase of salinity in the groundwater and soil from 1991 to 2006 is certain. Soils with a moderate content of salts can be used if a moderate leaching occurs. Water with high salinity and sodium (SAR) should not be used for water irrigation. However, in some places with water shortage, water with high salinity can be used as a supplement for other sources and with a good management and a control of salinity. If water with a very high salinity is used, a drainage system must be installed to overcome the soil salinity problem that is caused by using saline groundwater in irrigation. Moreover, drainage must be adequate and water must be applied in excess to provide considerable leaching. Amelioration of these soils needs a source of calcium (Ca^{2+}) that can replace the excess exchangeable sodium (Na^{+}). Additions of gypsum may help to ameliorate such soils to supply adequate Ca^{2+} and growing of certain crops that are tolerant to ambient soil salinity and sodicity. Further research will be carried out to determine the change in soil and groundwater properties over the next 15 years. Monitoring soil salinity, as well as, periodic analysis of soils and groundwater wells to determine the changes taking place in the salinity and other properties is recommended.

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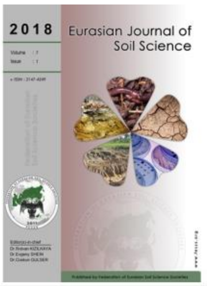

Relationship between phosphorus fractions of some selected Sudanese soil orders to phosphate availability

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Abstract

A laboratory experiment was conducted to determine the extent and the importance of phosphorus (P) fractions of some agriculturally important Sudanese soils on P availability. The soils were gathered from different locations in Sudan, to represent three different orders: Aridisols (Um Dum soil, North Kordofan state), Alfisols (Hagu soil, Senar state), and Vertisols (Hosh soil, Gezira state). The soil P was fractionated using an authenticated procedure. The results showed that the soils had low total, organic and available P contents. Most of the inorganic soil P was present in the Fe-Al fraction in Um Dum soil (> 50%), and about 40% of this fraction in Hagu soil, but, only 20% in alkaline Hosh soil. The Ca-P fraction constituted > 60% in Hosh soil, about 40% in Hagu soil and 20 % in Um Dum soil. The available P in the top soils studied was positively related to the percent sum of Al+Fe -P of the total P, and was negatively related to the percent Ca-P fraction content of the total P. It has been proposed that the P sorption starts by exchange with singly coordinate Fe or Al- OH clay (OH^- edge group) and quickly reorganizes into more stable and less soluble ring forms especially at pH more than 7.0, Alkaline pH more than 8.0 in soil like Hosh, will in presence of Ca, favour with time, the formation of inactive less soluble form like octacalcium phosphates and apatites at expense of the initial Al and Fe-P forms which are less stable at alkaline pH.

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Introduction

Phosphorus is an important element for all living organisms and, second to nitrogen as a limiting factor in plant growth and production (Arai and Sparks, 2007). The main P source is phosphate rocks, which are non-renewable. Consequently, it is high time to undertake new strategies to use P efficiently to conserve available P in soil. There are many factors that contribute to make plant available P below demand for optimum crops production such as very low total P in soil, the human activities causing imbalance between inputs and outputs of P nutrient in soil, precipitation of P with calcium (Ca), iron (Fe), and aluminum (Al), and adsorption of P in soil (Hunt et al., 2007; Melese et al., 2015). These factors become serious, especially in soils of inherently low P status. The Sudanese soils, similar to many agricultural soils of the world, are generally deficient in the amount of soil P. Although, several authors have reported independently that Sudanese agricultural soils are deficient in P, fertilizer experiments, conducted under Sudan soil condition, have shown erratic response of crops to the application of P, with few exceptions (Elsheikh et al., 2007; Abuswar and Omer, 2011). Plants take up P from the soil solution, which is replenished by various insoluble

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P pools in the soil (Mengel and Kirkby, 2001). Thus, knowledge and information about the different P pools are useful parameters to assessing P available to plant and can be helpful to provide proper management of fertilizer, leading to increase in P use-efficiency in in the soil-plant system (Mostashari et al., 2008; Halajnia et al., 2009). Extensive research has been conducted on the subject worldwide, whereas, there is a paucity of studies on P status of most tropical soils and indeed Sudanese soils. Therefore, the objective of this research was to characterize the extent of P in different P fractions of some major Sudanese soil orders and their impact on P availability.

Material and Methods

Soil materials

The study was conducted on three Sudanese soils, gathered from different locations that represent the main dominant soil orders, having different physical and chemical characteristics. These soils belong to three major orders: Aridisols (Um Dum soil, North Kordofan state), Alfisols (Hagu soil, Senar state), and Vertisols (Hosh soil, Gezira state). Some physical and chemical properties of these soils were presented in Table1. Particle size distribution was measured by pipette international method. Other soil properties were determined according to the procedures of Estefan et al. (2013).

Table 1. Characteristics of three Sudanese soils studied

		Soils					
		Um Dum		Hagu		Hosh	
Depth		Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Saturation, %		25.10	22.50	49.30	48.00	62.50	66.70
pH		7.10	7.00	7.90	7.80	8.20	8.20
ES, dS m^{-1}		0.80	0.70	1.15	1.25	1.00	2.00
Soluble cation, me/l	Ca^{2+}	5.00	6.00	6.00	6.00	1.00	1.00
	Mg^{2+}	2.00	4.00	2.00	3.00	2.00	4.00
	Na^{+}	0.87	1.74	9.57	6.70	9.57	20.00
Soluble anion, me/l	CO_3^{2-}	0.75	0.25	1.00	1.00	1.00	0.75
	HCO_3^{2-}	4.00	4.50	5.25	9.00	6.25	6.75
	Cl^{-}	3.50	3.50	6.25	6.50	5.25	7.00
Particle size distribution	Coarse sand, %	0.45	0.40	17.5	18.20	4.90	3.20
	Fine sand, %	90.10	90.30	31.10	32.70	15.20	18.60
	Silt, %	1.36	1.30	9.50	9.10	24.90	22.20
	Clay, %	8.00	8.00	40.00	42.00	50.00	56.00
CEC, $cmol_c\ kg^{-1}$		5.40	6.00	33.70	36.20	56.50	60.40
$CaCO_3$, %		0.20	0.22	1.10	0.94	2.00	2.00

Phosphorus fraction

The procedure of Chang and Jackson (1957) as modified by Petersen and Corey (1966) was used for determination of different forms of phosphorus. Saloid P was extracted by NH_4Cl and Al-P by 0.5M NH_4F. The letter was followed by extraction of Fe-P using 0.1 M NaOH, saturated NaCl plus a few drops of concentrated H_2SO_4. Occluded P was extracted by 0.1M NaOH and Ca-P by 0.25M H_2SO_4. Residual P was extracted by a mixture of HNO_3, HCl and H_2O. Organic P was determined by the ignition method of Legg and Black (1955). Reductant soluble P was estimated as the difference between total P and the sum of the organic P and inorganic P fractions. Available soil phosphorus was extracted by $NaHCO_3$ according to the procedures of (Olsen et al., 1954).

Results and Discussion

Total P

The surface soils under study varied in their total P amounts, which were: 537.0, 299.0 and 165.0 mg kg^{-1}, for Hosh, Hago and Um Dum respectively; the amount of subsurface P were 595.5, 279.5 and 169.0 mg kg^{-1} (Table 2). The soils under study could be classified according to their total P concentrations: Hosh >Hago >Um Dum, similar to order of percentage clay contents. The total phosphorus contents of normal soils vary from 100 to 2000 mg kg^{-1} (Kabata-Pendias and Pendias, 1992). The studied soils can be classified according to Tripathi et al., (1970) as low in P (<600 mg kg^{-1}). Because total P is an inherent property of soils, the generally low total P values in studied soils could be related to the nature of the parent material. Soil P occurs in inorganic and organic forms and their relative distribution varies with climate, vegetation, parent material and soil management practices.

Table 2. Total, organic, inorganic and $NaHCO_3$ extractable phosphorus

Soil	Total		Organic		Inorganic		$NaHCO_3$ extractable P	
	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Um Dum	165.00	169.00	9.50	7.25	155.50	161.75	5.30	3.10
Hagu	299.00	279.50	38.25	37.50	260.75	242.00	3.25	3.50
Hosh	537.00	595.50	30.00	27.00	507.00	568.50	2.50	2.75

Organic P

As shown in Table 2 the organic P for Um Dum soil are 9.5 and 7.5, for Hago soil are 38.3 and 37.5, whereas, for Hosh soil are 37.5 and 27.0 mg kg^{-1} for the top soil and subsurface, respectively. This amount consists of 5.6% – 4.4%,12.8% –13.4% and 5.6%–4.5 % of the total P of Um Dum, Hago and Hosh for the top and subsurface soil, respectively. The three soils were low in soil organic P values and these findings were expected as the organic matter is very low. In general, organic P content decreased with depth, as shown in Table 2. Under tropical conditions, organic P is readily mineralized into inorganic P (Tisdale and Nelson, 1995) and can thus be an important additional P source to plants.

Inorganic P

The amounts of inorganic P for top soil and subsurface were 155.5-161.7, 260.7-242.0 and 507.0-568.0 mg kg^{-1} for Um Dum, Hago, and Hosh, respectively (Table 2). This amount consists of 93.8-95.7, 87.2-86.6 and 94.4-95.5 percent of total P for top and subsurface soils for Um Dum, Hago and Hosh, respectively. According to Thomas and Peaslee (1973) there are three forms of inorganic P, the first is most available (precipitated) or chemisorbed on surface, and the second is somewhat available discrete particle (Ca-P, Al-P, Fe-P and Fe, Al-P) and the third is little available (occluded Ca-P in $CaCO_3$ or silica, occluded Al -P and Fe-P in iron oxides and redundant soluble Fe P occluded in Fe Oxides).

The large amount of the second form of the somewhat available discrete particle inorganic P forms, is a sign of high chemical weathering of the soils (Chang and Jackson, 1957). The form is called by many workers including Thomas and Peaslee (1973) as the active P forms which is the major sources of available P. It amounts to 81.0, 80.0, and 87.0% of total P of Um Dum, Hago, and Hosh, respectively, for topsoil, whereas it is 83.0, 71.0, and 87.0 % for subsurface of the three soils, respectively. The somewhat available discrete particle, constituted to 87.0, 86.0, and 92.0 % of the total inorganic P in the three of top soils, respectively, whereas, it is about 87.0, 82.0, and 92.0 % in sub-surface soil of the three soils, respectively. The somewhat available discrete particle P form, in Um Dum soil, in both top soil and subsurface soil was about 30% of total inorganic P, present as Fe-P, followed by Ca-P and then AI-P (Table 3). For both Hago and Hosh soils, most of inorganic P was present as Ca-P, followed by Fe-P, and then Al-P. Similar results were found (Uriyo and Kasseba, 1973; Udo and Ogunwale, 1977). Some of the inorganic P may be present in the lattices of silicate minerals and as inclusions in minerals, e.g., in quartz crystals (Black, 1968). The largest form of inorganic P in Hosh soil may be predominantly some form of the mineral apatite, perhaps most commonly calcium hydroxy or fluorapatite (Larsen, 1967). This means that most of the soil P may be in an unavailable form which the plants cannot use. Only the somewhat available discrete particle is generally accepted to be the main source of available inorganic P for plants (Thomas and Peaslee, 1973). The content of the three somewhat available discrete particles P forms varied among soil orders, reflecting the effect of different climatic and geographical conditions in which they were formed.

Table 3. Phosphorus inorganic fractions of three Sudanese soils

Parameters	Soil					
	Um Dum		Hagu		Hosh	
	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Saloid P	5.00	3.50	0.00	0.00	0.00	0.00
Al-P	35.00	30.00	49.25	43.75	45.50	61.25
Fe-P	52.80	61.25	52.5	47.25	50.00	52.50
OcclFe-P	8.00	9.00	20.00	20.00	19.00	21.00
OcclAl-P	7.50	7.50	16.50	22.50	17.50	23.75
Ca-P	47.70	50.50	122.50	108.50	375.00	410.00

Regarding the third form, the little available inorganic P, the amount of the reductant-soluble Fe –P, for top soil and subsurface were found 8.0-9.0, 20.0-21.0, and 19.0-21.0 % for Um Dum, Hago, and Hosh, respectively. In addition to this, the amount of occluded Al-P were 7.5- 7.5, 16.5 - 22.5, and 17.5-23.8% for Um Dum, Hago, and Hosh, respectively. The results clearly show that the occluded Fe and Al-P level were low. The reductant-soluble Fe-P is a semi active form which may be dissolved under anaerobic conditions. The occluded Fe-P and Al-P form, being inert to reactions with the soil solution is, therefore, of limited contribution as a source of plant available P.

Available soil P

Available P of Um Dum are 5.3 and 3.1 and for Hago 3.25 and 3.25, while in Hosh was 2.5, and 2.75 mg kg^{-1} for top and subsurface, respectively (Table 2). The soil available P, is low, indicating that the soils are infertile with respect to P. This may be due to the high clay contents of the latter soils which cause high P fixation. Figure 1 shows that the available P in top soils was positively correlated to the percent of sum of (Al-P+Fe-P) of the total P, and was negatively related to the percent Ca-P fraction content of the total P.

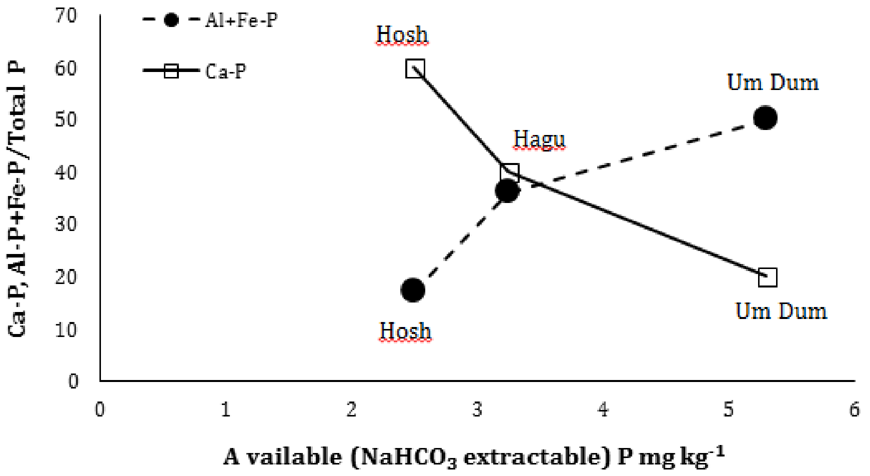

Figure 1. Relations between inorganic P fractions and available P in soils

Effect of phosphorus fractions on phosphate availability

Table 2 shows that the $NaHCO_3$ extractable P was highest in the sandy Un Dum soils (5.3 mg kg^{-1}) in top soil and 3.1 in the subsurface soil), very close to the amount of saloid P fraction (Table 3). It is noteworthy that Um Dum had the lowest active P fraction (Ca-P, Fe-P and Al-P) of the three soils studied. On the other hand, Hosh clay soil had the lowest $NaHCO_3$ extractable P, but the highest (523 mg kg^{-1}) active P, more than twice the active P of Um Dum, which was 240 mg kg^{-1}. It seems that the difference in available P between the two soils is not related to the magnitude of the active P, thought to be the source of available P, but rather to the nature and properties of the of individual constituents of active P fraction. It is logical to propose that Hosh soil with pH= 8.2 will push its high Ca-P fraction faster towards more stable forms of low solubility than Um Dum pH=7.1 (Lindsay and Moreno, 1960). Hosh Ca-P will more quickly ends up into sparingly soluble forms of apatite of very low activity. The third soil is Hagu of pH 7.9-7.8 may lie in between the two above mentioned soils.

It is relevant to note that despite the low $NaHCO_3$ extractable P in central Sudan soils of 2-3 mg kg^{-1}, many crops showed erratic response to P fertilization (Dawelbeit et al., 2010). The American Soil Science Society of Agronomy set a limit of 5 mg kg^{-1} between sufficiency and deficiency of soil P (Olsen and Sommers, 1982). It is known that the Sudan central clay plain soils originated from deposits carried by the Nile from Ethiopian high lands, having high rainfall and intensive vegetative cover. The soils there are organic, acidic and should fix considerable amount of Fe and Al phosphates. Particles of these phosphates which are transported by muddy waters of annual Nile floods are deposited on soil irrigation by Nile water of central clay plain fields (including Hosh). The Fe-Al phosphate particles will react with the alkaline central Sudan soils, producing sustained, but slow release of available P. Bohn et al. (1985) stated that both strengite and variscite would be good P fertilizer in basic soils.

$Fe(OH)_2H_2PO_4$ or $Al(OH)_2H_2PO_4$ → $H_2PO_4^- + Fe(OH)_3\downarrow$ or $Al(OH)_{3\downarrow}$

strengite or variscite → dihydrogen orthophosphate + ferric hydroxide ↓ or Alumuim hydroxide↓

Ahmed (1980) studied the fate of P applied to the alkaline Hosh and Hagu soil using conventional methods and radioactive ^{32}P. He found that about 80 % of the added P fertilizer was recovered after 12 months with Al-P fractions followed by Fe-P, but only about 6% were recovered in calcium form. However, P availability was not, governed by retained strengite and variscite, suggesting that the retained phosphate was present in forms less soluble than either of the two compounds Figure 2. Ahmed (1980) found that removal of sesquioxides from Hosh and Hagu soils slightly reduced the P adsorption maximum and concluded that most of the P adsorbed has been held by chemisorption Al and Fe clays edges. Ryden et al. (1974) suggested that phosphate first replaces singly coordinated Al or Fe OH groups and then quickly reorganizes into very stable and less soluble binuclear bridge between cations. Presence of the available Ca faver the formation and accumulation of the most stable phosphate form at high pH, hydroxyl apatites. This does not contradict with initial formation of Al and Fe phosphates as latter are soluble at high pH and will transform during long centuries of the soil genesis to the more stable and less soluble calcium phosphates observed today in alkaline soils.

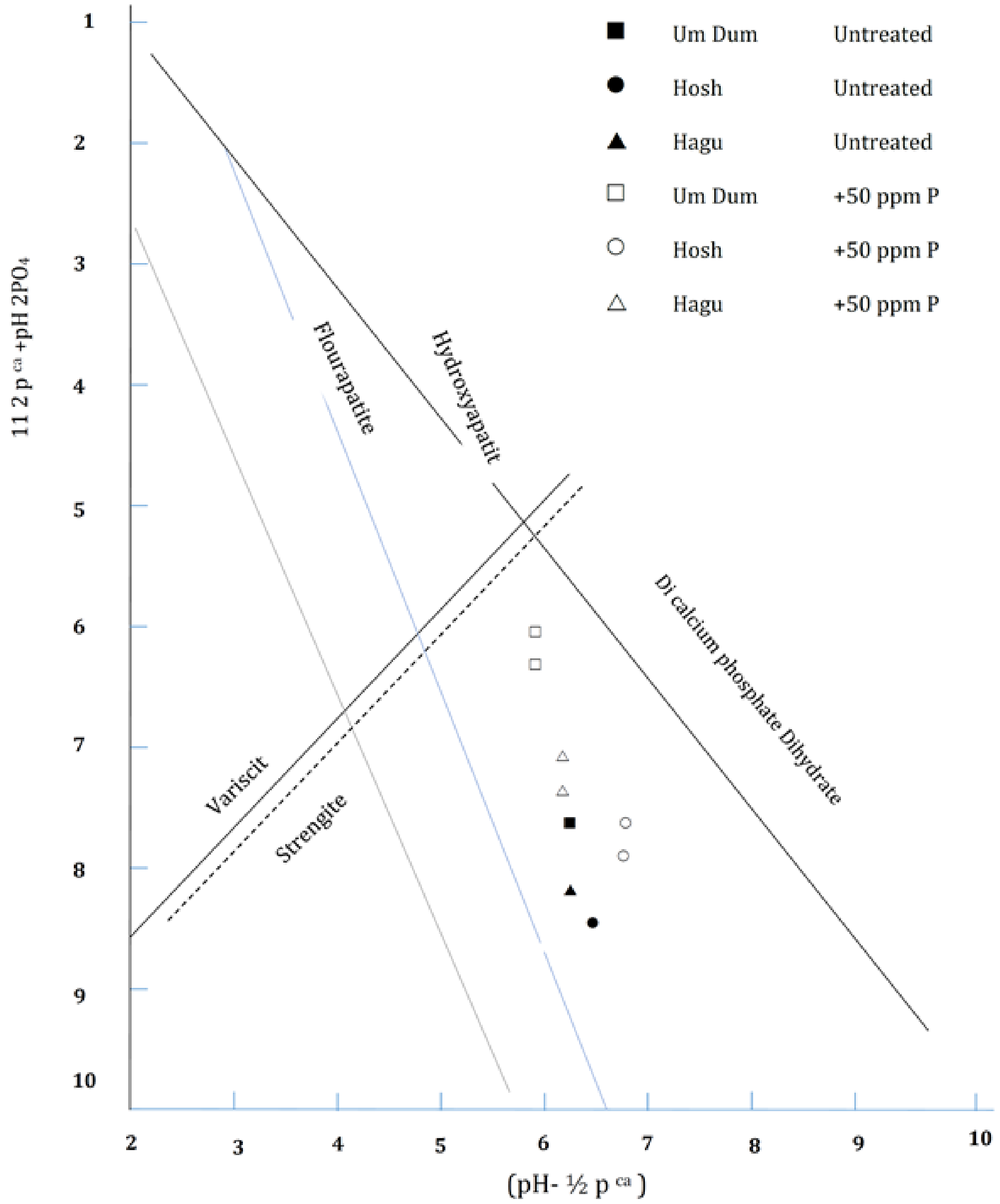

Figure 2. Solubility diagram for three soils

Conclusion

The study showed a wide range of differences in P status of major Sudanese soils orders. The three soils under study varied in the total P and were low in soil organic P values due to the very low organic matter content. Furthermore, the soil available P of above mentioned soils is low, indicating that the soils are infertile with respect to P. Available P was directly proportional to Al-P fraction and was inversely proportional to the larger Ca P fraction in alkaline Hosh soil, indicating that P was present in inactive forms at high pH.

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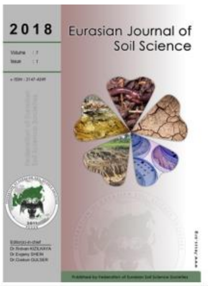

Trace minerals pollution in south indian branded tea, and from the tea waste disposal sites

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Abstract

We aim to quantify heavy metals in tea powders (packed and used), tea waste disposal sites and in the soil away from the site of disposal and to isolate the bacteria from both the soil sample. Atomic Absorption Spectrometer (AAS) analysis revealed chromium in the samples collected from Thanjavur (0.12 mg/kg) and Tiruchirappalli (4.77 mg/kg). The quantity of Copper was between 0.14 mg/kg and 0.97 mg/kg Namakkal and Erode samples respectively. We also found trace levels of other heavy metals. The spatial map distribution patterns of selected Physico-chemical parameters like pH, EC, Alkalinity, Total carbon in the disposal sites were presented. Some of the metal-intolerant strains isolated from the disposal sites became resistant. Further investigation would unravel the possible mechanism behind Chromium reduction by the selected isolates.

Keywords: Toxic metal, tea powder, AAS, spatial map, chromium, biosorption.

Introduction

Tea from the leaves of the shrub *Camellia sinensis* is the most preferred consumable beverage worldwide (Fernández-Cáceres et al., 2001). Approximately about 18-20 billion consumers drink tea daily. Despite its medicinal properties, it also contains numerous toxic elements (Fe, Mn, Cr, Zn, Cu) (TEs) in trace quantity (Shen and Chen, 2008). These TEs are present in domestic and industrial wastewater, dust, vehicular exhaust and industrial emissions etc. that affect agricultural lands and plants (Singh et al., 2010; Muntean et al., 2013). The TEs such as cadmium from fallouts of vehicular exhaust and dust were reported to affect tea plants by getting deposited on the leaves. Other TEs such as Mercury, Lead, Arsenic, Chromium, Iron and Cadmium were also found in tea leaves in trace level, however harmful to humans (Wang et al., 2008; Han et al., 2006; Sadeghi et al., 2011). Studies exist to demonstrate the ROS production along with oxidative stress play a major role in the toxicity and carcinogenicity of metals such as As, Cd, Cr and Hg (Tchounwou et al., 2001; Tchounwou et al., 2004; Yedjou and Tchounwou, 2006; Yedjou and Tchounwou, 2007). Due to their toxicity these heavy metals were ranked as priority metals that are of great public health significance (Tchounwou et al., 2012). The occurrence of TEs in tea plants is mainly by absorption from nutrient supplementation, growth media, industrial wastes, organic and inorganic fertilizers, and pesticides. These TEs cause delayed flowering, reduced chlorophyll content and shortening the shoot length (Mani et al., 2014). Chromium is reported to be one of the most popular TEs and is found to get added tea mainly from the crush-tear-curl rollers used to prepare tea which usually contain chromium (Seenivasan et al., 2008). No

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studies were performed hitherto on the estimation of toxic metals in tea powder and tea waste disposal sites, however these types of agro based waste has been used as adsorbents for heavy metal removal (Demirbas, 2008). Hence the present study has been framed with the following objectives.

The objective were to,

(i) analyze TEs in commercially available packed Tea Powder (TP), Used Tea Powder (UTP), soil samples collected from the tea waste disposal site (Soil Contaminated- SC) and the soil samples collected away from the disposal site (Soil Un-Contaminated- SUC).
(ii) Isolate the soil bacteria collected from disposal sites (SC and SUC)
(iii) Evaluate the metal resistance potential of the isolated bacterial strains against chromium and to determine MTC (Maximum Tolerance Concentration) of individual bacterial strains, and
(iv) To determine the physico-chemical characteristics of the soil with spatial map presentation.

Material and Methods

Sample collection

The soil samples were collected from various districts of Tamilnadu (South India) such as Chennai, Kanyakumari, Tiruchirappalli, Salem, Namakkal, Thiruvarur, Thanjavur, Pudukkottai, Madurai and Erode (Figure 1). We made a V-shaped cut (15-20 cm depth) and collected smooth side of the soil (1 cm slice) in a clean bucket and mixed well (Figure 2). The tools used for sampling includes shovel, spade and augers (Parker, 2009). The samples were homogenized, air-dried and sieved with a 2 mm wire mesh before analysis.

Figure 1. Study area- Sampling sites

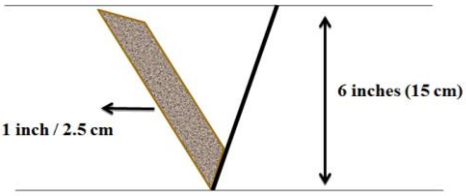


Figure 2. Sample collection method

Preparation of soil sample for Physico-chemical analysis

The preparation of soil sample is, 1 g of soil sample was dissolved in 20 mL of double distilled water and kept for 30 min in shaker. After mixing, the sample were filtered and subjected to the analysis of Physico-chemical parameters such as pH, electrical conductivity (EC), alkalinity and organic carbon (without water mixing) (APHA, 2005).

$$I=\surd X1=X2=X3=X4=X5/5$$

Note: This formula represented the spatial distribution of geographical map with weightage data included physico-chemical and Heavy metal analysis. (I=Index, X=Weightage of metals impact)

Quantification of Heavy metals in the samples

To quantify the heavy metals, 1 g of TP, UTP and 0.5 g of SC, SUC were digested using Microwave digester (MDS-6, SINEO Microwave Chemistry Technology Co., Ltd). The operating condition specific for each metals are summarized in Table 2, 3 and 4 (Xin et al., 2010). Samples were analyzed in triplicate using Graphite Furnace Atomic Absorption Spectrophotometer (Thermo Scientific ICE 3000 series, Solar data station (v.11.02)) to quantify Fe, Mn, Cr, Zn, and Cu.

Biosorption studies

The bacterial strains isolated from disposal sites (SC and SUC) were streaked onto the nutrient agar media supplemented with metal concentrations ranging from 100 to 1000 ppm. For biosorption studies, the plates were incubated at 30°C for 24 to 72 hours and the isolated bacterial strains were inoculated into 100 mL of nutrient medium supplemented with glucose (1%) and urea (1%) containing different concentrations of Cr (VI) as $K_2Cr_2O_7$ (100–500 ppm) followed by incubation at 37°C for 120 rpm for 24 hours in a mechanical shaker. The samples were centrifuged at 10,000 rpm for 15 min in a cooling centrifuge (Model: REMI C-24) at 4°C and the supernatant was subjected to ultra-sonication and chromium concentration was determined using di-phenyl carbazide reagent in acid solution (APHA, 1998) by measuring the absorbance at 540 nm in a spectrophotometer (2202- PC, Systronic). Thus Cr (VI)-reduction by the isolated strains was investigated. Samples were analyzed for the reduction of Cr (VI) at regular intervals.

Results and Discussion

The physico- chemical parameters such as pH, EC, alkalinity and total organic carbon were analyzed in used tea powder SC and SUC (Table 1) with representation of corresponding spatial map (Figure 3).

Table 1. Physico-chemical characteristics of tea waste SC and SUC: [Mean ±SD (N=3)].

Area of sample collection	Types of soil	pH	EC (µs/cm)	Alkalinity (mg/kg)	Carbon (mg/kg)
Tiruchirappalli	SC	5.183±0.015	0.866±0.014	33.33±5.773	5.486±0.195
	SUC	5.896±1.103	0.789±0.007	46.66±15.275	4.286±0.145
Salem	SC	8.066±0.055	0.616±0.007	46.66±05.773	2.613±0.208
	SUC	7.826±7.826	0.595±0.595	46.66±46.660	2.830±2.830
Namakkal	SC	7.813±0.051	0.587±0.004	80.00±10.000	1.720±0.206
	SUC	7.523±0.092	0.491±0.003	53.33±05.773	1.923±0.049
Chennai	SC	7.130±0.050	0.977±0.018	73.33±05.773	1.876±0.051
	SUC	7.156±0.020	0.818±0.002	96.66±5.773	2.946±0.020
Thanjavur	SC	6.146±0.404	0.639±0.005	46.66±10.000	2.333±0.055
	SUC	7.186±0.070	0.167±0.028	76.66±05.773	2.846±0.120
Thiruvarur	SC	6.833±0.404	0.153±0.005	50.00±10.000	2.943±0.055
	SUC	7.186±0.070	0.167±0.028	76.66±05.773	2.846±0.120
Madurai	SC	8.003±0.060	0.743±0.022	50.00±10.000	3.323±0.222
	SUC	7.386±0.180	0.448±0.022	70.00±10.000	1.653±0.150
Erode	SC	6.560±0.245	0.754±0.012	43.33±05.773	1.676±0.090
	SUC	7.036±0.572	0.806±0.032	60.00±10.000	1.913±0.120
Kanyakumari	SC	7.363±0.245	0.169±0.010	40.00±10.000	1.800±0.170
	SUC	6.793±0.410	0.267±0.219	43.33±05.773	1.897±0.068
Pudukkottai	SC	7.403±0.218	1.000±0.105	73.34±11.547	2.423±0.090
	SUC	6.556±0.196	0.620±0.404	73.33±05.773	1.913±0.058

Table 2. The acid composition of Microwave digester mixture.

Sample type	Gram (g)	HNO_3 (65%)	H_2O_2 (mL)	Time (min)
TP	1.0	6 mL	2.5	20
UTP	1.0	6 mL	2.5	20
SC	0.5	4 mL	6	30
SUC	0.5	4 mL	6	30

Table 3. Operating conditions with wavelength for GF-AAS.

Elements	Mn	Fe	Cr	Zn	Cu
Sampling volume	20	20	20	20	20
Wavelength (nm)	259.4	269.4	215.9	213.2	326.7
Lamp current (mA)	8	6	10	13	12
Gas flow (Inner /Outer)	1.5	1.5	1.5	1.5	1.5
Band Pass width	0.6	0.5	0.4	0.3	0.3

Table 4. Atomization temperature–time program

	Temp. ºC	Ramp (ºC s^{-1})	Hold (s)	Purge Argon flow
Drying	110	50	20	2
Pyrolysis I	600	30	10	2
Pyrolysis II	800	20	5	2
Atomization	2075	-	3	0
Cleaning	2300	-	2	2

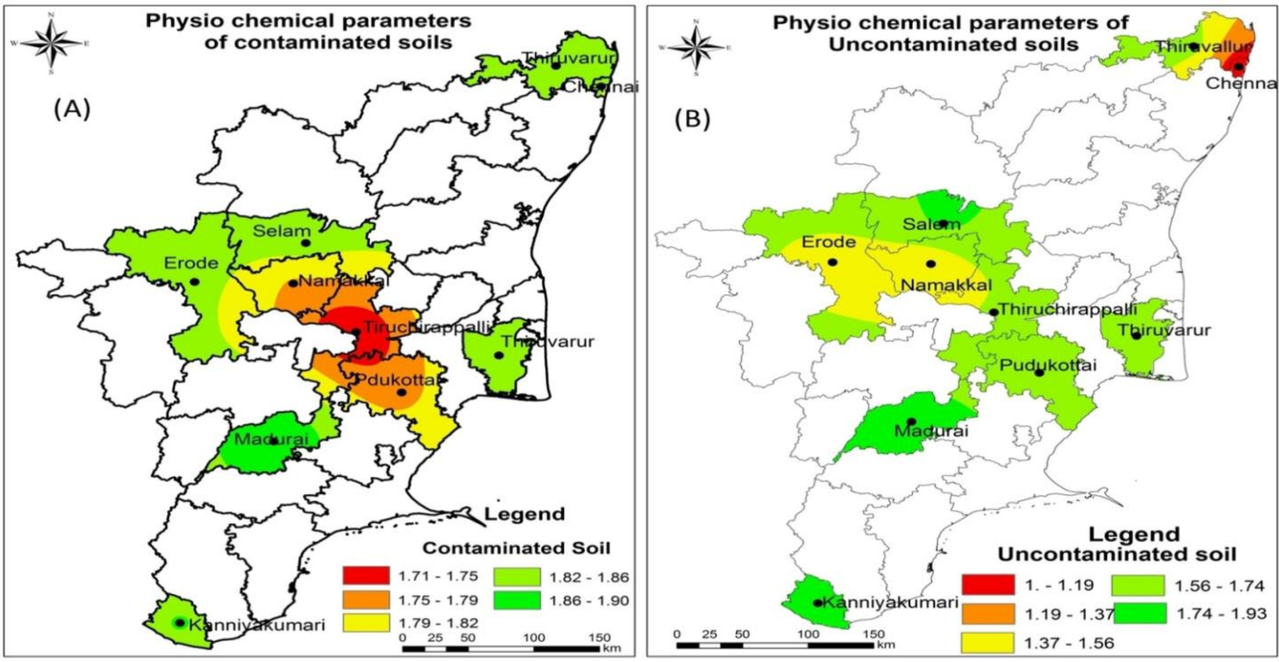


Figure 3. Spatial distribution of monitoring stations across Tamilnadu and this map shows the physicochemical (pH, EC, Alkalinity, Carbon) parameters. The picture named as (A). SC (B). SUC

The concentration of TEs from SC and SUC was determined. The quantity of Fe was 1.01 ppm in the samples collected at Salem and Thanjavur samples contained 13.27 ppm, which was the maximum in SC and 3.20 ppm in SUC. Zn was found to be in the range of 0.22 ppm to 3.29 ppm in SC, and the highest quantity was in Madurai and Namakkal samples and 0.85 ppm in SUC. The minimum concentration of Cr was 0.12 ppm, and as high as 4.77 ppm in Tiruchirappalli (SC) samples and 4.07 ppm in SUC. The concentration of Cu in SC was less (0.15 ppm) in Namakkal samples and it was higher in Chennai samples (1.386 ppm). The concentration of Cu in SUC was about 1.046 ppm in samples collected from Kanyakumari and it was 0.076 ppm in SUC collected from Tiruchirappalli. The least quantity of Mn (0.56 ppm) was in Namakkal samples, whereas the highest quantity (14.67 ppm) was present in Tiruchirappalli (SC) samples and 12.48 ppm in SUC. Further, the changes in the concentration of all heavy metals varied significantly between different districts (Figure 4).

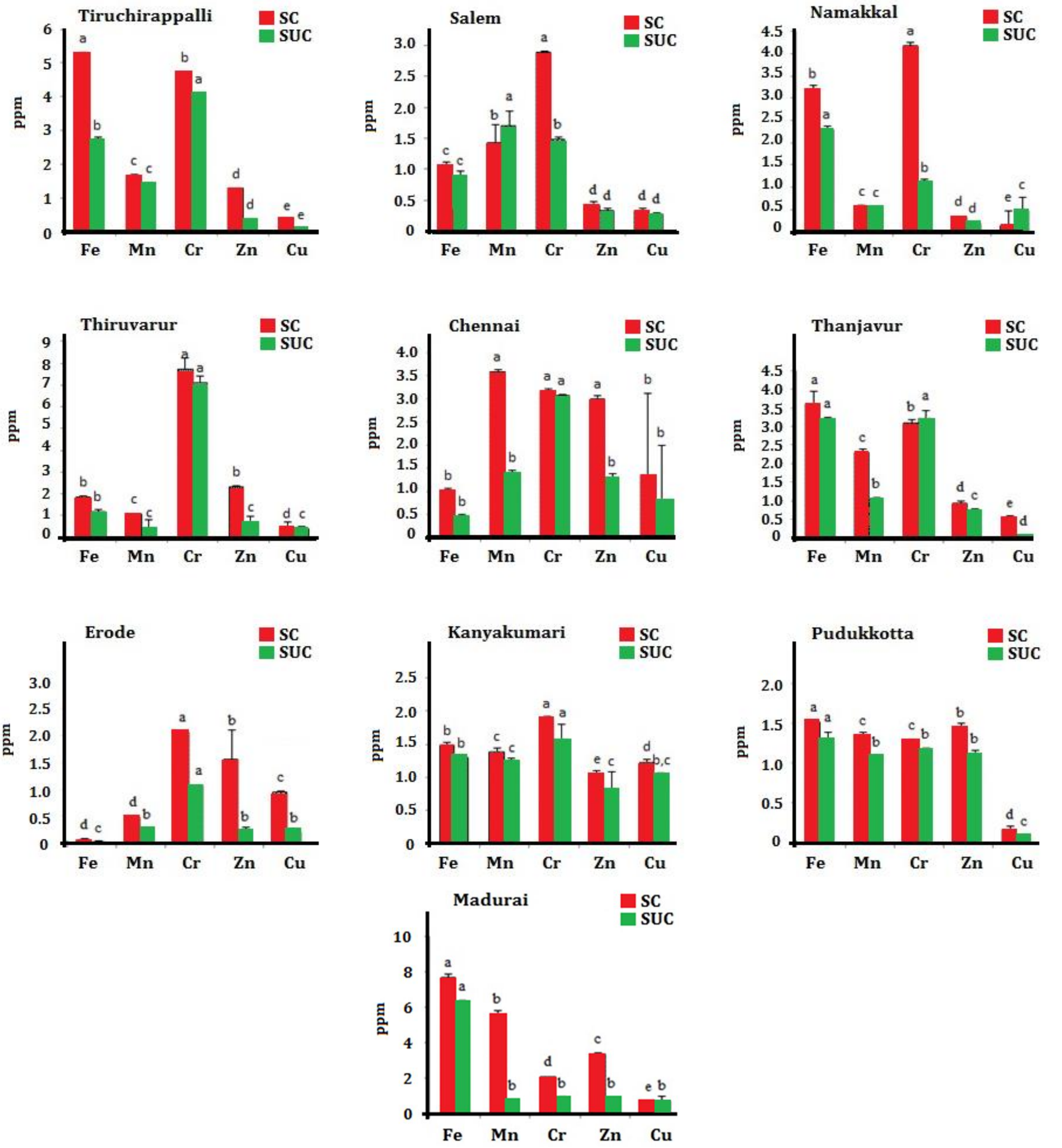


Figure 4. Changes of the heavy metals (Fe, Mn, Cr, Zn, Cu) concentration in soil contaminated (SC) and soil uncontaminated (SUC) using Atomic adsorption spectrophotometer values were expressed and Mean ± SD (N=3). Bar with different alphabets represents they are significantly different from each other and those with same alphabets have insignificant changes ($P<0.05$).

The presence of TEs in the soil samples and different tea powder samples was further represented as spatial maps. The color range (TEs-SC) of 1.34 – 1.48 indicated the areas with maximum contamination, followed by 1.48–1.62, which indicated higher contamination. The range of 1.62–1.76 represented moderate contamination, 1.76–1.90 indicated low level of contamination, and 1.90–2.04 revealed the least contamination. The spatial map of SUC showed that the range of TEs 1.48–1.58 exhibited highest contamination followed by 1.58 – 1.69 that indicated higher contamination. Subsequent moderate and lower contamination were indicated by the range of 1.69–1.79 and 1.79–1.89, respectively. The lowest level of contamination falls in the color range of 1.89 – 2.0 (Figure 5).

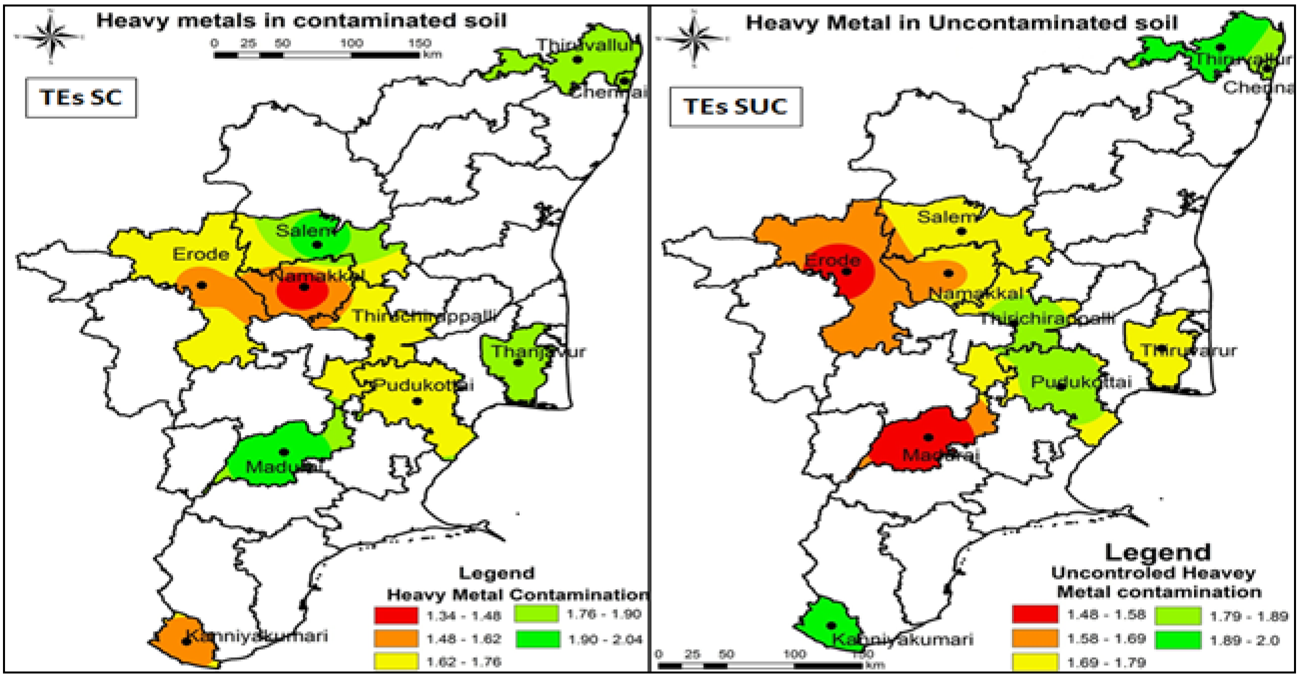


Figure 5. Spatial distribution and concentration of heavy metals in the study area TEs-SC and TEs-SUC.

TEs content was also analyzed in packed and used-tea powders. The concentration of Fe was 0.0011 ppm in Brand x3 as the minimum and the maximum was about found as 0.0128 ppm in Brand x7. Zn concentration was 0.0138 ppm in Brand x4 and in Brand x6 it was 0.0447 ppm. Cr was found at minimum concentration (0.0348 ppm) in Brand x7 and the maximum (0.0742 ppm) was found in in Brand x1. Cu in Brand x5 was 0.0189 ppm and in Brand x1 it was 0.0448 ppm. Mn content was 0.56 ppm, and 0.067 ppm in Brand x6 and Brand x7, respectively (Figure 6).

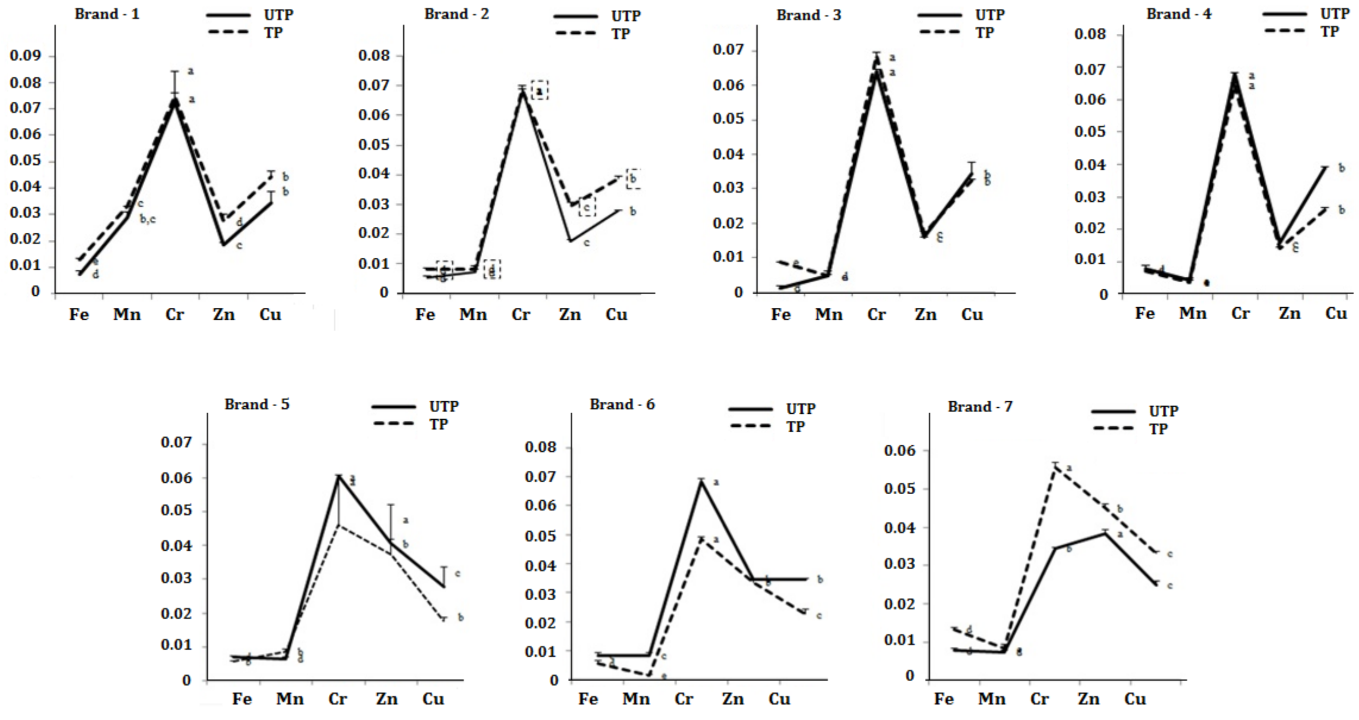


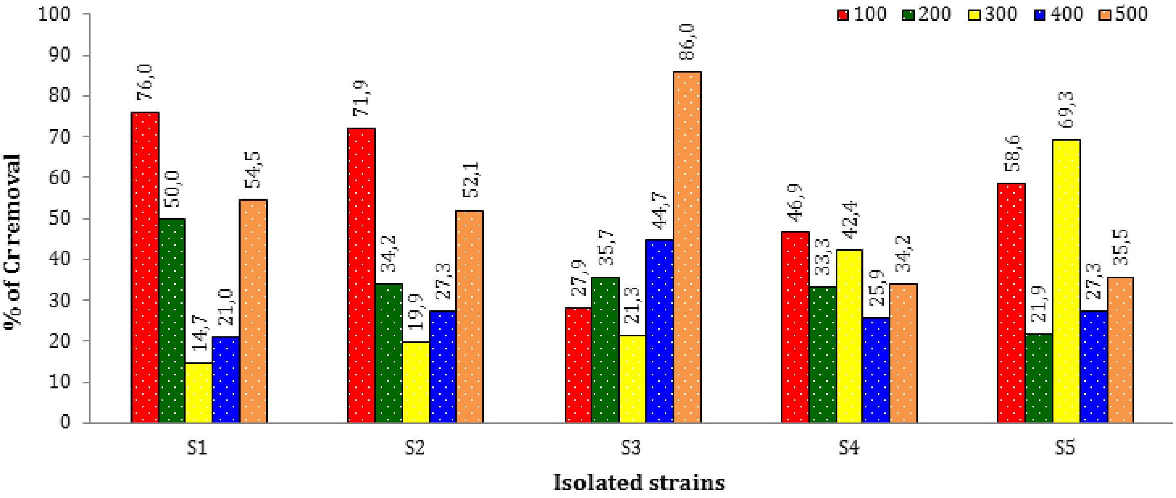
Figure 6. Changes in the TEs (Fe, Mn, Cr, Zn, Cu) concentration in Tea Powder (TP) and Used Tea Powder (UTP) using Atomic Adsorption Spectrophotometer. Values were expressed as Mean ±SD (N=3) Bar with different alphabets represents they are significantly different from each other and those with same alphabets have insignificant changes (P≤0.05) and the unit of TEs concentration is expressed as ppm.

The MTCs (Maximum tolerable concentration) of the bacterial strains present in various natural habitats such as soil, water, sediments and sewage amended soil have been studied (Abbas and Edwards, 1989). The majority of microbes were found to possess two types of uptake mechanisms to reduce the cations and anions. First one is fast, unspecific, constitutively expressed and obsessed by the chemi osmotic gradient across the cytoplasm covering of bacteria. The second one is inducible, possesses high substrate specificity and is slower, repeatedly uses ATP hydrolysis as the power supply and is only produced by the cell in times of need and under special metabolic conditions. Higher amount of essential and nonessential metals can affect the cell membranes; modify enzyme specificity; interrupt cellular functions; and damage the structure of DNA and impose oxidative stress on microbes too (Bruins et al., 2000). In this paper, the metal tolerant microbial strains were randomly selected for their level of resistance against Cr (VI) concentration. From the MTC analysis, a significant difference in the resistance levels of the bacterial strains isolated from both SC and SUC was noticed (Table 5). The MTC of all isolates *Bacillus sp* (S1), *Bacillus megaterium* (S2) (isolates collected from SC), (S3) and *Pasteurella haemolytica* (S4) (isolates from SUC) was 700 ppm. Altogether, all the isolates exhibited similar, tolerance against chromium. The reduction level was 76% in 100 ppm by strain 1, 50.01% and 69.30% in 300 ppm by strain S5, and 44.70% in 400ppm and 86.04% 500ppm by strain S3 (Figure 7).

Table 5. Cr tolerance of the isolated bacterial strains.

Isolated strains	Activity of isolated bacteria in different concentration (ppm) of Cr(VI)									
	100	200	300	400	500	600	700	800	900	1000
S1	R	R	R	R	R	R	R	S	A	A
S2	R	R	R	R	R	R	S	A	A	A
S3	R	R	R	R	R	R	S	A	A	A
S4	R	R	R	R	R	R	S	A	A	A

*R- Resistance; A- Absence of growth; S- Sensitive



*(S1-S4 refers to the isolated bacterial strains).

Figure 7. Cr reduction by isolated bacterial strains

Already reports exist to prove that the metal biosorption is a two-step process where the functional groups of the metal ions (phosphate, hydroxyl, carboxyl, amino, sulphide, sulphur group, etc.) gets adsorbed to the surface of cells by interaction. However, reports also suggest that TEs can also bind on the surface, which can be eventually eluted by other ions present in chelating agent or acid. Hence this work on identification and quantification of the metal ions in the soil samples is a need of the hour. Further work is needed to understand the mechanism of Biosorption of the metal ions by the autochthonous organisms present in the contaminated areas. Similarly, biosorption referring to the penetration of metal ions into the cell membrane has been already reported (Veglio and Beolchini, 1997; Madrid and Cámara, 1997). Studies exist to understand the biosorption of Cr (VI) and Fe (III) by *Streptococcus equisimilis, S. cerevisiae* and *Aspergillus niger* too (Goyal et al., 2003).

Conclusion

The heavy metal namely, Cr was present in higher quantities of TEs in used tea powder, which was about 0.0742 ppm. This data gives a clear understanding that certain quantity of heavy metal added to the soil and the soil had appreciable quantity of native heavy metals already; this may pose a threat to the environment and disturb the normal flora present in the disposal site. Further investigation is needed to explore the possible mechanism behind chromium reduction by the selected strains. This study thus focuses on some branded tea, tea waste and disposal site as sources of heavy metal contamination and recommends that the disposal of such used tea waste must not be done in pristine environment so as to conserve the same.

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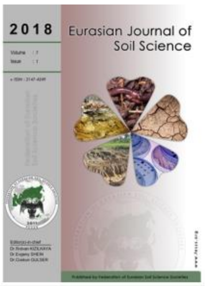

Spatial variability analysis of soil quality parameters in a watershed of Sub-Himalayan Landscape - A case study

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Abstract

Soil organic carbon (SOC) is a key component in maintaining soil quality. Mapping the local scale variations in the distribution and stratification of SOC and other soil quality parameters across different layers has always been a challenging task, in the current global scenario of changing climates. The study was aimed to investigate the spatial distribution of SOC and other soil quality parameters including SOC stratification ratio and CN ratio in a small hilly watershed (~ 10 km^2) located in the mid Himalayan region of Himachal Pradesh, India. Soil samples were collected in November 2015, from 75 points at two depths (0-15 cm and 15-30cm), along with their geographical coordinates using a Global Positioning System (GPS). The results revealed that SOC concentration (g kg^{-1}) decreased with increasing soil depth, throughout the study area and differed significantly ($P<0.01$) between the two depths in vertical soil profile. The SOC stratification ratio values were greater than 1.2 in major portion of watershed indicating a spatial improvement in soil quality. C: N ratio, another important soil quality attribute values were found to be <12:1, indicating high degree of soil quality and increased rate of organic matter mineralization. The spatial distribution maps of SOC content (g kg^{-1}), SOC stratification ratio as well as CN ratio of study area were generated using Inverse Distance Weighted (IDW) interpolation approach. Additionally soil quality index (SQI) was also computed using various soil quality parameters based on Analytical Hierarchy Process (AHP) and their spatial distribution was analyzed in the watershed. Nearly 76% of the study area had SQI values in the range of 60-75, whereas 22.16% of the area had SQI<60 and 2.59% had SQI>75. The overall results indicated that a higher degree of soil quality existed at the higher elevation regions of the watershed. Majority of the soils in the watershed accounted for only 60% of the maximum possible value of SQI, which necessitates the adoption of better management practices for improving the soil quality.

Keywords: Soil quality, Himalaya, IDW interpolation, watershed, soil organic carbon.

Introduction

Soil quality indicates the capacity of the soil to perform the various ecosystem services and by far it is the central element which determines the long term sustainability of any agricultural production system. It refers to the capacity of soil to function within natural or managed ecosystem boundaries and to sustain plant productivity while maintaining or enhancing water quality, supporting human health as well as habitation and reducing soil degradation (Doran et al., 1994; Karlen et al., 1997; Karlen et al., 2003). Comprehensive assessment of agricultural soil quality (Pieri et al., 1995; Stamatiadis et al., 1999) aids in making decisions in respect to improve crop production and environmental sustainability.

Soil quality being a complex functional concept, can't be measured directly in the field or laboratory (Stockings, 2003), but can only be ascertained from various soil properties or characteristics (Diack and

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Scott, 2001). Soil quality indicators are defined as soil processes and properties (combination of physical, chemical and biological) that are sensitive to changes in soil functions (Doran and Jones, 1996; Herrick et al., 2002,; Aparicio and Costa, 2007). An ideal soil quality indicator should possess specific characteristics like correlating well with ecosystem processes/soil functions. It should be sensitive to various management practices and climatic conditions as well as external change (natural or anthropogenic) in addition to easy interpretability and integration into larger, ecosystem-scale models (Doran and Parkin, 1996). Different sets of soil quality indicators have been proposed and used for evaluation of soil quality based on the total data set (TDS) indicator method (Larson and Pierce, 1994; Doran and Parkin, 1994; Karlen et al., 1998).

Among the various soil quality evaluation methods developed so far (Klingebiel and Montgomery, 1961; Ditzler and Tugel, 2002; Doran et al., 1994; Doran and Jones, 1996; Diodato and Ceccarelli, 2004; Larson and Pierce, 1994), soil quality indices are perhaps the most widely and commonly used methods for sustainability and soil management studies (Andrews, et al., 2002). Soil quality indices are particularly significant to soil management practices because of their ability to use site-specific indicators of soil status that can integrate anthropogenic effects over time and over numerous types of effects (Wang and Gong, 1998; Arshad and Martin, 2002).

Soil organic matter (SOM), more precisely soil organic carbon (SOC) content, is widely considered as a key indicator of soil quality. This can be attributed to the fact that presence of SOM/SOC has been found to be beneficial for nutrient retention/recycling, soil productivity, water holding capacity, carbon sequestration (Prescott et al., 2000; Munson and Carey, 2004; Seely et al., 2010; Six and Paustian, 2014). Studying soil organic carbon on a regional or watershed scale invites special attention these days as it is considered a key parameter, playing central roles in various environmental issues such as climate regulation, food and water security (Jague et al., 2016). Quantifying and estimating spatial distribution of SOC is vital for evaluating various soil functions and aids in understanding different soil carbon sequestration processes (Venteris et al., 2004). Similarly SOC stratification ratio has also been used as an indicator for dynamic soil quality (Franzluebbers, 2002; Wang et al, 2010).

Soil quality index estimation, an indirect approach for evaluating soil quality is based on various soil quality indicators and their relative importance for various soil functions (Qi et al., 2009). Scoring of various indicators using diverse scoring functions (Gaussian, sigmoid etc) and assigning weights for each of the attributes, forms the integral part of soil quality index development (Mandal et al., 2010). This approach is widely accepted because of its ability to evaluate the vital relationships between various soil indicators and soil productivity, through the use of various mathematical models (Burrough, 1989; Fu, 1991; Tang, 1997; Dobermann and Oberthur, 1997; McBratney and Odeh, 1997; Sun et al., 2003), apart from its capacity to identify the complexity of soil productivity under various natural conditions as well as different farming practices. For assigning weights to various attributes in determination of soil quality as well as land evaluation procedures, the analytical hierarchy process (AHP) is one of the widely adopted multi criteria decision analysis method (Saaty, 1977).

Thus, determination of soil quality becomes an important prerequisite for better planning and utilization of the land resources. Particularly if we consider the Himalayan ecosystem, it is typically characterized by its low input subsistence agriculture, dwindling productivity and climatic vulnerabilities which demands maximum focus on optimum land use practices for maintenance and improvement of soil quality. For planning and implementation of sustainable land management strategies, detailed spatial information of soil quality is an essential requirement (Zhang et al., 2012). However, there is a lack of quantitative information on spatial variability of soil quality of watershed in the hilly and mountainous terrain of Himalayan region, where easy accessibility is restricted due to ruggedness of the terrain.

Currently, various geostatistical methods such as Inverse Distance Weighted (IDW), kriging, co-kriging etc are widely being used to prepare continuous spatial distribution using point observations of various variables (Viscarra Rossel and McBratney, 1998; Lin and Chen, 2004). The different spatial interpolation techniques estimate parameter values such as SOC, at un-sampled locations using data from point observations and provide us with an ideal tool for meeting our requirement for spatial distribution data (Viscarra Rossel and McBratney, 1998; Lin and Chen, 2004). However, while comparing the various spatial interpolation techniques researchers reported that IDW produced less error in SOM content prediction measured by root mean square error (RMSE) values, in comparison to other interpolation techniques such as kriging (Liu et al., 2015). Spatial distribution maps of soil quality parameters generated by IDW can best represent the true situation prevailing in the watershed and helps us to make judicious interpretations and adoption of better management strategies (Liu et al., 2015).

Thus, keeping in view the importance of soil quality in land use planning and management, the present study was carried out to analyze the soil quality and its spatial variability using remote sensing techniques in a watershed of the North West Himalayan region. Considering the better performance of IDW over kriging, this technique was employed for generation of the spatial distribution map for SOC, SOC stratification and CN ratio of the watershed, which are the prime parameters on which soil quality is dependent. The SQI was also computed based on AHP and their distribution was analyzed to get an overview of the impact of different land use systems on soil quality.

Material and Methods

Study area

The study area is a hilly watershed located between latitudes 32° 4' 35.04" N to 32° 1' 3.8964" N and longitude 76° 39' 49.60" E to 76° 44' 15.84" E and covers a total geographical area of 1000 ha (10 km^2). The watershed is a part of the foothills of Shivalik range in the middle Himalayas (Figure 1). The elevation of the watershed ranges from 1,111 m to 1,651 m above mean sea level. The climate is warm and temperate with an average temperature of 19.1°C and average rainfall of 1250 mm. The coldest month of the year is January with an average temperature of 6.7°C and the hottest month of the year is June with a temperature around 39.6°C. The maximum precipitation occurs during the monsoon period extending from July to September. The slope in the watershed ranges from gently sloping to moderately sloping and around 55 percent of the area holds south west facing slopes. Geology of the watershed indicates presence of pre-cambrain period rocks and is a result of complex tectonism and geological evolution. The lithology of the area consists of shale, dolomite, siltstone, phyllite sandstone, limestone, glauconitic sandstone, carb, calcareous slate etc. Mostly Paddy (*Oryza sativa*) is grown in *kharif* (summer) season and wheat (*Triticum aestivum*) in *rabi* (winter) season and majority of the farmers practice low input subsistence organic agriculture.

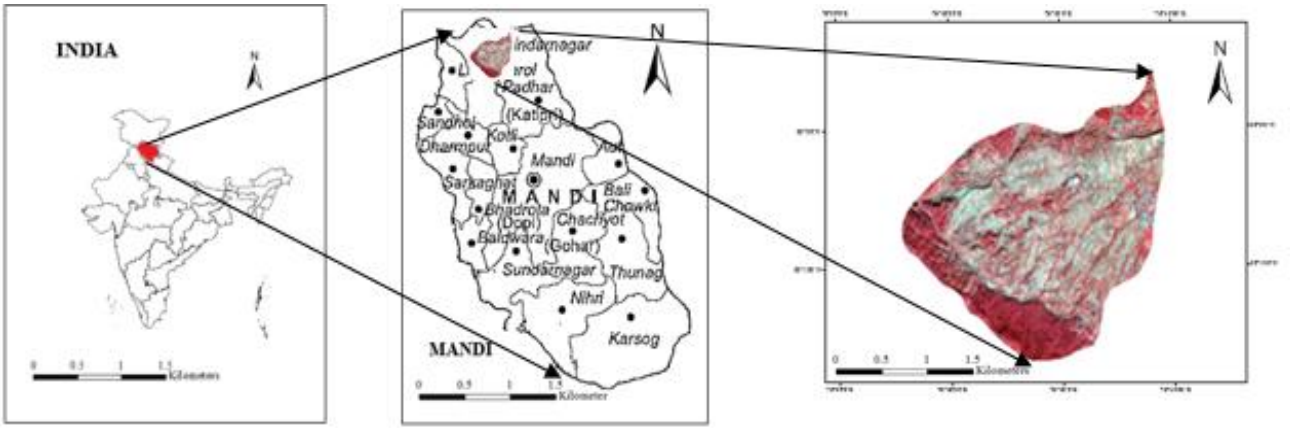


Figure 1. Location of the study area

Soil sampling and laboratory methods

A comprehensive sampling is a crucial step to ensure precise and accurate soil sampling. Grid sampling approach was adopted for soil sample collection, with a grid size of 250 m x 250 m on ground. Survey of India (SOI) topo sheet No. 52 D/12 was used to identify watershed and grids were drawn over Google earth image at 1:10000 scale, for ensuring systematic and well distributed sampling in the field. Using this grid sampling approach, total 150 soil samples (surface i.e., 0-15 cm and subsurface i.e., 15-30 cm) were collected from 75 sampling points, in the fallow period of November 2015. Care was taken to collect soil from exposed portion of field free from any weed growth or litter deposition as well as on or near field bunds. Geographic coordinates as well as elevation of each sampling point were recorded with the help of a portable GPS. The collected samples were air dried in the laboratory and sieved through 2 mm sieve. Air dried 2 mm sieved samples were homogenized and sieved again through 0.2 mm sieve for organic carbon analysis using TOC analyzer, in triplicate (Velmurugan et al., 2009). Similarly 2 mm sieved samples in three replications were homogenized and analyzed for total nitrogen using CHNS analyzer. The other soil parameters such as pH, electrical conductivity (EC), available phosphorus, available potassium as well as soil texture were estimated using standard analytical procedures.

Soil organic carbon (SOC) was estimated using TOC analyzer. Total nitrogen (TN) present in the soil samples were estimated using CHNS analyzer. Processed soil samples were used for estimation of pH and EC (1:2), using pH meter and conductivity meters respectively (Jackson, 1973). Soil texture (sand, silt and clay %) was estimated by dispersing soil samples in distilled water using sodium hexametaphosphate followed by Bouyoucos hydrometer method (Bouyoucos, 1962). Available phosphorus was estimated spectrophotometrically, by extraction of soil samples using Bray No.1 reagent followed by colour development using Murphey-Riley solution (Murphy and Riley, 1962). Available potassium in soil samples were estimated using a flame photometer, after extraction with ammonium acetate solution (Jackson, 1973). The C:N ratio was calculated using the soil organic carbon and total nitrogen contents of soil samples. The SOC values were divided by total nitrogen values to yield C:N ratio values of each soil sampling site.

SOC stratification ratio and soil carbon density

According to Franzluebbers (2002), stratification ratio is defined as the ratio of the value of a soil property at the soil surface to its value at a lower depth. It is generally used as an indicator of dynamic soil quality. In the present study, SOC stratification ratio was determined as the ratio of SOC content (g kg^{-1}) at 0-15 cm depth to that of 15-30 cm depth.

SOC density of each soil layer was estimated using the equation which was used by Schwager and Mikhailova (2002) as well as Wang et al. (2010). We used the upper 30 cm depth for estimation of SOC density, as suggested by earlier researchers like Bernoux et al., (2002), Bhatti et al. (2002) and Wang et al. (2010).

$$D_{oc} = SOC \times \gamma \times H \times \left(1 - \frac{\delta 2nm}{100}\right) \times 10^{-1} \qquad (1)$$

Where D_{oc} and SOC are the density (t ha^{-1}) and content (g kg^{-1}) of soil organic carbon, respectively; γ is the bulk density (g cc^{-1}); H is the thickness of soil layer (cm); and $\delta 2nm$ is the fraction (%) of soil particles with >2mm particle size. Since the soil in the study area was loamy type with particle size mostly below 2 mm, this was not calculated. In this study two different bulk density values were used, as earlier studies in the area (Kumar and Verma, 2005) indicated higher bulk densities in the lower depths, due to impact of various agricultural activities. So we used bulk density values of 1.3g cc^{-1} and 1.4 g cc^{-1} for the surface (0-15 cm) and subsurface (15-30 cm) layers respectively.

Soil Quality Index

For assessing the variation in soil quality, important soil properties like SOC, N, available P, available K, clay % and pH were used for the development of soil quality index.

The SQI was computed by assigning scores and weights to the various selected soil properties. The weights were allocated using AHP and the scores were allocated based on their function towards soil quality. It was computed for the surface soil layer collected from 75 sampling points.

Assigning Weights Using AHP

AHP is a powerful Multi-Criteria Decision Making (MCDM) tool based on mathematics, which enables to organize and analyze complex decisions and ensures consistency in judgment (Saaty, 1977; Mishra et al., 2015). Here the situation under consideration, namely assessment of soil quality index was studied and the criterions were established using AHP. The next and most important step performed is developing ratings for each criterion. It was achieved through pair wise comparison matrix and standardized matrix. The pair wise matrix enables to assign ratings for indicators under consideration and the standardized matrix enables normalization of these values. Then consistency ratio was calculated to check the appropriateness of ratings allocated.

The pair wise comparison in AHP enables allocation of comparative rating between each criterion involved in the study. This was achieved by following Saaty Scale for Pairwise comparison given in Table 1 (Saaty, 2008; Chandio, et al., 2011). Then the values or ratings were normalized through standardization matrix. It was achieved as each value is normalized to the scale of 1 by dividing it with the sum of total values within respective columns. Consistency Index (CI) analysis ensures that the ratings allocated to the indicators are consistent to the situation under consideration. The consistency index (CI) is calculated as

$$CI = \frac{\lambda MAX - N}{N - 1}$$

Where N=total number of criterion, λMAX = priority vector*column sum

Consistency Ratio (CR) is a measure of precision and acceptability of AHP. The value of CR should be less than 0.1 for the weights to be accepted. It is the ratio of CI by RI (Random Index).

$$CR = \frac{CI}{RI}$$

Where, RI is calculated for the number of criteria involved and is predefined by Saaty.

Table 1. The weight and relationship as per Saaty (2008)

Weight for Importance	Relationship
1	Equal Importance
2	Weak or Slight
3	Moderate Importance
4	Moderate Plus
5	Strong importance
6	Strong Plus
7	Very Strong
8	Very Very Strong
9	Extreme Importance

The RI values defined for number of criteria is given in Table 2.

Table 2. RI values against Number of Criteria

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Assigning scores for various indicators

Scoring was done distinctly for different parameters on a scale of 0 to 1 based on their function towards soil quality assessment. For parameters which improve/enhance soil quality with increase in their potential concentration in soil i.e. "more the better" condition, the values were divided by the highest observed value. Similarly for parameters which reduce the soil quality with increase in their concentration i.e. "less the better" condition, lowest observed value was divided by the parameter value (denominator). But for indicator values which follows normal distribution curve like pH, scoring is done as 'higher is better' upto a threshold level (value of 7), then scored as 'lower is better' above the threshold depending on the range into which the indicator value is falling (Andrews et al., 2002; Roy and Kumar, 2014).

Computation of Soil Quality Index (SQI)

Soil Quality Index (SQI) was calculated using the concept proposed by Wu and Wang (2007). It is estimated as summation of the product of weight and score assigned to each parameter or indicator under the consideration.

$$SQI = \sum_{i=1}^{n} (Wi * Si)$$

Where, W is the respective weight and S is the respective score assigned for each soil quality indicator, under consideration.

The values of scores and weights assigned to the respective indicators were multiplied and summed up to yield the SQI value at each sampling locations. The SQI thus generated for all the 75 sampling points were then interpolated to generate spatial distribution map of SQI of the watershed using IDW interpolation technique (Inverse Distance Weighting).

Spatial variation of soil quality parameters and Soil Quality Index

IDW, a widely used interpolation technique (Wang et al., 2010, Gong et al., 2010, Liu et al., 2015) was used for generating spatial distribution maps of SOC content (g kg^{-1}), SOC stratification ratio, C:N ratio as well as soil quality index in the watershed. This technique determines cell values at un-sampled locations using a linearly weighted combination of a set of sample points. It assumes that the variable being mapped decreases in influence with distance from its sampled location (Gong et al., 2010).

Software used and Statistical data analysis

Statistical analysis of soil data was carried out using Microsoft Excel and plots were obtained using R software ver 3.3.1. ArcGIS 10.3 software was used for handling of spatial data. IDW interpolation for spatial mapping of various soil quality parameters was done using ArcGIS 10.3 software. Various descriptive statistical parameters of the data were estimated to capture an idea about its trend. The major parameters estimated were mean, standard deviation (SD), variance, maximum and minimum values. To know the variation among individual observation of each layer coefficient of variation (CV) was calculated as ratio of standard deviation to the mean value. Differences in distribution of SOC at different soil depth layers were assessed by performing one-way ANOVA.

Results and Discussion

Distribution of SOC in the watershed

The various statistical parameters of SOC at two depths (0-15 cm and 15-30 cm) in the watershed are given in Table 3. The average SOC content of the watershed is 11.95 g kg^{-1} up to 30 cm depth. The coefficient of variation (Cv) was observed to be moderately high with values of 35.8 percent and 33.5 percent at 0-15 cm and 15-30 cm depths, respectively. The Cv values in the range 10 to 90 percent denotes moderate variability, thus the SOC have moderate variability in the study area. It indicates heterogeneous spatial distribution of SOC, which may be due to variation in land use, soil depth, terrain characteristics, topography and other factors (Fang et al., 2012).

Table 3. Statistical parameters of various soil quality indicators at different depths.

Soil quality indicators	Depth	Mean	S.D	Variance	Cv (%)
pH	0-15	4.85**	0.26	0.07	5.31
	15-30	5.17**	0.34	0.12	6.64
SOC	0-15	13.42**	4.80	23.08	35.8
	15-30	10.49**	3.51	12.34	33.5
Clay	0-15	3.47**	2.45	5.98	70.59
	15-30	4.67**	3.04	9.25	65.18
Nitrogen	0-15	0.16**	0.04	0.002	24.48
	15-30	0.12**	0.03	0.001	27.48
Available P	0-15	12.89#	3.90	15.21	30.25
	15-30	12.83#	3.70	13.69	28.83
Available K	0-15	127.93#	66.02	4358.76	51.61
	15-30	120.65#	56.65	3209.57	46.96

*** Means are significant at *P <0.01*   # Means are not significantly different

The SOC content varied significantly at depths of 0-15 cm and 15-30 cm depths ($P<0.001$), with average values of 13.42 g kg^{-1} and 10.49 g kg^{-1} respectively. The standard deviation as well as variance was also found to be higher in the surface layer compared to sub surface layer. The distribution ranges of SOC content at these depths are shown in the boxplot (Figure 2). It clearly indicates that SOC content decreased with increasing soil depth. Outlier values at both depths were also identified using the inter quartile range (IQR) relationship. These results are in agreement with the findings of various researchers who reported higher SOC contents at the surface soil in hilly watershed (Wang et al., 2010; Wen et al., 2015), mountainous landscape (Liu et al, 2015), terraced rice fields (Li et al., 2015), erosion affected landscape (Jague et al., 2016), as well as an altitudinal gradient in the mountainous region (Parras-Alcántara et al., 2015). Similar variation of soil organic carbon with depth, has also been reported by Bera et al. (2016), under corn production systems with addition of various organic amendments.

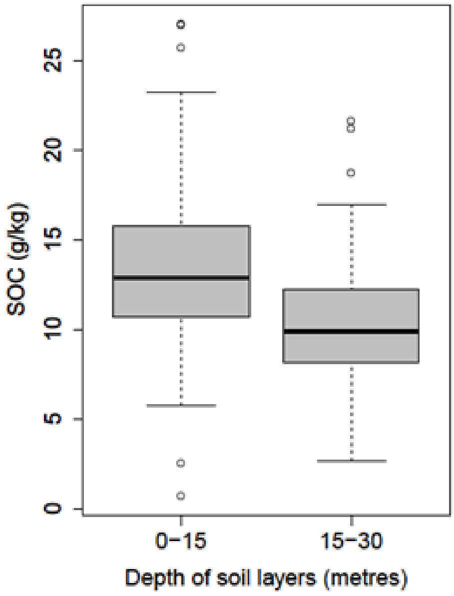
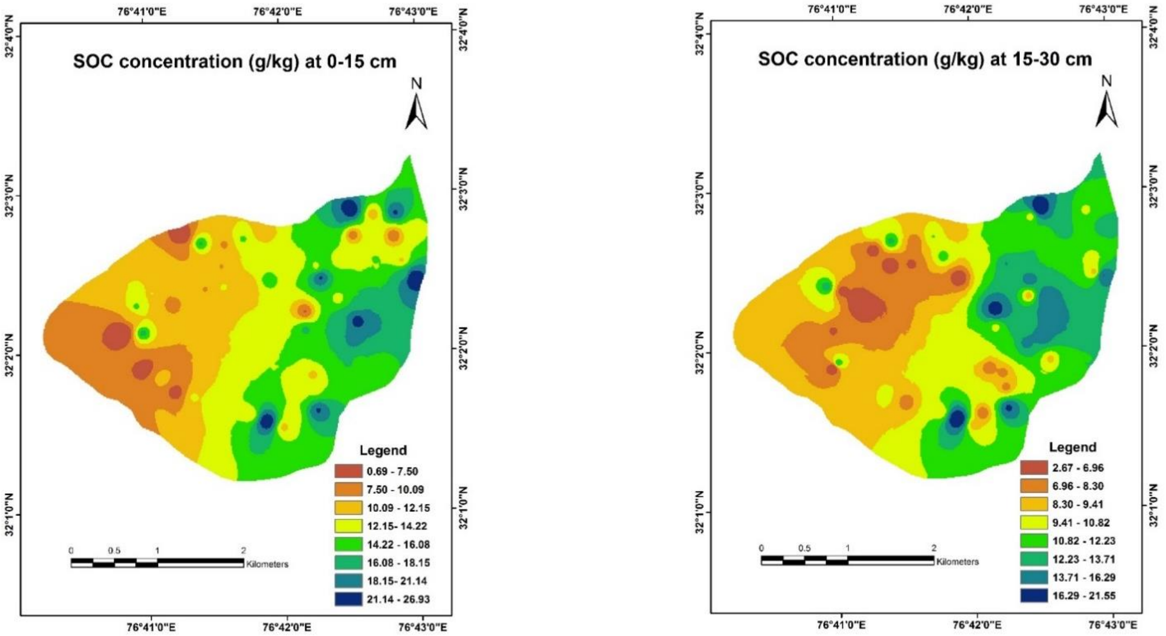


Figure 2. Boxplot showing SOC distribution at different depth layers

Spatial distribution of SOC

Spatial distribution maps of SOC at different depths were generated using IDW interpolation technique (Figure 3). The maps indicated spatial variation in the SOC distribution at both surface and subsurface layers. The maps indicate a gradient in SOC distribution, with lower SOC contents at the west side of watershed which increases gradually towards east. The pattern was evident in both the depths (0-15 cm and 15-30 cm). In the surface layer, nearly 15.48 percent, 56.52 percent and 27.99 percent area were found to have SOC content less than 10 g kg^{-1}, between 10 to 15 g kg^{-1} and more than 15 g kg^{-1}, respectively (Table 4). In the subsurface layer, the area under less than 10 g kg^{-1}, between 10 to 15 g kg^{-1} and more than 15 g kg^{-1} accounted for 50.77 percent, 47.27 percent and 1.96 percent of the total watershed area. This indicates the increased effect of disturbances and interventions in the form of tillage as well as residue addition at the surface layer (Diacono and Montemurro, 2010). The predicted spatial distribution maps were generated using IDW technique and it revealed large spatial variation of SOC content in the study area. Liu et al. (2015) reported lesser error in prediction of SOC by IDW, indicated by lower RMSE values, in comparison with Universal Kriging (UK) technique, in a hilly mountainous terrain.



(a) (b)

Figure 3. Spatial distribution of SOC concentration (a) 0-15 cm and (b) 15-30 cm

Table 4. Area distribution of SOC at different depths in the study area

SOC (g/kg)	Surface (0-15cm)	Subsurface (15-30 cm)
	Area (ha) (%)	Area ha (%)
< 10	154.78 (15.48%)	507.46 (50.77%)
10-15	564.91 (56.52%)	472.48 (47.27%)
>15	279.78 (27.99%)	19.54 (1.96%)

SOC stratification ratio

Stratification ratio is widely used as an alternative tool for soil quality assessment in order to overcome the inherent differences in the capabilities of varied environments for carbon sequestration. It is widely used as an indicator of dynamic soil quality induced by various management practices. It is used as a relative measure than absolute, where the extent of stratification is considered as indicator of soil quality, as surface SOC is vital in controlling erosion, infiltration as well as conservation and release of various soil nutrients (Franzluebbers, 2002). The SOC stratification ratio varied from 0.09 to 3.36 in the study area (Figure 4a). The spatial distribution of stratification ratio was generated by spatial interpolation using IDW method in the entire watershed.

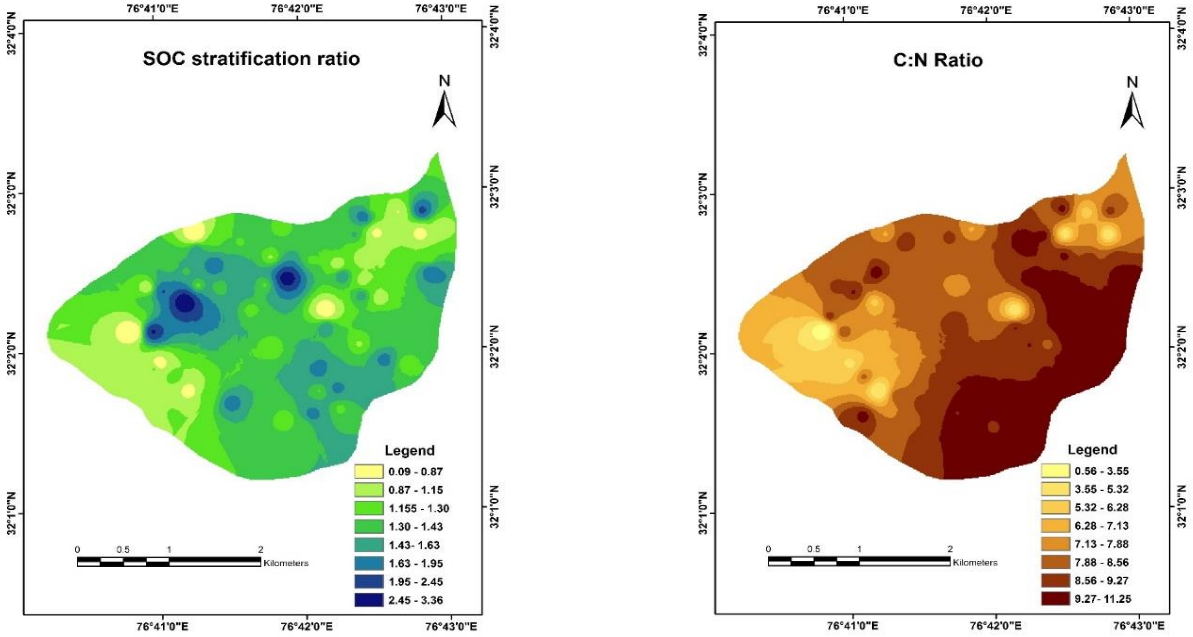
SOC stratification ratio value >2 indicates improvement of soil quality under no tillage (Franzluebbers, 2002). As the present study doesn't deal with no tillage situation, it will be inappropriate to use this threshold value for soil quality assessment. Wang et al. (2010) used a threshold value of SOC stratification ratio > 1.2 as an indicator of improving soil quality, using cropland and orchards as reference. In the watershed under study, nearly 77% area having SOC stratification values > 1.2, thus indicating good soil quality (Figure 4a). The high values of >2 are located at very few localized areas (nearly 1.73% of total area), which might be due to continous addition of farmyard manure (FYM) or organic matter by the farmers practicising subsistence agriculture (Table 5). Those areas with SOC stratification values < 1.2 may need special attention and management strategies for improving soil quality. These areas may be managed with improved addition of manures and crop residues in conjunction with proper incorporation and controlled soil disturbance for sustainable agricultural production.

Table 5. Areal distribution of SOC stratification ratio

SOC stratification ratio	Area (ha) (%)
< 1.2	228.93 (22.91 %)
1.2-2.0	753.19 (75.36 %)
>2.0	17.33 (1.73 %)

C:N Ratio

C:N ratio values varied from 0.56 to 11.25 in the watershed (Figure 4b). The C: N ratio varied as a smooth gradient in the east-west direction, with higher values observed at eastern region. C: N ratio values <12:1, indicated high degree of soil quality and increased rate of organic matter mineralization (Heal et al., 1997). This may be due to the low input organic agriculture including organic manure as well as green manure additions and non-mechanized ploughing (Ryals et al., 2014), adopted widely in the study area. It also indicates the presence of vibrant microbial population capable of adequately decomposing added organic matter and thus releasing the essential nutrients contained in it for plant growth (Diacono and Montemurro, 2010).



(a) (b)

Figure 4. Spatial distribution of (a) SOC stratification ratio (b) CN ratio

Soil Quality Index calculation

Soil quality index was computed using various soil parameters i.e., indicators which have a prominent influence on crop growth and yield. The soil parameters used to compute SQI were SOC, pH, N, clay percentage, available P and available K. The mean values along with the distribution of these soil quality parameters used for SQI development, at different depth layers in the watershed are shown in Figure 5. The weights were assigned to various soil quality indicators based on AHP analysis and are given in Table 6**.** The soil quality indicators for each sampling location were transformed using linear scoring functions, so that each indicator was assigned a score, ranged between 0 and 1. The linear scoring function adopted was based on the concepts of “more is better” and “less is better” or a combination of both. Soil parameters such as SOC, N, K and percent clay, where the higher values were considered better, the highest value of all the indicators received a score of 1, which is the maximum. The scores of all these indicators were then obtained by dividing the corresponding observed indicator values with the highest value. In case of the available P indicator, 'more is better' concept is valid upto a threshold value of 50 kg ha^{-1} (Wander et al., 2002) and thereafter 'less is better' concept was followed. In the study, the available P values were less than the threshold of 50 kg ha^{-1}, thus only the 'more is better' concept was used for scoring. Similar approach including the combination of both concepts was used for scoring the pH values, with the threshold fixed at a pH value of 7.0 (Andrews et al., 2002).

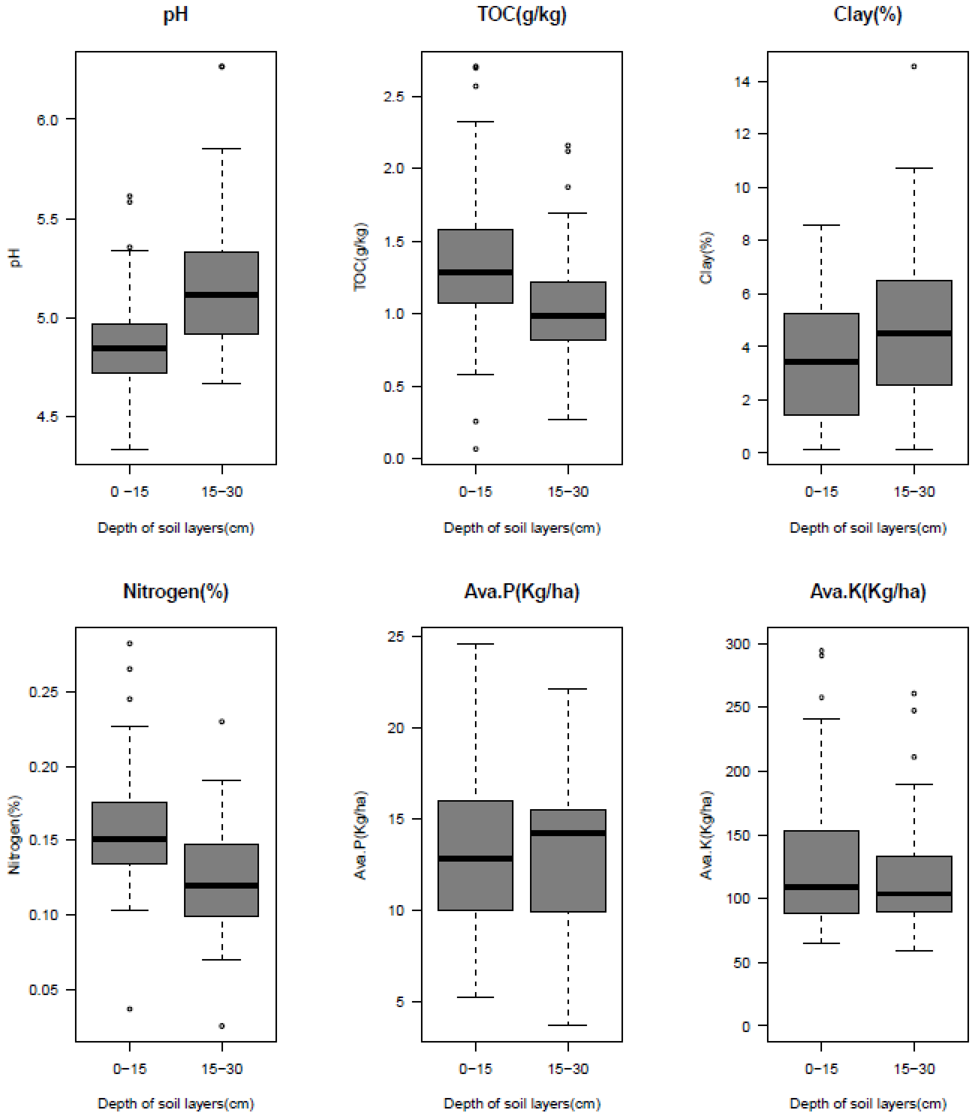


Figure 5. Boxplots showing distribution of various soil quality indicators at different depth layers

Table 6. Weights assigned for various soil properties using AHP

Sl No	Soil Property	Weight (%)
1	SOC	37.5
2	pH	23.1
3	N	16.5
4	Clay (%)	9.3
5	Available P	6.9
6	Available K	6.6

The scores for all the six indicators were multiplied by their corresponding weights (assigned using AHP) and summed up to derive the SQI value for all the 75 sampling points in the watershed. The average SQI value was observed to be 64.5, with the values ranging from a minimum of 47.4 to a maximum value of 87.8, within the watershed. The spatial distribution of SQI within the watershed was also generated by IDW interpolation (Figure 6), which depicted higher SQI values at the higher elevation region of the watershed in comparison to the lower values at lower region. It also indicated a gradient in SQI distribution, with comparatively lower values at the west side of watershed which increased gradually towards east. This may be attributed to the closer proximity to settlement area of farmers, which increased the addition of organic manures and other inputs. In comparison to fields at the higher elevation areas and eastern side of watershed, which are closer to farmer houses, the fields at lower elevation and western side are comparatively far away, which adversely affects the regular addition of organic manures. Nearly 76% of the study area had SQI values in the range of 60-75, whereas 22.16% of the area had SQI<60 and 2.59% had SQI>75 (Table 7). This shows that large area of the watershed had SQI values of 60 percent of the maximum possible value of SQI, which necessitates the adoption of better management practices for improving the soil quality.

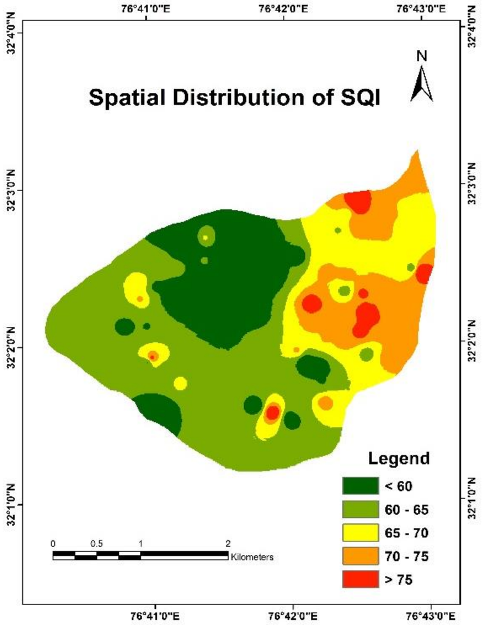


Figure 6. Spatial Distribution of Soil Quality Index (SQI)

Table 7. Areal distribution of SQI values in the watershed

Sl No	SQI range	Area (ha)	Area (%)
1	<60	221.65	22.16
2	60-65	420.90	42.90
3	65-70	181.12	18.11
4	70-75	149.91	14.99
5	>75	25.90	2.59

Conclusion

Understanding and characterizing soil quality is a key issue in sustainable soil and land management. It's inviting greater attention these days due to its key roles in global carbon cycle, mitigation of land degradation, enhancement of crop production and food security. Soil quality parameters as well as soil quality index (SQI) are used to assess sustainable use of land resources. The soils in study area had an SQI value ranging from 60-75 indicating good soil quality throughout the watershed. It indicates that the present land use and cropping pattern followed by the farmers are helpful in maintaining the organic C concentrations in the watershed area. Also, the remoteness of the location and difficult accessibility to improved fertilizers and high yielding varieties restricts the farmers to use the modern agriculture inputs needed for intensive agriculture. They are mainly dependent on the animal manures and composts to supply nutrients to the crop plants which helps to maintain high organic C and hence the high SQI.

However this study gives only a glimpse of the variation in SQI due to land management practices for the Himalayan region. More intensive studies on this aspect will help in generating vital information required for sustainable land use planning and assessing soil quality under various management practices and appropriate nutrient management in fragile ecosystems of hilly area. Also, since North West Himalayan states have great potential for different high value horticulture crops which can be adopted under organic practices these studies would help the policy makers to frame the policies for promoting organic agriculture in the areas because of the intangible benefits of high soil quality and organic C and better income generation of the farmers in these areas.

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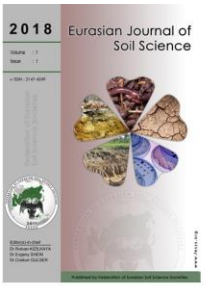

Heavy metal analysis in the soils of in and around Robe town, Bale zone, South Eastern, Ethiopia

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Abstract

The purpose of this study was to assess physicochemical parameter and heavy metal concentration of the soil in and around Robe town, Bale zone, Ethiopia. Seven soil samples (three from dump sites and four from farm lands) were collected and analyzed through different methods for analyzing the physicochemical parameters like, pH Sand/Silt/Clay Content, MC, OM. and the heavy metals including Cr, Cd, Cu, Fe, Zn and Pb, were investigated using Flame atomic absorption spectrophotometer (FAAS). The analyzed result of all sites revealed that, high moisture content % (14.83 ± 2.57to 19.96 ± 0.72), pH slightly acidic except S2 which is slightly basic, (5.77 ± 0.08 to 7.60 ± 0.33),high organic matter % (13.83 ± 0.49 to 16.60 ± 0.90), sand % (53.00 ± 4.51 to 65.33 ± 2.42), silt % (19.33 ± 1.03 to 24.84 ± 4.62), clay % (11.33 ± 1.03 to 19.50 ± 2.50) sandy nature of soil were observed and the concentration of heavy metals such as: Cr (32.53 ± 3.51 to 41.81 ± 1.06) ppm, Cd (0.57 ± 0.21 to 0.93 ± 0.24) ppm, Cu (26.54 ± 0.68 to 37.44 ± 2.72) ppm, Zn (66.98 ± 1.09 to 170.48 ± 1.51) ppm Fe (33483.55 ± 1470.02 to 49012.18 ± 2692.20) ppm and Pb (18.04 ± 0.37 to 20.77 ± 0.46) ppm were obtained. The results showed that all of the assessed heavy metals below maximum permissible limit except Fe, which is above maximum permissible limit that recommended by Ewers, Based on the results obtained from the study the level of metals concentrations safe for agricultural activities. But different measures must be taken to minimize additional soil pollution.

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Introduction

Soil can be defined as unconsolidated minerals or organic material on the immediate earth's surface and it serves as a natural medium for plant growth and other activities (Brady and Weil, 2008). It is one of the important and valuable resources of the nature, which has complex functions beneficial to human and other living organism (Addis and Abebaw, 2014). It also acts as a filter, buffer storage, transformation system and thus protects the global ecosystem against the adverse effects of environmental pollutants (Sumithra et al., 2013). Environmental sustainability largely depends on the availability of soil ecosystem and any alterations as a result of either pollution or contamination that alters the ecosystems and agricultural activities (Hong et al., 2014). Fertile soil and a congenial climate for productivity are valuable assets for any nation. But, due to human activities, soil has become a receptor of many pollutants including pesticides, fertilizers, particulate matters, and heavy metals. Contamination of soils by different pollutants results serious environmental problem and it has significant influence on human health processes (Rahaman et al., 2015).

Heavy metals are metals and metalloids having atomic densities greater than 5g/cm^3. Heavy metals include: copper, iron, mercury, zinc, arsenic, silver, lead, chromium etc. Since heavy metals are not biodegradable; they persist and accumulate over a long time in the soils and vegetation resulting to serious environmental pollution (Mtuazi et al., 2015). Due to natural existence of heavy metals are in soil; high concentrations of

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these metals exhibit chronic effects as well as fatality (Olayinka et al., 2011). Various forms of heavy metals in the soil of greatest concern are the exchangeable and the soluble, because these, are the forms that are available to plants. All negative effects of heavy metals start from their absorption by plants, and to a lesser extent by ground water contamination through leaching. As metals are absorbed by plants, they introduced into the food chain (Dawaki et al., 2013).

In Ethiopia, day to day drastically increases the usage of chemical fertilizers instead of manures for crop productivity but because of chemical fertilizers the quality of the soil is reducing. Therefore, it is essential to analyze the physicochemical characteristics of soil. Results of physical and chemical tests provide the information about the ability of the soil to supply mineral nutrients. The soil condition is an important factor as it is an universal medium for plant growth, which supplies essential nutrients to the plants (Wodaje and Alemayehu, 2014). Soil physicochemical parameters like, soil pH, texture and organic matter contents are important with regards to the forms of the heavy metals and their bioavailability (Aydinalp and Cresse, 2009). On the other side, in developing countries the open dumping strategy is common due to the low budget for waste disposals and non-availability of trained manpower (Ali et al. 2014). The municipal solid waste has been found to contain an appreciable quantity of heavy metals, which may eventually end up in the soil and leach down the profile. This makes municipal solid waste one of the principal sources of heavy metals in the environment (Parameswari et al., 2015). Indiscriminate and unscientific dumping of municipal wastes is very common in many cities of Ethiopian. The present study is an attempt to evaluate and compare the potentially bioavailable concentrations of some principal heavy metals, particularly, Fe, Zn, Cu, Pb, Cr and Cd in some selective farm lands and dumpsites in and around the Robe town, Ethiopia..

Material and Methods

Description of the Study Area

The study was carried out at around Robe town, which is located North-Eastern of Ethiopia, with a latitude and longitude of 7°7′N 40°0′E7.117°N 40.000°E and an elevation of 2,480 meters (8,175 ft) above sea level with average annual rain fall of 1100mm. It has a moderately highland climate with average minimum and maximum temperature ranges of 8 °C and 22°C, respectively (source Robe meteorology station office). The seven sampling points of the study area were randomly selected from dump sites and farm lands, using GPS (global positioning systems) (Figure 1). Site 1, Maddawalabu University farm land; site 2, dump site were found in Maddawalabu University; site 3, dump site were found around Mebrat Hayle; site 4, Radio station dump site; site 5,farm land were found out of the town; site 6, Robe TVET school farm land; site 6, the farm land found around Shaya river.

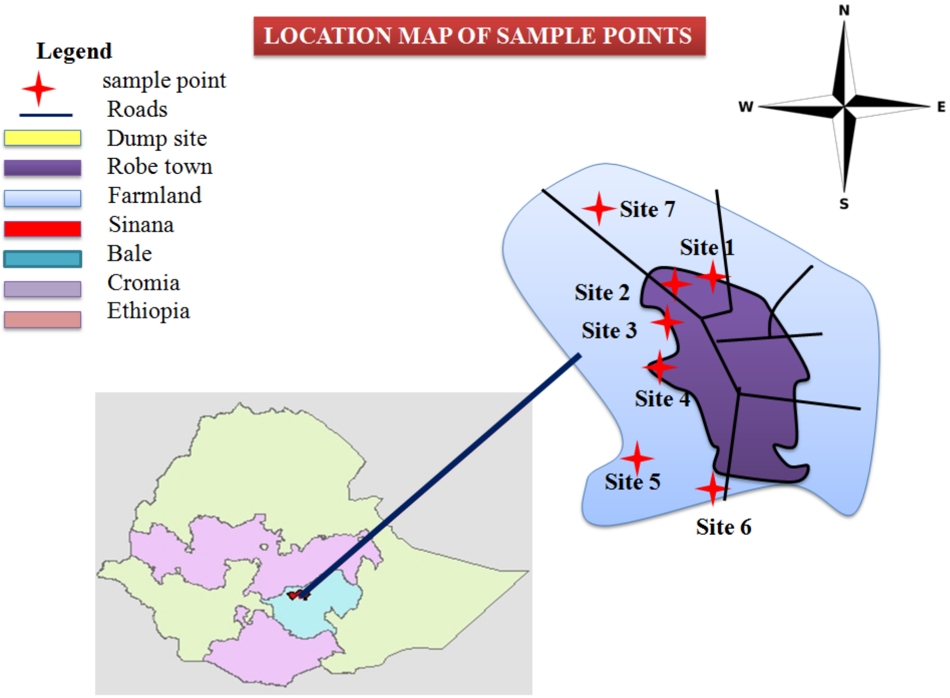

Figure 1. Map of the study area with sampling sites.

Sample Collection

The composite soil samples were collected from each seven sampling sites using Auger from 0-15 cm borehole after the removal of grassy part. Polyethylene bag was used to collect the soil samples. The soil samples were air dried until constant weight were obtained, then grounded with ceramic pestle and mortal and sieved with 2mm sieve. The dried soil samples were kept packed with plastic bag till analysis.

Soil physicochemical analysis

Soil pH was determined using a digital pH meter, according to the methodology suggested by Estefan et al. (2013). Sand/Silt/Clay and moisture content of the soil determined by hydrometer method and Gravimetric method, respectively (Wufem et al., 2014). The organic carbon content of the soil samples were determined by loss on ignition method (Maguire and Heckendorn, 2005).

Soil heavy metal analysis

Heavy metals (Fe, Zn, Cu, Pb, Cr and Cd) in soil samples were analyzed using aqua regia digestion method and determined by flame atomic absorption spectrometer at Ezana mining laboratory as described in the manufacturer's instruction manual after the digestion procedure (Ščančar et al., 2000; Adagunodo et al., 2018).

Data analysis

All the data were captured and entered in to computer and using Microsoft excels statistically using SPSS 16.0. Variation of each parameter between sites was analyzed using one way ANOVA at 95% confidence level were calculated and the results were presented as mean and standard deviation (Mean ± SD).

Results and Discussion

Results of Physicochemical Parameters

The soil samples collected from in and around Robe town were analyzed for five physicochemical parameters.

Moisture content (MC)

As described in Table 1, the moisture contents of all sampling area ranged from 14.83 ± 2.57 to 19.96 ± 0.72 %. Soil collected from dump site (S3) has relatively lower moisture content than the remaining sites but, Soil collected from Robe TVET school farm land (S6) has relatively higher moisture content this may be due to repeated activity of farming. These indicate that the metal ion concentration in Mebrat Hayle dump site might be higher than Around Robe TVET school farm land due to the effect of reducing conditions on the metal ion (Angle et al., 2006). With the exception of S1 the experimental findings of 95% confidence level showed no significant difference between the farm lands. Comparably there was also no significant difference in all dump sites. Similarly, a study evaluated how different combinations of air temperature and soil moisture content, reflecting realistic climate change scenarios, affect the bioaccumulation kinetics of Zn and Cd (González-Alcaraz et al., 2018).

Table 1. Mean ± SD values of the physicochemical parameters of each sampling point (N=6).

Sampling point	Physicochemical Parameters					
	MC %	pH	OM%	Sand (%)	Silt (%)	Clay (%)
Site 1*	15.86 ± 1.93^{b}	6.48 ± 0.04^{a}	13.83 ± 0.49^{a}	53.00 ± 4.51^{b}	24.84 ± 4.62^{a}	22.16 ± 0.75^{c}
Site 2**	17.20 ± 2.37^{a}	7.60 ± 0.33^{b}	16.43 ± 1.87^{a}	65.33 ± 2.42^{a}	23.33 ± 2.06^{a}	11.33 ± 1.03^{a}
Site 3**	14.83 ± 2.57^{a}	6.37 ± 0.34^{a}	15.93 ± 0.81^{a}	61.33 ± 2.42^{b}	24.33 ± 1.96^{a}	14.33 ± 2.33^{b}
Site 4**	17.03 ± 0.83^{a}	6.25 ± 0.25^{a}	14.05 ± 0.63^{b}	57.66 ± 1.96^{c}	25.00 ± 2.75^{a}	17.33 ± 1.63^{c}
Site 5*	18.56 ± 1.35^{a}	5.77 ± 0.08^{b}	16.28 ± 2.40^{b}	61.16 ± 2.56^{a}	19.33 ± 1.03^{b}	19.50 ± 2.50^{b}
Site 6*	19.96 ± 0.72^{a}	6.01 ± 0.32^{b}	14.56 ± 0.49^{a}	61.33 ± 2.42^{a}	24.00 ± 3.79^{a}	14.33 ± 1.96^{a}
Site 7*	19.66 ± 3.88^{a}	6.54 ± 0.17^{a}	16.60 ± 0.90^{b}	62.00 ± 3.57^{a}	24.66 ± 4.50^{a}	13.33 ± 3.01^{a}

*= Farm land, **=Dump site, MC : Moisture content, OM : Organic matter

NB: The mean with the same latter in the same star are not significantly different (P≤ 0.05).

Soil pH

The pH values of the soil samples in all the sites ranged from 5.77 ± 0.08 to 7.60 ± 0.33. This result seems that the soils obtained from all sampling area were slightly acidic except Maddawalabu University dump site which is slightly basic. Since at low pH (acidic) metals are more soluble and more bioavailable in the soil solution, the range of pH values obtained in all study area except site S2 will favors plant uptake of heavy metal and hence toxicity problems are possible (Osakwe et al., 2015). Horeboka farm land shows slightly acidic from the other farm lands; this may be due to application of fertilizer in the farm lands. Apart this soil acidity cause by the removal of basic elements through leaching and crop uptake (Wufem et al., 2014). At 95% confidence level S2 has significant difference from the two remaining dump sites this may be only house hold garbage is dumped in the area. and in farm lands S1 and S7 has significance difference from S5 and S6.

Organic matter (OM) content

The OM contents of all sampling area were ranged from 13.83 ± 0.49 at S1 to 16.60 ± 0.90 at S7. The values obtained from the dump sites did not differ significantly at 95% confidence level except S4, but significant difference showed S1 and S6 with S5 and S7 in farm lands. Brady and Weil (2008) classified organic matter level of soil into classes: < 0.4% organic matter of soil as very low, 1.0 – 1.5% as moderate organic matter soil and > 2.0% as high organic matter soil. Based on this, all the soils may consider under high organic matter. The deposition and decomposition of huge quantities of many organic wastes and sewage sludge might be responsible for the organic matter enrichment in this soil. Apart from this accumulation and subsequent decomposition of plant residues also result in building organic matter (Gairola and Soni, 2010; Ai et al., 2018).

Sand/Silt/Clay Content

As described in table 1 the sand/silt/clay content of the soil ranged from 53.00±4.51 (S1) to 65.33 ± 2.42 (S2), 19.33 ±1.03 (S5) to 24.84 ± 4.62 (S1) and 11.33 ± 1.03(S2) to 19.50 ± 2.50 (S5) present of sand, silt and clay respectively, these indicate that the soil contained higher composition of sand followed by silt and clay in all the sampling sites. The statistical analysis showed that there was significant difference in the sand content between the dump sites, but no significant difference showed in farm lads with exception of S1 were ($P \leq 0.05$). The silt content was also not significantly differ at 95% confidence level except at S5 among the farm lands and not differ significantly in all dump sites, while in clay content S6 and S7 of farm lands sites has significance difference from S1 and S5 but, all dump sites were significantly different at the 95% confidence level. Trace metals have preferential accumulation in the clay and silt fraction of soil, the concentrations of heavy metal in soil increase with decrease in the sizes of the soil particles (Inobeme et al., 2014). This sandy nature of the soil might be due to the depletion of humus from the soil.

Heavy metal concentrations in soil samples

As per results from Table 2, the level of Cr content in different sampling area was ranged from 32.53 ±3.51 (S5) to 41.81±1.06 ppm (S2). The result reveals that the concentration of Cr is higher in dump sites than the farm lands except S4 sampling area. The highest level of Cr content recorded at S2 dumpsite, that may be due to different contaminants such as disposal of Cr containing wastes and the lowest value of S5 which is Horeboka farm land indicates that the place is less polluted due to less existence of anthropogenic activities because the area is far from the dump site and also from the Town. Statistical analysis at 95% confidence level also showed that there was no significant variation in the Cr concentrations among dump sites with the exception of S4. There were no significant variations among all farmland except at S7. High concentration of Cr obtained in S7 from the farm lands might be due to more liquid waste reach the area. The concentration of Cr is in all sites were below the maximum permissible limit (Ewers, 1991).

Table 2. Heavy metal concentrations in soil samples

	Metal concentration of soil sample, ppm					
Sites	**Cr**	**Cd**	**Cu**	**Zn**	**Fe**	**Pb**
S1*	34.90±1.09^{a}	0.88±0.24^{a}	37.44±2.72^{b}	96.41±1.13^{a}	44583.22±3067.42^{a}	19.10±0.65^{ab}
S2**	41.81±1.06^{a}	0.93±0.24^{a}	37.06±2.10^{b}	170.48±1.51^{a}	49012.18±2692.20^{a}	19.43±1.98^{b}
S3**	41.47±1.57^{a}	0.67±0.22^{a}	28.54±1.00^{a}	83.67±1.93^{b}	36482.75±1838.83^{b}	20.77±0.46a
S4**	34.77±4.90^{b}	0.76±0.22^{a}	27.69±0.86^{a}	74.05±8.09^{c}	33483.55±1470.02^{c}	20.51±0.85^{ba}
S5*	32.53±3.51^{a}	0.57±0.21^{c}	26.54±0.68^{a}	72.79±3.30^{b}	33973.75±1320.36^{b}	18.04±0.37^{a}
S6*	32.91±1.43^{a}	0.79±0.26^{ac}	27.93±1.03^{a}	66.98±1.09^{c}	35753.48±340. 31^{b}	19.64±0.64^{b}
S7*	35.49±0.84^{b}	0.84±0.13^{a}	34.35±1.59^{c}	97.01±2.69^{a}	45008.2±1665.74^{a}	16.08±0.32^{c}
Ewers (1991)	100	3.00	100	300	5000	100

**=dump site, *= farm lands

NB: the mean with the same latter in the same star are not significantly different (P≤ 0.05).

The Cd content was the lowest at S5 while the highest at S2 with the mean values that ranged from 0.57 ± 0.21 ppm to 0.93 ± 0.24 ppm, respectively. The lowest concentration of S5 might be due to no waste disposal in the area. The highest Cd content recorded in site S2 might be due to disposal of impurity in several products, including phosphate fertilizers, detergents. The statistical analysis using one way of ANOVA at 95% confidence level showed no significant difference in the concentrations of cadmium among in all dump sites, and also with the exception of S5 no significant difference was showed among the farm lands. The concentration of Cd in all sampling area shows below the maximum permissible limits that recommended by Ewers.

The value of Cu in soil content is highest at S1 with mean value of 37.44 ± 2.72 ppm while the lowest at S5 with mean value of 26.54±0.68 ppm. The one way ANOVA analysis showed that there are not significantly differ within the dump sites except S2, and also except S1 with S7 no significance difference showed within the farm lands. The highest value of Cu in S1 might be derived from chemical fertilizers and pesticides used in agricultural land. Concentrations Cu of in all seven sites are below the maximum permissible agricultural soil concentration recommended by Ewers (1991).

The Zn content was lowest at S6 the mean value was ranged from 66.98 ± 1.09 ppm while highest value is observed at S2 the mean value ranged of 170.48 ± 1.51 ppm at the 95% confidence level indicated that there was statistically significance difference among all dump sites and also among farm lands except S1 with S7. The higher Zn content in S2 is recorded might be due to repeated activity of waste combustion and dumping of pesticide can. While the lowest value of S6 recorded might be due to less existence of anthropogenic activities. The level of Zn concentration observed in all sites was below the maximum permissible that recommended by Ewers. The level of Fe content in different sampling sites was ranged from 33483.55 ± 1470.02 ppm of S4 to 49012.18 ± 2692.20 ppm S2. The one way ANOVA analysis showed that S1 and S7 are significantly different from S5 and S6 in farm lands and also in all dump sites at the 95% confidence level, this might be because of the same contaminant reach S1 with S7 and S5 with S6 due to the area were not far each other. High concentration of Fe in Maddawalabu dump site might be due to high discharge and burning of cosmetics material, thin and cans. While relatively less in the others. The experimental value of Fe concentration from all sites was far higher than the maximum permissible agricultural soil concentration recommended by Ewers.

The value of Pb in sampling area was ranged from 18.04 ± 0.37 ppm to 20.77 ± 0.46 ppm, the lowest value observed in Horeboka farm land while the highest value observed at Mebrat Hayle dump site. There was no significant difference in concentration of Pb across the farm lands except S7 and also dump sites except S3 with S4 at 95% confidence level. The lowest value of S5 might be due to less existence of anthropogenic activities in area, while the highest value of S3 might be due to disposal of more wastes from garages and combustion of fossil fuels. The levels of Pb obtained in the soil from all site below the maximum permissible limit of agricultural soil concentration that reported by Ewers (1991). The obtained results showed that the metal concentration decreased in the order of Fe > Zn > Cr > Cu > Pb >Cd, in both dump sites and farm lands. From the analyzed metals, the concentration of most metal were higher in dump site than the farm lands except radio station dump site, lower concentration of this site might be due to less and only domestic waste were dumped in the area. Generally, in dump sites disposal of high metal wastes, sewage sludge and waste combustion might be responsible for high concentration of metal.

Conclusion

The present study showed that the results obtained from the physicochemical analysis of all soil samples were slightly acidic except S2 which is slightly alkaline and contained high amounts of organic matters and sandy nature of soil followed by silt and clay content. The results of heavy metals indicated that, they are in lower concentrations in all sites than of the maximum permissible limit reported by Ewers with the exception of Fe. Finally, based on the results, we concluded that the obtained level of metals concentrations was low in all sites and safe for agricultural activities. But, researchers reported there is an indication that heavy metals are not biodegradable, while they are accumulated in the environment (Mtuazi et al., 2015); it may detoriate the soil quality. Therefore we recommended that Different measures must be taken to minimize soil pollution; the farmers should be educated on the problems associated with excessive usage of fertilizers and other chemicals. New modern sanitary landfill need to be developed thus the open dumping of waste should be discouraged and proper drainage should maintain for liquid wastes. Periodic monitoring of soil environment for heavy metals in the study area is recommended and in future, further study should be done to investigate the levels of different heavy metals, common cations, sediment concentrations, and other soil physicochemical parameters of the soils in the study area.

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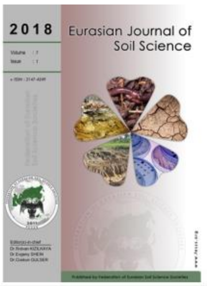

Irrigated common bean (*Phaseolus vulgaris L.*) performance on calcareous alkaline soils as influenced by previous crops in North of Sudan

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Abstract

This study examines the ability of different cropping sequence (including or not including alfalfa) to improve bean productivity in calcareous and alkaline soils of the old Nile (high) terraces in North of Sudan. The soil in the experimental site is sandy clay to sandy clay loom. Soil properties were examined before planting and after bean harvest. Salinity which was greater in non-reclaimed soil decreased regardless of the cropping sequence. Soil alkalinity remain higher than 8 in all cropping sequence after more than 6-7 cropping seasons. P (Olsen) and calcium carbonate showed inconsistent trends regardless of the cropping sequence. Organic carbon increased after bean cultivation in both cropping sequence. Change in growth parameters as affected by cropping sequence were significant in various levels, however, that determining yield were not. Presence of alfalfa in the cropping sequence increased seed yield, number of pods per plant, number of seeds per pods, pod length, plant length, leaf length, leaf width, fresh plant weight, nodule number. However seed weight was decreased.

Keywords: Alfalfa, calcareous soils, common bean, cropping sequence, Sudan.

Introduction

Common bean (*Phaseolus vulgaris L*) is one of the most favorable grain legumes valued for its nutritional value, especially its high protein content (20- 25%). The crop also has the ability to maintain soil fertility through biological nitrogen fixation, and thus may be required to maintain soil productivity.

In Northern Sudan Common bean is conventionally competing for areas where fertile soils of the recent terrace of the Nile alluvial are available. It mostly grown under pump irrigation or river flood recession areas during the winter season. The limited areas of these types of soils can no longer being available to satisfy the increasing domestic demand for cool season legumes including common bean. Most soil resources in Northern states of Sudan are available in the old Nile (high) terraces. As desert soils, they exhibit low nutrient levels with a high trend of nutrient deficiency due to their fragile nature (Elhagwa, 2011). Newly reclaimed desert soils exist in Northern Sudan are usually sandy or calcareous in nature or, some time, saline-sodic when there is high content of reactive clays. In both cases, it exhibits high pH values (Elhagwa et al., 2007; Ibrahim et al., 2013) .

Calcareous soils are common in arid and semi-arid climates affecting over 1.5 billion acres of soil worldwide. Calcareous soils are identified by the presence of the mineral calcium carbonate ($CaCO_3$ or lime). The pH of these soils is usually above 7 and may be as high as 8.5 (Ceyhan et al., 2014). When these soils contain sodium carbonate, the pH may exceed 9. Yet these types of soils can be extremely productive for agricultural use when they are managed properly. Limited availability of phosphorus and micronutrient are often the most limiting factor for plant growth in alkaline and calcareous soils. A series of fixation reactions occur that

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gradually decrease the solubility and availability of these nutrients to plants even if applied to the soil in solvable forms (Leytem and Mikkelsen, 2005).

Inoculation of legume crops with nitrogen-fixing soil bacteria, collectively known as rhizobia, has been widely used to improve legume productivity in fields. Problems of establishment of the introduced inoculants were frequently encountered by several edaphic factors, such as soil chemical and physical conditions. However, improvement of biological N fixation is widely reported by decreasing soil alkalinity and improvement of P availability (Attar et al., 2012).

Michiels et al. (1998) investigated the symbiotic relationship between common bean and approximately 100 tropical rhizobium strains in Amazon region. More than 90% of the strains tested induced nodules or nodule-like structures on the bean cultivar, 32% of which reduced atmospheric nitrogen. These results deny the assumption that common bean bears a poor symbiotic relationship with rhizobia, and confirm the other that it is a non-selective host for nodulation.

Alfalfa is a widely grown fodder legume known to perform well on recently reclaimed calcareous soils and have the ability of nitrogen fixation and removing of high amounts of calcium from calcareous soils, It usually remain for more than three years as productive fodder crop. It is roots and litter residues usually recommended to improve soil chemical and physical properties. This study was conducted to investigate alfalfa effect on soil properties as a soil reclamation crop and common bean performance as a subsequent crop.

Material and Methods

Experimental site and design

An on field experiment was conducted at food security scheme, Ed Damer in River Nile State, Sudan during 2015/16 and 2016/17 winter seasons. The field is situated at 17°32' N latitude and 33°59' E longitude. The climate of the area is an arid to marginal semiarid. The present investigation was carried out on desert moderately calcareous loamy soil classified as Aridisol (Buursink, 1971) which is usually found in the new agricultural fields of third (high) terrace of the Nile. Seeds of local popular cultivar Berber of *Phaseolus vulgaris* (L) were sown on the first week of November on 70 cm ridges and 20 cm within row spacing. Two seeds were sown per hole. Experiment was laid out in randomized complete block design with three replications with larger plot size 6X7 m to represent similar farmer conditions. Di-ammonium phosphate fertilizer was added as starter doze at rate of 100 Kg/ha. Pendamate and Persuit (pendimethalin and imazythapyr) were sprayed before watering for control of both broad leafed and monocot weeds as recommended.

The experiment treatments was laid out as indicated in Table 1.

Table 1. The experiment treatments

Treatments	Cropped bean plots
T_1	On reclaimed soil with crops including alfalfa
T_2	On reclaimed soil with crops not including alfalfa

Analysis of soil properties

The soil in the experimental site was sandy clay to sandy clay loom. Soil samples were collected from 0-20 cm depth in two different periods: initial (before bean cultivation) and final (after bean harvesting in the first season) from three sites representing non reclaimed soil, reclaimed and cropped soil with crops not including alfalfa and reclaimed soil with crops including alfalfa.

Available soil phosphorus was extracted with $NaHCO_3$ then acidified and determined calorimetrically after treating with ammonium molybdate at a wavelength of 660 nm, according to Olsen method by PG – T 60 spectrophotometer (UK) adapted by Patel and Ladawala (2013). Some of the physical and chemical characteristics of the soil at the experimental site shown in Table 2 were analyzed as indicated by Estefan et al. (2014).

Measurement of growth and yield parameters

Ten plants were randomly selected for the measurement of various morphological growth parameters (shoot length, leaf width and length, number of root nodules, root and shoot dry weight) and yield parameters (pod length, number of seeds/pod, number of pods/plant and 1000 seed weight) were determined at and after harvest. The results were statistically analyzed using Analysis of Variance and means were separated with LSD using the computer program SAS (2003).

Results and Discussion

Analysis of soil revealed slight change in soil properties with various cropping system of soil reclamation. As indicated in Table 2 salinity which was greater in non-reclaimed soil (1.5 d Sm^{-1}) was decreased to (0.2 - 0.4 d Sm $^{-1}$) regardless of the cropping sequence. Soil alkalinity expressed as pH range was 9.23 in non-reclaimed soil and remain higher than 8 in all cropping sequence after more than 6-7 cropping seasons, although both Na and SAR within non harmful range. The relationship between P (Olsen) and calcium carbonate showed inconsistent trends as both of them were high in non-reclaimed soil sample, however, P showed higher levels and calcium carbonate showed moderate levels in cropping sequence with alfalfa before bean cultivation and P with low levels and carbonate different levels before and after bean cultivation in cropping system with no alfalfa.

Table 2. Soil analysis

	pH	EC, dSm^{-1}	CaCO$_3$, %	Na, Mmol.L^{-1}	SAR	Sol. K, mmol L^{-1}	Olsen-P, mg kg^{-1}	Org.C, %	Sand, %	Silt, %	Clay, %	Textural Class
1	9.23	1.5	10.3	0.05	0.018	o.o3	20	0.25	56	10	34	SCL
2	8.01	0.4	8.4	0.02	0.009	0.03	5	0.68	52	14	34	SCL
3	8.11	0.2	8.7	0.02	0.009	0.03	8	0.75	49	14	37	SC
4	8.07	0.9	8.4	0.05	0.016	0.03	19	0.40	47	8	45	SC
5	8.13	0.8	10.9	0.05	0.015	0.03	5	0.40	52	14	34	SCL

1- Non reclaimed soil

2- Three seasons wheat, 3 years alfalfa, one season fodder sorghum, soil sample taken after growing common bean

3-Three seasons wheat, one season fodder sorghum, one season tomato, one season faba bean, one season fodder sorghum, soil sample taken after growing common bean

4- Three seasons wheat, 3 years alfalfa, one season fodder sorghum, soil sample taken before growing common bean

5-Three seasons wheat, one season fodder sorghum, one season tomato, one season faba bean, one season fodder sorghum, soil sample taken before growing common bean

Organic carbon revealed higher values after bean cultivation in both cropping sequence (T$_1$ and T$_2$) compared to other sampled soils. Observation of growth and yield parameters revealed that absence of alfalfa from the cropping sequence reduced yield, number of pods per plant, number of seed per pods, pod length, plant length, leaf length, leaf width, fresh plant weight and nodule number. Seed weight (1000 seed weight) were greater where alfalfa was absent from the cropping sequence (Table 3 and 4). The effect on growth parameters was significant in various levels with the exception of leaf width in the first season, however, it was not significant in yield parameters with the exception of pod length in both seasons and seeds /pod in the first season.

Table 3. Performance of common bean (Phaseolus Vulgaris L.) yield and yield components under different soil reclamation means using different cropping sequence over two seasons

Treatments	Yield, kg/ ha		1000 seed weight, g		Pods/ plant		Seeds/ pod		Pod length, cm	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
T1	1801	1330.7	301.7	304.7	26	19	6.1	9.3	9.17	9.3
T2	1598	1262.0	310.7	301.3	24	17.7	5.94	8.4	7.8	8.4
Mean	1699.5	1296.4	306.2	303	25	18.4	6	8.9	8.5	8.9
Cv %	2.01	5.6	14.2	1.4	4.90	23.6	.68	1.4	3.37	1.4
Sig. level	NS	NS	NS	NS	NS	NS	NS	*	*	*
LSD	847.8	255.7	21.7	14.34	4.3	15.5	.15	0.43	1.004	0.43

T1 On reclaimed soil with crops including alfalfa

T2 On reclaimed soil with crops not including alfalfa

Table 4. Common bean (Phaseolus Vulgaris L.) growth parameters performance under different soil reclamation means using different cropping sequence

Treatments	Plant length, cm		Leaf length, cm		Leaf width, cm		Fresh Plant weight,g		Nodule No.	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
T1	88	84.3	11.57	10.5	7.7	7.3	472	378	12.3	11.6
T2	45.3	56	8.6	8.6	7.13	5.8	304	292.7	2.3	2
Mean	66.7	70.2	10.1	9.6	7.4	6.6	388	325.4	7.3	6.8
Cv %	9.02	7.3	7.76	5.1	19.08	3.8	1.90	6.9	9.64	15.8
Sig. level	**	*	*	*	NS	*	**	*	**	**

Results from this study indicated substantial improvement in soil properties including soil reaction and salinity after applying amendment treatments. The added organic mulch biomass from the different crop residues likely led to enhanced nutrient mineralization and subsequent uptake of nutrients by the growing bean crop. However, the relationship between biomass production and seed yield was not consistent, as good growth obtained by T_1 dos not reflected in similar significant seed yield increase by T_2 treatment. Although biomass production is closely related to yield, this relationship may be difficult to establish in legumes including bean. This suggest that reduced above ground growth in T_2 bean treatment mean that larger amount of assimilates were directed to seed production and although pod number and length is rather smaller, seed weight was rather greater compensating some of yield difference.

Vargas and Graham (1988) found a large variation in the number of nodules on bean roots and reported that this was mostly dependent on the genotype. They observed that the number of nodules ranged from 0 to 190 per plant. Increased number of root nodules in T_1treatment, suggested that alfalfa as soil amendments for bean cultivation is of comparative advantage in establishment of nitrogen-fixing bacteria in bean cultivation leading to an improved soil physical and chemical environment for rhizobium activity.

Conclusion

In calcareous and alkaline soils, phosphorus and micronutrients unavailability usually affect negatively bean productivity. Cropping systems is particularly good mean for desert soil reclamation, it can be used for improving soil for maximum crop productivity with minimal financial and environmental cost in comparison to chemical reclamation means. The relatively higher productivity by the cropping sequence including alfalfa treatment may be due to the improvement of physical, chemical and biological properties of the soil.

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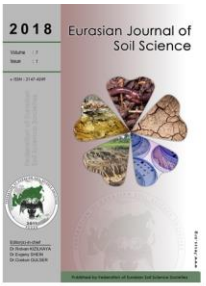

Physico-chemical characterization of Oak, Pine and Sal forest soil profiles of Betalghat Region of Kumaun Himalaya

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Abstract

Soil is one of the basic natural resources on which all forms of terrestrial life co-exist. The soils of three forest types i.e., banj-oak (*Quercus leucotrichophora* A. Camus) chir-pine (*Pinus roxburghii* Sargent) and sal (*Shorea robusta* Gaertn. f.) of Betalghat block, Nainital District, (Kumaun Himalaya). Soils were drawn from three depths viz. 0-10 cm, 11-20 cm, 21-30 cm. The present study were studied resulted to soil physico-chemical properties i.e. maximum soil texture (sand 34.30 %, silt 57.21 % and clay 33.23 %), soil moisture (12.6 %), bulk density (1.43 g.cm^{-3}), porosity (52.06%), water holding capacity (69.27%) and the maximum values of chemical analysis i.e. pH (6.80), total carbon (3.82 %), organic matter (6.57 %), total nitrogen (0.36 %), available potassium (267 mg/kg) and available phosphorous (62 mg/kg). Banj-oak forest shows rich physical properties followed by sal and chir-pine forest while chir-pine forest shows rich chemical properties in compared to sal and banj-oak forest.

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Keywords: Soil physico-chemical characterization, Betalghat region, banj-oak, chir-pine, sal forest, Kumaun Himalaya.

Introduction

Physico-chemical characteristics of forest soils vary in space and time because variation in climate, topography, weathering processes, vegetation cover and several other biotic and abiotic factors (Paudel and Sah, 2003; Sheikh and Kumar, 2010). Forest soil influenced the composition of forest stand and ground cover, rate of tree growth (Bhatnagar, 1965). The vegetation influences the physico-chemical properties of the soil to a great extent. It improves the soil structure, infiltration rate and Water Holding Capacity and aeration (Ilorkar and Totey, 2001; Kumar et al., 2004; Champan and Reiss, 1992). The nutrient thus, returned in the soil, exerts a strong feedback on the ecosystem processes (Pastor et al., 1984). Plants are the main source of soil organic matter, which influences the physico-chemical characteristics of soil such as, texture, pH, water holding capacity and nutrients availability (Johnston, 1986). The nature of soil profile, pH and nutrient cycling between the soils and plants are the important dimensions to determine the forest site quality. The forests of central Himalayan region have vast variations in the topography, climate and soil conditions, which form a complex ecosystem. Since, the vegetation zones in this region clearly reflect climatic and edaphic variations (Bhatt and Purohit, 2009; Bhatt, 1981) and at the same time the knowledge of physical and chemical properties of soils and climatic conditions of different forest types of temperate region of central Himalaya is meagre.

In the Western Himalayan region (Uttarakhand, India), Oak (*Quercus leucotrichophora* A. Camus) and Pine (*Pinus roxburghii* Sargent) are the two major forest types spread over a large part of the forested landscape. Oak is a deep-rooted and moderate-sized evergreen tree that occurs in the moist and cool aspects in the

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lower Western Himalayan temperate forest between altitudes 1000 to 2300 m asl (Singh and Singh, 1987; Joshi and Negi, 2015). Pine is a shallow-rooted and large evergreen conifer and a principal species of the Himalayan subtropical forests, which occurs between 800 to 1700 m asl (Champion and Seth, 1968).

Sal (*Shorea robusta* Gaertn. f.) belonging to the family Dipterocarpaceae is one of the most important timber trees in India (Deka et al., 2012; Sapkota et al., 2009). Sal forest is widely distributed in tropical India and covers approx. 13.30 per cent of the total forest area of the country (Satya and Nayaka 2005). As per Champion and Seth (1968) it is one of the dominant tree species in the tropical moist as well as dry deciduous forests in India. Some previous studies about physico-chemical characterization of soil were also done by researchers in various forests of Kumaun and Garhwal Himalaya (Joshi and Negi, 2015; Khera et al., 2001; Singh et al., 2009; Semwal et al., 2009; Sharma et al., 2010; Jina et al., 2011; Gairola et al., 2012; Kumar et al., 2013; Joshi, et al., 2013; Mehta et al., 2014; Upreti et al., 2016; Tewari et al., 2016; Bharti, et al., 2016). Present study is focused on the comparison of soil physico-chemical profiling of three different forest types (Oak, Pine and Sal) of Betalghat region of Kumaun Himalaya, Uttarakhand.

Material and Methods

Study area

The Present study was carried during the year 2017 in Betalghat region of Nainital district lies between $29^0 38'925''$ N and $79^0 49'465''$ E, covering an area of 256.33 Km^2 with an altitudinal range from 700 to 1800 m asl. The region is bounded by Tarikhet and Bhikyasain block of Almora district on the north, Kotabag block of Nainital district on the south, Sult block of Almora district on west and Ramgarh block of Nainital district on the east. The vegetation of the region mainly comprises of tropical, sub-tropical and temperate forest.

Collection of soil samples

Soil samples were collected from three dominated forest types i.e. banj-oak, chir-pine and sal forest of Betalghat region, Nainital District of Kuamun Himalaya.Samples were collected from three different depths with core viz., (i) upper (0–10 cm), (ii) middle (11–20 cm) and (iii) Lower (21-30 cm) for assessing the physico-chemical profiling of the soil. Soil sample was packed in a separate labelled plastic zipper bags and transported to the laboratory for further analysis. The soil samples were oven dried at 45 °C for 24 h to reduce the moisture. The detailed description of studied sites was given in Table1. Analytical procedure for soil physico-chemical characterization was done by various methods viz., soil texture (sieve method) (Piper, 1966), soil moisture (Jackson, 1958), water holding capacity (Piper, 1950), soil bulk density (gcm^{-3}) (Black, 1965), soil porosity (Gupta and Dhakshinamoorthy, 1980), pH (Jackson, 1958), soil organic carbon by wet digestion method (Walkley and Black, 1934), total nitrogen by Kjeldahl digestion method (Kjeldahl, 1883), available phosphorus by 0.5 M $NaHCO_3$ (pH 8.5) extraction method (Olsen and Sommers, 1982), available potassium by 1 N NH4OAc (pH 7.0) extraction method (Black, 1965). Soil chemical properties were performed by soil testing laboratory (Uttarakhand Tea Development Board, Almora) situated at Bhowali, Uttarakhand.

Table 1.Detail description about study sites

Site	Forest Types	Altitude (m asl)	Latitude	Longitude
KP	Banj-oak	1800	29° 29' 366'' N	79° 24' 240'' E
HG	Chir-pine	1400	29° 28' 151'' N	79° 27' 444'' E
SM	Sal	700	29° 32' 870'' N	79° 15' 912'' E

Statistical analysis

The data were analyzed by Analysis of Variance (ANOVA) and the means were compared by Duncan tests at a level of significance of $p < 0.05$ using SPSS 22.0 statistical software, to see the level of correlation between different soil parameter, Pearson's correlation matrix was performed while for Cluster analysis, Ward's method was applied.

Results and Discussion

Soil physical characterization

Soil is an essential component of our ecosystem, as it serves as an anchorage and source of nutrients for plants. Thus it is the seat, the medium and fundamental raw material for plant growth and maintenance of forest ecosystem by different ecological processes. Among the three forest types percentage of sand ranged from 20.17 to 34.30 whereas silt ranged from 40.37 to 57.21 and percentage of clay ranged from 22.25 to 33.23. Soil moisture content ranged from 4.60 to 12.6. Bulk density ranged from 1.25 to 1.43. The percentile of porosity ranged from 45.15 to 52.06 and maximum percentage of water holding capacity ranged from 33.90 to 69.27 (Table 2).

Soil chemical characterization

Among the three forest type pH ranged from 5.57 to 6.80. Total organic carbon ranged from 1.72 to 3.82. Organic matter ranged from 2.96 to 6.57. Total nitrogen content ranged from 0.15 to 0.36. Potassium ranged from 93 to 267 whereas phosphorus ranged from 25 to 62 (Table 3). Nitrogen, phosphorous and potassium are referred to as the primary macronutrients of soil and most important to provide the vitality and performance of plant grown. A comparative analysis of soil physico-chemical properties of oak, pine and sal forest in different parts of the region studied by various workers is given in Table 4.

Correlation among soil physico-chemical properties

In Banj-oak forest on the basis of correlation matrix sand, carbon and phosphorous showed maximum positive correlation with four physico-chemical properties. Sand with potassium, carbon, organic matter and phosphorus. Carbon with phosphorus, sand, potassium and organic material. Phosphorus with sand, potassium, carbon and organic material while water holding capacity show maximum negative correlation with sand, potassium, carbon, organic material and phosphorus while in Chir-pine forest carbon showed maximum positive correlation five physico-chemical properties viz. sand, clay, potassium, organic matter, nitrogen while water holding capacity showed maximum negative correlation with four physico-chemical properties viz. sand, potassium, carbon and organic material and in Sal forest silt, c:n ratio, potassium, carbon and nitrogen showed maximum correlation with all physico-chemical properties. Silt with c:n ratio, potassium, carbon, organic matter and nitrogen. c:n ratio with silt, potassium, carbon, organic material, and nitrogen. Potassium with silt, c:n ratio, carbon, organic material and nitrogen. Carbon with organic material, nitrogen, silt, c:n ratio and potassium. Nitrogen with silt, c:n ratio, potassium, carbon, and organic material while clay showing maximum negative correlation with silt, c:n ratio, potassium, carbon, organic material and nitrogen (Table 5, 6, 7).

Cluster analysis for physical properties

Cluster analysis of sand showed three clusters, cluster I (four sites), cluster II (three sites) and cluster III (two sites). While silt showed four clusters, cluster I (three sites), cluster II (three sites), cluster III (two sites) and cluster IV (one site), clay showed four clusters, cluster I (four sites), cluster II (two sites), cluster III (one site) and cluster IV (two site), moisture content showed four clusters, cluster I (three sites), cluster II (three sites), cluster III (two site) and cluster IV (one site), bulk density showed three clusters, cluster I (three sites), cluster II (three sites) and cluster III (three site), porosity showed three clusters, cluster I (three sites), cluster II (three sites) and cluster III (three site) and water holding capacity showed five clusters, cluster I (three sites), cluster II (Two sites), cluster III (One site), cluster IV (Two site) and cluster V (one site) (Figure 1).

Cluster analysis for chemical properties

Cluster analysis of pH showed five clusters, cluster I (three sites), cluster II (Two sites), cluster III (One site), cluster IV (Two site) and cluster V (one site). While carbon showed four clusters, cluster I (three sites), cluster II (Two sites), cluster III (One site) and cluster IV (three site), organic matter showed four clusters, cluster I (three sites), cluster II (Two sites), cluster III (One site) and cluster IV (three site), nitrogen content showed four clusters, cluster I (three sites), cluster II (two sites), cluster III (three site) and cluster IV (one site), c:n ratio showed four clusters, cluster I (four sites), cluster II (one sites), cluster III (two site) and cluster IV (Two site), potassium showed four clusters, cluster I (two sites), cluster II (three sites), cluster III (two site) and cluster IV (Two site) and phosphorus showed three clusters, cluster I (five sites), cluster II (Two sites) and cluster III (two site) (Figure 2).

Factor analysis for soil physico-chemical properties

In banj-oak forest factor analysis showed that sand, bulk density, porosity, potassium, carbon, organic matter, phosphorus and nitrogen were positively correlated in comparison to other physico-chemical properties (Figure 4a). Similarly in chir-pine forest nitrogen, porosity, sand, clay and carbon were positively correlated in comparison to other physico-chemical properties (Figure 5a). In sal forest factor analysis showed that potassium, silt, moisture content, c:n ratio, carbon, organic matter and nitrogen were positively correlated in comparison to other physico-chemical properties (Figure 6a). On the basis of observation plots upper depths (0-10 cm) of all the forest (KP1: banj-oak, HG1: chir-pine, SM1: Sal) showed close correlation with soil physico-chemical properties (Figure 4,5,6b).

Table 2. Soil physical properties of three forest types (Oak, Pine, Sal) of Betalghat

Sites	Forest Types	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Moisture Content (%)	Bulk Density (gm/cm^3)	Porosity (%)	Water Holding Capacity
KP	Banj-oak	0-10	34.30±0.56 ^{e}	40.37±0.65 ^{a}	25.33±0.65 ^{b}	10.1±0.56 ^{c}	1.40±0.026 ^{bc}	46.13±0.57 ^{abc}	54.97±0.85 ^{e}
KP	Banj-oak	11-20	31.22±0.59 ^{d}	42.39±0.66 ^{b}	26.39±0.66 ^{bc}	12.1±0.51 ^{d}	1.41±0.015 ^{bc}	45.82±0.56 ^{ab}	62.57±0.68 ^{f}
KP	Banj-oak	21-30	27.12±0.57 ^{c}	41.62±0.56 ^{ab}	31.25±0.59 ^{e}	12.6±0.80 ^{d}	1.43±0.009 ^{c}	45.15±0.50 ^{a}	69.27±0.58 ^{g}
HG	Chir-pine	0-10	26.35±0.56 ^{bc}	44.63±0.56 ^{c}	29.02±0.56 ^{d}	6.38±0.37 ^{ab}	1.25±0.009 ^{a}	52.06±0.73 ^{e}	33.90±0.91 ^{a}
HG	Chir-pine	11-20	24.86±0.93 ^{b}	48.03±0.97 ^{d}	27.11±0.56 ^{bc}	6.84±0.59 ^{b}	1.26±0.012 ^{a}	51.52±0.56 ^{e}	38.57±0.69 ^{b}
HG	Chir-pine	21-30	21.04±0.56 ^{a}	52.72±0.56 ^{e}	26.24±0.56 ^{bc}	5.49±0.27 ^{ab}	1.27±0.031 ^{a}	51.14±0.57 ^{e}	49.23±0.54 ^{d}
SM	Sal	0-10	20.54±0.56 ^{a}	57.21±0.58 ^{f}	22.25±0.56 ^{a}	6.38±0.66 ^{ab}	1.34±0.025 ^{b}	48.51±0.73 ^{d}	42.90±0.91 ^{c}
SM	Sal	11-20	20.39±0.69 ^{a}	46.38±0.56 ^{cd}	33.23±0.56 ^{f}	4.60±0.80 ^{a}	1.35±0.015 ^{b}	48.03±0.56 ^{cd}	50.23±0.51 ^{d}
SM	Sal	21-30	20.17±0.57 ^{a}	51.74±0.56 ^{e}	28.09±0.51 ^{cd}	5.49±0.63 ^{ab}	1.36±0.034 ^{bc}	47.60±0.79 ^{bcd}	61.23±0.52 ^{f}

Abbreviations: Soil depths in cm: 1, 2, 3 (0-10cm, 11-20cm, 21-30cm), Sites: KP: Banj-oak forest, HG: Chir-pine forest, SM: Sal forest, BD: Bulk density, MC: Moisture content, WHC: Water Holding Capacity.

Table 3. Soil chemical properties of three forest types (Oak, Pine, Sal) of Betalghat

Sites	Forest Types	Depth (cm)	pH	Total Carbon (%)	Organic Matter (%)	Total Nitrogen (%)	C:N ratio	Available Potassium (mg/kg)	Available Phosphorus (mg/kg)
KP	Banj-oak	0-10	5.66±0.03 ^{a}	3.34±0.04 ^{e}	5.74±0.03 ^{g}	0.35±0.022 ^{cd}	9.65±0.07 ^{c}	267±0.60 ^{i}	54±0.49 ^{e}
KP	Banj-oak	11-20	5.64±0.04 ^{a}	3.16±0.03 ^{de}	5.44±0.02 ^{f}	0.33±0.015 ^{cd}	9.58±0.07 ^{bc}	241±0.73 ^{h}	48±0.71 ^{d}
KP	Banj-oak	21-30	5.57±0.04 ^{a}	2.89±0.05 ^{cd}	4.97±0.07 ^{e}	0.30±0.012 ^{c}	9.70±0.05 ^{c}	213±0.91 ^{f}	41±0.60 ^{c}
HG	Chir-pine	0-10	6.66±0.05 ^{a}	2.78±0.03 ^{c}	4.78±0.04 ^{d}	0.23±0.023 ^{b}	12.09±0.03 ^{g}	167±0.54 ^{e}	62±0.54 ^{g}
HG	Chir-pine	11-20	6.74±0.03 ^{a}	2.08±0.05 ^{b}	3.58±0.04 ^{c}	0.19±0.015 ^{ab}	10.95±0.03 ^{e}	112±0.82 ^{b}	61±0.63 ^{fg}
HG	Chir-pine	21-30	6.80±0.05 ^{a}	1.79±0.13 ^{a}	3.08±0.03 ^{b}	0.15±0.035 ^{a}	11.93±0.04 ^{f}	93±1.05 ^{a}	56±1.21 ^{e}
SM	Sal	0-10	6.31±2.55 ^{a}	3.82±0.14 ^{f}	6.57±0.03 ^{h}	0.36±0.003 ^{d}	10.61±0.03 ^{d}	220±1.31 ^{g}	33±0.49 ^{b}
SM	Sal	11-20	5.95±4.23 ^{a}	1.72±0.10 ^{a}	2.96±0.04 ^{a}	0.20±0.006 ^{ab}	8.60±0.01 ^{a}	132±1.41 ^{c}	25±0.89 ^{a}
SM	Sal	21-30	6.18±3.31 ^{a}	2.93±0.13 ^{cd}	5.04±0.03 ^{e}	0.31±0.002 ^{cd}	9.45±0.01 ^{b}	160±1.20 ^{d}	59±0.80 ^{f}

Abbreviations:K: Potassium, C: Carbon, P: Phosphorus, N: Nitrogen

Table 4. Comparative studies of soil physico-chemical properties of oak, pine and sal forests.

Forest type	Sand (%)	Silt (%)	Clay (%)	Moisture Content (%)	Bulk Density (gm/cm^3)	Porosity (%)	Water Holding Capacity	References	Regions
Oak	34.30	42.39	31.25	12.60	1.36	46.13	69.27	Present study	Kumaun
	29.80	34.84	39.02	-	-	-	-	Semwal et al. (2009)	Garhwal
	53.50	23.70	18.30	13.00	1.29	51.25	67.17	Sharma et al. (2010)	Garhwal
	74.93	17.82	17.67	13.18	-	-	-	Sheikh and Kumar (2010)	Garhwal
	43.74	52.08	4.17	6.82	1.62	38.93	43.34	Jina et al. (2011)	Kumaun
	80.17	37.97	9.67	18.79	1.44	-	59.50	Kumar et al. (2013)	Garhwal
Pine	26.35	52.72	29.02	6.84	1.27	52.06	49.23	Present study	Kumaun
	39.57	29.45	35.30	-	-	-	-	Semwal et al. (2009)	Garhwal
	46.20	17.35	36.42	7.11	-	-	31.28	Sheikh and Kumar (2010)	Garhwal
	45.88	49.56	4.55	7.25	1.94	94.00	43.44	Jina et al. (2011)	Kumaun
	40.87	29.52	9.67	6.29	1.45	-	47.88	Kumar et al. (2013)	Garhwal
Sal	20.54	57.21	33.23	6.38	1.36	48.51	61.23	Present study	Kumaun
	60.12	28.59	12.24	7.34	-	-	43.03	Paudel et al. (2003)	Eastern Nepal
	27.70	23.36	62.86	5.82	1.47	47.87	54.80	Bharti et al. (2016)	Kumaun

Forest type	pH	Total Carbon (%)	Organic Matter (%)	Total Nitrogen (%)	C:N ratio	Available Potassium (mg/kg)	Available Phosphorus (mg/kg)	References	Regions
Oak	5.66	3.34	5.74	0.35	9.54	267 mg/kg	54 mg/kg	Present study	Kumaun
	6.90	2.83	4.87	0.24	11.80	2.86 %	0.92 %	Semwal et al. (2009)	Garhwal
	6.27	2.19	3.77	0.23	9.52	225.76 kg ha^{-1}	22.25 kg ha^{-1}	Sheikh and Kumar (2010)	Garhwal
	5.50	2.93	5.05	0.33	8.88	388.57 kg ha^{-1}	56.00 kg ha^{-1}	Jina et al. (2011)	Kumaun
	5.90	1.40	2.41	0.07	19.40	-	-	Kumar et al. (2013)	Garhwal
	6.28	3.28	5.64	0.57	5.75	-	-	Joshi & Negi (2015)	Kumaun & Garhwal
	7.06	0.78	1.35	0.66	-	0.0463%	0.0105%	Tewari et al. (2016)	Uttarakhand
	5.50	2.44	4.21	0.17	14.49	40.67 mg/kg	5.75 mg/kg	Gairola et al. (2012)	Garhwal
Pine	6.80	2.78	4.78	0.23	12.09	167.00 mg/kg	62.00 mg/kg	Present study	Kumaun
	5.50	2.86	4.92	0.23	12.43	3.66 %	0.92 %	Semwal et al. (2009)	Garhwal
	6.16	1.63	2.80	0.15	10.87	16.88 kg ha^{-1}	164.22 kg ha^{-1}	Sheikh and Kumar (2010)	Garhwal
	6.50	2.76	4.75	0.19	14.53	263.67 kg ha^{-1}	48.36 kg ha^{-1}	Jina et al. (2011)	Kumaun
	6.97	1.13	1.94	0.056	20.18	-	-	Kumar et al. (2013)	Garhwal
	6.33	1.64	2.82	0.28	5.86	-	-	Joshi & Negi (2015)	Kumaun & Garhwal
	7.07	1.51	2.59	0.352	-	0.0403%	0.0163%	Tewari et al. (2016)	Uttarakhand
Sal	6.31	3.82	6.57	0.36	10.61	220 mg/kg	59 mg/kg	Present study	Kumaun
	4.33	1.41	2.42	0.12	11.75	267.73 kg ha^{-1}	76.64 kg ha^{-1}	Paudel et al. (2003)	Eastern Nepal
	6.30	0.79	1.36	0.06	13.17	-	-	Sapkota et al. (2009)	Nepal
	7.20	1.37	2.36	0.28	4.89	0.0109 %	0.0098 %	Bharti et al. (2016)	Kumaun

Table 5. Correlation matrix among soil physico-chemical properties of Banj-oak Forest, Betalghat

	Sand	Silt	Clay	BD	MC	Porosity	WHC	CN	K	C	OM	P	N	pH
Sand	1	-0.179	-.794*	-0.277	-0.527	.678*	-.903**	-0.131	.908**	.911**	.957**	.914**	.684*	0.608
Silt		1	0.431	0.291	.804**	0.457	0.555	0.226	-0.413	-0.405	-0.335	-0.346	-0.087	0.03
Clay			1	0.439	.741*	-0.172	.916**	0.468	-.863**	-.903**	-.888**	-.822**	-0.568	-0.478
BD				1	0.451	0.091	0.421	-0.101	-0.578	-0.271	-0.337	-0.309	-0.024	-0.208
MC					1	0.179	.810**	0.058	-.678*	-0.66	-0.61	-0.614	-0.382	-0.164
Porosity						1	-0.316	0.123	0.441	0.39	0.477	0.414	0.472	0.417
WHC							1	0.254	-.946**	-.944**	-.949**	-.914**	-0.597	-0.488
CN								1	-0.206	-0.339	-0.284	-0.178	-0.086	-0.07
K									1	.904**	.929**	.844**	0.57	0.54
C										1	.979**	.902**	.692*	0.643
OM											1	.954**	.671*	0.664
P												1	0.536	0.56
N													1	.841**
pH														1

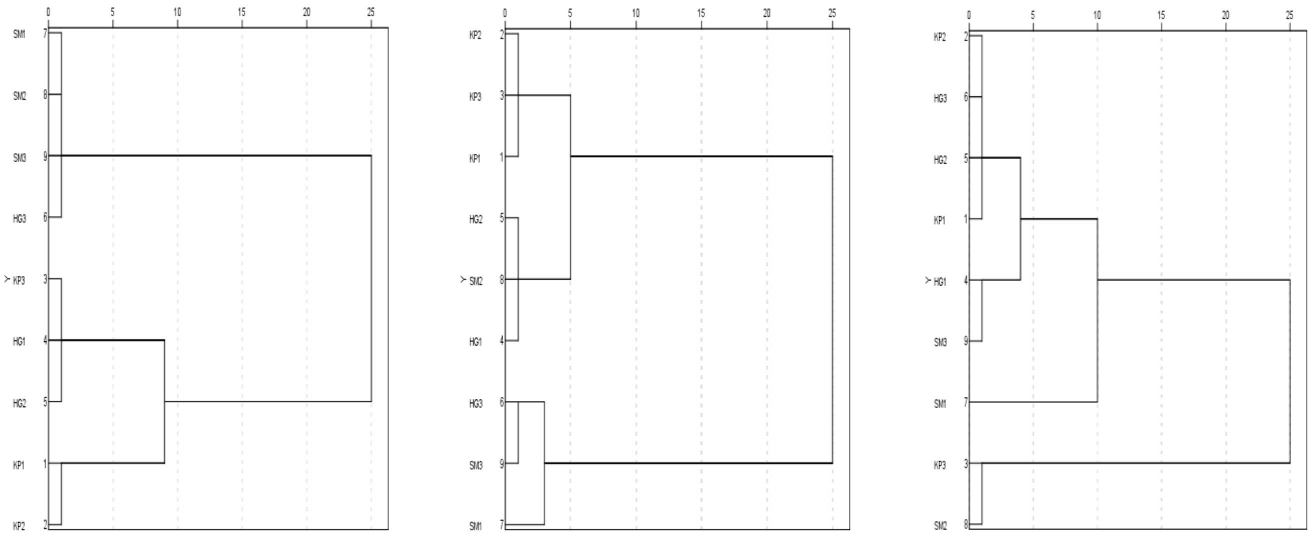
Abbreviations:BD: Bulk density, MC: Moisture content, WHC: Water Holding Capacity, CN: Carbon Nitrogen ratio, K: Potassium, C: Carbon, P: Phosphorus, N: Nitrogen

Table 6. Correlation matrix among soil physico-chemical properties of Chir-pine forest, Betalghat

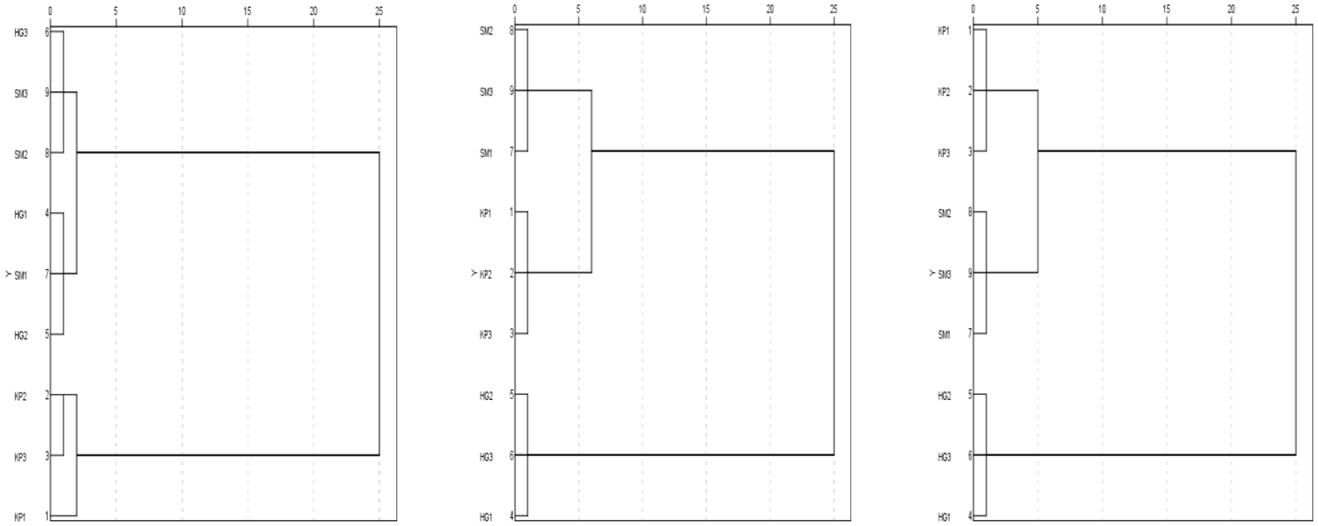
	Sand	Silt	Clay	BD	MC	Porosity	WHC	C:N	K	C	OM	P	N	pH
Sand	1	-.805**	.862**	-0.299	0.626	0.611	-.850**	-0.126	.797*	.810**	.815**	.697*	0.574	-0.56
Silt		1	-0.607	0.314	-0.539	-0.148	.960**	-0.031	-.886**	-.858**	-.890**	-.673*	-0.657	.725*
Clay			1	-0.305	0.23	.783*	-.679*	0.244	.831**	.828**	.843**	0.422	0.471	-0.486
BD				1	-0.017	-0.224	0.293	-0.057	-0.347	-0.091	-0.302	-0.05	0.45	0.53
MC					1	0.243	-0.48	-0.425	0.292	0.322	0.317	0.56	0.39	-0.297
Porosity						1	-0.235	0.068	0.401	0.413	0.413	-0.029	0.118	-0.052
WHC							1	0.109	-.863**	-.844**	-.881**	-.681*	-0.659	.695*
CN								1	0.368	0.323	0.339	-0.203	0.064	-0.19
K									1	.952**	.993**	0.519	0.631	-.675*
C										1	.959**	0.544	.799**	-0.541
OM											1	0.539	0.649	-.710*
P												1	0.568	-0.566
N													1	-0.156
pH														1

Table 7. Correlation matrix among soil physico-chemical properties of Sal forest, Betalghat

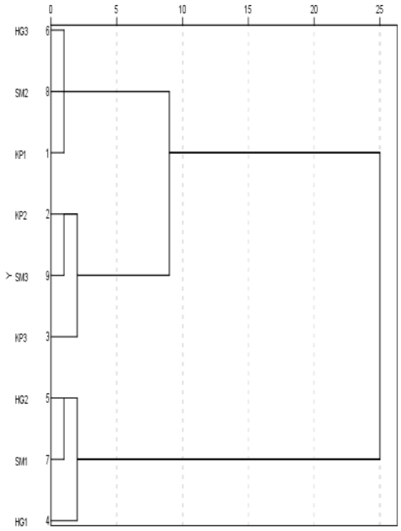
	Sand	Silt	Clay	BD	MC	Porosity	WHC	CN	K	C	OM	P	N	pH
Sand	1	0.239	0.086	0.433	.745*	.834**	-0.073	0.084	-0.223	0.013	0.05	-0.148	0.022	0.204
Silt		1	-.941**	-0.051	.704*	0.328	-0.374	.981**	.800**	.955**	.979**	0.21	.960**	0.047
Clay			1	0.21	-0.469	-0.051	0.438	-.984**	-.915**	-.962**	-.979**	-0.186	-.956**	0.002
BD				1	0.386	0.381	0.277	-0.128	-0.514	-0.034	-0.103	0.234	-0.061	0.495
MC					1	.773*	-0.15	0.592	0.312	0.579	0.582	0.172	0.552	0.518
Porosity						1	-0.237	0.21	-0.061	0.167	0.157	-0.217	0.115	0.408
WHC							1	-0.471	-0.521	-0.305	-0.313	.794*	-0.209	0.037
CN								1	.869**	.966**	.984**	0.139	.956**	0.029
K									1	.819**	.844**	0.024	.798**	-0.027
C										1	.978**	0.318	.978**	0.087
OM											1	0.304	.991**	0.015
P												1	0.401	0.139
N													1	-0.02
pH														1



Sand Silt Clay

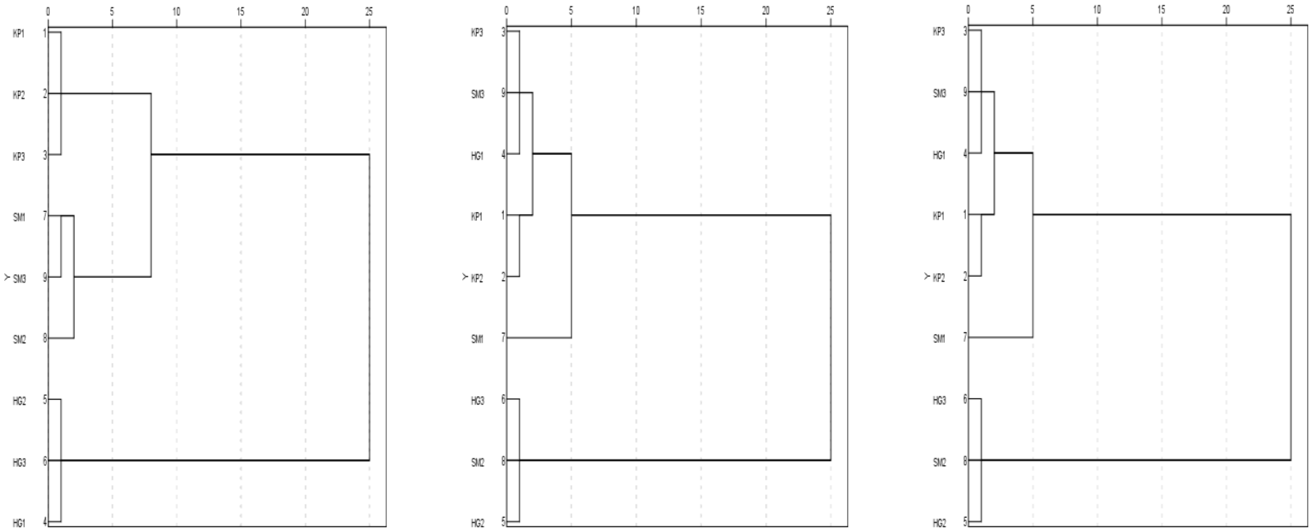


Moisture Content Bulk Density Porosity



Water Holding Capacity

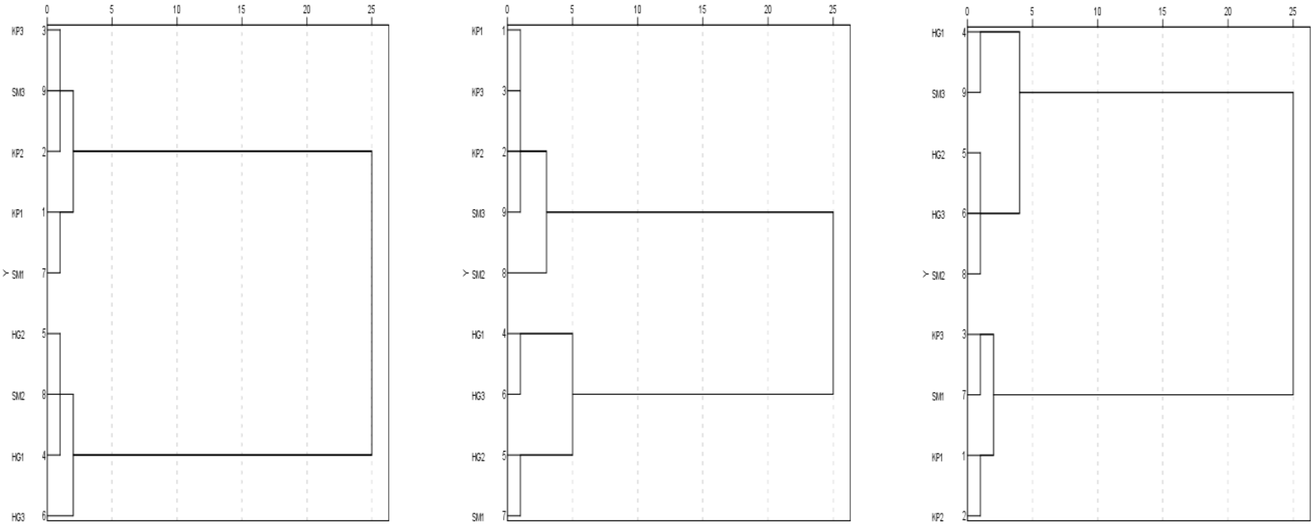
Figure 1. Dendrogram for soil physical properties of Banj-oak, Chir-pine and Sal Forest



pH

Carbon

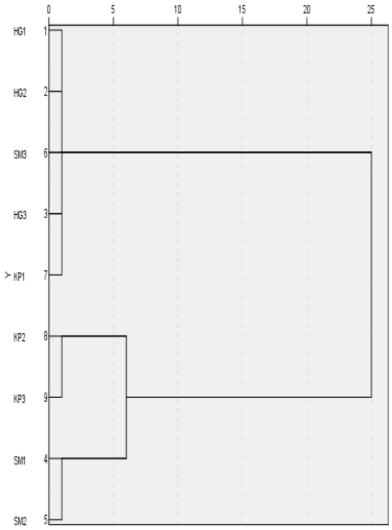
Organic Material



Nitrogen

C:N Ratio

Potassium



Phosphorus

Figure 2. Dendrogram for soil chemical properties of Banj-oak, Chir-pine and Sal Forest (Abbreviations: Soil depths in cm: 1, 2, 3 (0-10cm, 11-20cm, 21-30cm), KP: Banj-oak forest, HG: Chir-pine forest, SM: Sal forest)

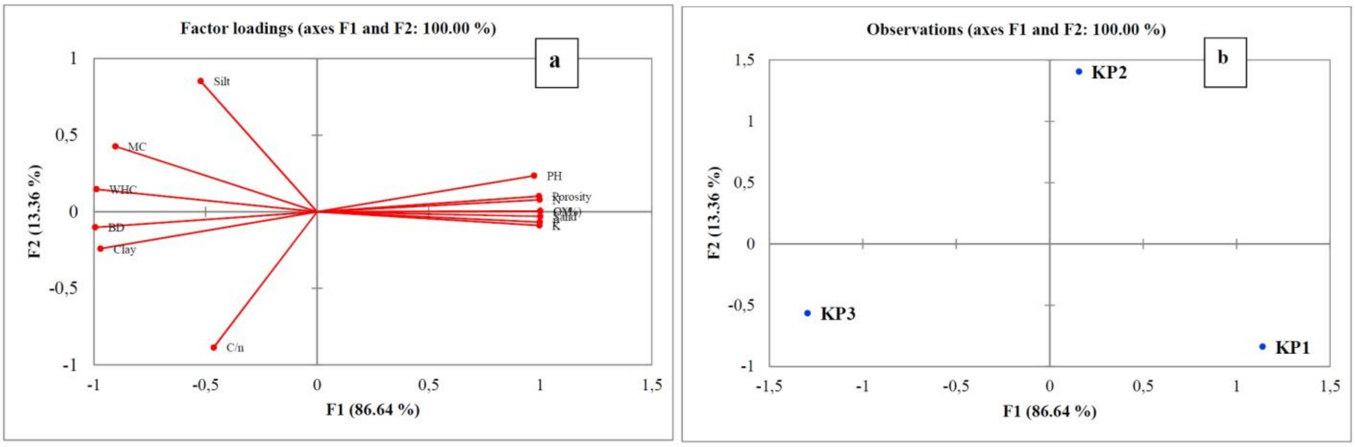


Figure 4. Factor analysis and observation plot for Physico-chemical properties of Banj-oak forest(a,b)

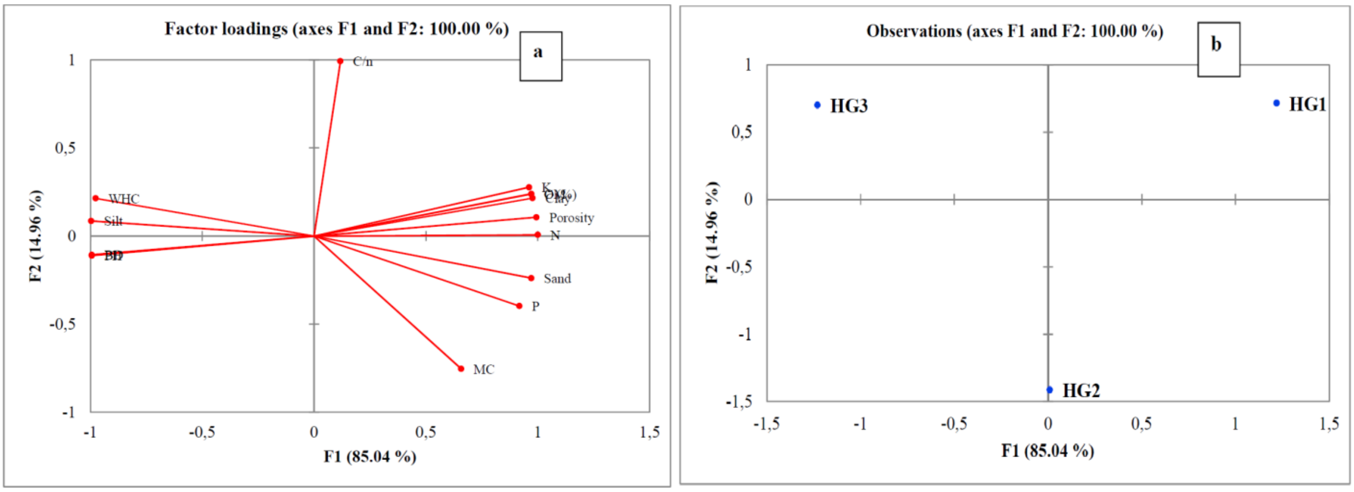


Figure 5. Factor analysis and observation plot for Physico-chemical properties of Chir-pine forest (a,b)

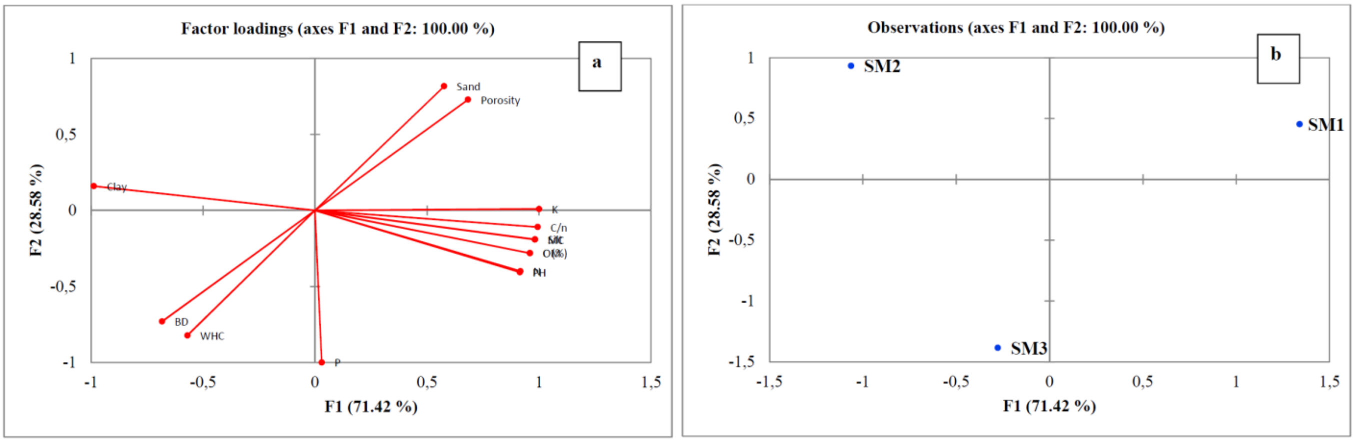


Figure 6. Factor analysis and observation plot for Physico-chemical properties of Sal forest (a,b)

Conclusion

Observation shows that soil nutrients in banj-oak forest are rich at (21-30cm) depth while in sal and chir-pine forest soil nutrients are rich in upper most depth (0-10cm). Among all three forest type banj-oak forest shows rich values of soil physical properties (moisture content, bulk density, water holding capacity), while sal forest shows richness of chemical properties (organic carbon, organic matter, nitrogen content). Correlation analysis of soil physic-chemical properties showed that silt, c:n ratio, potassium, carbon and nitrogen have maximum positive correlation with physico-chemical properties while clay showing maximum negative correlation with physico-chemical properties. The cluster analysis concluded that soil physico-chemical properties of three depths (0-10cm, 11-20cm, 21-30cm) from three forests differentiated from each other. The factor analysis concluded that sand, porosity, carbon and nitrogen in all the forest have maximum positive correlation in compared to other physico-chemical properties. The observation analysis concluded that upper depths (0-10 cm) of all the forest have close correlation in compared to other depths. It is a very important soil property influencing soil structure, stability, nutrient availability, soil pH and soil's reaction toward fertilizers and other amendments (Hazelton and Murphy, 2007). On the basis of above observation we concluded that mixed forest like banj-oak should promote for better soil health, which is good for germination of seeds because of high moisture content and water holding capacity.

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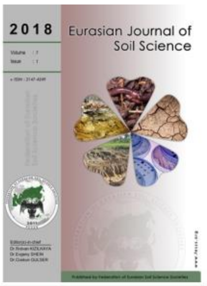

Organic and inorganic amendments on soil chemical properties at different period of incubation of acidic soil

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Abstract

Soil acidity is a critical issue necessitating urgent attention in most highlands of Ethiopia due to its impact on crop production productivity. Application of organic and inorganic amendments could effectively minimize the problem and improve the fertility level of the soil. Accordingly, a greenhouse experiment was conducted to evaluate the effects of sole and combined applications of lime, FYM, compost and P on soil chemical properties incubated at 20, 40 and 60 days. The treatments were arranged in a completely randomized design with three replications. The results indicated that various treatment combinations raised the soil pH at the 40 days of incubation. All treatments showed increased P availability consistently with increasing time of incubation. Maximum available P was observed at the 60 days of incubation due to application of 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1} followed by 8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}. Exchangeable acidity and Al were reduced at the 40 and 60 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM or compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Highest exchangeable Ca was obtained at 20 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t ha^{-1} FYM + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Sole addition of 10 t lime ha^{-1} elevated ECEC from 19.29 to 22.30 $cmol_c$ kg^{-1} at the 40 days of incubation. Likewise, combined applications of 30 kg P ha^{-1} + 10 t lime ha^{-1} improved ECEC of the soil from 19.53 to 24.27 $cmol_c$ kg^{-1} at the 40 days of incubation. Integrated applications of organic and inorganic amendments were found more effective to reduce soil acidity and Al^{3+} concentration with increasing the fertility of the soil.

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Introduction

Soil acidity is a critical issue requiring urgent attention in most highlands of Ethiopia due to its impact on crop production and productivity (Tessema et al., 2012). Recent studies have also indicated that soil acidity affects large areas of the cultivated lands in different parts of Ethiopia (Wassie and Shiferaw, 2009; Melese and Yli-Halla, 2016).

Most acidic soils have been found to be low in fertility, have poor chemical and biological properties. Strong soil acidity is associated with Al, H, Fe, Mn toxicities to plant roots in the soil solutions and corresponding deficiencies of the available P, Mo, Ca, Mg and K (Kisinyo et al., 2014). Aluminum toxicity primary affects the root apex and causes stunting of the primary root and inhibition of lateral root formation.

Several practices have been recommended to reclaim acidity and upgrade the productivity of strongly acidic soils. These include the cultivation of acid tolerant plants, covering the surface with non-acidic soil, the use

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of organic fertilizers, and liming. Of these practices, liming and the application of organic fertilizers are generally considered to be the best measures, because their effects are more persistent (Chen et al., 2001). However, the unaffordability of fertilizers and lime, and unsustainable crop production calls for use of locally available low cost organic sources through manures, green manures, and mineral fertilizers in a harmonized combination for sustainable production and soil quality. Lime in the form of calcium carbonate or dolomite is applied to acid soils to increase the pH, Ca concentration, CEC and base saturation, and to eliminate Al and Mn toxicity and P fixation (Fageria and Baligar, 2003; Ano and Ubochi, 2007). Another research indicated liming can increase, decrease, or have no effect on P availability (Anjos and Rowell, 1987). However, the recent studies (Crawford et al., 2008; Osundwa et al., 2013; Melese and Yli-Hall, 2016) indicated a significant increase in Olsen P due to liming acidic soils.

Addition of manure and compost to acidic soils is potentially a feasible approach for increasing soil pH, decreasing concentrations of Al, reducing lime requirements (Mokolobate and Haynes, 2002; Crawford et al., 2008; Opala et al., 2012). Application of OM like compost and manures provide nutrients and improve the physical properties the soil (Chiu et al., 2006). The role of composts as a complimentary amendment for improving the soil aggregation, increasing the microbial biomass, improving the moisture holding capacity, raising the CEC and pH of the soil has been recognized by various researchers (Valarini et al., 2009; Martínez-Blanco et al., 2013).

Although all these mentioned organic and inorganic amendments have significant contribution to reduce soil acidity and improve soil fertility and nutrient transfer, farming in the highlands of Ethiopia is characterized by low agricultural productivity as compared with developed countries due to progressive soil fertility decline over the years, and inadequate applications of amendments. The amount and the time of separate or combined applications of lime, manure, compost and inorganic fertilizers applied to the soil and the chemical effects observed are not sufficiently investigated in various areas of Ethiopia.

Improved soil fertility, and acidity management through the use of combining organic and inorganic amendments enable efficient use of the inputs applied and increase agricultural productivity. However, manure or compost is used mostly on small plots that are located around the household's residence, and the quantity of amendments and the time of application is not research based to ameliorate the soil and meet the need of crops. Hence, this study was proposed with the objective of determining the effects of lime, mineral P, FYM and compost on selected soil chemical properties at different period of incubation of cultivated acidic soils at Lay Gayint district.

Material and Methods

Description of the study area

The study was conducted at Lay Gayint district of South Gondar Zone of the Amhara National Regional State (ANRS), Ethiopia. Lay Gayint district is located at about 175 km northeast of Bahir Dar, along the Woreta-Woldia highway (Figure 1). The district lies between the coordinates of 11°32'-12°16' N and 38°12'-38°19' E, and covers an estimated area of 1511 km^2. Altitude of Lay Gayint district varies between 1500 and 4235 meters above sea level (masl). Physiographically, the area is characterized by plain (10%), undulating (70%), mountainous (15%) and gorges and valleys (5%). The major land use patterns of the study area comprise of cultivated land (44%), grazing land (14%), forest/bush land (5%), water body (2%) infrastructure and settlement (6%), and unproductive land (29%). Agro-ecologically, the district is divided into four elevation and temperature zones, namely: lowland (*kolla*) (12.5%), midland (*woina-dega*) (39.42%), highland (*dega*) (45.39%), and *wurch* (very cold or alpine) (2.71%) (Addisu and Menberu, 2015). Lay Gayint district receives a mean annual rainfall of 1020 mm. The main rainy season, which represents the long rainy season (*meher*), occurs between June and September, and the small rainy season (*belg*) occurs between March and May. The mean minimum and maximum air temperature of the district are 6.9 and 21.9 ^{0}C, respectively (ENMSA, 2017).

Soil sampling and sample preparation

Surface soil samples of cultivated lands at Lay Gayint district, with pH less than 5.5 was measured at field condition using portable pH meter, were collected in bulk using auger and spade at 0 to 20 cm soil depth. The collected soil samples were bulked to make a composite sample. The soil samples were air dried, crushed and made to pass through a 2 mm sieve size for the analysis of soil pH, texture, available P, exchangeable bases, exchangeable acidity and Al, and CEC. For analysis of OC and total N, samples were made to pass through 0.5 mm sieve size. The composite soil samples were analyzed based on standard laboratory procedures.

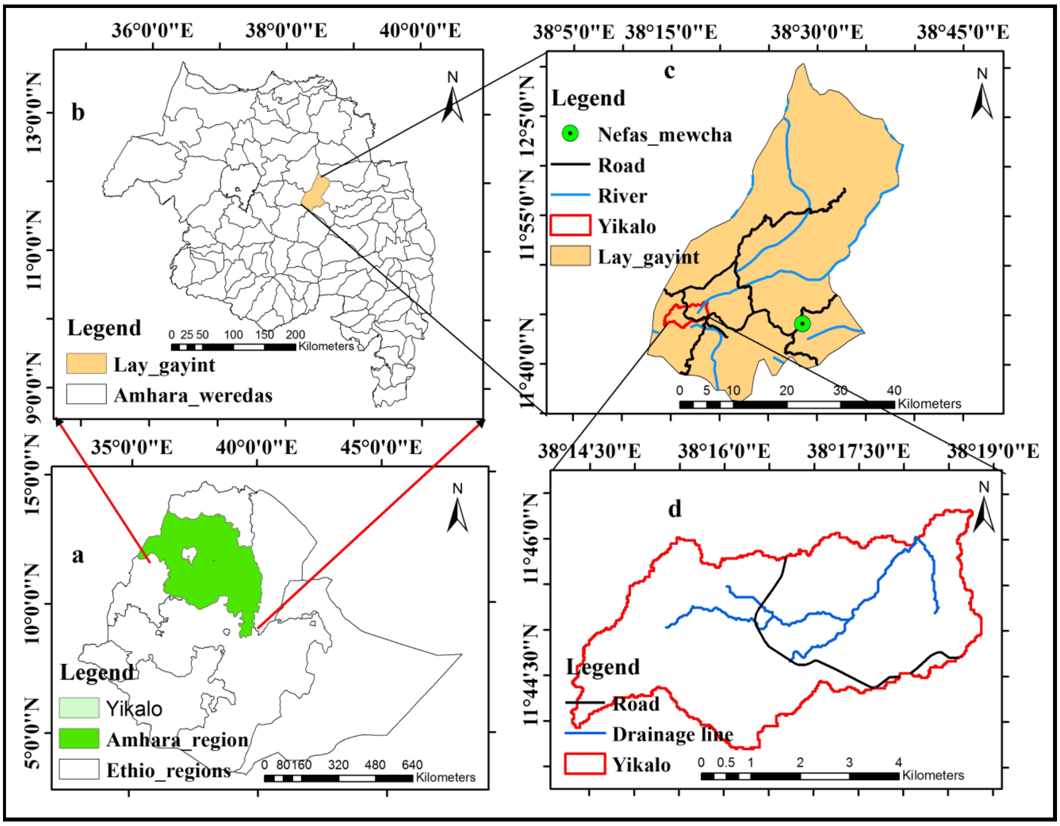

Figure 1. Location map of the study area: (a) ANRS in Ethiopia (b) Lay Gayint district in ANRS (c) Study area (d) Drainage lines.

Soil texture was determined using Bouyoucos hydrometer method (Day, 1965). Bulk density (BD) was determined from undisturbed (core) soil samples collected using core samplers, weighed at field moisture content and then dried in an oven at 105 °C (Baruah and Barthakur, 1997). The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter. Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) where the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid (H_2SO_4) solution. Total N was determined by the Kjeldahl method (Jackson, 1967) while available P was extracted using the sodium bicarbonate solution following the procedure described by Olsen et al. (1954). The exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M ammonium acetate (NH_4OAc) solution at pH 7.0 (Jackson, 1967). Exchangeable Ca and Mg in the leachate were determined by atomic absorption spectrophotometer (AAS), while exchangeable K and Na were determined by flame photometry (Rowell, 1994). Lime requirement (LR) of the soil was determined by Shoemaker, McLean and Pratt (SMP) single buffer procedure (Shoemaker et al., 1961). The potential cation exchange capacity (CEC) of the soil was determined from the NH_4^+ saturated samples that were subsequently replaced by K^+ using KCl solution. The excess salt was removed by washing with ethanol and the NH_4^+ that was displaced by K^+ was measured using the micro-Kjeldahl procedure (Chapman, 1965) and reported as CEC. Total exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution and was titrated with 0.02 M NaOH as described by Rowell (1994). From the same extract, exchangeable Al in the soil samples was determined by application of 1 M NaF which formed a complex with Al and released NaOH and then NaOH was back titrated with a standard solution of 0.02 M HCl. The analytical soil data is indicated in Table 1.

Manure and compost pH was measured in water (soil: solution ratio of 1:5) using a pH meter with a glass and reference calomel electrode after the suspensions was shaken for 30 minutes and allowed to stand for 1 hour (John, 2003). Total N content was determined by Kjedahl method as described by Jackson (1967). The organic carbon was determined by wet oxidation method through chromic acid digestion (Walkley and Black, 1934). Total P, K, Ca, Mg and Fe were determined following wet digestion with H_2O_2/H_2SO_4 (Okalebo et al., 2002). Total Ca, Mg, K and Na were determined by AAS and P measured as described by Murphy and Riley (1962). The neutralization value of the Dejen lime was determined by dissolving a graduated amount of lime with excess of standard 0.5 M HCl (Table 2). The excess acid was back titrated with standard 0.1 M NaOH solution using phenolphthalein as an indicator after filtration. From the amount of NaOH used to neutralize the excess acid of the blank and the filtrate, the neutralization value of the lime was calculated.

Table 1. Selected physical and chemical properties of the experimental soil

Parameter	Value
Sand (%)	19
Silt (%)	36
Clay (%)	45
Textural class	clay
Bulk density (g cm^{-3})	1.4
pH (H_2O)	4.93
Exchangeable Ca ($cmol_c$ kg^{-1})	9.98
Exchangeable Mg ($cmol_c$ kg^{-1})	4.26
Exchangeable K ($cmol_c$ kg^{-1})	0.45
Exchangeable Na ($cmol_c$ kg^{-1})	0.38
Cation exchange capacity ($cmol_c$ kg^{-1})	33.7
Exchangeable acidity ($cmol_c$ kg^{-1})	4.04
Exchangeable Al ($cmol_c$ kg^{-1})	1.77
Organic carbon (%)	1.27
Total nitrogen (%)	0.19
Olsen P (mg kg^{-1})	5.87

Table 2. Chemical characteristics of FYM and compost

Amendment	pH-H_2O (1:5)	N	C	P	Ca	K	Mg	Na
		(%)						
Farmyard manure	7.6	1.11	13.87	0.31	1.52	1.51	0.72	0.14
Compost	7.2	0.51	18.40	0.29	1.43	1.63	0.59	0.15

Incubation study

Based on the pH and the LR, composite soil samples of the acidic soil were selected for this experiment. The composite soil samples were air dried ground and passed with 2 mm sieve and then placed separately in plastic containers and mixed with different treatments in a laboratory. The treatments were lime, mineral P fertilizer, FYM and compost which were applied separately and in systematic combination at different rates (Table 1). Manure and compost, dried and ground to pass through a 0.25 mm sieve, were added. Lime with a known mesh size was added based on the LR of the soil. The lime used for the experiments was found to have a neutralization value of 93.8 %. A completely randomized design (CRD) was used and treatments were replicated three times. The study was conducted in plastic containers with 500 g of soil in each plastic container. Lime, mineral P fertilizer, manure and compost were incubated for two months in the greenhouse. All pots were subjected to wetting and drying cycles during the incubation period. Soil samples were drawn at 20, 40 and 60 days of the incubation period and then were air dried, ground and sieved through a 2 mm sieve and used for analysis of soil pH, exchangeable acidity, exchangeable Al, exchangeable bases, ECEC and available P.

Statistical analysis

The data obtained was subjected to analysis of variance (ANOVA) following procedures that are appropriate to experimental design with the help of statistical analysis system (SAS) software package version 9.1. Duncan's Multiple Range Test (DMRT) was employed to test the significance difference between means of treatments.

Results and Discussion

Effects of organic and inorganic amendments on soil pH and available P

Soil pH was significantly ($P < 0.001$) increased with single or combined applications of treatments except sole P. Soil pH improvement was observed at the 20 days of incubation and continued rise to the 40 days and declined to the 60 days for some of the treatments (Table 4). Application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1} showed a marked increase in pH at the 20 and 40 days of incubation and a decrease at 60 days of incubation. Regarding to separately applied treatments, the effect of lime to reduce the level of soil acidity was observed more immediate as depicted in Table 4.

Application of organic and inorganic amendments significantly improved available P at various period of incubation over the control. All treatments showed increased P availability consistently with increasing time of incubation. Maximum available P was observed at the 60 days of incubation due to application of 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1} followed by 8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}. On the other hand, more available P was obtained at the 20 days of incubation with combination of 30 kg P ha^{-1} with 10 t lime ha^{-1}. Separate addition of 30 kg P ha^{-1} and 8 t FYM ha^{-1} resulted in increased available P by 52 and 48%, respectively over the control at the 60 days of incubation. Combined applications of 8 t FYM ha^{-1}, 30 kg P ha^{-1} with 5 t lime ha^{-1} added significantly more available P with an increase of 70%, over the control at the 60 days of incubation.

Table 4. Effects of organic and inorganic amendments on soil pH and available P

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Soil pH			Available P (mg kg^{-1})		
Control	4.85m	4.87lm	4.95lm	5.87q	6.27l-q	6.76f-l
8 t compost ha^{-1}	5.21lm	5.21klm	5.36l	6.60 n-q	6.79m-q	9.27b-h
8 t FYM ha^{-1}	5.19lm	5.29klm	5.35klm	6.22 pq	6.54opq	10.01a-g
30 kg P ha^{-1}	4.99lm	4.89lm	4.89klm	8.33 e-n	9.19b-k	10.28a-d
10 t lime ha^{-1}	5.99d-h	6.22b-e	6.11c-g	6.19 pq	7.61i-q	9.27b-k
30 kg P ha^{-1} + 10 t lime ha^{-1}	6.26bcd	6.59a	6.10c-g	10.33 a-d	9.40b-k	10.87a-d
30 kg P ha^{-1} + 5 t lime ha^{-1}	5.76ghi	6.12c-f	5.93e-i	6.82 l-q	7.92g-q	10.12a-f
8 t compost ha^{-1} + 5 t lime ha^{-1}	5.87g-j	5.91f-i	5.56jk	7.46 j-q	7.69i-q	9.35b-k
8 t FYM ha^{-1} + 5 t lime ha^{-1}	5.91e-i	6.11c-g	5.89f-i	6.82 l-q	7.29k-q	9.21b-k
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	5.94e-i	5.95d-i	5.87g-j	7.91 e-l	8.05f-o	11.10ab
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	5.91f-i	5.94e-i	5.79ghi	9.45 a-j	10.05a-f	11.52a
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	6.03c-h	6.32abc	6.03c-h	9.69 a-i	9.84a-h	10.43a-d
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	6.43ab	6.48ab	6.19b-f	8.81 d-m	8.91c-l	10.93abc
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	5.56jk	5.91f-i	5.86g-j	6.72m-q	7.82h-q	8.80d-m
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	5.67ij	5.97d-i	5.75ghi	6.81l-q	8.66e-n	9.99a-g
CV (%)		3.32			11.75	

Means within a column followed by the same letter are not significantly different at $P > 0.001$; CV = coefficient of variation

Effects of organic and inorganic amendments on exchangeable acidity and Al

Exchangeable acidity and Al were affected significantly due to application of treatments and over incubation period. Maximum reduction of exchangeable acidity and Al were recorded with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM or compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}.

Table 5. Effects of organic and inorganic amendments on exchangeable acidity and Al

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex acidity(cmol$_c$ kg^{-1})			Ex Al (cmol$_c$ kg^{-1})		
Control	4.16a	4.07a	3.95ab	1.78a	1.77a	1.74a
8 t compost ha^{-1}	3.72b	2.78de	1.31ij	1.57b	1.23c	0.64f
8 t FYM ha^{-1}	3.27c	2.53e	1.26ij	1.26c	0.82e	0.58f
30 kg P ha^{-1}	4.12a	4.04a	3.95ab	1.76a	1.74a	1.73a
10 t lime ha^{-1}	0.66lmn	0.26opq	0.07q	0.16j-m	0.03mn	0.00m
30 kg P ha^{-1} + 10 t lime ha^{-1}	0.63lmn	0.38n-q	0.04o	0.17i-l	0.05klm	0.00m
30 kg P ha^{-1} + 5 t lime ha^{-1}	2.95d	1.86fg	0.53l-p	0.99d	0.65f	0.39g
8 t compost ha^{-1} + 5 t lime ha^{-1}	2.76de	1.52hi	1.20ijk	1.15c	0.35gh	0.15j-m
8 t FYM ha^{-1} + 5 t lime ha^{-1}	2.15f	1.29ij	0.55l-o	0.81e	0.35gh	0.00m
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	1.81gh	1.19ijk	0.80klm	0.63f	0.31ghi	0.16j-m
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	1.08jkl	0.65lmn	0.21pq	0.43g	0.11lmn	0.00m
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.75klm	0.15q	0.09q	0.23hij	0.03lm	0.00m
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.50m-p	0.11q	0.08q	0.14j-m	0.00m	0.00m
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	1.31ij	0.88klm	0.26opq	0.22jkl	0.05klm	0.00m
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	1.24ij	0.76klm	0.13q	0.16j-m	0.03lm	0.00m
CV (%)		11.34			14.59	

Means within a column followed by the same letter are not significantly different at $P > 0.001$; CV = coefficient of variation

Statistically, application of 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1} was as effective as the above two treatments in reducing exchangeable acidity and Al. Among sole treatments, application of 10 t lime ha^{-1} reduced exchangeable acidity and Al significantly over the control (Table 5).

Effects of organic and inorganic amendments on exchangeable bases

Exchangeable Ca was significantly affected by organic and inorganic treatments and incubation period (Table 6). However, there was not statistically difference obtained as a result of organic and inorganic amendments on exchangeable Mg, K and Na (Table 6 and 7). Highest exchangeable Ca was obtained at 20 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t ha^{-1} FYM + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Among sole treatments, lime at the 20 days and FYM at the 60 days gave highest exchangeable Ca. Period of incubation did not show consistency for exchangeable Ca and Mg. In most treatments of only lime and combinations having lime, exchangeable Ca and Mg showed antagonistic relationships. For example, applications of 10 t lime ha^{-1}, 30 kg P ha^{-1} + 10 t lime ha^{-1}, 8 t compost ha^{-1} + 5 t lime ha^{-1}, 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t ha^{-1} lime ha^{-1} brought about a decrease in exchangeable Ca with an increase in exchangeable Mg with increasing incubation period.

Table 6. Effects of organic and inorganic amendments on exchangeable Ca and Mg

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex Ca (cmol$_c$ kg^{-1})			Ex Mg (cmol$_c$ kg^{-1})		
Control	9.98lm	10.43lm	11.11i-m	4.26	4.11	3.82
8 t compost ha^{-1}	10.82j-m	11.22i-m	13.16f-m	4.26	4.18	2.97
8 t FYM ha^{-1}	10.64j-m	10.48klm	13.29f-l	4.87	5.29	3.21
30 kg P ha^{-1}	9.32m	11.11i-m	11.50h-m	4.81	3.53	3.26
10 t lime ha^{-1}	17.48a-e	17.06a-f	15.40b-h	2.15	3.97	4.05
30 kg P ha^{-1} + 10 t lime ha^{-1}	19.54a	18.69abc	14.11d-k	2.68	4.24	4.58
30 kg P ha^{-1} + 5 t lime ha^{-1}	14.61d-j	13.50e-l	14.56d-j	2.66	4.87	3.81
8 t compost ha^{-1} + 5 t lime ha^{-1}	15.83a-g	15.22c-h	14.32d-k	2.73	3.84	4.00
8 t FYM ha^{-1} + 5 t lime ha^{-1}	16.06a-g	15.01c-i	15.35c-h	2.50	4.13	3.18
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	15.06c-i	14.03d-k	14.85c-i	3.29	3.55	3.55
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	15.90a-g	14.48d-j	14.22d-k	2.39	5.23	6.50
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	17.53a-e	16.64b-f	16.22b-f	3.24	5.23	5.55
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	19.35ab	17.85a-d	17.14a-f	2.37	4.23	4.92
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	15.58b-g	12.80g-m	13.23f-l	2.21	3.25	3.55
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	16.15a-f	15.30d-h	14.36d-j	2.50	3.55	3.67
CV (%)		13.10			42.37	

Means within a column followed by the same letter are not significantly different at $P > 0.001$; CV = coefficient of variation

Table 7. Effects of organic and inorganic amendments on exchangeable K and Na

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex K (cmol$_c$ kg^{-1})			Ex Na (cmol$_c$ kg^{-1})		
Control	0.50	0.48	0.55	0.38	0.44	0.37
8 t compost ha^{-1}	0.55	0.50	0.49	0.34	0.49	0.33
8 t FYM ha^{-1}	0.45	0.53	0.55	0.29	0.42	0.39
30 kg P ha^{-1}	0.47	0.53	0.54	0.29	0.37	0.39
10 t lime ha^{-1}	0.47	0.54	0.49	0.30	0.45	0.36
30 kg P ha^{-1} + 10 t lime ha^{-1}	0.49	0.52	0.51	0.30	0.44	0.37
30 kg P ha^{-1} + 5 t lime ha^{-1}	0.47	0.51	0.57	0.37	0.36	0.43
8 t compost ha^{-1} + 5 t lime ha^{-1}	0.48	0.51	0.51	0.31	0.35	0.36
8 t FYM ha^{-1} + 5 t lime ha^{-1}	0.44	0.56	0.54	0.35	0.47	0.36
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	0.49	0.53	0.56	0.39	0.53	0.42
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	0.55	0.47	0.54	0.32	0.34	0.39
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.53	0.53	0.54	0.32	0.39	0.38
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.49	0.50	0.53	0.30	0.41	0.36
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	0.41	0.45	0.51	0.41	0.32	0.38
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	0.55	0.52	0.54	0.35	0.33	0.36
CV (%)		11.05			18.32	

CV = coefficient of variation

Effects of organic and inorganic amendments on ECEC and exchangeable cation ratios

Effective cation exchange capacity was affected significantly due to organic and inorganic treatment applications (Table 8). Sole or combined applications of lime, compost and FYM improved the ECEC of the soil. Considering sole treatment applications compared with the control, addition of 10 t lime ha^{-1} elevated ECEC from the respective control to 21.08 and 22.30 cmol$_c$ kg^{-1} at the 20 and 40 days of incubation, respectively. Likewise, combined applications of 30 kg P ha^{-1} + 10 t lime ha^{-1}, 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}, and 8 t FYM ha^{-1} + 5 t lime ha^{-1} improved ECEC of the soil from 19.53 to 24.27, 23.06, and 21.47 cmol$_c$ kg^{-1}, respectively at the 40 days of incubation.

The effects of separate or combined application of organic and inorganic amendments on the ratio of exchangeable Ca/K was significant but it was found non-significant on the ratio of Ca/Mg and Mg/K (Table 8). However, it was observed that numerical variations exist among the treatments and the incubation periods. Application of 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}, and 10 t lime ha^{-1} + 30 kg P ha^{-1} increased the ratio of Ca/K from 19.98 to 40.75 and 40.54, respectively at the 20 days of incubation.

Table 8. Effects of organic and inorganic amendments on exchangeable cation ratios and ECEC

Treatments	20 days	40 days	60 days	20 days	40 days	60 days	20 days	40 days	60 days	20 days	40 days	60 days
		Ex Ca/Mg			Ex Ca/K			Ex Mg/K			ECEC ($\text{cmol}_c\ \text{kg}^{-1}$)	
Control	2.38	3.32	3.37	19.98ij	21.69g-j	20.47ij	8.48	8.52	7.01	19.29d-h	19.53c-h	19.80c-h
8 t compost ha^{-1}	2.55	2.81	4.51	19.67j	22.15f-k	26.51d-k	7.76	8.26	6.09	19.70c-h	19.19d-h	18.28g-h
8 t FYM ha^{-1}	2.24	1.99	3.41	24.97d-k	19.96ij	24.31e-k	11.89	9.99	7.53	19.53c-h	19.26d-h	19.67c-h
30 kg P ha^{-1}	2.11	3.51	4.15	19.84j	21.05ij	21.15hij	10.32	6.71	6.18	19.02d-h	19.58c-h	19.67c-h
10 t lime ha^{-1}	11.19	4.31	3.84	38.83abc	31.11a-k	31.54a-g	4.48	7.31	8.37	21.08a-h	22.30a-e	20.38b-h
30 kg P ha^{-1} + 10 t lime ha^{-1}	10.40	4.55	3.08	40.54ab	36.45abc	27.46c-k	5.18	8.41	15.19	23.66ab	24.27a	22.62a-d
30 kg P ha^{-1} + 5 t lime ha^{-1}	10.29	4.55	3.85	31.18a-k	26.65d-k	25.57d-k	5.67	9.64	6.69	18.24i-l	21.07a-h	19.92c-h
8 t compost ha^{-1} + 5 t lime ha^{-1}	6.46	3.98	4.23	33.28a-g	29.57a-k	28.41c-k	5.63	7.46	7.90	22.12a-f	21.45a-g	20.40b-h
8 t FYM ha^{-1} + 5 t lime ha^{-1}	6.48	3.76	6.26	36.27abc	27.08d-k	28.35c-k	5.69	7.40	5.76	21.52a-g	21.47a-g	19.99c-h
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	4.85	4.40	4.41	30.22a-k	26.54c-i	26.53d-k	6.69	6.83	6.31	21.05a-h	19.85c-h	20.19b-h
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	9.08	7.21	4.60	29.18b-k	32.79a-h	26.58d-k	4.24	7.90	6.45	20.25b-h	19.18d-h	18.87e-h
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	5.61	7.96	3.54	32.92a-i	31.61a-g	30.13a-k	6.07	7.15	9.50	22.39a-d	21.36a-g	22.28a-e
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	11.30	4.54	7.44	40.75a	35.90a-e	33.21a-e	4.80	8.29	4.52	23.01abc	23.06abc	20.42b-h
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	7.12	4.26	3.74	38.82abc	27.23c-k	26.17d-k	5.41	6.59	7.02	19.92c-h	18.65e-h	17.90gh
4 t FYM ha^{-1} 15 kg P ha^{-1} + 5 t lime ha^{-1}	6.50	4.33	3.91	29.40a-k	29.86a-k	26.63d-k	4.60	6.91	6.81	20.75a-h	20.57b-h	19.04d-h
CV (%)		68.15		19.00			46.13					8.19

Means within a column followed by the same letter are not significantly different at P > 0.001; CV = coefficient of variation

Discussion

The effect of FYM or compost when applied separately to increase the pH was less as compared to sole lime application. However, when 4 t ha^{-1} of either FYM or compost was applied with half rate of lime brought the soil pH to 5.97 and 5.75, respectively at the 40 days of incubation which could be considered as the favorable pH range for crop production. Although increasing the lime rate from 5 to 10 t ha^{-1} in the combination showed a linear increase in soil pH, combined application of half FYM or compost with half lime and P could be sufficient to improve soil pH to a level where soil acidity is reduced and nutrient availability is increased. Unlike this finding of gradual pH change due to FYM or compost, Whalen et al. (2000) reported an immediate increase in the pH of acid soils after application of fresh cattle manure, and the effect persisted during 60 days of incubation of soil manure mixtures. The high initial pH, exchangeable bases and proton consumption capacity may contribute to raise pH of FYM or compost amended soil. Ortiz Escobar and Hue (2008) indicated similar effects on soil pH after manure or compost applications. Another justification could be due to the buffering of carbonates and bicarbonate and other compounds, such as organic compounds with carboxyl and phenolic hydroxyl functional group, which consume proton and control the variation of pH in soils and their ability of buffering to neutralize soil acidity (Mokolobate and Haynes, 2002; Naramabuye and Hayes, 2007). In the case of lime, the increase in soil moisture causes the dissociation of the carbonates of Ca at the end of the reaction, the release of OH^- ions in the solution, which increases soil pH (Verde et al., 2013; Moreira et al., 2015). The pH decline after 40 days of incubation was attributed to the H^+ produced during the conversion of organic N and S to NO_3^- and SO_4^{2-}, respectively. However, this acidification is an artefact of incubation in closed area favoring NO_3^- accumulation (Samake, 2014). But under field conditions much nitrate produced would be absorbed by growing plants leading to OH^- releasing that can neutralize soil acidity (Heyar and Porter, 1989).

The increased availability of P with time due to application of FYM or compost separately or in the combination could be the result of gradual mineralization of OM (Opala et al., 2010) and the release of organic acids that bound with Al and decreased P fixation (von Wandruszka, 2006). Net P mineralization would also be expected to occur because FYM had a higher P concentration (0.31%) than the critical level of 0.25% required for net P mineralization (Nziguheba et al., 1998). The presence of humic acid and fulvic acid on soil and oxide surfaces restricted subsequent P adsorption (Mokolobate and Haynes, 2002). The observed earlier availability of highest P with lime and P application might be due to the rapid neutralization of soil acidity and increased solubility of the applied TSP fertilizer. An increase in the available P content in strongly acidic soil after liming was also recorded in other experiments (Özenç and Özenç, 2009; Jaskulska et al., 2014). Generally, incubation of all various combinations for 60 days, and incubation of 30 kg P ha^{-1} plus 10 t lime ha^{-1} for 20 days could improve the soil available P to the moderate range.

When full or half rate of FYM, or compost was combined with half or full rate of lime in the treatment combinations, exchangeable Al^{3+} was observed to the level of non toxicity at the 60 days of incubation, indicating that including organic amendments could reduce soil acidity but with a relatively slower rate. This may be ascribed to the time taken for complete decomposition of the applied OM. Although both lime and FYM contributed in reducing exchangeable acidity and Al, the changes observed were largely attributed to the applied lime. Because it was shown that among separate treatment applications, lime was superior to reduce soil acidity. Application of lime tends to raise the soil pH and reduce acidity by displacement of H^+, Fe^{2+}, Al^{3+} and Mn^{4+} ions from soil adsorption site (Osundwa et al., 2013; The et al., 2006). Similarly, Fageria and Baligar (2008) explained the presence of cations such as Ca^{2+} in lime exchange and/or replace H^+ on the exchange sites and anions such as CO_3^{2-} and OH^- to neutralize the H^+ released from the exchange sites and hydrolyzing Al species to the soil solution. Liming of acidic soils increased soil pH and exchangeable bases thereby reducing the magnitude of soil acidity, exchangeable acidity and Al saturation (Osundwa et al., 2013).

Ano and Ubochi (2007) indicated that animal manures significantly increased the soil pH from 4.6 to values above 5.6 and also reduced exchangeable acidity from 3.00 cmol kg^{-1} to values below 0.35 cmol kg^{-1}. Another study conducted in acidic soil in Kenya reported application of FYM increased the soil pH and reduced the exchangeable acidity and Al in the short term, but the inorganic P sources did not significantly affect these parameters (Opala et al., 2012). Many studies have indicated that addition of OM to acidic soils can reduce Al toxicity (Liasu et al., 2008; Melese and Yli-Halla, 2016). Organic matter reduces Al toxicity and its acidulating effects either by chelating or encapsulating the Al^{3+} (Obiri-Nyarko, 2012). An increase in soil pH due to manure application apparently results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides thus reducing concentration of Al in soil solution (Ano and Ubochi, 2007; Melese and Yli-Halla, 2016).

Several researchers reported increased Ca and Mg as a result of lime (Fageria and Baligar, 2003) and FYM (Kheyrodin and Antoun, 2012; Verde et al., 2013) applications on acid soils. The increased Ca could be due to the dissociation of lime and the decomposition of OM (Fageria and Baligar, 2003). In agreement with this result, Rahman et al. (2002) also found increased available Ca in the soil as a result of applied manure either alone or combined with lime and attributed the increase to improved Ca availability as a result of improved soil pH, as was observed in this study. The observed antagonistic relation between exchangeable Ca and Mg could be due to the rapid dissolution of $CaCO_3$ to increase more exchangeable Ca that compete Mg to take the exchange site whereas the effect of decomposition of FYM or compost gradually improved the exchangeable Mg with increasing period of incubation from 20 to 60 days.

The elevation of ECEC is due to the effect of lime that increase the Ca^{2+} concentration in the exchange site. Moreover, the improvement could also be attributed to the integrated effect of the amendments by improving soil pH, microbial activity, and exchangeable bases from FYM and compost decomposition. Increased ECEC and nutrient concentrations in acidic soils amended with compost or manure were observed in Senegal's peanut basin (McClintock and Diop, 2005). Other researchers (Ano and Ubochi, 2007; Naramabuye and Hayes, 2007) have reported significant increases in exchangeable Ca, Mg and ECEC following the application of organic materials. In the same way, Fageria et al. (2014) reported liming acidic soil significantly increased base saturation and ECEC.

The observed increased ratio of Ca/K was due to the availability of Ca from the applied lime rate. Although statistically, non significant values were obtained for Ca/Mg and Mg/K ratios, the nutrient balance is more affected by the magnitude of the ratio. The influence of liming on cation ratio has been reported (Fageria et al., 2014). Graham (1959) proposed that for production of annual crops, ratio ranges of 7.1 to 10.8 for Ca/Mg, 17.0 to 32.5 for Ca/K, and 2.4 to 3.0 for Mg/K in soils are needed. Calculated values of Ca/Mg ratio for the applied 30 Kg P ha^{-1} + 5 or 10 t lime ha^{-1} at the 20 days incubation, and 8 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}at the 40 days incubation showed in the proposed range. The ratio of Ca/K in most of separate or combined treatments across the incubation period could be considered as the favorable ratio for most crops whereas the Mg/K ratio obtained was higher than the proposed values. Kopittke and Menzies (2007) reviewed that examination of data from numerous studies would suggest that, within the ranges commonly found in soils, the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K.

Conclusion

Application of lime, FYM and compost brought significant change in the selected soil chemical properties of acidic soil incubated at various periods. Application of 10 t lime ha^{-1} alone or 5 t lime ha^{-1} combined with 4 t ha^{-1} FYM or compost showed a marked increase in pH at the 20 and 40 days of incubation. All treatments showed increased P availability consistently with increasing time of incubation. Maximum available P was observed at the 60 days of incubation due to application of 8 t ha^{-1} FYM + 30 kg P ha^{-1} + 5 t lime ha^{-1} followed by 8 t ha^{-1} compost + 30 kg P ha^{-1} + 5 t lime ha^{-1}. Highest exchangeable Ca was obtained at 20 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t ha^{-1} FYM + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Among sole treatments, lime at the 20 days and FYM at the 60 days gave highest exchangeable Ca. Maximum reduction of exchangeable acidity and Al were recorded with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM or compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1} at the 40 and 60 days of incubation. Considering the incubation period, application of all treatments except sole P consistently reduced exchangeable acidity and Al with increasing time. More exchangeable acidity and Al were reduced at the 40 and 60 days of incubation with the combined application of FYM, P and lime. Application of 8 t FYM ha^{-1} was as effective as 5 t lime ha^{-1} in reducing soil acidity and Al toxicity. Sole or combined applications of lime, compost and FYM improved the ECEC of the soil. Thus, combined application of 4 t FYM ha^{-1}, 15 kg P ha^{-1} + 10 t lime ha^{-1} or 8 t FYM ha^{-1}, 30 kg P ha^{-1} + 5 t lime ha^{-1} could be taken as alternative strategy in the efforts of acidic soil management and improve soil nutrient status in Lay Gayint district.

Generally, it would be possible to increase the soil nutrient content and reduce the level of soil acidity with integrated application of organic and inorganic amendments but the time of application should be considered. For lime, FYM and compost combinations, 40 to 60 days of incubation earlier to planting would allow decomposition and chemical reaction with the soil. Since the experiment was done in the greenhouse for only one round, it should be repeated in the field for long years to obtain consistent results.

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