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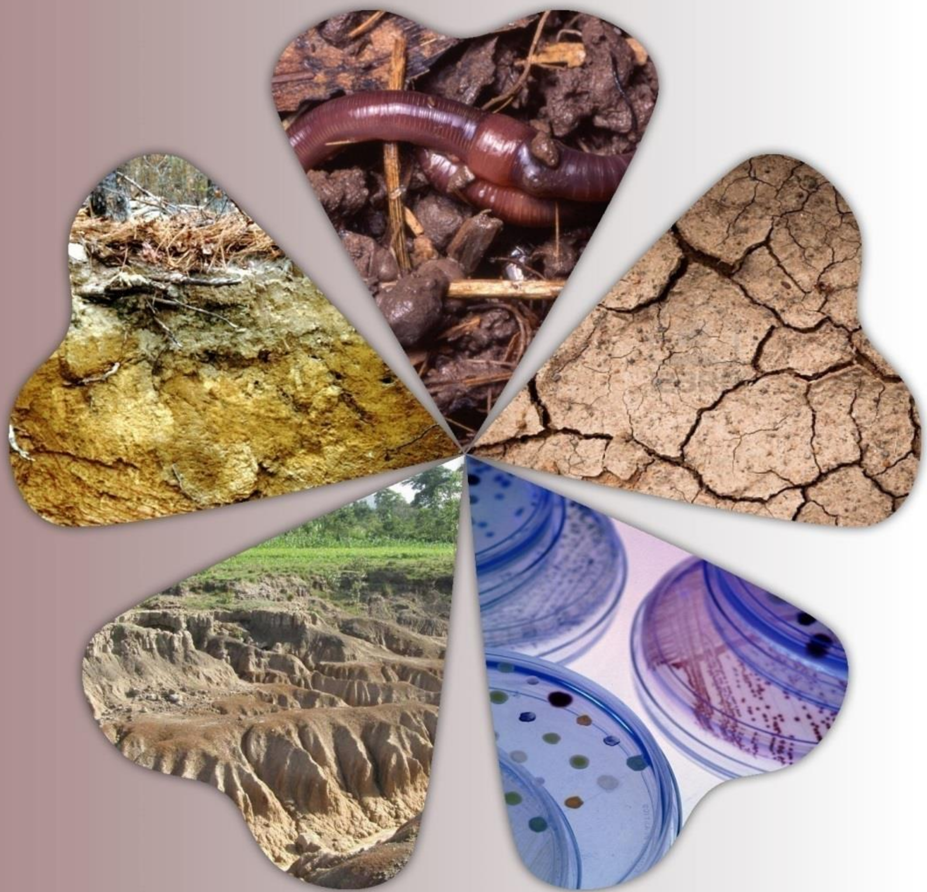

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Screening for *Lotus creticus* growth promoting rhizobacteria under greenhouse conditions

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Abstract

Utilization of plant growth promoting rhizobacteria (PGPR) is now gradually increasing in agriculture and offers an attractive way to replace chemical fertilizers, pesticides, and supplements. This study was conducted with a view to isolate bacteria from the rhizosphere of the legume *Lotus creticus* (*L. creticus*) and to assess their plant growth promoting functional potentialities. A total of 113 rhizobacteria was isolated from the rhizosphere of *L. creticus* and were tested for their capacity of solubilizing tricalcium phosphate (TCP) on Pikovskaya (PVK) solid medium. Out of 29 phosphate solubilizing bacteria (PSB), 5 isolates were selected for their solubilization diameters (between 0.6 and 1.5 cm). These isolates were characterized for plant growth promoting (PGP) traits. The results showed that the highest concentration of indole acetic acid (IAA) was produced by LCR33 (19.08 ± 0.96 mg L^{-1}). All 5 isolates could produce hydrogen cyanide (HCN), siderophores, ammonia and amino-cyclopropane carboxylate (ACC) deaminase. The isolates were evaluated for TCP solubilizing quantitative assay in PVK liquid medium. The concentrations of solubilized P were between 43.34±0.18 mg L^{-1} and 173.57±0.77 mg L^{-1}. This solubilization was accompanied by a pH decrease of the culture media from 7 to 4.06. Furthermore, the 5 selected PSB were tested in vitro for antagonism against phytopathogenic fungus *Fusarium oxysporum*. In fact, all the PSB, were capable of inhibiting its growth and the highest percentages of inhibition were obtained for LCP27 and LCR33 (48.15±0.99% and 40.74±0.45%). Also, the effect of these 2 PSB on growth of *L. creticus* plants was investigated under greenhouse conditions. Significant increases were obtained for shoot and root length and dry and fresh matter production of plants as compared to the uninoculated control. These PSB could be recommended as biofertilizers for contributing to the rehabilitation of degraded soils.

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Introduction

It is estimated that about 15% of the total land area in the world is facing serious problems caused by physical or chemical factors including salinization, erosion, low availability of nutrients and the absence of fertility (Wild, 2003). The main challenges faced in the reclamation of severely degraded lands is the management of the systems and finding plant species that will grow under the harsh conditions common in degraded soils.

Concerning these reasons, introducing legumes to improve soil fertility is considered as a sustainable management practice, due to their capacity of establishing symbiotic interactions with soil living microorganisms; almost all legumes are known for their ability to establish symbiotic interactions with soil

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living bacteria, this increases their competitiveness in nutrient deficient soils, so they are usually regarded as "pioneer" plants (Hirsch et al., 2001).

Leguminosae family comprises 800 genera and 20.000 species (Lewis et al., 2005). They have a cosmopolitan distribution, representing important ecological constituents in almost all biomes across the globe and occur in even the most extreme habitats (Schrire et al., 2005). Legumes constitute significant elements in terms of both species diversity and abundance, in lowland wet tropical forests in Africa, South America, and Asia (Yahara et al., 2013). Lotus is a large cosmopolitan genus (150 spp.) that occupies two major centers of diversity, the Mediterranean region (including portions of Europe, Africa, and western Asia) and Western North America (Allan et al., 2004). The adaptive characteristics shown by several Lotus species make them good candidates for restoration and phytoremediation of degraded environments, and the species with the higher potentials are *L. creticus, L. tenuis, L. uliginosus* and *L. corniculatus* (Escaray et al., 2012).

Free soil living bacteria that enhance plant growth are collectively known as plant growth promoting rhizobacteria (PGPR). They can be found in the rhizosphere and are capable of promoting plant growth by colonizing their roots and can play an essential role in helping plants to establish and grow in nutrient deficient conditions. Their use in crop production can reduce the agro-chemical use (chemical fertilizers and pesticides) and support ecofriendly sustainable agriculture. PGPR helps plants by various mechanisms to increase plant growth-promoting attributes such as increase in seedling emergence, effective nodulation as well as nodule functioning, increase in indigenous plant hormones, root hair proliferation, root hair deformation and branching, early mineral and water uptake, accumulation of carbohydrates and increasing the yield (Podile and Kishore, 2006). The exact mechanism by which PGPR promote plant growth are not fully understood. However, studies carried out by different researchers suggest some of these as follows (i) the ability to produce or change the concentration of plant hormones as the indole acetic acid (IAA), gibberellic acid, cytokinins and ethylene (ii) asymbiotic N2 fixation (iii) antagonism against phytopathogens by production of siderophores, 1-3- Glucanase (EC 3.2.1.6), chitinase (EC 3.2.1.14) and cyanide (iv) solubilization of mineral phosphate and other minerals (Singh, 2015).

The advantages of legumes stimulated their adoption in the ancient agriculture and then became an important part of sustainable agricultural systems (Singh et al., 2007). The present study was designed to evaluate the capacity of plant growth promoting rhizobacteria to enhance the growth of *L. creticus* so that they can be exploited in the rehabilitation of degraded soils.

Material and Methods

Isolation of rhizobacteria

The rhizobacteria were isolated from the rhizosphere soil of *L. creticus* that was collected from in Northwest of Morocco (35.79339°N, 5.937434°W, 23m above sea level). One gram of rhizospheric soil was suspended in 9 mL of sterile physiologic water. After 1h of agitation aliquots of 100 µL of each dilution (10-1 to 10-7) were plated on Tryptic Soy Agar (TSA) medium. Plates were incubated at 30 °C for 24 to 48 h. Colonies were isolated and purified on the same medium.

Selection of phosphate solubilizing bacteria

The isolates were screened for phosphate solubilization; the purified isolates were transferred on PVK medium (Pikovskaya, 1948), and then incubated at 28 °C. The plates were examined after 7 days of incubation and data were recorded. The phosphate solubilizing ability of bacteria is possible by plate screening methods that show clear zone around the colonies in media containing insoluble mineral phosphate (TCP) as P source. The diameter of solubilization was calculated by subtracting colony diameter from the total diameter.

Determination of indole acetic acid (IAA) production

The tested bacterial strains were cultured for 2 days in sucrose-minimal salts (SMS) medium (sucrose 1%; $(NH_4)_2SO_4$ 0.1%; K_2HPO_4 0.2%; $MgSO_4$ 0.05%; NaCl 0.01%; yeast extract 0.05%; $CaCO_3$ 0.05%; pH 7.2) supplemented with 0.05% of L-tryptophan. After incubation, 1mL of supernatant was mixed with 2 mL of Salkowski reagent and the development of a pinkish color indicated the production of IAA (Gordon and Weber, 1951). The absorbance of pink color developed after 25 minutes of incubation at room temperature was read at 535 nm.

Production of hydrogen cyanide (HCN)

To estimate HCN production, 100 µL of bacterial culture were streaked on TSA supplemented with 4.4 g L-1glycine. Filter paper discs (9 cm diameter) soaked in 2% sodium carbonate in 0.5% picric acid solution, and were placed in the lid of each Petri dish (Bakker and Schippers, 1987). The plates were sealed with parafilm and incubated at 28 °C. Change in color from yellow to orange or brown indicated the synthesis of HCN production.

Production of siderophores

The bacteria were spot inoculated on TSA medium and the plates were incubated for 3 days at 28 °C. A layer of chrome azurol S medium (CAS) (Schwyn and Neilands, 1987) was poured on the surface of these plates. After 24 h in the dark, change in color of CAS medium from blue to orange indicated the production of siderophores.

Production of ammonia

All the bacterial isolates were tested for the production of ammonia as described by Cappuccino and Sherman (1992). Twelve hours old bacterial cultures were inoculated in peptone water (10 mL) and incubated for 48-72 h at 36 ± 2 °C. Development of brown to yellow color after addition of Nesseler's reagent indicates the production of ammonia, no color change indicates negative test.

Testing ability of rhizobacteria to use 1-aminocyclopropane-1-carboxylate (ACC) as sole source of nitrogen

The existence of ACC deaminase (EC 3.5.99.7) is determined by the ability of bacterial strains to use ACC as the sole source of nitrogen. According to the method described by Jacobson et al. (1994), bacterial strains cultured in the presence of two sources of nitrogen, ACC and ammonium sulfate $(NH_4)_2SO_4$ and a mineral source magnesium sulfate ($MgSO_47H_2O$) are compared according to their growth rate.

A volume of 122 µL of the minimum DF salt medium (Dworkin and Foster, 1958) was distributed per well in a 96-well microplate. A volume of 15 µL of a solution of $MgSO_47H_2O$ (0.1 M) is added in lines 3, 6, 9 and 12 of the microplate, 15 µL of $(NH_4)_2SO_4$ (0.1 M) in lines 2, 5, 8, and 11 and 15 µL of the ACC solution (3.0 mM) in lines 1, 4, 7, and 10. The bacterial cultures were inoculated in TSB (Tryptic soy broth) and incubated for 24h at 30°C. These cultures are diluted 1:10 in MgSO4 and 22 µL of each dilution is used to inoculate a well of each successive line. The negative control is inoculated with 22 µL of $MgSO_47H_2O$. The optical density is measured at 600 nm after 0, 24, 48, 72, and 96 hours. Optical densities (OD) values are compared. The isolates with OD higher than that of the $MgSO_47H_2O$ solution are considered to be positive for the production of ACC.

Qualitative phosphate solubilization assay

Isolates were tested for their ability to solubilize the TCP in the liquid medium; this is realized by inoculating 50 mL of PVK liquid medium by 500µL of bacterial culture. Autoclaved and not inoculated media were used as controls. The inoculated media and controls were incubated for 7 days at 28 °C on shaker (180 rpm). The media were centrifuged at 13.000 rpm for 20 min. The concentration of soluble P of the supernatant was determined by the colorimetric method of Ames (1966) and the pH of the medium was also determined.

Antagonism against *Fusarium oxysporum*

The antifungal activity was tested using potato dextrose agar (PDA) (Rabindran and Vidhyasekaran, 1996). Bacterial isolates were tested for their ability to inhibit the growth of the plant pathogenic fungus *Fusarium oxysporum* isolated and characterized by El Aaraj et al. (2015). A 5 mm agar disk of the fungus was deposited in the center of the PDA Petri plates. A volume of 20µL of each bacterial culture was seeded in 3 cm spot of the fungal strain. A negative control of the fungal strain is tested in the absence of bacteria. Plates were incubated for 7 days at 25ºC and examined for evidence of fungal growth inhibition. The zone of inhibition was determined using the following formula: % Inhibition of radial growth = $100 \times ((r1-r2) \div r1)$

With r1 is the radial growth of the mycelium in control and r2 is the radial growth of the mycelium in treatment. The results represent the average of three replicates.

Inoculation of *Lotus creticus*

The seeds of *L. creticus* were surface sterilized by agitation in 95% ethanol for 1 min then in 1.2% sodium hypochlorite for 20 min, followed by several washings with sterile water. Seeds were then placed on filter paper discs (9 cm diameter) soaked in 10 mL of sterile water on petri dish. The plates were then incubated for 3-4 days at 28± 2 °C. After germination, each pot filled with *L. creticus* soil was sowed by 5 germinated seeds and each seed was inoculated directly with 1 mL of bacterial culture (108 CFU mL^{-1}) grown in TSB. Uninoculated pots were used as controls. All pots were maintained under greenhouse conditions. Three replications were maintained for each treatment. Plants were harvested after 90 days. To evaluate the response of the selected PSB, growth parameters (shoot and root length, dry and fresh weight of shoot and root) were measured.

Statistical analysis

The data are reported as means ± SD (standard deviation) for three replicates. The results were compared by analysis of variance (ANOVA) according to Fisher protected LSD test ($p < 0.05$).

Results and Discussion

Isolation and selection of phosphate solubilizing bacteria

A total of 113 rhizobacteria were isolated from the rhizosphere of *L. creticus*, of which 25.66% (29 PSB) were able to solubilize TCP on solid PVK medium. The solubilization is indicated by the formation of a clear halo around the bacterial colony. The P-solubilizing potential varied amongst these isolates as evidenced by the size of halo on Pikovskaya's agar plates. Five PSB were selected based on their halo diameters ⩾ 0.6 cm (Table 1). The most important halo diameter was formed by the isolate LCP27 (1.5 cm) followed by LCP28 (1.3 cm). This phosphate solubilization mechanism is generally correlated with the production of organic acids (OA) via the direct oxidation pathway that occurs on the outer face of the cytoplasmic membrane, with concomitant drop in pH value (Khan et al., 2009). The OA(s) released chelate mineral ions or drop the pH to bring P into solution (Maliha et al. 2004). The OA produced by bacteria leads to acidification of microbial cells and their surroundings and, consequently, the release of P-ions from the P-mineral by H+ substitution for Ca2+ (Goldstein, 1986).

Table 1.Halo diameters and plant growth promoting activities of the selected rhizobacteria.

Isolates	HD	IAA mg L-1	HCN	SID	NH_3	ACCD	P mg L-1	pH
LCP26	0.8	7.00 ± 0.99 c	+++	+	+	+	59.57 ± 0.6 b	5.95 ± 0.04 b
LCP27	1.5	6.88 ± 0.74 d	++	+	+	+	43.34 ± 0.18 b	5.37 ± 0.4 b
LCP28	1.3	5.64 ± 0.91 e	++	+	+	+	173.57 ± 0.77 a	4.49 ± 0.63 a
LCR14	0.9	8.76 ± 0.55 b	++	+	+	+	145.53 ± 0.13 a	5.39 ± 0.89 b
LCR33	0.6	19.08 ± 0.96 a	+++	+	+++	+	58.54 ± 0.32 b	4 .06 ± 0.09 a

+ HD: halo diameter, IAA: Concentration of indole acetic acid, HCN: Hydrogen cyanide, SID: Siderophores, NH_3: Ammonia, ACCD: 1-aminocyclopropane-1-carboxylate deaminase, P: Concentration of solubilized P. The data presented are the mean of 3 replicates. Means in the same column followed by the same letter are not significantly different $P < 0.05$ (Fisher's least significant difference (LSD) test; ± values indicate standard errors of the means).

Screening of plant growth promoting traits

Screening results of PGP activities of the selected bacteria are shown in the Table 1. IAA production was detected in all the 5 isolates with different amounts that were significantly different. The highest concentration was produced by LCR33 (19.08 ± 0.96 mg L^{-1}) while the lowest value was presented by LCP28 (5.64 ± 0.91 mg L-1). The production of IAA is one of the most common mechanisms of action implicated in PGPR (Vessey, 2003). It affects the division, extension, and differentiation of plant cells. Besides, IAA stimulates seeds and tuber germination, increases the rate of xylem and root development, controls processes of vegetative growth; initiates lateral and adventitious root formation; mediates responses to light and gravity; affects photosynthesis, pigment formation, biosynthesis of various metabolites and resistance to stressful conditions (Gupta et al., 2015). The potential for IAA synthesis varies with different species and strains as well as cultural condition, growth stage and availability of substrate (Mirza et al., 2001).

All 5 PSB were able to produce hydrogen cyanide, siderophores, ammonia and ACC deaminase. This could make our selected rhizobacteria, powerful biofertlizing and biocontrol agents. In fact, according to Singh (2015), the presence or absence and intensity of HCN production can play a significant role in antagonistic potential of soil bacteria against phytopathogens. Moreover, the production of siderophores that scavenge iron by formation of soluble Fe3+ complexes is a very important mechanism of biofertilization and biocontrol; they improve iron availability to plants (Barness et al., 1992; Sharma et al., 2003) and deprive other pathogenic bacteria from iron (Miethke and Marahiel, 2007). The production of ammonia is also considered to be an important mechanism, it fulfils several biological roles. In addition to its important metabolic role in many organisms, ammonia's toxicity is well known. One prerequisite for toxic functionality appears to be its rapid diffusion through the majority of biological membranes (Kleiner et al., 1998). Deamination of ACC is another direct phytostimulator feature that may influence plant growth by reduction of ethylene levels (Glick et al., 2007). By producing ACC deaminase, our PSB could utilize ammonia as N source thereby restricting the ethylene accumulation consequently rescuing the plant growth from the stress (Khan et al., 2009). This could be of great interest to use our PSB as inoculants for rehabilitation of degraded soils due to their capacity of resisting stress conditions.

The quantitative test of phosphate solubilization was also checked for selected bacteria. The concentration of solubilized P was between 43.34±0.18 and 173.57±0.77 mg L^{-1}. This solubilization was accompanied by a significant decrease in pH of the media from 7 to 4.06. Solubilized P values were significantly negatively correlated (r=-0.51, p<0.01) with the final pH of the culture medium. Several studies demonstrated the existence of negative correlation between pH of the culture and the release of P (Wani et al., 2008; Bhatt and Vyas, 2014). This consolidates the hypothesis of OA involvement in the solubilization of insoluble P (Maliha et al., 2004). Yet, acidification could not be presumed the sole mechanism of inorganic P solubilization (Yang et al., 2012). Altomare et al. (1999) demonstrated that Trichoderma harzianum Rifai has not produced any known organic acid but solubilized P by chelating and reducing molecules. Additionally, it has been demonstrated that siderophores and exopolysaccharides synthesized by PSB bring out locked P into soluble form probably by charge related interactions (Yi et al., 2008; Sharma et al., 2013).

Antagonism against *Fusarium oxysporum*

The selected isolates were evaluated for their antagonistic effect against Fusarium sp. (Figure 1 and 2). All the tested PSB were able to inhibit its growth. Statistical analysis showed that LCP27 had maximum inhibition (48.15±0.99%), whereas LCP28 showed the lowest inhibitory effect (25.93±1.03 %). The percentages of inhibition registered by LCP26, LCP27 and LCR33 were significantly different from LCP28. All 5 isolates were positive for the production of HCN, siderophores and ammonia. So, the production of these compounds can result in fungal growth inhibition (Dubey and Gupta, 2012; Prashar et al., 2013). However, Kumar et al. (2011) showed that toxins and enzymes may also play a role in the growth inhibition process of the phytopathogen fungus *Fusarium oxysporum*.

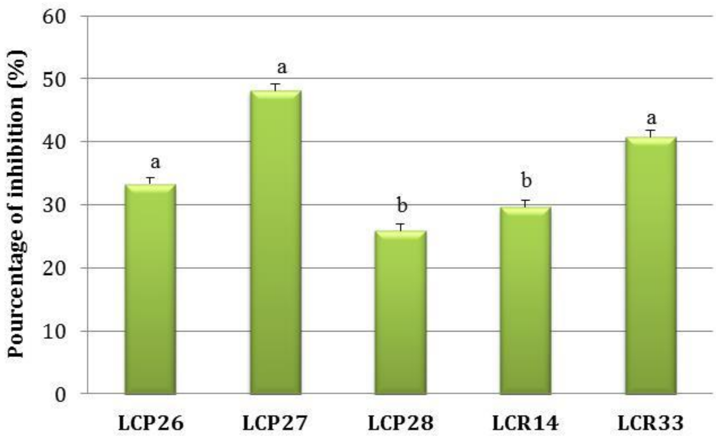

Figure 1. Pourcentage of inhibition of the selected isolates against Fusarium oxysporum. The data presented are the mean of 3 replicates. Means in the same column followed by the same letter are not significantly different P < 0.05 (Fisher's least significant difference (LSD) test).

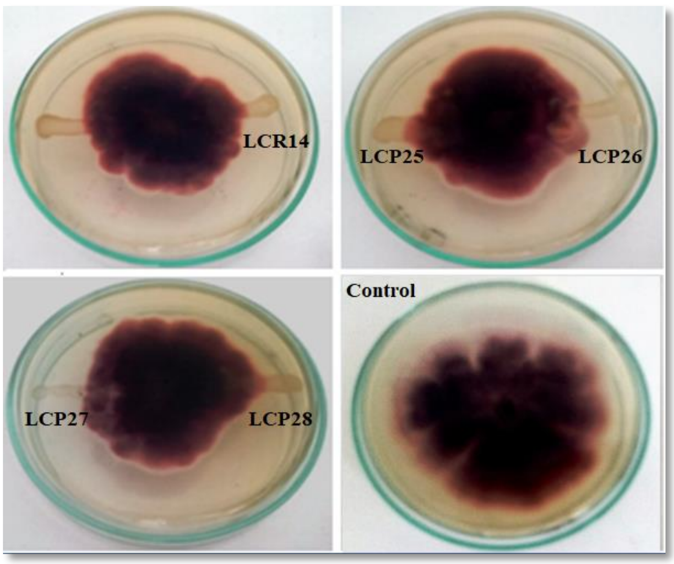

Figure 2. Antagonistic activity of the selected isolates against *Fusarium oxysporum* on potato dextrose agar medium

Inoculation of *Lotus creticus*

The 2 bacterial isolates that presented the highest antagonistic activity against *Fusarium oxysporum* (LCP27 and LCR33) were selected to test their effect on *L. creticus* growth under greenhouse conditions. Results regarding fresh and dry matter and shoot and root length were presented in Figures 3 and 4. Bacterial inoculation of these two rhizobacterial isolates showed positive influence on *L. creticus* growth significantly in comparison to un-inoculated control. In fact, results showed a significant increase in shoot fresh matter in presence of LCR33 and LCP27 compared to the un-inoculated control, while fresh matter yield was significantly increased by LCR33 compared to LCP27 and the control. Concerning the dry matter yield, a significant stimulation was registered by inoculation with LCR33 and LCP27. Inoculation test showed also a significant increase of shoot and root length (Figure 4) with the application of LCR33 compared to LCP27 and the un-inoculated control. The most significant positive effect on *L. creticus* growth was obtained by LCR33 inoculation. Increase in fresh and dry biomass, shoot and root length by inoculation with the selected PSB could be linked to the production of phytohoromones, siderophores, hydrogen cyanide (HCN), ACC deaminase and solubilization of phosphates (Sessitsch et al., 2002; Glick et al., 2007; Sachdev et al., 2009; Mia and Shamsuddin, 2010).

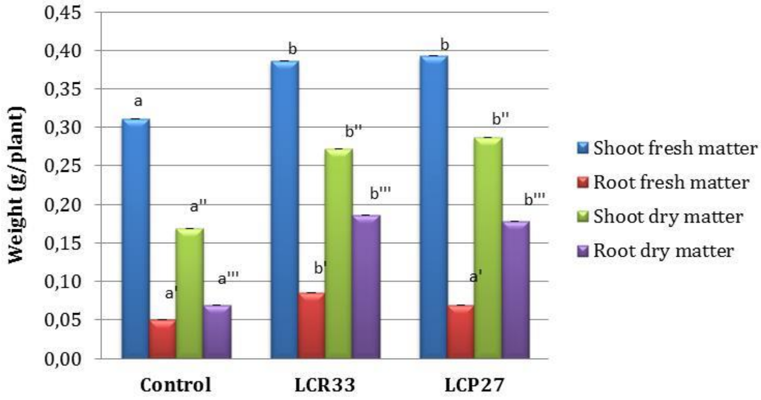

Figure 3. The dry and fresh matter of shoot and root of plants after 90 days of growth in pots. The data presented are the mean of 3 replicates. Means in the same column followed by the same letter are not significantly different P < 0.05 (Fisher's least significant difference (LSD) test).

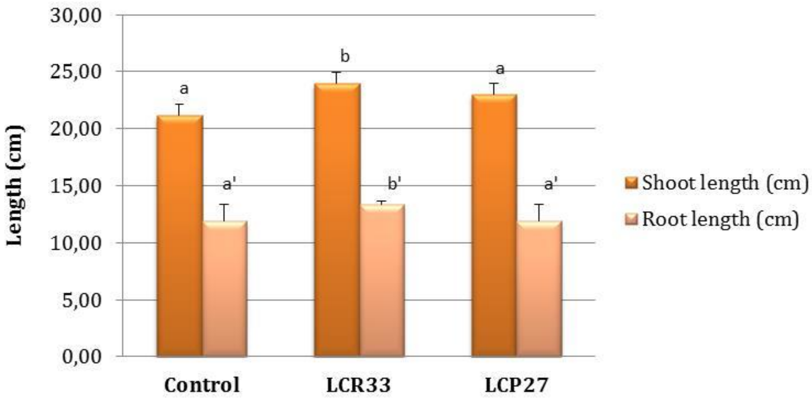

Figure 4. The length of shoot and root of plants after 90 days of growth in pots. The data presented are the mean of 3 replicates. Means in the same column followed by the same letter are not significantly different P < 0.05 (Fisher's least significant difference (LSD) test).

Conclusion

The present study emphasizes the positive effects of PSB isolated from the rhizosphere of *L. creticus* on the growth of this legume. LCP27 and LCR33 can stimulate plant's nutritional intake capacity and growth as well; they could be used as biofertilizers and biocontrol agents based on their positive effect on growth under greenhouse conditions. The use of these rhizobacteria as inoculants may present an efficient alternative to inorganic phosphate fertilizers and could contribute to the rehabilitation of degraded soils. However, tests in the field are necessary to complete this work, in order to evaluate the effect of biotic and abiotic factors on these isolates efficiency.

References

Allan, G.J., Francisco-Ortega, J., Santos-Guerra, A., Boerner, E., Zimmer, E.A., 2004. Molecular phylogenetic evidence for the geographic origin and classification of Canary Island Lotus (Fabaceae: Loteae). *Molecular Phylogenetics and Evolution* 32(1): 123–138.

Altomare, C., Norvell, W.A., Björkman, T., Harman, G.E., 1999. Solubilization of phosphates and micronutrients by the plant growth-promoting and biocontrol fungus *Trichoderma harzianum Rifai* 1295-22. *Applied and Environmental Microbiology* 65(7): 2926-2933.

Ames, B.N., 1966. Assay of inorganic phosphate, total phosphate and phosphatases. *Methods in Enzymology* 8: 115-118.

Bakker, A.W., Schippers, B., 1987. Microbial cyanide production in the rhizosphere in relation to potato yield reduction and *Pseudomonas* spp.-mediated plant growth stimulation. *Soil Biology and Biochemistry* 19(4) : 451-457.

Barness, E., Hadar, Y., Chen, Y., Romheld, V., Marschner, H., 1992. Short-term effects of rhizosphere microorganisms on Fe uptake from microbial siderophores by maize and oat. *Plant Physiology* 100(1): 451-456.

Bhatt, P.V., Vyas, R.M.B., 2014. Screening and characterization of plant growth and health promoting rhizobacteria. *International Journal of Current Microbiology and Applied Sciences* 3(6): 139-155.

Cappuccino, J.C., Sherman, N., 1992. Microbiology : A Laboratory Manual. 3th Edition, Benjamin-Cummings Publishing Company, New York, USA.

Dubey, P., Gupta, G.P., 2012. Synergistic and anagonistic interactions among endophytic bacterial isolates of Vigna mungo (L .) Hepper. *Journal of Current Perspectives in Applied Microbiology* 1: 1–12.

Dworkin, M., Foster, J., 1958. Experiments with some microorganisms which utilize ethane and hydrogen. *Journal of Bacteriology* 75(5): 592-601.

El Aaraj, C., Bakkali, M., Infantino, A., Arakrak, A., Laglaoui, A., 2015. Mycotoxigenic fungi in cereals grains and coffee from the North of Morocco. *American Journal of Research Communication* 3(2): 130-142.

Escaray, F.J., Menendez, A.B., Gárriz, A., Pieckenstain, F.L., Estrella, M.J., Castagno, L.N., Carrasco, P., Sanjuán, J., Ruiz, O.A., 2012. Ecological and agronomic importance of the plant genus Lotus. Its application in grassland sustainability and the amelioration of constrained and contaminated soils. *Plant Science* 182: 121–133.

Glick, B.R., Cheng, Z., Czarny, J., Duan, J., 2007. Promotion of plant growth by ACC deaminase-producing soil bacteria. *European Journal of Plant Pathology* 119(3): 329-339.

Goldstein, A.H., 1986. Bacterial solubilization of mineral phosphates: historical perspectives and future prospects. *American Journal of Agricultural Economics* 1(2): 57–65.

Gordon, S.A., Weber, R.P., 1951.Colorimetric estimation of indole-acetic acid. *Plant Physiology* 26: 192-195.

Gupta, G., Parihar, S.S., Ahirwar, N.K., Snehi, S.K., Singh, V., 2015. Plant growth promoting rhizobacteria (PGPR): Current and future prospects for development of sustainable agriculture. *Journal of Microbial and Biochemical Technology* 7: 96-102.

Hirsch, A.M., Lum, M.R., Downie, J.A., 2001. What makes the rhizobia-legume symbiosis so special?. *Plant Physiology* 127 (4): 1484–1492.

Jacobson, C.B., Pasternak, J.J., Glick, B.R., 1994. Partial purification and characterization of ACC deaminase from the plant growth-promoting rhizobacterium *Pseudomonas putida* GR12–2. *Canadian Journal of Microbiology* 40(12): 1019-1025.

Khan, M.S., Zaidi, A., Vani, P., Oves, M. 2009. Role of plant growth promoting rhizobacteria in the remediation of contaminated soils. *Environmental Chemistry Letters* 7(1): 1–19.

Kleiner, D., Traglauer, A., Domm, S., 1998. Does ammonia production by *Klebsiella* contribute to pathogenesis?. *Bulletin de l'Institut Pasteur* 96(4): 257–265.

Kumar, H., Dubey, R.C., Maheshwari, D.K., 2011. Effect of plan growth promoting rhizobia on seed germination, growth promotion and suppression of *Fusarium wilt* of fenugreek (Trigonella foenum-graecum L.). *Crop Protection* 30(11): 1396–1403.

Lewis, G., Schrire, B., Mackinder, B., Lock, M., 2005. Legumes of the world. Royal Botanic Gardens, Kew Publishing. UK 592 p.

Maliha, R., Samina, K., Najma, A., Sadia, A., Farooq, L., 2004. Organic acids production and phosphate solubilization by phosphate solubilizing microorganisms (PSM) under in vitro conditions. *Pakistan Journal of Biological Sciences* 7(2): 187–196.

Mia, M.A.B., Shamsuddin, Z.H., 2010. *Rhizobium* as a crop enhancer and biofertilizer for increased cereal production. *African Journal of Biotechnology* 9(37): 6001-6009.

Miethke, M., Marahiel, M., 2007. Siderophore-based iron acquisition and pathogen control. *Microbiology and Molecular Biology Reviews* 71(3): 413–451.

Mirza, M.S., Ahmad, W., Latif, F., Haurat, J., Bally, R., Normand, P., Malik, K.A., 2001. Isolation, partial characterization, and the effect of plant growth-promoting bacteria (PGPB) on micro propagated sugarcane in vitro. *Plant and Soil* 237(1): 47-54.

Pikovskaya, R.I., 1948. Mobilization of phosphorous in soil in connection with vital activity of some microbial species. *Microbiologiya* 17: 362-370.

Podile, A.R., Kishore, G.K., 2006. Plant growth-promoting rhizobacteria. In: Plant associated bacteria. Gnanamanickam, S.S. (Ed.). Springer, Dordrecht, The Netherlands. pp.195–230.

Prashar, P., Kapoor, N., Sachdeva, S., 2013. Isolation and characterization of *Bacillus* sp with in vitro antagonistic activity against *Fusarium oxysporum* from rhizosphere of Tomato. *Journal of Agricultural Science and Technology* 15: 1501-1512.

Rabindran, R., Vidhyasekaran, P., 1996. Developpment of powder formulation of Pseudomonas Pf ALR 2 for the management of rice sheath blight. *Crop Protection* 15(8): 715-721.

Sachdev, D.P., Chaudhari,H.G., Kasture, V.M., Dhavale, D.D., Chopade, B.A., 2009. Isolation and characterization of Indole acetic acid (IAA) producing *Klebsiella pneumoniae* strains from rhizosphere of wheat (*Triticum aestivum*) and their effect on plant growth. *Indian Journal of Experimental Biology* 47(12): 993-1000.

Schrire, B.D., Lavin, M., Lewis, G.P., 2005. Global distribution patterns of the Leguminosae: Insights from recent phylogenies. *Biologiske Skrifter - Det Kongelige Danske Videnskabernes Selskab* 55: 375–422.

Schwyn, B., Neilands, J.B., 1987. Universal chemical assay for the detection and determination of siderophores. *Analytical Biochemisty* 160(1): 47-56.

Sessitsch, A., Howieson, J.G., Perret, X., Antoun, H., Martínez-Romero, E., 2002. Advances in *Rhizobium* research. *Critical Reviews in Plant Sciences* 21(4): 323-387.

Sharma, A., Johri, B.N., Sharma, A.K., Glick, B.R., 2003. Plant growth-promoting bacterium *Pseudomonas* sp. strain GRP3 influences iron acquisition in mung bean (Vigna radiata L. Wilzeck). *Soil Biology and Biochemistry* 35(7): 887-894.

Sharma, S.B., Sayyed, R.Z., Trivedi, M.H., Gobi, T.A., 2013. Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *Springer Plus* 2: 587.

Singh, B.P., 2015. Screening and characterization of plant growth promoting rhizobacteria (PGPR): An overview. *Bulletin of Environmental and Scientific Research* 4(1-2): 1-14.

Singh, R.J., Chung, G.H., Nelson, R.L., 2007. Landmark research in legumes. *Genome* 50(6): 525–537.

Vessey, J. K., 2003. Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil* 255(2): 571–586.

Wani, P.A., Khan, M.S., Zaidi, A., 2008. Chromium-reducing and plant growth-promoting *Mesorhizobium* improves chickpea growth in chromium-amended soil. *Biotechnology Letters* 30(1): 159–163.

Wild, A., 2003. Soils Land food: Managing the land during the twenty-first century. Cambridge University Press, Cambridge, UK. 258p.

Yahara, T., Javadi, F., Onoda, Y., Queiroz, L.P., Faith, D., Prado, D.E., Akasaka, M., Kadoya, T., Ishihama, F., Davies, S., Slik, J.W.F., Yi, T., Ma, K., Bin, C., Darnaedi, D., Pennington, R.T., Tuda, M., Shimada, M., Ito, M., Egan, A.N., Buerki, S., Raes, N., Kajita, T., Vatanparast, M., Mimura, M., Tachida, H., Iwasa, Y., Smith, G.F., Victor, J.E., Nkonki, T., 2013. Global legume diversity assessment: Concepts, key indicators, and strategies. *Taxon* 62 (2): 249–266.

Yang, P.X., Ma, L., Chen, M.H., Xi, J.Q., He, F., Duan, C.Q., Mo, M.H., Fang, D.H., Duan, Y.Q., Yang, F.X., 2012. Phosphate solubilizing ability and phylogenetic diversity of bacteria from p-rich soils around Dianchi Lake drainage area of China. *Pedosphere* 22: 707-716.

Yi, Y., Huang, W., Ge, Y., 2008. Exopolysaccharide: a novel important factor in the microbial dissolution of tricalcium phosphate. *World Journal of Microbiology and Biotechnology* 24(7): 1059-1065.

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Characterization and classification of soils of Wolkite University research sites, Ethiopia

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Abstract

The main purpose of this study was to characterize and classify soils of Wolkite University research sites, Gurage zone, Ethiopia. In each five research sites, Wabe (RS1), Geche (RS2), Yefereze (RS3), Kotergedra (RS4) and Keratemo (RS5), representative pedons were opened and described. Almost all the pedons were deep (>150 cm) with argillic B horizons and had clay textural class. The pH of the surface soils ranged from strongly acidic (4.5) to moderately acidic (5.6). The soils had medium (2.60%) to high (3.84%) organic carbon content and very low (1.46 mg kg^{-1}) to low (10.34 mg kg-1) available phosphorus. The status of cation exchange capacity (CEC) and base saturation were ranged from medium (23.15) to very high (66.32 cmolc kg^{-1}) and low (33%) to high (99%), respectively. According to WRB classification, pedon RS1 was classified as Haplic Vertisols (Hypereutric) with USD equivalent of Typic Haplusterts. Pedons RS2 and RS3 were classified as Vertic Alisols (Hyperdysric), which is correlated with Ultisols (Typic Haplustults) in USDA classification. Pedon RS4 and RS5 classified as Vertic Luvisols (Hypereutric), which is correlated with Alfisols (Vertic Haplustalfs) in USDA classification. Generally, the soils of the research sites were acidic with low status of available phosphorus, which need amelioration of soil acidity and nutrient management.

Keywords: Argilic, nutrient management, pedon, soil acidity.

Introduction

Soils have diverse morphological, physical, chemical and biological properties. As a result, they differ in their responses to management practices, their inherent ability to deliver ecosystem services, as well as their resilience to disturbance and vulnerability to degradation (FAO, 2017). Characterization and classification of soils have therefore paramount importance in using those resources based on their capability and to manage them in sustainable manner. Soil information obtained through systematic identification and grouping use for effective planning of different land uses, as they provide information related to potentials and constraints of the land (Lufega and Msanya, 2017).

Soil characterization studies are major building block for understanding the soil, classifying it and getting the best understanding of the environment (Onyekanne et al., 2012). Soil characterization provides the information for our understanding of the physical, chemical, mineralogical and microbiological properties of soil. It also helps to organize our knowledge, facilitates the transferring of experience and technology from one place to another (Chekol and Mnalku, 2012; Adhanom and Toshome, 2016).

In Ethiopia, the studies that have been made so far were mostly at small scale, which could not be applicable for site specific land use and soil management. Therefore, adequate knowledge on soil characteristics at large scale and or local watershed or farm level is essential in tackling specific and local problems of agricultural production (Hailu et al., 2015).

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Wolkite University, one of the Universities in Ethiopia, has established five research sites in different location of Gurage zone. The main purpose of establishing those sites were to conduct research by the academic staff of the University, based on the identified thematic areas. To undertake soil related problem solving researches, it is mandatory to have information about the soils of the research sites: the morphological, physical, chemical, biological properties and their management requirements. In view of this fact, this research was initiated and conducted to characterize and classify soils of Wolkite University research sites.

Material and Methods

Description of the study area

The study was conducted at research sites of Wolkite University, which is found in south western Ethiopia. The study encompasses five sites which are found in Gurage Administrative Zone of Southern Nations, Nationalities and Peoples Regional State. Generally, the research sites are located in three Districts of Gurage zone: Wabe (Abeshege), Geche, Kotergedra and Keratemo (Eza), Yefereze (Cheha) and geographically lies between 8°00'00"N to 8°20'00"N and 37°40'00"E to 38°10'00"E as indicated in the figure below (Figure 1).

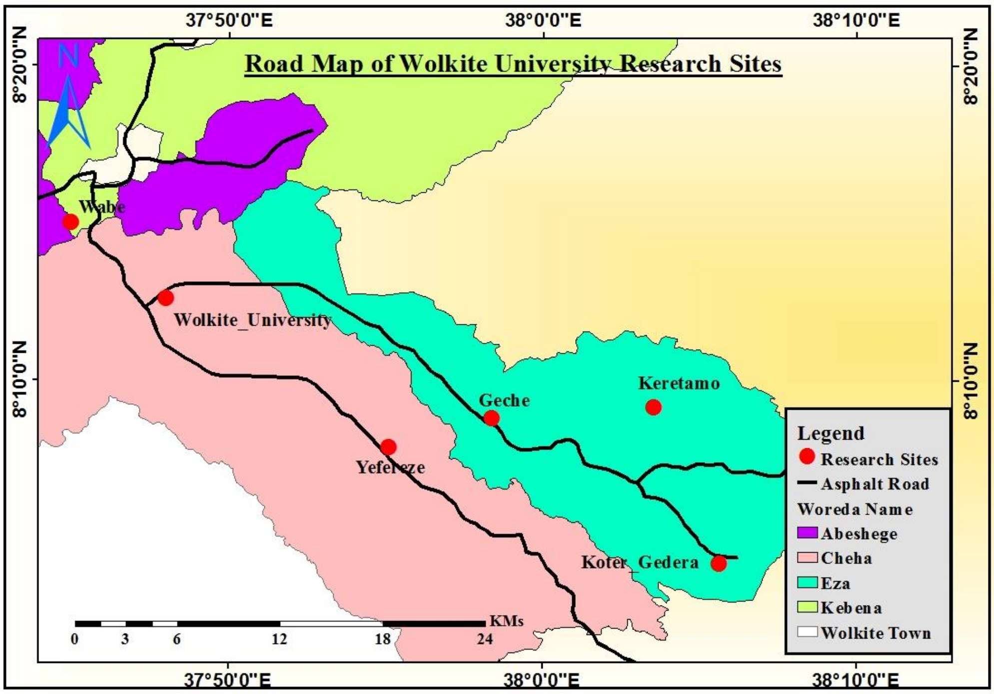

Figure 1. Location map of research sites of Wolkite University

The main rainy season which accounts for around 70-90% of the total annual rainfall occurs from June to September. Two main distinct seasons, dry and wet seasons are recognized in the area. The dry season starts from November to May, while the wet season covers the remaining part of the year, when most of the precipitation takes place. Rain usually starts in March, but the effective rainy season is from June to October with the peak in July, receiving a monthly mean of 222.8 mm of rainfall. Based on the Ethiopian agro ecological classification Wabe, Geche and Yefereze sites are located in the Woyena Dega zone, where as Kotergedera and Keratemo sites are located on the Dega agro-ecological zones. Ten years' data obtained from Meteorology Agency indicated that the mean annual temperature ranges from 14 to 24^{0}C with an average of 20.5^{0}C. The slope steepness of Wabe, Geche and Yefereze sites are characterized by nearly level to sloping, while Kotergedera and Keratemo sites are characterized as nearly level to steep slope as indicated in the table below (Table 1).

Table 1. Location, elevation and slope description of Wolkite University research sites

Site	Latitude	Longitude	Elevation (meter)	Slope (%)	Area (hectare)
Geche	8.15	37.95	2190-2202	0.5-13	1.2
Keratemo	8.14	38.04	2409-2437	0.5-24	6.6
Kotergedra	8.15	38.05	2495-2732	0.6-37	3.5
Wabe	8.25	37.75	1667-1680	1-8	1.3
Yefereze	8.10	37.90	2022-2046	0.6-6	6.1

Soil description and analysis

A representative pedon, 1.5x2 m, was opened in each research site and described in situ following the Guidelines for Field Soil Description (FAO, 2006a). General site information and soil description were recorded and samples were collected from every identified horizon. Based on the morphological properties and the laboratory analysis, the soils of the study area were classified according to WRB (FAO, 2014) and Soil Taxonomy (Soil Survey Staff, 2014).

The physical and chemical properties which were considered for the study were texture, pH, organic matter, total nitrogen, phosphorus, CEC and exchangeable bases. Particle size distribution was analyzed by hydrometer method (Bouyoucos, 1962). Soil pH was measured in the supernatant suspension of a 1:2.5 soil: water mixture using pH meter. Soil organic carbon was determined using the Walkley and Black wet oxidation method (Walkley and Black, 1934). Total nitrogen was determined using the Kjeldahl procedure (Wilke, 2005). Available phosphorus was determined using Olsen method (Olsen and Sommers, 1982), the reading was made using spectrometer at 880 nm. The cation exchange capacity was determined following ammonium acetate method (Sarkar and Haldar, 2005). From the aliquots of the same extract, exchangeable bases were determined. The reading was made with Atomic Absorption Spectrophotometer.

Results and Discussion

Morphological properties

The pedons of the research sites, Wabe (RS1), Geche (RS2), Yefereze (RS3), Kotergedra (RS4) and Keratemo (RS5) were deep (>150 cm) with argillic B horizons (Table 2). Slickensides were noticed in the subsoil horizons of pedon RS1. The moist color of surface horizons varied from brown (10YR 4/3) to dark brown (7.5YR 3/4), whereas the color of the subsurface horizons varied from dark reddish brown (2.5YR 2.5/4) to very dark gray (10YR 3/1) (Table 2). The surface horizons were darker as compared to the subsurface horizons that mainly could be due to accumulation and decomposition of organic materials, as it was also discussed by previous studies (Mulugeta and Sheleme, 2010).

The surface horizons had granular structure with varied grade and size, whereas the subsurface horizons had moderate to very strong, and fine to extremely coarse angular blocky structure (Table 2). The dry consistence of the surface soil was slightly hard (Table 2), whereas the moist and wet consistencies were friable, and sticky/plastic, respectively. Likewise, the subsurface horizons had slightly hard to extremely hard (dry), friable to extremely firm (moist), and slightly sticky/plastic to very sticky/very plastic (wet) consistence.

Selected physical and chemical properties

The clay proportion was highest in all horizons of the pedons and as a result the textural classes of the soils of the research sites were clay (Table 3). Its content varied from 58 to 86%, and generally increased with depth.

The textural differentiation might be caused by an illuvial accumulation of clay, predominant pedogenetic formation of clay in the subsoil, selective surface erosion of clay, upward movement of coarser particles due to swelling and shrinking, biological activity and a combination of two or more of these different processes (FAO, 2014). In the surface horizons of the pedons, silt and sand contents varied from 12 to 26 % and 8 to 30 %, respectively, whereas their respective values varied from 9 to 32 % and 2 to 11 % in the subsurface horizons.

The pH (H2O) of the surface soil of the research sites ranged from 4.5 to 5.6, whereas the subsurface values were between 4.8 and 6.9 (Table 3) indicating that the soils are strongly acidic to neutral (Horneck et al., 2011). In most of the pedons, the pH values increased with increasing depth. Considering the optimum pH for many plant species to be 5.5 to 6.8, the pH of the soils in study area less than 5.5 could be considered as unsuitable for most crop production.

The organic carbon (OC) content ranged from 2.60 to 3.84 % in the surface layers of the pedons and categorized under medium to high (Tekalign et al., 1991). The values decreased with increasing depth in all pedons (Table 3), as observed in previous studies (Dengiz, 2010; Mulugeta and Sheleme, 2010; Paramasivan and Jawahar, 2014). The total N content of the surface soils ranged 0.26 to 0.39%, and rated as high (Tekalign et al., 1991). Similar to OC, total N content decreased with depth in all pedons (Table 3). According to Hartz (2007), soils with less than 0.07% total N have limited N mineralization potential, while those having greater than 0.15% total N would be expected to mineralize a significant amount of N during the succeeding crop cycle, showing that most of the soils have good potential of N mineralization.

Table 2. Selected morphological properties of the pedons

Pedon[1]	Horizon	Depth (cm)	Boundary[2]	Color		Texture (Feel method)	Structure[3]	Consistency[4]	Special features
				Dry	Moist				
RS1	Ap	0-38	CS	10YR 5/2	10YR 4/1	Clay	ST,ME,GR	SHA,FR,ST,PL	Crack
	Bi1	38-120	GS	10YR 4/2	10YR 3/1	Clay	VST,CO,AB	HA,FI,VST,VPL	Slickenside
	Bi2	120-200+	-	10YR 5/4	10YR 4/4	Clay	VST,VC,AB	VHA,EFI,VST,VPL	Slickenside
RS2	Ap	0-26	CS	10YR 5/4	10YR 4/3	Clay	MO,FI,GR	SHR,FR,SST,SPL	-
	Bt1	26-42	CS	7.5YR 4/3	7.5YR 3/3	Clay	ST,ME,AB	SHA,FR,ST,PL	-
	Bt2	42-92	GS	7.5YR 4/4	7.5YR 3/4	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	92-200+	-	10R 4/4	10R 4/5	Clay	ST,ME,AB	SHA,FR,ST,PL	-
RS3	Ap	0-28	CS	7.5YR 4/6	7.5YR 3/4	Clay	ST,FI,GR	SHA,FR,ST,PL	-
	Bt1	28-139	GS	2.5YR 4/6	2.5YR 5/4	Clay	ST,ME,AB	SHA,FR,ST,PL	-
	Bt2	139-200+	-	7.5YR 4/6	2.5YR 2.5/4	Clay	ST,FM,AB	SHA,FF,ST,PL	-
RS4	Ap	0-17	CS	7.YR 5/4	7.5YR 4/4	Clay	MO,FM,GR	SHA,FR,ST,PL	-
	Bt1	17-53	GS	7.5YR 5/3	7.5YR 5/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt2	53-92	GS	7.5Y 4/3	7.5YR 4/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	92-200+	-	7.5YR 4/4	10YR 4/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-
RS5	Ap	0-20	CS	7.5YR4/4	7.5YR3/4	Clay	MO,FM,GR	SHA,FR,ST,PL	-
	Bt1	20-60	GS	7.5YR4/3	7.5YR3/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt2	60-90	GS	7.5YR4/2	7.5YR3/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	90-150+	-	7.5YR4/4	7.5YR3/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-

[1] RS1 = Wabe research site; RS2 = Geche research site; RS3 = Yefereze research site; RS4 = Kotergedra research site; RS5 = Keratemo research site

[2] CS = Clear and smooth; GS = Gradual and smooth;

[3] ST= Strong; MO= Moderate; VST= Very strong; FI= Fine; FM= Fine and medium; ME= Medium; CO = Coarse; VC= Very coarse; GR= Granular; AB= Angular blocky

[4] SHA= Slightly hard; HA= Hard; VHA= Very hard; FR=Friable; FI=Firm; EFI=Extremely firm; ST= Sticky; SST= Slightly sticky; VST = Very sticky; PL= Plastic; SPL= Slightly plastic; VPL= Very plastic;

Table 3. Selected physical and chemical proprieties of soils of Wolkite University research sites

Pedon[1]	Horizon	Depth (cm)	Particle size distribution (%)			Textural class	pH	Organic C (%)	Total N (%)	Available P (mg kg-1)
			Sand	Silt	Clay					
RS1	Ap	0-38	20	22	58	Clay	5.6	3.78	0.38	1.46
	Bi1	38-120	7	12	81	Clay	6.9	1.22	0.12	1.51
	Bi2	120-200+	5	9	86	Clay	6.8	0.29	0.03	0.50
RS2	Ap	0-26	19	24	57	Clay	5.3	2.77	0.28	6.05
	Bt1	26-42	4	32	64	Clay	5.9	0.49	0.05	0.74
	Bt2	42-92	3	21	76	Clay	5.8	1.36	0.14	0.75
	Bt3	92-200+	2	14	84	Clay	5.8	0.63	0.06	0.49
RS3	Ap	0-28	8	26	66	Clay	4.9	2.60	0.26	1.27
	Bt1	28-139	2	16	82	Clay	4.9	0.93	0.09	0.50
	Bt2	139-200+	4	12	84	Clay	5.1	0.42	0.04	0.77
RS4	Ap	0-17	30	12	58	Clay	4.5	3.84	0.39	10.34
	Bt1	17-53	4	26	70	Clay	4.9	3.05	0.31	6.52
	Bt2	53-92	7	22	71	Clay	4.9	1.14	0.12	8.09
	Bt3	92-200+	11	23	66	Clay	5.1	0.57	0.06	8.79
RS5	Ap	0-20	9	25	66	Clay	5.9	3.63	0.37	9.40
	Bt1	20-60	9	28	63	Clay	5.3	2.14	0.22	3.14
	Bt2	60-90	3	20	77	Clay	4.8	2.06	0.21	2.50
	Bt3	90-150+	2	26	72	Clay	5.2	1.56	0.16	3.82

[1]RS1 = Wabe research site; RS2 = Geche research site; RS3 = Yefereze research site; RS4 = Kotergedra research site; RS5 = Keratemo research site;

The available phosphorus content of the pedons ranged from 0.49 in subsoil to 10.34 mg kg-1 in surface horizon (Table 3), which could be categorized from very low to low (Jones, 2003). Relatively the maximum available P was recorded in pedon RS4, where the OC was highest (3.84). According to Carrow et al. (2004), P-Olsen between 12 to 18 mg kg^{-1} is considered as sufficient and hence the available P in surface horizons of all pedons was insufficient range. Available P values declined with increasing depth which could be attributed to decrease in soil OM. The increase in clay content with depth could have also contributed to decrease available P (Mulugeta and Sheleme, 2010).

Cation exchange capacity, exchangeable bases and base saturation

The overall cation exchange capacity of the soils ranged between 23.15 and 66.32 cmolc kg^{-1} (Table 4), which is medium to very high in accordance with the rating of Hazelton and Murphy (2007). The highest CEC was recorded in pedon RSS1, where the highest pH (6.9) was observed and as the pH values of the pedons decrease the CEC also decreased. This showed that soil pH and CEC have direct relation.

Table 4. Exchangeable bases, cation exchange capacity, and percent base saturation

Pedon	Depth (cm)	Exchangeable bases $cmol_c\ kg^{-1}$					CEC [2], $cmol_c\ kg^{-1}$		ESP[3] (%)	PBS[4] (%)
		Ca	Mg	K	Na	TEB[1]	Soil	Clay		
RS1	0-38	19.37	18.33	0.75	0.35	38.8	46.73	81	0.7	83
	38-120	33.05	17.88	1.30	1.00	53.23	66.32	82	1.5	80
	120-200+	35.74	20.35	1.44	1.15	58.68	59.14	69	1.9	99
RS2	0-26	4.63	3.60	0.48	0.06	8.77	28.85	51	0.2	30
	26-42	7.99	1.60	0.24	0.13	9.96	23.15	36	0.6	43
	42-92	9.16	3.77	0.41	0.18	13.52	29.12	38	0.7	46
	92-200+	4.86	3.78	0.49	0.16	9.29	26.56	32	0.6	35
RS3	0-28	8.65	6.79	0.84	0.11	16.39	33.59	51	0.4	49
	28-139	5.96	5.96	0.50	0.14	12.56	28.50	35	0.5	44
	139-200+	6.0	4.98	0.64	0.19	11.89	31.00	37	0.6	38
RS4	0-17	5.70	5.06	1.25	0.02	21.23	25.73	44	0.1	83
	17-53	3.22	3.87	0.27	0.05	26.32	30.44	43	0.2	86
	53-92	3.22	2.66	0.24	0.05	22.84	24.48	34	0.2	93
	92-200+	5.99	7.98	0.28	0.15	18.18	28.92	44	0.5	63
RS5	0-20	4.81	9.23	1.38	1.02	23.22	36.56	55	1.9	64
	20-60	4.45	2.54	0.49	0.02	22.13	32.46	52	0.1	68
	60-90	3.20	5.13	0.28	0.05	25.48	33.31	43	0.2	76
	90-150+	3.20	5.11	0.31	0.02	26.86	31.42	44	0.1	85

[1]TEB= Total exchangeable bases; [2] CEC = Cation exchange capacity; [3] ESP = Exchangeable sodium percentage; [4] PBS = Percent base saturation

The results revealed that the contents of exchangeable Ca and Mg varied from 3.20 to 35.74 and 1.60 to 20.35 cmolc kg-1, respectively, whereas exchangeable K varied from 0.24 to 1.44 cmolc kg-1. In accordance with the ratings of FAO (2006b), the soils are categorized under low to very high for Ca, medium to very high for Mg and low to very high for K content. Calcium and magnesium were the predominant basic cations in the soils. Similar observations had been made in the previous studies (Sharu et al., 2013, Paramasivan and Jawahar, 2014; Kebede et al., 2017). The exchangeable Na accounted only 0.1 to 1.9% of the exchangeable cations (Table 4). The Na content throughout the profiles of all pedons was low indicating the absence of sodicity problem. The percent base saturation of the pedons ranged from 33 to 99% (Table 4), which could be categorized under low to very high contents (Hazelton and Murphy, 2007).

Classification of soils of Wolkite University research sites

Soil classification based on WRB legend

Pedon RS1 possessed thick (≥ 25 cm) subsurface horizons that had greater than 30% clay, with cracks that open and close periodically and had slickensides in the subsurface horizones, which qualify it for vertic diagnostic horizons and also had base saturation (by 1M NH4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer between 20 and 100 cm of the soil surface (Table 4), that qualify hypereutric with haplic principal qualifier. Thus, the pedon is classified as Haplic Vertisols (Hypereutric).

The remaining four pedons: RS2, RS3, RS4 and RS5 had subsurface horizons with distinct higher clay content than the overlying horizons, qualifying for argic subsurface diagnostic horizon. Pedon RS2 and RS3 had low base status, vertic principal qualifier and hyperdystric (base saturation <50% by 1M NH_4OAc) supplementary qualifier, as a result the pedons classified as Vertic Alisols (Hyperdysric). Alisols correlates with Ultisols in USDA classification. However, pedons RS4 and RS5 had base saturation (by 1M NH4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer between 20 and 100 cm of the soil surface (Table 4), as a result the pedons classified as Vertic Luvisols (Hypereutric). Luvisols correlates with Alfisols in USDA classification.

Table 5. Diagnostic horizons, properties, quantifiers and soil types of Wolkite University research sites according to WRB (FAO, 2014)

Pedon	Diagnostic horizon	Diagnostic properties	Soil type	Area (hectare)
RS1	Vertic	Vertic	Haplic Vertisols (Hypereutric)	1.2
RS2	Argic	Vertic	Vertic Alisols (Hyperdysric)	6.6
RS3	Argic	Vertic	Vertic Alisols (Hyperdysric)	3.5
RS4	Argic	Vertic	Vertic Luvisols (Hypereutric)	1.3
RS5	Argic	Vertic	Vertic Luvisols (Hypereutric)	6.1

Soil classification based on Soil Taxonomy

Pedon RS1 had 30 percent and more clay, exhibit slickensides and cracks that open and close periodically. Thus, the pedons were classified under Vertisols. If not irrigated during the year, the cracks remained opened for 90 or more cumulative days per year, qualifying it for Usterts suborder; and Haplusterts and Typic Haplusterts at great group and subgroup, respectively.

Pedon RS2 and RS3 had argillic diagnostic horizons with a base saturation (by sum of cations) of less than 35 percent, and hence categorized under the order Ultisols (Soil Survey Staff, 2014). The pedons were further grouped under Ustults at suborder level due to their ustic soil moisture regime and Haplustults and Typic Haplustults, at great group and subgroup levels, respectively. Pedon RS4 and RS5 also had argillic diagnostic horizons with a base saturation (by sum of cations) of greater than 35 percent, and hence categorized under the order Alfisols. The pedons were further grouped under Ustalfs at suborder level due to their ustic soil moisture regime and Haplustalfs and Typic Haplustalfs, at great group and subgroup levels, respectively (Table 6).

Table 6. Diagnostic horizons and soil types of Wolkite University research sites according to Soil Taxonomy (Soil Survey Staff, 2014)

Pedon	Diagnostic horizon	Subgroup	Area (hectare)
RS1	Vertic	Typic Haplusterts	1.2
RS2	Argillic	Typic Haplustults	6.6
RS3	Argillic	Typic Haplustults	3.5
RS4	Argillic	Vertic Haplustalfs	1.3
RS5	Argillic	Vertic Haplustalfs	6.1

Conclusion

Field study was carried out to characterize and classify soils of Wolkite University research sites. Five representative pedons (RS1, RS2, RS3, RS4 and RS5) were opened and described. Three soil types: Haplic Vertisols (Hypereutric), Vertic Alisols (Hyperdysric) and Vertic Luvisols (Hypereutric) were identified according to WRB and with their Soil Taxonomy equivalent as Typic Haplusterts, Typic Haplustults and Vertic Haplustalfs, respectively. The soils of the research sites were acidic with low status of available phosphorus, which need amelioration of soil acidity and nutrient management, especially available phosphorus as it is more influenced by soil acidity.

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References

Adhanom, D., Toshome, T., 2016. Characterization and classification of soils of Aba-Midan sub watershed in Bambasi Wereda, West Ethiopia. *International Journal of Scientific and Research Publications* 6(6): 390-399.

Bouyoucos, G.J., 1962. Hydrometer method improvement for making particle size analysis of soils. *Agronomy Journal* 54(5): 179-186.

Carrow, R.N., Stowell, L., Gelernter, W., Davis, S., Duncan, R.R., Skorulski, J., 2004. Clarifying soil testing: III. SLAN sufficiency ranges and recommendations. *Golf Course Management* 72(1): 194-198.

Chekol, W., Mnalku, A., 2012. Selected Physical and Chemical Characteristics of Soils of the Middle Awash Irrigated Farm Lands, Ethiopia. *Ethiopian Journal of Agricultural Sciences* 22(1): 127-142.

Dengiz, O., 2010. Morphology, physico-chemical properties and classification of soils on Terraces of the Tigris River in the South-east Anatolia Region of Turkey. *Journal of Agricultural Sciences* 16(3): 205-212.

FAO, 2006a. Guidelines for soil description. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 97p. Available at: [Access date: 06.01.2018]: http://www.fao.org/docrep/019/a0541e/a0541e.pdf

FAO, 2006b. Plant nutrition for food security. A Guide for Integrated Nutrient Management; FAO Fertilizer and Plant Nutrition Bulletin 16, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 347p. Available at [Access date : 06.01.2018]: http://www.fao.org/docrep/010/a0443e/a0443e00.htm

FAO, 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192p. Available at [Access date : 06.01.2018]: http://www.fao.org/3/a-i3794e.pdf

FAO, 2017. Voluntary Guidelines for Sustainable Soil Management. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 16p. Available at [Access date : 06.01.2018]: http://www.fao.org/3/a-bl813e.pdf

Hailu, A.H., Kibret, K., Gebrekidan, H., 2015. Characterization and classification of soils of Kabe Subwatershed in South Wollo Zone, Northeastern Ethiopia. *African Journal of Soil Science* 3(7): 134-146.

Hartz, T.K., 2007. Soil Testing for Nutrient Availability. Procedures and Interpretation for California Vegetable Crop Production. University of California, Vegetable Research and Information Center, USA. Available at [Access date : 06.01.2018]: http://vric.ucdavis.edu/pdf/fertilization_Soiltestingfornutrientavailability2007.pdf

Hazelton, P., Murphy, B., 2007. Interpreting Soil Test Results: What do all the numbers mean? Second edition. CSIRO Publishing. Australia. 52p.

Horneck, D.A., Sullivan, D.M., Owen, J.S., Hart, J.M., 2011. Soil Test Interpretation Guide. Oregon State University, Extension Service, USA. Available at [Access date : 06.01.2018]: https://ir.library.oregonstate.edu/downloads/00000020g

Jones, J.B. 2003. Agronomic Handbook: management of crops, soils, and their fertility. CRC Press, Boca Raton, Florida, USA. 482p.

Kebede, M., Skimbir, T., Kasa, G., Abera, D., Girma, T., 2017. Description, characterization and classification of the major soils in Jinka Agricultural Research Center, South Western Ethiopia. *Journal of Soil Science and Environmental Management* 8(3): 61-69.

Lufega, S.M., Msanya, B.M., 2017. Pedological characterization and soil classification of selected soil units of Morogoro District, Tanzania. *International Journal of Plant and Soil Science* 16(1): 1-12.

Mulugeta, D., Sheleme B., 2010. Characterization and classification of soils along the toposequence of Kindo Koye Watershed in Southern Ethiopia. East African Journal of Sciences 4 (2): 65–77.

Olsen, S.R., Sommers, L.E.,1982. Phosphorus. In: Methods of soil analysis. Part 2 Chemical and microbiological properties. 2nd edition. Page, A.L. (Ed.). American Society of Agronomy, No. 9, Madison, WI, USA. pp. 403-430.

Onyekanne, C. F., Akamigbo, F. O., Nnaji, G. U., 2012. Characterization and classification of soils of Ideato North local government area. *Nigerian Journal of Soil Science* 22(1): 11-17.

Paramasivan, M., Jawahar D., 2014. Characterization, classification and crop suitability of L.E. some black cotton soils of southern Tamil Nadu. *Agropedology* 24 (1): 111-118.

Sarkar, D., Haldar, A., 2005. Physical and Chemical Methods in Soil Analysis: Fundamental Concepts of Analytical Chemistry and Instrumental Techniques. New Age International Limited Publishers, 176p.

Sharu, M.B., Yakubu, M., Noma, S.S., Tsafe, A.I., 2013. Characterization and classification of soils on an agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Sciences* 21(2): 137-147.

Soil Survey Staff, 2014. Keys to Soil Taxonomy. 12rd Edition. United States Department of Agriculture (USDA), Natural Resources Conservation Service. Washington DC, USA. 360p. Available at [Access date : 06.01.2018]: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1252094&ext=pdf

Tekalign, T., Haque, I., Aduayi, E.A., 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Plant sciences division working Document No: B13. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Walkley, A., Black, C.A., 1934. An examination of Digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-38.

Wilke, B.M., 2005.Determination of chemical and physical soil properties. In: Manual of soil analysis: monitoring and assessing soil bioremediation, R. Margesin, F. Schinner (Eds.). Vol 5, Springer-Verlag, Berlin Heidelberg, pp.79-82.

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Theoretical and practical aspects of basic soil treatment in the conditions of modern soil management systems in Russia

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Abstract

The questions of inserting and implementing the different methods of basic soil treatment in the different crop plantings in the conditions of steppe zone in Nizhnee Povolzhye and Central Part of Non-chernozem Belt of the Russian Federation are analyzed. Systemize and complex research of the above questions are caused by multivalued opinions of agrarian scientists that are involved in the practical aspects of agrarian production towards them. On the results of long term researches is defined that the most effective and practice in cereal crop rotations are the basic soil management systems combining the different methods of tillage, mini-till and no-till soil treatment along with usage of modern machines and aggregates. In the conditions of field experiment at Centre of Precision Farming of Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, along with the others, the tasks on economic efficiency and ecological safety that are the basis of precision farming concept are being solved.

Keywords: Soil treatment methods, tillage, no-tillage, mini-till, no-till, resource saving, soil management system, crop rotation, combined soil treatment, regions of the Russian Federation.

Introduction

Soil treatment is most energy and fund consuming process in agrarian production. Treatment of one soil hectare demands 18-320 kilowatt-hour or 50-80 kg of fuel. Soil treatment along with the positive effect influenced negatively on the fertility, e.g., using the heavy tractors and units increases the density of arable and sub-arable soil layers. The frequent loosening treatments along with activation of biological processes and mineralization of organic matter cause the significant loses of accessible nitrogen, decrease the humus content and development of erosion processes. In this regard, developing the most economical soil treatment technologies that provide effective decreasing the energy expenduteres is the important condition for modern soil management. The high level of soil treatment intensification (systematic fertilizing and implementing the herbicides and ameliorants) caused changing in function of soil treatment and decreasing its determination of crop yield up to 8- 12 %. The above processes are characterizing the soils with high potential level of fertility and favorable agrophysical characteristics for crop development. In the above conditions the soil treatment could be minimalized and used only for fertilizing, implementing the ameliorants and herbicides, etc. The main task is aimed to maintaining soil fertility, regulation of water and air conditions, erosion protection (Belenkov et at., 2015).

Nowadays the soil treatment is not considered as predictably consuming and not progressing link of soil treatment system. Soil treatment became much more mobile and dynamic in its development. The theoretical and practical aspects of soil treatment both for the separate crops and in crops rotations point out the new

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approaches of solving the important question of economizing the materials and funds that, in its turn, causes increasing the crop yield and stabilization of soil fertility. Soil treatment, along with crops rotation, is the most significant link of soil treatment system due to defining its intensity and consuming level, level of anthropogenic load, soil resistance to erosion, the characteristics of machines and tools using in agrotechnologies.

Material and Methods

In field experiments carried out at the end of XX century – at the beginning of XXI century in chernozem dry-steppe and semi-arid zones of Volgograd region the variants of terms, treatments and depths of implementing permanent and combined basic autumn and early spring soil treatment for separate crops and in the system of crops rotations were searched.

In the field experiment No1 carried out in the experimental farm "Gornaya Polyana" at Volgograd State Agrarian University and in the farm "Tingutinsky" in Svetloyarsk district of Volgogard region in the period of 1986-1989 in crops rotation fallow - winter wheat - barley the following variants of the basic soil treatment at 25-27 cm were studied:

1. mouldboard ploughing;
2. subsurface loosing;
3. treatment by pillars;
4. chisel treatment.

In the field experiment No 2 carried out in the experimental farm "Gornaya Polyana" at Volgograd State Agrarian University in the period of 1989-1993 in crops rotation fallow - winter wheat (kernel) - sorgo (kernel) - barley the following variants of the basic soil treatment were studied:

1. mouldboard ploughing at 25-27 cm for all crops;
2. pillar treatment at 25- 27 cm for winter wheat - mouldboard ploughing at 25-27 cm for sorgo - pillar treatment at 25- 27 cm for barley;
3. pillar treatment at 20- 22 cm for winter wheat - mouldboard ploughing at 25-27 cm for sorgo - pillar treatment at 20 - 22 cm for barley;
4. pillar treatment at 12-14 cm for winter wheat – mouldboard ploughing at 25-27 cm for sorgo - pillar treatment at 12- 14 cm for barley.

In the field experiment No 3 carried out in JSC "Gelio Park-Agro" in Mikhaylovsky district of Volgograd region in the period of 2000-2003 in the conditions of southern chernozem soil in crops rotation fallow - winter wheat - spring wheat – barley the following variants of the basic soil treatment were studied:

1. mouldboard ploughing;
2. subsurface loosing;
3. pillar treatment, 1,2,3 - at 25-27 cm;
4. ripper disk treatment;
5. combined treatment, 5,6 - at 10-12 cm for all crops.

The shallow soil treatments at 10-12 cm of depth for spring wheat during the spring season were implemented:

1. ripper disk treatment;
2. combined treatment;
3. rod cultivator treatment.

In field experiment № 4 carried out in the period of 2000-2003 in Nighne-Volghsky Research Institute of Agriculture the following variants of the basic autumn soil treatment for fallow as predecessor of winter wheat were studied:

1. mouldboard ploughing at 25-27 cm in spring for early fallow;
2. mouldboard ploughing at 25-27 cm;
3. cultivator treatment at 12-14 cm;
4. combined treatment at 12- 14 cm;
5. ripper disk treatment at 8-10 cm;
6. cultivator treatment at 8-10 cm.

In industrial experiment №5 carried out in the period of 2000-2003 in JSC "Sovkhoz "Karpovsky" in Gorodischensky district of Volgograd region in crops rotation fallow – winter wheat – barley the following variants of the basic soil treatment were studied:

1. mouldboard ploughing in autumn at 25-27 cm for fallow along with soil treatment in spring;
2. pillar treatment at 25-27 cm for barley along with soil treatment in spring;
3. ripper disk treatment at 8-10 cm;
4. cultivator treatment at 12-14 cm;
5. combined treatment at 12-14 cm.

In field experiment №6 carried out in the period of 2007-2009 in the experimental farm of Vocational School No 56 in Pallasovsky district of Volgograd region in crops rotation fallow – spring wheat – barley the following variants of the basic soil treatment were studied:

1, 2. mouldboard ploughing at 20-22 cm and subsurface loosing at 20-22 cm for spring wheat and barley;

3. mouldboard ploughing at 20-22 cm for spring wheat and subsurface loosing at 12-14 cm for barley;

4. subsurface loosing at 20-22 cm for spring wheat and mouldboard ploughing at 12-14 cm for barley;

5. mouldboard ploughing at 20- 22 cm for spring wheat and null treatment (sowing without soil treatment) for barley;

6. scuffling treatment at 8 -10 cm in spring for fallow and subsurface loosing at 20-22 in autumn for barley (Belenkov, 2010).

In the field experiment of Centre of Precision Farming at Russian State Agrarian University - Moscow Timiryazev Agricultural Academy during recent 10 years, starting from 2009, in the conditions of sod-podzol soil the comparison of 1- mouldboard ploughing, 2 -Mini-till and 3 – No-Till soil treatments in cereal and tilling crops rotation: vetch and oat feeding mixture – winter wheat with reap mustard for siderite - potato - barley were carried out (Balabanov et al., 2013).

Results

The yield of cereal crops obtained during the researches in the period of 1986-1989 performed in Table 1. Variants of basic soil treatment - ploughing, subsurface and pillar treatment - was practically equal on the yield; chisel treatment performed the decreased yield.

Table 1. Results of the field experiments on searching the basic soil treatments in farm crops rotations in Volgogard region

Basic soil treatment	Crop yield in crops rotation, t-ha	Profitability, %	Energy efficiency coefficient	Soil humus balance, t-ha
Field experiment No1. Experimental farm “Gornaya Polyana” at Volgograd State Agrarian University and farm “Tingutinsky” in Svetloyarsk district (1986-1989)				
Ploughing at 25-27 cm	1.22	72.6	2.12	-2.4
Subsurface cultivator treatment at 25-27 cm	1.23	84.0	2.12	-2.4
Chisel ploughing at 25-27 cm	0.97	76.9	2.07	-2.6
Pillar treatment at 25-27 cm	1.21	48.5	1.65	-2.3
Field experiment No 2. Experimental farm “Gornaya Polyana” at Volgograd State Agrarian University (1989-1993)				
P 25 - P 25 - P 25*	1.96	99.4	2.97	-1.7
Pl 25 - Pl 25 - Pl 25	1.95	104.4	3.07	-1.7
Pl 20 - P 25 - Pl 20	1.97	108.2	3.15	-1.6
Pl 12 - P 25 - Pl 12	1.91	105.6	3.13	-1.4

* - P, Pl - mouldboard ploughing, pillar treatment; 12, 20, 25 – at 12-14, 20-22, 25-27 cm: in crops rotation fallow – winter wheat – sorgo (kernel) – barley

Defect of chisel treatment with chisel plough is not complete loosing of the soil surface with the widely arranged tools. While chisel treatment the intrasoil consolidated ridges are left between the passes of tool that is the arable soil layer is treated within the passes only. This construction defect causes aggravating the water and mechanical soil properties and nutrition regime of crops, decreasing the crop and soil weeding and, as the result, the crop yield. Variant of chisel treatment is less energetically and economically effective in comparison with the other variants of basic soil treatment. Results of the field experiment No 2 in the period of 1989-1993 are presented in Table 2.

Variant of basic soil treatment - pillar treatment at 20-22 cm for winter wheat and barley with ploughing at 25-27 cm for sorgo (kernel) performed the increased yield.

In the conditions the southern chernozem soils the subsurface treatment at 25-27 cm performed higher economic and energy efficiency along with the equal parameters on yield in comparison with the other variants of basic soil treatment.

Table 2. Results of the field experiments on searching the basic soil treatments in farm crops rotations in Volgogard region

Basic soil treatment	Crop yield in crops rotation, t^{-ha}	Profitability, %	Energy efficiency coefficient	Soil humus balance, t^{-ha}
Field experiment №3. JSC "Gelio Park-Agro" in Mikhaylovsky district (2000-2003)				
Autumn season				
Ploughing at 25-27 cm	1.76	80.7	2.22	-2.0
Subsurface cultivator treatment at 25-27 cm	1.76	93.9	2.54	-2.0
Pillar treatment at 25-27 cm	1.65	86.7	2.30	-1.9
Heavy ripper disk treatment at 10-12 cm	1.50	92.6	2.45	-1.7
Combined treatment at 10-12 cm	1.64	96.1	2.58	-1.9
Spring season				
Rod cultivator treatment at 10-12 cm	1.28	84.9	2.28	-1.5
Heavy ripper disk treatment at 10-12 cm	1.09	75.8	2.03	-1.3
Combined treatment at 10-12 cm	1.03	63.1	1.83	-1.3

The most effective basic soil treatment for winter wheat, spring wheat and barley in spring season was rod cultivation treatment at 10-12 cm.

Table 3. Results of the field experiments on searching the basic soil treatments in farm crops rotations in Volgogard region

Basic soil treatment	Crop yield in crops rotation, t^{-ha}	Profitability, %	Energy efficiency coefficient	Soil humus balance, t^{-ha}
Field experiment No 4. Nighne-Volghsky Research Institute of Agriculture (2000-2003)				
Autumn season				
Ploughing at 25-27 cm	1.35	82.6	2.15	-2.7
Spring season				
Ploughing at 20-22 cm	1.05	71.5	2.06	-2.5
Heavy ripper disk treatment at 10-12 cm	1.18	79.3	2.25	-2.5
Anti-erosion cultivator treatment at 12-14 cm	1.26	78.4	2.20	-2.6
Steam cultivator treatment at 10-12 cm	1.18	73.2	2.05	-2.5
Combined treatment at 12-14 cm	1.20	75.2	2.11	-2.5
Industrial experiment No 5. JSC "Sovkhoz "Karpovsky" in Gorodischensky district (2000-2003)				
Autumn season				
Ploughing at 25-27 cm	1.24	66.9	1.84	-2.7
Pillar unit treatment at 25-27 cm	1.14	55.8	1.92	-2.5
Spring season				
Heavy ripper disk treatment at 8-10 cm	0.97	45.3	1.80	-2.2
Anti-erosion cultivator treatment at 12-14 cm	1.02	52.7	1.95	-2.0
Combined treatment at 10-12 cm	1.01	48.0	1.91	-2.0

In accordance with the results obtained in field experiment in Nighne-Volghsky Research Institute of Agriculture and in industrial experiment in JSC "Sovkhoz "Karpovsky" in Gorodischensky district the anti-erosion treatment at 12-14 cm with cultivator along with ploughing performed the most effective results.

Table 4. Results of the field experiments on searching the basic soil treatments in farm crops rotations in Volgogard region

Basic soil treatment	Crop yield in crops rotation, t^{-ha}	Profitability, %	Energy efficiency coefficient	Soil humus balance, t^{-ha}
Field experiment № 6. Vocational School №56 in Pallasovsky district (2007-2009)				
P20 – P20*	0.41	10.65	1.08	-3.3
S20 - S20	0.37	7.02	1.02	-3.4
S20 – S12	0.36	7.65	1.03	-3.0
S20 – P12	0.48	14.98	1.23	-3.3
P20 – «0»	0.30	5.79	0.94	-2.8
Sc10 – S20	0.40	11.92	1.19	-3.5

* - P, S, Sc, «0» - mouldboard ploughing, subsurface treatment, scuffling treatment, No-Till treatment (bold shrift – treatment in spring season) at 20-22, 12-14, 8-10 cm

Results of the field experiment №6 in the period of 2007-2009 are presented in Table 6. In the conditions of Zavolghsky region among the variants of basic soil treatment the most effective results in the crops rotation performed combined soil treatment that included subsurface loosing for spring wheat at 20-22 cm and ploughing for barley at 12-14 cm. It is necessary to point out in crops rotation the variant of subsurface stubble treatment for first crop combined with subsurface treatment in spring season for second crop.

In Table 5 the following results on crop yield obtained in Centre of Precision Farming at Russian State Agrarian University - Moscow Timiryazev Agricultural Academy are presented: in average for the research period in the variant of ploughing the high yield performed potato and vetch and oat feeding mixture; in variant of no-till treatment – winter wheat; barley had the equal parameters of yield for both variants of soil treatment.

Table 5. Crop yield in Centre of Precision Farming at Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, t^{-ha}

Basic soil treatment	Crop yield									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	In average
Vetch and oat feeding mixture										
Mouldboard ploughing	21.3	20.5	10.8	20.6	22.1	24.5	31.2	25.3	22.2	22.1
No-Till	25.0	19.4	9.4	27.3	24.3	25.3	28.9	27.5	6.1	21.5
LSD_{05}	3.40	1.08	2.59	3.10	2.0	0.83	3.07	3,10	5.46	-
Winter wheat										
Mouldboard ploughing	4.23	4.63	3.70	6.31	6.12	2.75	6.74	5.00	5.39	5.0
No-Till	5.09	4.11	3.55	6.15	5.87	4.59	6.73	5.52	5.09	5.19
LSD_{05}	0.23	0.25	0.23	0.14	0.19	1.42	0.11	0.39	0.24	-
Potato										
Mouldboard ploughing	41.5	21.7	24.4	19.9	28.6	25.1	31.4	31.0	24.2	27.5
Mini-Till	37.5	20,7	23,2	18.3	25.9	24.6	26.2	26.7	20.7	24.9
LSD_{05}	1.74	1.42	0.50	0.56	0.16	0.90	1.08	2.11	3.3	-
Barley										
Mouldboard ploughing	5.40	3.35	2.62	4.33	5.16	3.85	5.52	4.03	4.21	4.27
Mini-Till	5.78	2.99	2.83	4.20	5.00	4.01	5.22	3.99	4.04	4.23
LSD_{05}	0.26	0.21	0.41	0.90	0.13	0.17	0.28	0.19	0.17	-

While the analysis of crop yield, it is necessary to pay attention that during the majority of the years the yield of winter wheat in variant of mouldboard ploughing exceeded the variant of No-Till treatment. Only in 2014, the yield of winter wheat in variant of mouldboard ploughing was in 1,7 times higher in comparison with No-Till treatment due to thin shoots caused by high level precipitations in autumn of 2013. In addition, in average for the period of 2009-2017 the yield of winter wheat in variant of No-Till at 0, 19 t^{-ha} exceeds mouldboard ploughing.

The influence of mouldboard ploughing and minimum treatment on yield of barley is not equal. In half number of years, Mini-Till treatment exceeds the ploughing on yield. Only in 2015 and 2016 the variant of mouldboard ploughing performed the higher yield of barley that caused the higher average parameters of yield, but, the difference between the variants is not significant as the absolute difference was 0,03 t^{-ha} only.

In a number of years number the higher yield of vetch and oat feeding mixture in variant of No-Till treatment is obtained. The above results indicate the possibility to use this mixture as fallow crop with sowing into untreated soil.

In accordance with crop physiology, potato had the higher yield in variant of moulboard ploughing. In average during the research period the yield of potato in variant of mouldboard ploughing exceeded Mini-Till treatment at 2,6 t^{-ha} (Belenkov, 2010).

Discussion

In the conditions of low level of soil management, insufficient fertilizing and implementing the crop protection chemical means, etc. the significance of soil treatment increases and is aimed to mobilization of potential soil fertility, increasing the accessibility of nutrients, maintaining the soil structure and phytosanitary situation that are favorable for crop cultivation (Belenkov, 2016).

Modern agriculture is based on implementing the new tools and machines for soil treatment that allow to a considerable extent to protect and maintain soil fertility at the appropriate level, stably increase the crop production, use natural and technogenic potential economically and efficiently. It is a high importance the ecological and energy consumption aspects of modern crop production technologies, in the first instance, which connected with modernization of soil treatment methods both for single crops and in crops rotation along with considering the biological characteristic of crops and resource potential of agrarian producers.

Modern soil management systems include implementing differential technologies of basic soil treatment along with considering the biological characteristic of crops, landscape conditions, weed number, climatic conditions, erosion level, including fallow in crops rotation ant the other relevant conditions (Cherkasov, 2006).

Until now, the opinions on possibility and necessity of using the mouldboard plough as a tool for basic soil treatment differ. It is necessary to underline the necessity of using the mouldboard soil treatment with the aim to create the homogeny structure of arable soil level and favorable agrophysical and microbiological parameters of soil, increase the quality of weeding and crop protection measures. The above facts of positive results the implementing of the mouldboard treatment in a significant extent allow to compensate for some negative effects connected with significant energy and fund consumption, increasing the possibility of erosion processes and soil deflation, decreasing water accumulation.

The main positive aspects of using the subsurface soil treatment are protection from soil erosion, decreasing the water accumulation especially in drought conditions, balancing the humus content, first of all, in the upper soil levels, decreasing the costs for soil treatment; the negative aspects – aggravating the phytosanitary situation, differentiation the arable level on soil fertility, restriction to proper crop residues, fertilizers and ameliorants placement and regulation of agrophysical properties of soil.

The opinion of implementing such soil treatment methods as Mini-Till, No-till treatments, sowing without treatment, etc, in the majority of the regions in Russia has not sufficient scientific basis (Shulmeister, 1995; Shukhov et al., 2011; Pleskachev et al., 2013).

In accordance with the informational resources (data of 2008), the intense mechanical soil treatment caused the following negative results:

- area of soil erosion - 42,6 mln ha, annual increase of area - 400-500 thousand ha, annual loses of soil - 15-20 t^{-ha} (loses of 2,5 cm of arable soil are equal to loses of 980 kg of nitrogen, 200 kg of phosphorus, 3500 kg of potassium;
- consolidating the upper soil levels. For example, in case when field area is equal to 100%, the area of machine's tracks could reached up to 200-300 % as the number of passes along the field is up to 20. The soil consolidating cases the loses of crop production up to 40 - 60%;
- intense mechanical treatment prevents increasing crop production;
- long period of implementing the moulboard soil treatment cased decreasing the initial soil fertility and humus content;
- deep mouldboard ploughing destroyed soil structure (Sheptukhov, 2009).

In this connection during the recent years the methods of subsurface soil treatment, including Mini-Till are widely implemented. Implementing of the exact method of soil treatment depends on the following factors: soil type, soil density, biological characteristics of crop. For example, the cereal crops are not requiring the deep loosening and, in this case, it is possible to implement subsurface treatment at 14-15 cm. Implementing the subsurface treatment with preliminary scuffling of straw residues instead of mouldboard ploughing causes increasing the humus content

In the system of soil treatment without ploughing the preventive weeding starts in the period between harvesting the preceding crop and sowing the coming crop. The other effective methods of weeding without placement of weeds should be planned and implemented. The soil treatment with evenness placement of straw is effective and provoke germination of fallen kernels and weeds. The succeeding fertilizing significantly decreases the number of weeds. In accordance with the conditions, the placement of herbicide with continuity weeding effect should be implemented in 2 days before sowing or in 3-4 days after sawing but before germination of cereal crop.

Implementing Mini-Till treatments allows achieving the high yields without destroying the soil fertility due to decreasing the level of mechanical treatment and return of straw into the soil (Keller, 2001).

Covering the soil with reaped restudies depresses growing the weeds, so-called "herbicide effect" and decreases the costs for chemical weeding of crops. Annual mouldboard ploughing due to putting deeper the upper soil level causes distraction the soil microflora (aerobic microorganisms) and decreasing initial soil fertility that increases the placement of mineral fertilizers and production costs (Sdobnikov, 2000).

Nowadays No-Till system of soil treatment that assists to funds and water accumulation is widely used in many countries. But, Now-Till system and sowing without any treatment were implemented even in 6 century BC. Uning the planting peg allowed to get the yield of cereal crops up to 200-300 center-ha (Turusov et al., 2014).

In XIX century, the European scientists started discussions about the possibility of implementing the No-Till soil treatment system, at the beginning of XX century the scientific papers on this question were published in Russia. In the above scientific papers the possibility of guaranteed increasing of yield from 8 up to 80 center-ha in the conditions of southern regions in Europaen part of Russia along with decreasing the labor and fund costs in four time and increasing soil fertility was presented (Ovsinsky, 1902). In the middle of XX century, the positive effect of No-Till teratment due to recovering the soil structure in the conditions of absence during the long period the intensive soil treatment was discussed in the scientific papers of Russian scientists (Maltsev, 1998). The activity of soil microorganisms causes the recovering of soil. The number of Russian and foreign scientists in the scientific paper presented the information about increasing the erosion processes and decreasing the humus content in soil in two times in many regions from the beginning to the 80th of XX century. In the above conditions, only implementing the system of No-Till soil treatment allowed to decrease the degradation processes in soil. No-Till soil treatment started to be widely used in agrarian industry in the middle of XX century due to implementing of innovations and modem technical achievements (Baraev, 1978).

Launching the industrial implementing the system of No-Till soil treatment started in 1950th from development of herbicides with wide weeding effect that allowed the farmers in the USA to deny using the plough and to sow without previous mouldboard ploughing. But, the herbicides are used not only in the system on No-Till soil treatment. In traditional ploughing system of soil management, the herbicides are used along with ploughing as the additional method of weeding in the postharvest period. In No-Till and resource saving system of soil management using the herbicides is considered as the "alter variant" for successful soil management. Modern technical and technological methods allow decreasing the costs during sowing, crop protection and harvesting. Within No-Till system of soil management, ploughing and cultivation are excluded that launches the initial mechanisms of regulating the soil parameters.

Sowing without the previous soil treatment is considered as denying the mouldboard ploughing, sowing into cutting resuides and conservation of residues in the field that is of high importance in the process of crop planting. The positive effects of the above soil treatment technology are the following: effective using the water; decreasing the erosion processes (up to 90%); optimization of humus balance; preventing the formation of soil crust; increasing the work efficiency of machines and tools; sufficient water accumulation for sowing process; extending the period of production operations during the crop planting; stability of yield level; extending the service period of machines and aggregates; decreasing the labor costs; decreasing, in comparison with traditional ploughing, the number of machines and tools at 40% and gasoline consumption; increasing the economic efficiency at 25-20% (Penn State Cooperative Extension, 2016).

No-Till system of soil management, as one of agrotechnical methods of year-round soil protection from erosion processes and decreasing the costs of sowing (planting) process, was successfully implemented in 1950th in the USA. No-Till system is the alternative for traditional ploughing, which causes the wind and water soil erosion, and used at almost 40% of arable lands in the USA (Unger, 2002).

Many scientists from the Central Europe mention such positive ecological and economic effects of using not traditional systems of soil management as saving energy and labor costs, decreasing pollution and production costs. Using No-Till treatment destroys the soil structure in the minimum degree and includes the other methods of weeding except mechanical soil treatment. No-Till system of soil treatment restricts the infiltration rate especially in the regions with low precipitation level. Organic matter on the surface of field absorbs the major amount of precipitations which slowly migrate in the down level of soil (Atkinson et al., 2007).

In some drought regions of Pakistan on sandy loam soil the positive tillage effect on the yield of wheat in comparison with Mini-Till was observed. The soil treatment was based on the mouldboard ploughing. The above soil treatment technology is both gasoline and labor consuming and ecologically unfavorable. It is defined that 55-65% of gasoline is consumed during the operations on deep soil treatment (Ishaq et al., 2001).

In accordance with data of Food and Agricultural Organization of the United Nations No-Till system of soil treatment is used on the area of above 7,5 mln ha over the word, including 52% - in the USA and Canada, 44% - in Latin America, 2% - in Australia, 2% - the other countries in Europe and Africa. The potential for extending the area of soil under resource saving treatment should be realized along with the consideration of climatic and economic factors. As the example, in the USA possess 19,7% of arable land, but the area treated with No -Till soil system in the country is the biggest in the world. In Paraguay the area under No-Till system of soil treatment is about 60 %.of arable lands. In China the rate of extending the area under No-Till soil treatment is rather significant. Nowadays in China No-Till system of soil treatment is used on above 300 thousand ha in 10 northern provinces. In accordance with the forecast of the Ministry of Agriculture of the People's Republic of China in the period of 7 - 10 years No-Till soil treatment will be used over the majority of arable lands in the northern part of the country. Many authors present in the papers the results of the positive ecological and economic effect from using the soil treatment without ploughing, e.g. energy and labor saving, decreasing pollution and costs. By the way, nowadays in Croatia 93,7% of arable land are under tillage soil treatment (Jiang et al., 2005).

Nowadays No-Till system of soil treatment with the aim of soil protection and costs saving is widely used in the USA, countries of Western Europe and Latin America, Australia and other regions. In Russia the tendency of using the resource saving technologies of soil treatment is extending.

Conclusion

In Russia the design of field and industrial experiments on effectiveness of the different soil treatment systems should be renovated due to development and the usage of innovative machines and tools in industrial agrarian enterprises and small farms. On the results of long-term experiments, the effectiveness of combined soil treatment in field crops rotation of different climatic zones of the Russian Federation is defined.

References

Atkinson, R.S., Sparkes, D.L., Mooney, S.J., 2007. Using selected soil physical properties of seedbeds to predict crop establishment. *Soil and Tillage Research* 97(2): 218-228.

Balabanov, V.I., Zhelezova, S.V., Berezovsky, E.V., Belenkov, A.I., Egorov, V.V., 2013. Navigation systems in agriculture. Precision farming. Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, p. 148. [in Russian]

Baraev, A.I., 1978. Theoretical basis of protective soil management/Problems of soil management. Kolos, Moscow, pp. 212 – 220. [in Russian]

Belenkov, A.I., 2010. Crops rotation and soil treatment in steppe and semiarid zone of Nighnee Povojgye region. Monography, Moscow, p. 279. [in Russian]

Belenkov, A.I., 2015. Principles of resource saving in protective soil management/Protective soil management in Russia. Kursk Research Institute of Soil Management and Erosion Protection, pp. 77 – 81. [in Russian]

Belenkov, A.I., Shevchenko, V.A., Trofimova, T.A., Shachnev, V.P., 2015. Scientific and practical basis for development of soil treatment methods in modern adaptive land scape soil management systems. Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Moscow, p. 500. [in Russian]

Cherkasov, G.N., 2006. Effectiveness of combined soil treatment systems. Soil Management (6): 20 – 22. [in Russian]

Ishaq, M., Ibrahim, M., Lal, R., 2001. Tillage effect on nutrient uptake by wheat and cotton as influenced by fertilizer rate, *Soil and Tillage Research* 62 (1–2): 41–53.

Jiang, X., Li, Z., Hou, L., Wang, Y., Wang, X., Yan, H., 2005. Impacts of minimum tillage and no-tillage systems on soil NO-3-N content and water use efficiency of winter wheat/summer corn cultivation. *Transactions of the Chinese Society of Agricultural Engineering (CSAE)* 21(7): 20-24.

Keller K., 2001 Soil management without plough: scientific achievements and practical experience in Western Europe and other regions. Achievements of Science and Technology of Agro-Industrial Complex (AIC) 11: 47 [in Russian]

Maltsev, T.S., 1988. Soil management system without ploughing. Agropromizdat, Moscow, p. 127. [in Russian]

Ovsinsky, I.E., 1902. New soil management system. St.-Petersburg, p. 325 [in Russian]

Penn State Cooperative Extension, 2016. The Penn State Agronomy Guide. Available at [Access date : 05.03.2016]: http://www.extension.psu.edu/agronomy-guide/cm/sec1/sec11f

Pleskachev, Yu. N., Koscheev, I.A., Kondybin, S.S., 2013. Tillage effect on yield of cereal crops. *Proceeding of Altay State Agrarian University* 1 (99): 23 – 26. [in Russian]

Sdobnikov, S.S., 2000. Soil treatment and soil fertility: to till or not to till. Moscow, p. 28 [in Russian]

Sheptukhov, V.N., 2006. Mechanical soil treatment and formation of crop roots level of soil. Moscow, p. 168. [in Russian]

Shulmeister, K.G., 1995. Selected works. Volgograd, Vol.1. p. 456, Vol. 2. P480. [in Russian]

Sukhov, A.N., Imangaliev, K.A., Imangalieva, A.K., 2011. Agroecological basis of field crops rotation and soil treatment in adaptive and land scape soil management systems in steppe and semiarid zone of Nighnee Povojgye region. Monography. Volgograd State Agrarian Academy, Volgograd, p. 192. [in Russian]

Turusov, V.I., Garmashov, V.M., Shevchenko, V.A., Dudchenko, S.E., 2014. The possibilities for Mini-Till system of soil management on black soils of Voronegh region. Acievements of Science and Technology of Agro-Industrial Complex (AIC) (12): 5 – 8. [in Russian]

Unger, P.W., 2002. Residue management for winter wheat and grain sorghum production with limited irrigation. Soil Science Society of America Journal 58(2): 537-542.

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Scaling of infiltration rate using the similar media theory and dimensional analysis

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Abstract

The infiltration rates of variable soils were scaled using factors derived from the steady state infiltrability (K_o) and the saturated hydraulic conductivity (K_s) based on the similar media theory and dimensional analysis. Infiltration rates were successfully scaled when the characteristic scaling infiltration rate equations were formulated through combination of the similar media theory and dimensional analysis. This study disproved the earlier notion that to successfully scale variable infiltration measurements, both sorptivity and steady state infiltrability were required. Thus, the study revealed that using the saturated hydraulic conductivity as a substitute for the steady state infiltrability could predict and scale infiltration rates more accurately. The study further highlighted the importance of the scaling factor (α) in any characteristic equation supposedly to have been developed from the similar media theory. Invariably, the ability of any characteristic scaling equation containing no scaling factor to scale variable infiltration measurements successfully could be fortuitous and not evolved from the similar media theory.

Keywords: Dimensional analysis, saturated hydraulic conductivity, scaling factor, similar media, steady state infiltrability.

Introduction

Infiltration is an important soil hydrological process useful in irrigation systems design, erosion and runoff modeling of a watershed and general water budget studies (Tuffour and Bonsu, 2015). Since soils exhibit a high degree of variability in both space and time, soil physical properties alone cannot be used to evaluate the hydrological response to a watershed, especially in the tropics where soils may exhibit natural spatial variability due to uncontrollable factors such as worm and ant holes, dead root channels and pore, as well as inconsistent soil management practices (Tuffour et al., 2016). Thus, invariably, heterogeneity is a general problem in soils; management, topographic as well as pedogenic factors may all contribute to soil heterogeneity. Besides, spatial variability in hydraulic properties and hydrologic processes continue to be an unresolved problem, which has attracted research attention of past and present scientists (e.g. Sharma and Luxmoore, 1979; Wu and Pan, 1979; Berndtsson and Larson, 1987; Sharma et al., 1987; Bonsu, 1997; Wu et al., 1999; Tuffour et al., 2014).

Differences in soil texture and structure may reflect in the extent of spatial variability of tropical soils. Bonsu and Laryea (1989) noted that soil texture and structure significantly influenced the hydraulic behavior of an Alfisol in the semi-arid tropics in India. Bonsu and Lal (1982) also recognized anisotropic characteristics in

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horizontal and vertical hydraulic properties of an Alfisol in Nigeria. The implication is that this combined vertical and horizontal spatial variability of soil hydraulic properties may play a negative influence on the response and sensitivity of hydrological models to estimate runoff and erosion, especially in tropical watersheds. Rowland (1993) further contends that this spatial variability of tropical soils may in part be the reason for recognizing about twenty-two broad soil units for tropical soils in the FAO Legend of soil map of the world. Thus spatial variability is an unresolved problem in the management of tropical soils.

Similar Media Concept

Data on soil hydraulic and hydrologic parameters require large data sets in order to make meaningful inferences and recommendations for field water management. However, handling, manipulation and analyses of such large, complex, variable and fast moving data sets are difficult to process for decision making. This requires appropriate analytical techniques to be used to their extent. Such techniques involve pedometrics, a discipline in soil science concerned with the development of mathematical and statistical methods for handling variable soil properties and processes for robust and reliable conclusions (Lark, 2006). Examples of such effective techniques include similar media scaling, fractal dimension and Geostatistics, which have been developed to address these challenges to improve the effectiveness and accuracy in the description of large soil hydraulic and hydrologic data for effective decision-support information in soil hydrology.

The application of soil physics using the similar media theory to deal with the problem of spatial variability in soil hydraulic properties was proposed by Miller and Miller (1956), and several workers (e.g. Peck et al., 1977; Warrick et al., 1977; Jury et al., 1987; Bonsu and Laryea, 1989; Zavattaro et al., 1999; Zhu and Mohanty, 2006; Tuffour et al., 2014) have successfully used the theory to describe the spatial variability of field and laboratory measured soil hydraulic properties. Scaling theory based on the similar media concept, provides a basis for representing soil spatial variability in terms of a single stochastic variable, the scaling factor, which is related to the microscopic characteristic length of the soil. Two soils are considered to be similar when they only differ with respect to their internal microscopic geometries. It is, therefore, assumed that the heterogeneity in the soil hydraulic properties is represented by a scaling factor, which is considered as recognition of a spatially stochastic variable.

The application of similar media concept involves developing scaling factors, which are simple conversion factors relating the characteristics of one system to corresponding characteristics of another (Tillotson and Nielsen, 1984). The use of the similar media concept has offered scope for coalescing variable field infiltration measurements of a given location into a single representative curve as demonstrated by Sharma and Luxmoore (1979), Sharma et al. (1980), Young and Price (1981), Wells et al. (1986) and Tuffour et al. (2014). The use of similar media concept in studying field heterogeneity with regard to variable field measured infiltration curves is still in vogue. However, the dimensional validity of the similar media theory proposed by Warrick et al. (1985) is inappropriate, in that, the characteristic time scale (t_c) has dimension of time per distance [T/L], hence, defining the scaled time as t/t_c yields a dimension of distance [L] which is a dimension for space, but not for time. Similarly, Wu and Pan (1997) used a characteristic infiltration equation (i_c), which when dimensionally analyzed, is equal to the steady state infiltrability (K_o), and contains no scaling factor (α). In this regard, these parameters have to be reduced in the most efficient form using dimensional analysis under the scaling laws.

Scaling Theory

Invariably, the scaling factors used in scaling variable infiltration curves have been derived from sorptivity (S) and steady state infiltrability (K_o), which are respectively the first and the second terms of the truncated Philip's (1957) infiltration equation:

$$I = St^{1/2} + K_o t \tag{1}$$

Sharma et al. (1980) were of the view that both S and K_o were needed in order to develop appropriate scaling factors for measured field infiltration. On the contrary, Bonsu (1997) noted that using both S and K_o to develop scaling factors for field infiltration measurement of a highly variable Alfisol of the semi-arid tropics in India partitioned the scaled infiltration curves into two dissimilar curves. Zavattaro et al. (1999) have used the similar media concept to derive scaling factors from the steady state infiltrability K_o alone. They used the scaling factors to study spatial dependence of K_o using variogram analysis which showed a clear dependence of the scaling factors on distance. The work of Zavattaro et al. (1999), therefore, demonstrates how scaling factors derived from K_o, using the similar media theory, can be combined with Geostatistics to describe spatial variability in soil of a given site. In this study, the steady state infiltrability

(K_o) and the laboratory-column measured saturated hydraulic conductivity (K_s) were used in place of the field saturated hydraulic conductivity (K_{fs}) to scale the infiltration rate measurements. In recent times, the use of K_o in place of K_{fs} is becoming popular because of the relatively longer time and tedium required to measure field K_{fs}. For example, Wu and Pan (1997), Wu et al. (1999) and Zavattaro et al. (1999) have all used K_o instead of K_{fs} to scale infiltration. However, the limitation that K_o is slightly lower than K_{fs} is well appreciated. However, the use of K_s will be much more convenient in terms of time and ease of computation (Elrick et al., 2002). Based on the Similar Media Concept, Warrick et al. (1977) evoked a relationship of the form:

$$K_i = {\alpha_i}^2 K^* \tag{2}$$

Where,
K_i = Steady state infiltrability and saturated hydraulic conductivity of location i
K^* = Scaled mean steady state infiltrability and saturated hydraulic conductivity
α_i = Scaling factor for location i.
Equation (2) can be re-written as:

$$\sqrt{K_i} = \alpha_i \sqrt{K^*} \tag{3}$$

By convention:

$$\sqrt{K^*} = {}^{i}/_{n} \sum_{n=1}^{n} \sqrt{K_i} \tag{4}$$

In equation (4) n is the number of sample spots. By combining equations (3) and (4), a relationship of the form given in equations (5) is obtainable.

$$\sqrt{K_i} = {}^{\alpha_i}/_{n} \sum_{i=1}^{n} \sqrt{K_i} \tag{5}$$

Therefore, from equation (5) it is seen that:

$$n\sqrt{K_i} = \alpha_i \sum_{i=1}^{n} \sqrt{K_i} \tag{6}$$

Hence the scaling factor α_i for location i is defined as:

$$\alpha_i = \frac{n\sqrt{K_i}}{\sum_{i=1}^{n} \sqrt{K_i}} \tag{7}$$

By dimensional analysis, the characteristic infiltration equation i_c is defined as:

$$i_c = \frac{\alpha K_i}{\theta_s - \theta_a} \tag{8}$$

Where,
θ_s = Saturated volumetric water content
θ_a = Initial water content of the soil before the infiltration measurement.
Therefore, the scaled infiltration rate, i^* is defined as:

$$i^* = {}^{i}/_{i_c} \tag{9}$$

Where i is the measured infiltration rate, and i_c is obtained from equation (8). The scaled time t^* is also defined as:

$$t^* = \alpha t \tag{10}$$

Where t is the measured time, and α is the scaling factor.

The objective of this study was to propose a technique of using dimensional analysis as a tool to evaluate the reasonableness of the similar media theory.

Material and Methods

Study areas

Field infiltration studies were carried out in the Department of Horticulture and Plantations Section of the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Ghana. Infiltration measurements were conducted using a single ring infiltrometer of diameter of 30 cm and a height of 30 cm. The measurements were carried out during the dry periods of early September, 2016 to January, 2017. The sites chosen for the measurements were Turf grass field (located in the Department of Horticulture, Cocoa plantation (Plantation crops section of the Department of Crop and Soil Sciences) and Pastureland (Beef and Dairy Cattle Research Station), where spatial variability was anticipated because of expected worm activity and the presence of dead root channels. The soils were classified as Ofin series (Stagni-Dystric Gleysol), Kumasi series (Plinthi Ferric Acrisol or Typic Plinthustult) and Asuansi series (Plinthic Acrisol) in the horticulture, arable and grazed fields, respectively (FAO/UNESCO, 1990; Soil Survey Staff, 1998).

Field infiltration measurements

The infiltration measurements were carried out in 15 spots selected randomly in a grid of 10 m apart in each of the fields. The infiltrometer was worked into the soil using a template and a hammer to a depth of 10 cm, leaving a height of 20 cm protruding above the soil surface. The surface of the soil in the infiltrometer was lightly covered with dead grass mulch to prevent soil surface disturbance when the soil surface in the infiltrometer was instantaneously ponded with water. A marker of 5 cm inserted in the center of the cylinder was used to maintain a constant head of 5 cm by adding water from 1-liter plastic measuring cylinder. The volume of water that was used to maintain a constant head of 5 cm infiltrometer in a chosen time represented the amount of water that entered the soil at the stipulated time. Initial measurements were recorded every 30 seconds and the recording time was extended to 60, 120 and 300 seconds, as infiltration decreased over time. The infiltration measurement was carried out for a period of 60 minutes on each spot.

The cumulative infiltration amount (I) from the field measurements were computed by converting the cumulative volume of water infiltrated at each time step to depth as follows (Tuffour, 2015):

$$I = \frac{Q}{A}$$

where,

Q = Cumulative volume of water (ml); 1 ml = 1 cm^3

A = Surface area of the ring, given by:

$A = \pi r^2$

$r = {}^1\!/_2$ Ring diameter

The cumulative infiltration amounts were plotted as a function of time on a linear scale. The slopes of the cumulative infiltration amounts taken at different time scales represented the infiltration rates. The infiltration rates were plotted against time and the steady state infiltrability obtained at a point where the infiltration rate curve became almost parallel to the time axis. Soil samples were taken to determine the initial moisture content before the infiltration measurement. The field saturated water content was assumed to approximate the total porosity of the soil (van Genuchten, 1980).

Saturated hydraulic conductivity

The saturated hydraulic conductivity was determined using the falling head permeameter on laboratory soil columns as described by Bonsu and Laryea (1989) and Tuffour (2015). Soil samples in cores were collected from the 0 – 20 cm depth from each spot in the field and soaked for 24 hours in water until they were completely saturated. The soil core was placed on a large plastic container with perforated bottom filled with fine gravel. The system was placed in a sink and water was gently ponded over the surface of the soil core to give hydraulic head in the extended cylinder. The fall of the hydraulic head h_t at the soil surface was measured as a function of time t using a water manometer with a 5 meter scale. Saturated hydraulic conductivity was then calculated by the standard falling head equation as:

$$K_s = \left(\frac{aL}{At}\right) \ln\left(\frac{h_o}{h_t}\right) \quad (11)$$

where,

a = Surface area of the cylinder [L^2]

A = Surface area of the soil [L^2]
h_o = Initial hydraulic head [L]
L = Length of the soil column [L]
h_t = Hydraulic head after a given time t [L]

By rewriting equation (11), a regression of $\ln\left(\frac{h_o}{h_t}\right)$ on t with slope b = $K_s\left(\frac{A}{La}\right)$ was obtained. Bases on the assumption that a $= A$ in this particular case, K_s was simply calculated as:

$$K_s = \mathrm{b}L \quad (12)$$

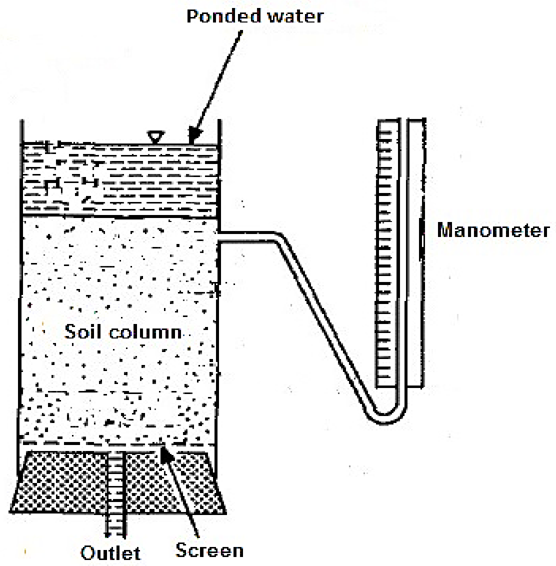

Figure 1. Laboratory setup for the determination of saturated hydraulic conductivity (Modified from Tuffour, 2015)

Statistical analysis

The question of whether or not the use of K_s in place of K_o provides an accurate prediction of infiltration rate was addressed using correlation analyses of the scaling parameters derived from both properties. To quantitatively evaluate the performance of K_s and K_o in the proposed scaling method, the coefficient of regression (R^2) of the reference curve was computed. The computation of the scaling parameters and plotting of the graphs were done using Microsoft EXCEL and GraphPad Prism version 6.

Results and Discussion

Some properties of the topsoil of the site used for the study are presented in Table 1. The texture of the topsoil for the various sites were sand (in Turf grass) loamy sand (in both Cocoa plantation and Pastureland). The calculated parameters used in scaling operation are given in Tables 2. The plots of the infiltration rates as a function of time for all 15 spots in each field are illustrated in Figure 2. Both the cumulative infiltration amount curve and the infiltration rate curve depict spatial variability among the spots used for the study.

Table 1. Soil physical properties of the experimental sites

Soil property	Experimental field		
	Turf grass	Cocoa plantation	Pastureland
Sand (%)	89.00 (3.90)	86.00 (2.90)	83.00 (3.10)
Silt (%)	5.30 (3.50)	6.70 (2.20)	9.00 (1.80)
Clay (%)	5.30 (3.50)	7.20 (1.20)	7.50 (2.30)
Texture	Sandy	Loamy sand	Loamy sand
ρ_b (g cm^{-3})	1.50 (0.12)	1.40 (0.075)	1.20 (0.13)
f (%)	43.00 (4.30)	47.00 (0.029)	53.00 (6.10)
af (%)	24.00 (8.00)	34.00 (4.00)	50.00 (5.80)
θ_v (%)	20.00 (6.90)	12.00 (3.60)	4.10 (2.50)

*Numbers in the parentheses represent standard deviation values; ρ_b = Bulk density; f = Total porosity; af = Air-filled porosity; θ_v = Initial volumetric water content

Table 2. Infiltration properties at the different study sites

Parameter	Turf grass				Cocoa plantation				Pastureland			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
S	0.05	2.40	0.75	0.66	0.71	4.70	2.60	1.20	0.84	7.80	3.40	2.10
I	0.75	23.00	9.60	7.80	5.90	52.00	33.00	15.00	16.00	110.00	44.00	22.00
i	0.01	0.39	0.16	0.13	0.099	3.20	0.87	0.47	0.26	1.80	0.73	0.37
K_o	0.01	0.57	0.20	0.17	0.12	0.97	0.62	0.27	0.27	1.90	0.76	0.38
K_s	0.022	0.69	0.25	0.21	0.18	1.50	0.94	0.40	0.41	2.80	1.20	0.58

S (cm/min$^{1/2}$) = Sorptivity; I (cm) = Cumulative infiltration amount; i (cm/min) = Infiltration rate; K_s (cm/min) = Saturated hydraulic conductivity; K_o (cm/min) = Steady state infiltrability

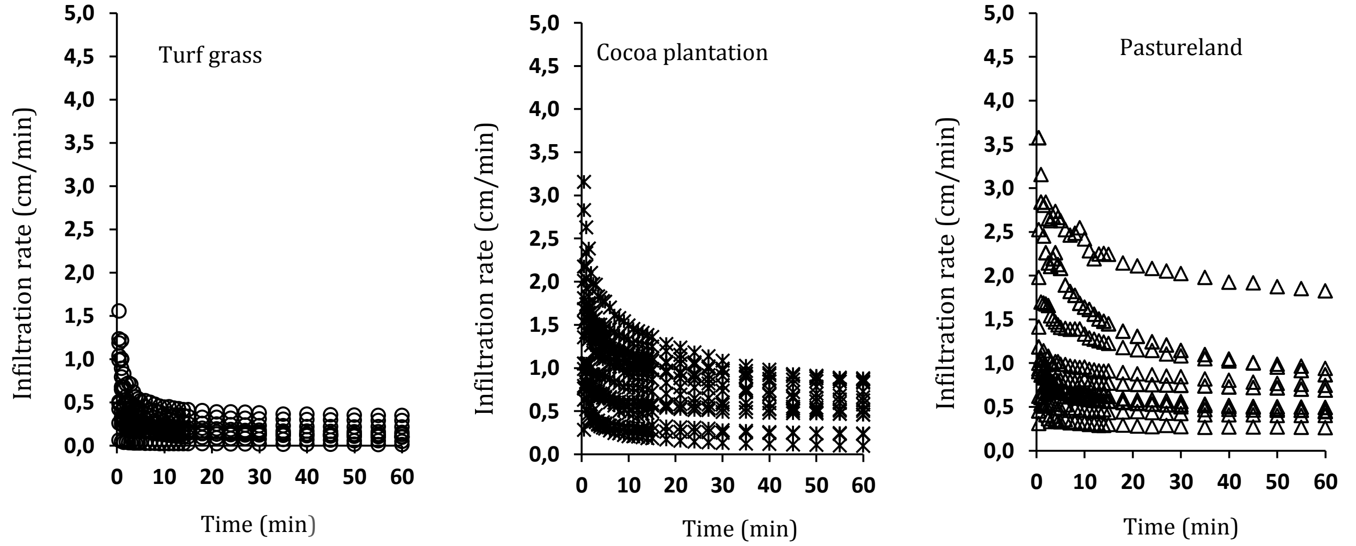

Figure 2. Variability of infiltration rate in the experimental fields

The number of scaling factors generated were too small to enable variograms to be developed to study the structure of the variability using the scaling factors as was done by Wu and Pan (1997). However, the infiltration data were enough to use scaling technique to deal with this kind of variability precisely. The range of scale factors generated for each location in the three fields follows the trends reported by various researchers (e.g. Warrick et al., 1977; Sharma and Luxmoore, 1979, Sharma et al., 1980; Bonsu and Laryea, 1989; Bonsu, 1997; Zhu and Mohanty, 2006; Tuffour et al., 2014). The very purpose of the effective (scaled) parameters obtained for this study was to show whether the behavior of the parameters in the soil could be assumed as a set of soil parameters, in order to replace the heterogeneity in the soil system by an equivalent homogeneous system (Zhu and Mohanty, 2006; Tuffour et al., 2014). With regard to this same idea, reports have shown that these parameters are site specific and there are no universal effective properties due to the great nonlinearity of soil hydraulic properties and various boundary conditions that exist under different flow states (Zhu and Mohanty, 2002; Tuffour et al., 2014). The 'equivalent' soil properties produced in this study were therefore expected to, somewhat, yield very similar water budget as the mean water budget in agreement with the soil hydraulic properties and the variation of the microtopography of the study area (Zhu and Mohanty, 2006; Tuffour et al., 2014).

The characteristic infiltration rate (i_c) developed from K_o and K_s, respectively, through dimensional analysis (equation 7) and used to form the dimensionless scaled infiltration rate (equation 8) was plotted against the scaled time (equation 9) as shown in Figures 3a – b.

It was observed that all the variable infiltration rates of the 15 spots in each field coalesced into a single representative curve. The level of success of the scaling exercise is evidenced by the degrees of scatter in Figures 2 and 3a – b, and of dispersion as shown by the standard of deviation in Tables 2 and 3. Thus, the use of scaling factors was effective in reducing the degree of variability of infiltration rates in the different fields to produce a significant representative curve (Tuffour et al., 2014). Thus, by plotting the normalized data on a graph, a representative reference infiltration rate curve was obtained. This was expected, since the use of scaling factor is known to reduce the overall spot-to-spot variability of measured variables into unison (Vogel et al., 1991; Tuffour et al., 2014). The standard deviation (SD) values provided a means of measuring the validity of the interrelation conditions and the validity of the scaling theory. Based on the SD values (0.25

– 0.46), it is clear that the theory worked efficiently for all three fields when K_o and K_s were used for scaling. The nature of the graphical plots as presented in Figures 3a and b indicates a lognormal distribution of infiltration rate, implying that scaling factors are lognormally distributed (Clausnitzer et al., 1992; Kosugi and Hopmans, 1998; Tuffour et al., 2014). This, according to Tuffour et al. (2014) was based on the assumption lognormally distributed soil pore radius and random sampling of effective pore volume in the study.

Table 3. Calculated scaling parameters for the different study sites

Parameter	Turf grass				Cocoa plantation				Pastureland			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
$K_o^{1/2}$	0.14	0.90	0.47	0.22	0.35	0.98	0.77	0.19	0.52	1.40	0.89	0.22
αK_o	0.30	1.90	1.00	0.46	0.45	1.30	1.00	0.25	0.58	1.60	1.00	0.25
$i_c K_o$	0.032	13.00	1.90	3.20	0.17	3.70	2.00	1.20	0.28	5.40	1.90	1.30
$i^* K_o$	0.0040	6.97	0.44	0.52	0.23	1.40	0.45	0.18	0.26	2.30	0.65	0.25
$t^* K_o$	0.13	89.54	14.13	16.30	0.23	77.00	17.00	18	0.29	94.00	17.00	18.00
$K_s^{1/2}$	0.17	1.10	0.58	0.27	0.42	1.20	0.94	0.24	0.64	1.70	1.10	0.27
αK_s	0.30	1.90	1.00	0.46	0.19	1.50	0.99	0.43	0.58	1.60	1.00	0.25
$i_c K_s$	0.048	19.00	2.80	4.80	0.11	6.40	3.10	2.20	0.41	8.10	2.80	2.00
$i^* K_s$	0.15	115.00	17.00	20.00	0.13	7.10	0.49	0.62	0.17	1.50	0.43	0.17
$t^* K_s$	0.0027	4.60	0.29	0.35	0.096	93.00	18.00	20.00	0.29	94.00	17.00	18.00

αK_o = Scaling factor from K_o; $i_c K_o$ (cm/min) = Characteristic infiltration rate from K_o; $i^* K_o$ = Scaled infiltration rate from K_o; $t^* K_o$ (min) = Scaled time from K_o; αK_s = Scaling factor from K_s; $i_c K_s$ (cm/min) = Characteristic infiltration rate from K_s; $i^* K_s$ = Scaled infiltration rate from K_s; $t^* K_s$ (min) = Scaled time from K_s

Although the infiltration rate values fall within a wide range as revealed by the descriptive statistical analysis (Table 2; Figure 2). Figures 3a and b indicate that the scaled infiltration rates coalesced into a unified curve and could be well described by a logarithmic model of the form presented in equation 13:

$$i^* = -m\ln(t^*) + i_i^* \tag{13}$$

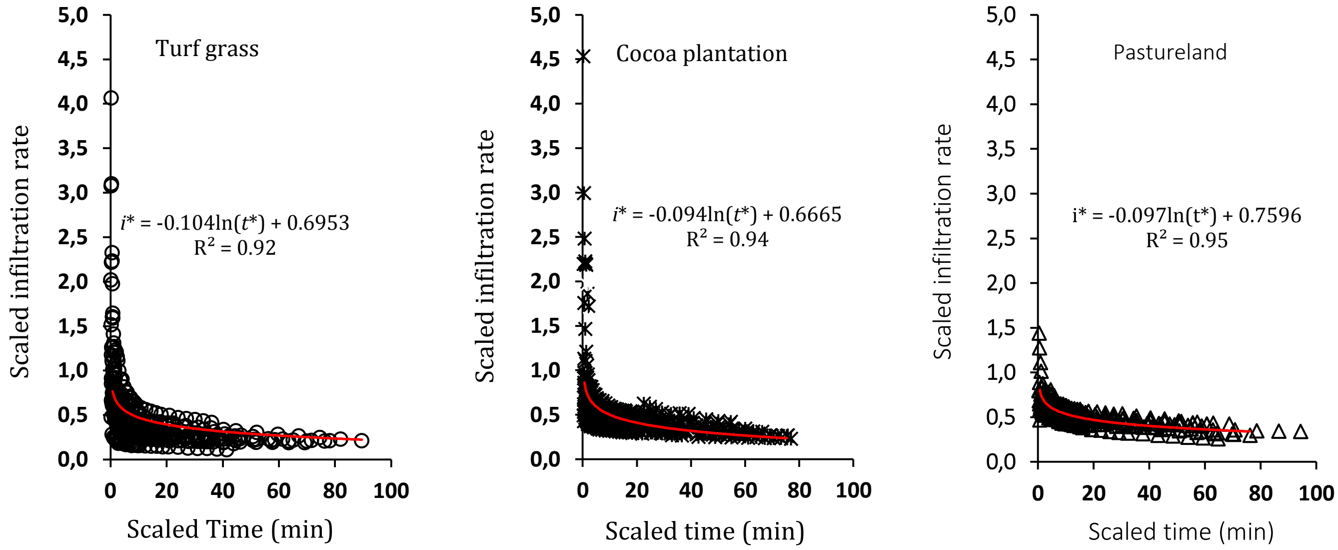

Figure 3a. Scaled infiltration rate curves from K_o in the experimental fields

The parameters m and i_i^* are empirical fitting parameters describing the scaled infiltration rate (i^*) when scaled time (t^*) is zero. Additionally, the R² of the representative curves lends credence of 94 – 99% to the reliability of this equation, which presents a linear-log fit between the dimensionless scaled infiltration rate with respect to time. Thus, a good agreement exists using a single solution to approximate the infiltration rate of the experimental fields. A general comparison of the transformed data (Figures 3a,b) indicates that, the scaling performance was high with K_o than K_s in both fields, as evidenced by the R² values. The poor performance of K_o relative to K_s in scaling could be justified by the invalidity and over simplification of the assumption of complete field saturation at steady state during infiltration as defined in the Philip's equation. However, from Table 4, the various scenarios (i.e., scaling under K_o and K_s) show that the scaling parameters are nearly invariant with limited scattering about the mean. Hence, assuming that the two scenarios are held for a range of soils and selected initial conditions, the proposed scaling method can be generalized to numerous other cases in this range leading to approximations of the similar media theory. This study demonstrates that scale factors developed through the similar media theory is a strong tool to equally deal with spatial variability of field infiltration measurements. However, in developing the characteristic infiltration rate and the characteristic time scale equations, dimensional analysis should be employed to ensure their dimensional validity.

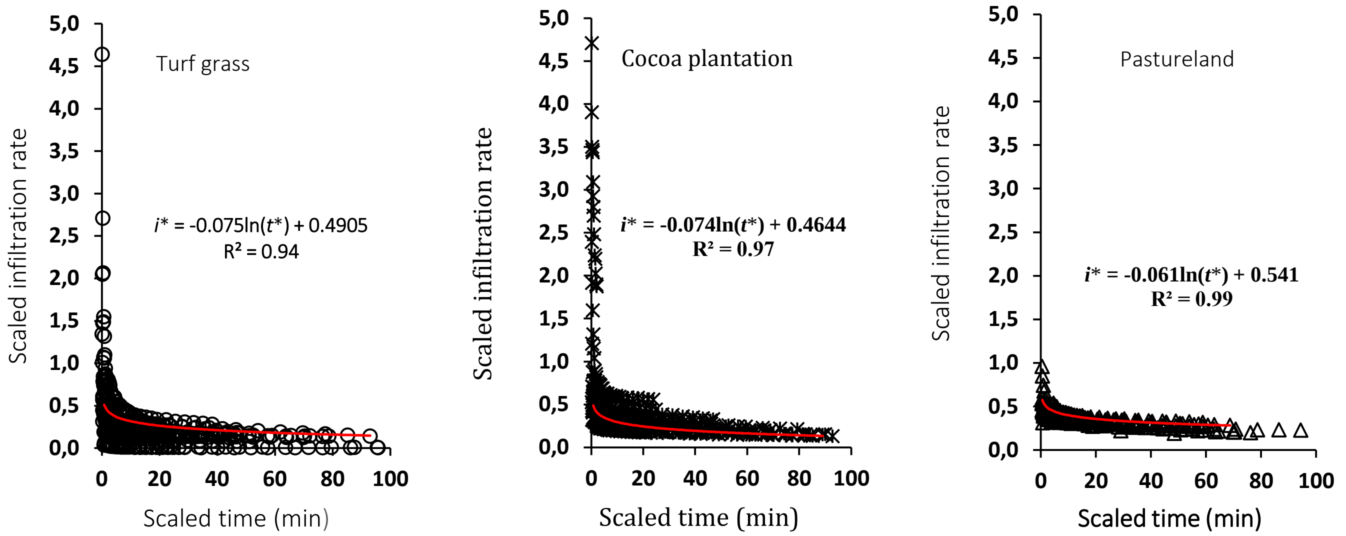

Figure 3b. Scaled infiltration rate curves from K_s in the experimental fields

Effectively, any characteristic scaling equation developed from the similar media theory that contains no scaling factor (α) cannot be said to have evolved from the similar media theory. Since in the similar media theory, α is the controlling element, it is imperative that any characteristic equation developed to be used in the scaling operation must contain α. The ability of a scaled equation supposedly to have been developed from the similar media concept without the incorporation of α to successfully scale could be fortuitous because of its deviation from the original concept of similar media theory. The original view of Sharma et al. (1980) that both sorptivity and steady state infiltrability are required in order to obtain successful scaled infiltration might not be totally correct in reference to the work of Wu and Pan (1997), Zavattaro et al. (1999) and the present work.

The Pearson correlation coefficients are given in Table 4. Notice a very good correspondence between scaling parameters obtained from K_o and K_s in all three experimental fields (Table 4) as revealed by the correlation coefficient (r) and the p (0.05) value. Analysis of both hydraulic parameters (K_o and K_s) showed that estimation of infiltration rate and scaling parameters can be obtained with far less effort and information when K_s is employed. It is therefore, not necessary to differentiate the contribution of K_o to infiltration rate from that of K_s.

Table 4. Summary of Pearson correlation between scaling parameters from K_o and K_s

Experimental field	Correlated parameters	r	†Confidence interval (95%)	
			Lower limit	Upper limit
Turf grass	i^*K_o vs i^*K_s	0.99	0.97	0.99
	t^*K_o vs t^*K_s	1.00	0.98	0.99
	αK_o vs αK_s	0.99	0.98	0.99
	i_cK_o vs i_cK_s	1.00	0.99	1.00
Cocoa plantation	i^*K_o vs i^*K_s	0.96	0.96	0.97
	t^*K_o vs t^*K_s	0.98	0.97	0.98
	αK_o vs αK_s	0.99	0.97	0.99
	i_cK_o vs i_cK_s	1.00	0.99	1.00
Pastureland	i^*K_o vs i^*K_s	0.99	0.97	0.98
	t^*K_o vs t^*K_s	1.00	0.99	1.00
	αK_o vs αK_s	0.99	0.98	1.00
	i_cK_o vs i_cK_s	1.00	0.98	0.99

†p (0.05) = < 0.0001

The scaling factor (α), characteristic infiltration rate (i_c) and the scaled infiltration rate (i^*) derived from K_o and K_s for the sites were almost identical and indistinguishable from each other as evidenced by the close match of scaling parameters obtained, in spite of the different soil hydraulic parameters that were employed in the scaling analyses. This could be as a result of the high dependency of the soil hydraulic properties on soil texture and structure which are major components in pedotransfer functions (PTFs). It is therefore imperative to know that the observed positive relationships between the K_o– K_s scaling parameters were not just artifacts of correlations. Furthermore, the observed positive correlations were all linear. The uncertainties of the scaling parameters were of the same order of magnitude in both fields

Conclusion

Scaled infiltration rates from both steady state infiltrability (K_o) and saturated hydraulic conductivity (K_s) were found to be nearly invariant for the three study areas. This study showed that scaling factors derived from K_o and K_s can each be employed successfully to scale variable infiltration rates in soils. However, scaling was found to be more sensitive to K_o than K_s. Thus, it is possible to describe the hydraulic functions of all soils by a reference soil by means of a single scaling factor assigned to each soil. Generally, the observations made in the study suggest that the proposed scaling method can be successfully applied for coarse-textured soils provided that the initial profile is not deeply wetted. Furthermore, the ability of a characteristic equation to scale variable infiltration using the similar media theory must always be verified through dimensional analysis to prove its authenticity.

References

Berndtsson, R., Larson, M., 1987. Spatial variability of infiltration in a semi-arid environment. *Journal of Hydrology* 90(1-2): 117 – 133.

Bonsu, M., 1997. Scaling infiltration using parameters of Philip infiltration equation. *Journal of Applied Science and Technology* 2(1-2): 1 – 6.

Bonsu, M., Lal, R., 1982. Hydrological properties of some Alfisols of Western Nigeria: A comparison of field and laboratory methods. *Nigerian Journal of Soil Science* 3: 101 – 119.

Bonsu, M., Laryea, K.B., 1989. Scaling the saturated hydraulic conductivity of an alfisol. *European Journal of Soil Science* 40(4): 731 – 742.

Clausnitzer, V., Hopmans, J.W., Nielsen, D.R., 1992. Simultaneous scaling of soil water retention and hydraulic conductivity curves. *Water Resources Research* 28(1): 19 – 31.

Elrick, D.E., Angulo-Jaramillo, R., Fallow, D.J., Reynolds, W.D., Parkin, G.W., 2002. Infiltration under constant head and falling head conditions. In: Environmental Mechanics: Water, Mass and Energy Transfer in the Biosphere. Raats, P.A.C., Smiles, D., Warrick, A.W. (Eds.). Geophysical Monograph Series Vol 129, American Geophysical Union, USA. pp. 47 – 53.

Jury, W.A., Russo, D., Sposito, G., 1987. The spatial variability of water and solute transport properties in unsaturated soil: II. Scaling models of water transport. *Hilgardia* 55(4): 33 – 57.

Kosugi, K., Hopmans, J.W., 1998. Scaling water retention curves for soils with lognormal pore size distribution. *Soil Science Society of America Journal* 62(6): 1496 – 1505.

Lark, R.M. 2006. Soil properties and Pedometrics. Land Use and Land Cover, from Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO. Oxford: EOLSS Publishers. Available at [Access date : 18.01.2018]: https://www.eolss.net/Sample-Chapters/C19/E1-05-07-03.pdf

Miller, E.E., Miller, R.D. 1956. Physical theory for capillary flow phenomena. *Journal of Applied Physics* 27: 324.

Philip, J.R., 1957. The theory of infiltration. 4: Sorptivity and algebraic infiltration equations. *Soil Science* 84(3): 257 – 264.

Rowland, J.R.J., 1993. Dryland Farming in Africa. The Macmillan Press Ltd. London, England. 336p.

Sharma, M.L., Gander, G.A., Hunt, C.G., 1980. Spatial variability of infiltration in a watershed. *Journal of Hydrology* 45(1-2): 101 – 122.

Sharma, M.L., Luxmoore, R.J. 1979. Soil spatial variability and its consequences on simulated water balance. *Water Resource Research* 15(8): 1567–2573.

Tillotson, P.M., Nielsen, D.R.,1984. Scaling factors in soil science. *Soil Science Society of America Journal* 48(5): 953 – 959.

Tuffour, H.O., 2015. Physically based modelling of water infiltration with soil particle phase. Kwame Nkrumah University of Science and Technology, Department of Crop and Soil Sciences, PhD. Thesis, Kumasi, Ghana.

Tuffour, H.O., Abubakari, A., Bashagaluke, J.B., Djagbletey, E.D., 2016. Mapping spatial variability of soil physical properties for site-specific management. *International Research Journal of Engineering and Technology* 3(2): 149 – 163.

Tuffour, H.O., Bonsu, M., 2015. Application of green and ampt equation to infiltration with soil particle phase. *Interna¬tional Journal of Scientific Research in Agricultural Sciences* 2(4): 76 – 88.

Tuffour, H.O., Bonsu, M., Khalid, A.A., Adjei-Gyapong, T., 2014. Scaling approaches to evaluating spatial variability of saturated hydraulic conductivity and cumulative ınfiltration of an acrisol. *International Journal of Scientific Research in Knowledge* 2(5): 224 – 232.

Tuffour, H.O., Bonsu, M., Khalid, A.A., Adjei-Gyapong, T., Atakora, W.K., 2013. Evaluation of spatial variability of soil organic carbon and pH in an uprooted oil palm field. *Indian Journal of Applied Agricultural Research* 1(1): 69 – 86.

van Genuchten, M.Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* 44(5): 892–898.

Vogel, T., Cislerova, M., Hopmans, J.W., 1991. Porous media with linearly variable hydraulic properties. *Water Resources Research* 27(10): 2735 – 2741.

Warrick, A.W., Lomen, D.O., Yates, S.R. 1985. A generalized solution to infiltration. *Soil Science Society of America Journal* 49(1): 34 – 38.

Warrick, A.W., Mullen, G.J., Nielsen, D.R. 1977. Scaling field-measured soil hydraulic properties using a similar media concept. *Water Resource Research* 13(2): 355 – 362.

Webster, R., 1985. Quantitative spatial analysis of soil in the field. In: Advances in Soil Science. Stewart, B.A. (Ed.). Springer-Verlag Inc. New York, USA. pp. 1–70.

Wells, L.G., Ward, A.D., Moore, I..D., Philips, R.E., 1986. Comparison of four infiltration models in characterizing infiltration through surface mine profiles. *Transactions of ASAE* 29(3): 785 – 793.

Wu, L., Pan, L., Mitchell, J., Sanden, B., 1999. Measuring saturated hydraulic conductivity using a generalized solution for single-ring ınfiltrometers. *Soil Science Society of America Journal* 63(4): 788 – 792.

Young, E.G., Price, R.I., 1981. Scaling of infiltration behavior in dissimilar porous materials. *Water Resource Research* 17(4): 1065 – 1070.

Zavattaro, L., Jarvis, N., Persson, L., 1999. Use of similar media scaling to characterize spatial dependence of near saturated hydraulic conductivity. *Soil Science Society of America Journal* 63(3): 486 – 492.

Zhu. J., Mohanty, B.P., 2002. Spatial averaging of van genuchten hydraulic parameters for steady-state flow in heterogeneous soils. *Vadose Zone Journal* 1(2): 261 – 272.

Zhu. J., Mohanty, B.P., 2006. Effective scaling factor for transient infiltration in heterogeneous soils. *Journal of Hydrology* 319(1-4): 96 – 108.

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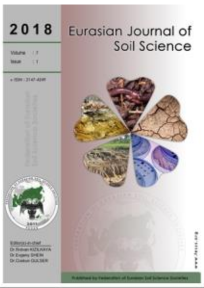

Dynamics of earthworm species at different depths of orchard soil receiving organic or chemical fertilizer amendments

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Abstract

We investigated the dynamics of different earthworm species through the soil profile, which had received short-term amendments of either organic or inorganic fertilizer in an orchard during the spring of 2016. Earthworm populations were sampled at two consecutive depths of soil on 20 and 60 days after addition of fertilizers. The dominant earthworm species were *Eisenia fetida* (Savigny, 1826), *Dendrobaena veneta* (Rosa, 1886), *Dendrobaena hortensis* (Michaelsen, 1890), *Lumbricus terrestris* (Linnaeus, 1758) and *Aporrectodea longa* (Ude, 1885). Seven different types of fertilizers including Urea, Ammonium sulfate (AS), Diammonium phosphate (DAP), Solupotas, NPK (15-5-25), (NPK+OM) and organic manure (OM) as experimental treatments were studied. Fluctuations in earthworm numbers and biomass were attributed to changes in time and depth of sampling, in addition to the types of fertilizers. The results of the means comparison showed that on the 20th day, at 0-20 cm soil depth, *E. fetida* species abundance was decreased significantly in AS and Urea treatments compared to the control plot ($p<0.05$). We highlighted that from epigeic group, *D. hortensis* species had a better chance to survive and its population in AS treatment was more than that of Urea treatment. Results also showed that the anecic *L. terrestris*, had a greater tolerance to chemical fertilizers compared to the *A. Longa* species. The results of this study outline more clear horizons in managing the use of chemical fertilizers while simultaneously maintaining the biodiversity of soil organisms.

Keywords: Chemical fertilizer, organic fertilizer, earthworm species, abundance, biomass.

Introduction

The emphasis on increasing agricultural production has led to the addition of a wide variety of chemicals, pesticides and inorganic fertilizers to agricultural land. It is well known that earthworms influence nutrient cycling processes in terrestrial ecosystems significantly (Lee, 1985; Blair et al., 1995; Edwards and Bohlen, 1996), and as farm managers continue to move towards reduced input agriculture, earthworms could become even more important in affecting soil productivity and fertility in agroecosystems. Soil is a habitat supporting different forms of life and reservoir of all the agrochemicals. By entering the soil, these materials may disturb the soil ecosystems and undermine the physical, chemical and biological components, in particular, of non-target beneficial microorganisms and earthworms (Anderson, 1978; Edwards and Bohlen, 1992). Brown et al. (1999) showed significant increases in plant growth due to earthworm inoculation in 72% of the studied cases, with the effects varying with earthworm species and soil type. Because of their useful role in agro-ecosystems, earthworms are used as indicator species to monitor the impact of pollutants, changes in soil structure and agricultural practices (Eijsackers, 2004).

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The number of earthworms in soil represents the health of the soil ecosystem and indicates environmental safety and a large population of earthworms is often recognized as a sign of a healthy soil (Romig et al., 1996). In light of the importance of earthworms in the dynamics of organic matter and soil structure, ecologists such as Hendrix et al. (1992); Edwards et al. (1995); and Ernst (2009) believe that long-term sustainability of agricultural soils could be improved by employing management practices that increase the number of earthworms. Several studies have been carried out on the toxic impact of some pesticides on soil organisms, especially earthworms, although little research has been done on the toxicity of different fertilizers on earthworms in a soil profile. A number of studies have found the positive effects of fertilizers on earthworms and their populations (Syers and Springett, 1984; Estevez et al., 1996; Curry et al., 2008). Few researchers also emphasized the negative effects of chemical fertilizers on earthworms (Marhan and Scheu, 2005; Bunemann et al., 2006; Tindaon et al., 2011; Bhattacharya and Sahu, 2014). Nearly all cultivated soils are treated with either organic or chemical fertilizers. The effects of these fertilizers on earthworms may be direct, for instance, by changing the acidity of soil or through toxicity (e.g. the ammonium radical), or indirect, by changing the form and quantity of the vegetation that ultimately turns into decaying organic matter that supplies food for earthworms. There is evidence that some inorganic nitrogenous fertilizers help the build-up of large numbers of earthworms, probably due to increased amounts of crop residues being returned to the soil (Lofs-Holmin, 1983). Rai et al. (2014) found a positive correlation between the mortality of *Eisenia fetida* and the concentration of urea fertilizer. Other studies showed that the application of fertilizers with nitrogen and phosphorous caused significant increases in earthworm number and biomass in an oxisoil (Iordache, and Borza, 2010). Whalen et al. (1998) concluded that the types of fertilization significantly influences the abundance and biomass of earthworms in corn fields. They demonstrated that earthworm numbers and biomass were significantly greater in manure-amended plots compared to inorganic fertilizer treated plots during the majority of the study period, so that the population of *Lumbricus* spp in organic fertilization was 18.5% higher than mineral nitrogen fertilizer. It seems there have been no comprehensive research on response of earthworm to inorganic fertilizers at two consecutive depths of soil profile. Due to the importance of gardening in Iran, assessing the dynamics of earthworm communities in different depths of an orchard soil receiving amendments of organic or inorganic fertilizer is the main purpose of this paper.

Material and Methods

The study was carried out in an apple orchard (31° 39' 05" N, 51° 55' 27" E and 2200 m above mean sea level), located in Esfarjan village in Isfahan Province, central Iran. The climate of the study area is BSk according to the agro-climatic classification of Koppen Geiger (Peel et al., 2007). Over the past 15 years, no inorganic fertilizer has been used in orchards of the target village. Compound soil samples from two depth of soil were taken to determine soil properties. The soil was classified as fine loamy, carbonatic, thermic, Typic Calcixerols with 27% silt, 25% clay, and 48% sand (Soil Survey Staff, 2010). Basic properties of the soil are given in Table 1. Earthworms were washed in fresh water and stored on the presence or absence of clitellum and clitellated earthworms were narcotized in 70% ethyl alcohol, fixed in 5% formalin for 6–8 h, and finally preserved in 5% formalin. The preserved samples were studied morphologically and dissected for study diagnostic taxonomic character such as spermathecae (number and location), prostate gland (location and shape), prostomium shape, and clitellum position. Finally, they were identified according to Sims and Gerard (1999) and Blakemore (2008). One square meter area of the soil surface with three replicates at a one-meter interval were considered as experimental plots. After plowing and grooving at depth of five centimeters per plot, common fertilizers, based on the soil test were applied. Chemical fertilizers such as Urea (30 mg/kg soil), Ammonium sulfate (AS) (38 mg/kg soil), Diammonium phosphate (DAP) (19 mg/kg soil), Solupotas (20 mg/kg soil), complete macro fertilizer containing nitrogen, phosphorus and potassium (NPK, 15-5-25) at a rate of 23 mg/kg of soil (NPK), the combination of decayed organic manure and complete macro fertilizer (NPK+OM) with the ratio of two to one including 15 mg/kg of soil NPK and decayed organic manure at 1.5 g/kg of soil, decayed organic manure (OM) at a rate of four grams per kilogram of soil were used as experimental treatments together with control plot with no chemical or organic fertilizer (Control). During the experiment, soil moisture was maintained at the field capacity level (FC) and the surface of the test plots was covered with gunny bag. Abundance and live weight of worms were measured in two stages of time and in 2 depths of 0-20 and 20-40 cm of soil profile. In the first stage, 20 days after addition of fertilizers, and in the second stage, 60 days after fertilization, earthworms were sampled by hand sorting method (Edwards and Bohlen, 1996) and their number were measured. The worms were also allowed to evacuate their digestive system on a filter paper and their live weight (biomass) was measured. Treatments were applied in three replications and data were transformed when necessary to improve homogeneity of variances using a square-root transformation (Zar, 1996). Untransformed data are presented in the figures. Meanwhile the data were analyzed using two-way ANOVA (using the GLM process) by SPSS software. In addition, means comparisons were tested with the least significant difference (LSD) at the probability level of 5%. Variables (response traits) included in the analysis were earthworm biomass (expressed as g.m-^{2}) and density (expressed as no.m-^{2}).

Table 1. Chemical and physical properties of experiment soils

Soil texture	BD, g.cm^{-3}	K, mg.kg^{-1}	P, mg.kg^{-1}	Total N, %	OC, %	$CaCO_3$, %	EC, dSm^{-1}	pH	Soil depth, cm
SL	1.42	185	19.5	0.14	1.2	24	0.5	7.0	0-20
SL	1.47	192	17.7	0.14	1.2	26	0.5	7.1	20-40

Results and Discussion

The results of means comparisons are given in details at two stages of time and two soil depths.

20th day, depth of 0-20 cm

In shallow depths of soil (0-20 cm), the highest number of worms in the control plots belonged to *D. veneta* and *E. fetida* of epigeic ecological group and *L. terrestris* species of anecic ecological group respectively. The results of the mean comparison showed that on 20th day and in the depth of 0-20 cm, *E. fetida* species decreased significantly in AS and Urea treatments compared to the control plot ($p<0.05$).) Hendrix et al. (1992) showed that the use of nitrogenous fertilizers could reduce the number of worms in the soil. Other researchers found similar results for the Enchytraeidae worms (Zajonc, 1975). However, Edwards and Lofti (1982) reported that there is a positive correlation between the amount of inorganic nitrogen and the number of worms in agricultural soils. They also concluded that the effect of organic fertilizers on the populations of *L. terrestris* was higher than *Allolobofora longa*, *A. caliginosa* and *A. chorotica*. NPK+OM treatment significantly increased the number of *E. fetida* species compared to the control. Comparison of the effect of two nitrogen supplier fertilizers (AS and Urea) showed that *D. hortensis* species had a better chances to survive and its population in AS treatment was more than that of Urea treatment. The relatively high numbers of D. veneta compared to the *E. fetida* in Urea and AS treatment are hard to explain, but might be related to the differences of physiology and biology of these earthworms species. The remaining species did not reveal any significant statistical differences in these two treatments (Figure 1A). No significant differences were observed between different species abundance of the two phosphorus compounds, DAP, NPK. Although, the combination of NPK+OM showed a significant increase in the population of both epigeic *E. fetida* and *D.veneta* compared to DAP and NPK treatments and it confirms the indisputable role of organic fertilizers in this regard. Curry (2004) and Jordan et al. (2004) reported that addition of farmyard manures and animal slurries increased earthworm populations rapidly. However, some liquid organic manures that have not been aged or composted can have short-term adverse effects on earthworm populations (Curry, 1976), due to their ammonia and salt contents. Timmerman et al. (2006) found that earthworm numbers in no fertilization treatment were higher than in the slurry manure treatment. This is in contrast with the general observation that earthworm abundance is higher under fertilized conditions. It was not unexpected that OM treatment alone had the same effect. It seems that chemical fertilizers had the most negative effect on the earthworms living in this depth of soil and time of sampling; meanwhile, using organic fertilizers reduces their harmful impact on earthworms. In case of biomass, a similar trend was also observed with earthworm populations. The results indicated a significant negative reaction of *L. terrestris* biomass to AS and DAP treatments compared to the control. Simultaneously, *E. fetida* and *L. terrestris* species in NPK + OM plots, encountered a significant increase in biomass compared to the control and the biomass of *A. longa* was increased in the OM treatment compared to the control plot (Figure 1B). The comparison of Urea and AS fertilizers showed that *L.terrestris* species have more biomass in Urea than AS treatment ($p<0.05$). The results in this section of the experiment showed that the anecic *A. longa* had a higher biomass in the NPK+OM treatment than in NPK because of organic compound (OM). Whilst, other species did not show any differences. Impacts of phosphate fertilizers on worms are also paradoxically reported, and these effects probably vary with the soil conditions. Gerard and Hey (1979) concluded that superphosphate decreased the number of earthworms in grass plots. Meanwhile, no significant effect was seen in earthworms biomass by fertilizer containing potassium (Solupotas).

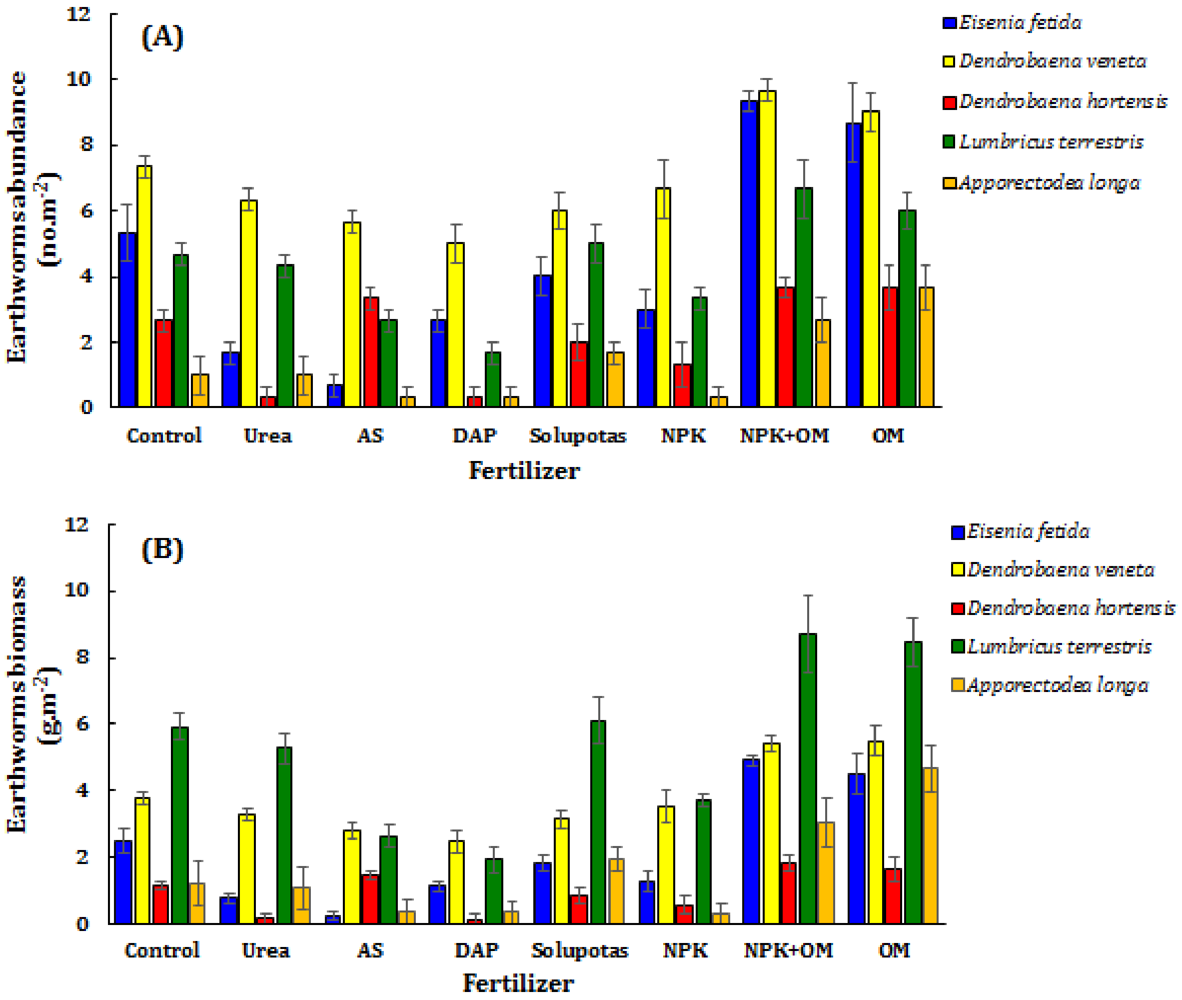

Figure 1. Means' comparisons of (A) earthworms species' abundance and (B) earthworms species' biomass in plots receiving different fertilizer amendments on 20th day at depth of 0-20 cm. P<0.05 (LSD).

20th day, depth of 20-40 cm

At lower depth, the highest number of worms belonged to *L. terrestris* and *A. longa*, respectively, and D. hortensis species recorded the lowest number. Comparison of means of earthworms species abundance showed that none of the fertilizer treatments could have a significant effect on earthworms species at 20-40 cm soil depth compared to control plots (Figure 2A). Earthworms seem to be less damaging from the negative effects of chemical fertilizers in deeper soil. The highest *L. terrestris* population was observed in Sulopotas containing plots, which showed a significant difference with the same species in AS treatment. From the point of view of earthworm biomass at depths of 20-40 cm, data clearly indicated that the most biomass content belonged to *L. terrestris* and *A. longa* as the same as worms population. Comparisons of earthworms species' biomass showed that fertilizer treatments did not have a statistically effect on earthworms as compared to the control plots (Figure 2B). We found that *L. terrestris* had grater biomass in Urea treatment than that in AS treatment ($p<0.05$). Moreover, DAP and NPK treatments did not differ significantly. Most of the biomass weights at depth of 20-40 cm belonged to *L. terrestris* species in OM treatment. Probably the influence of organic matter on all species is mainly through increasing their food supply, whether they feed directly on the organic matter or on microorganisms growing upon it.

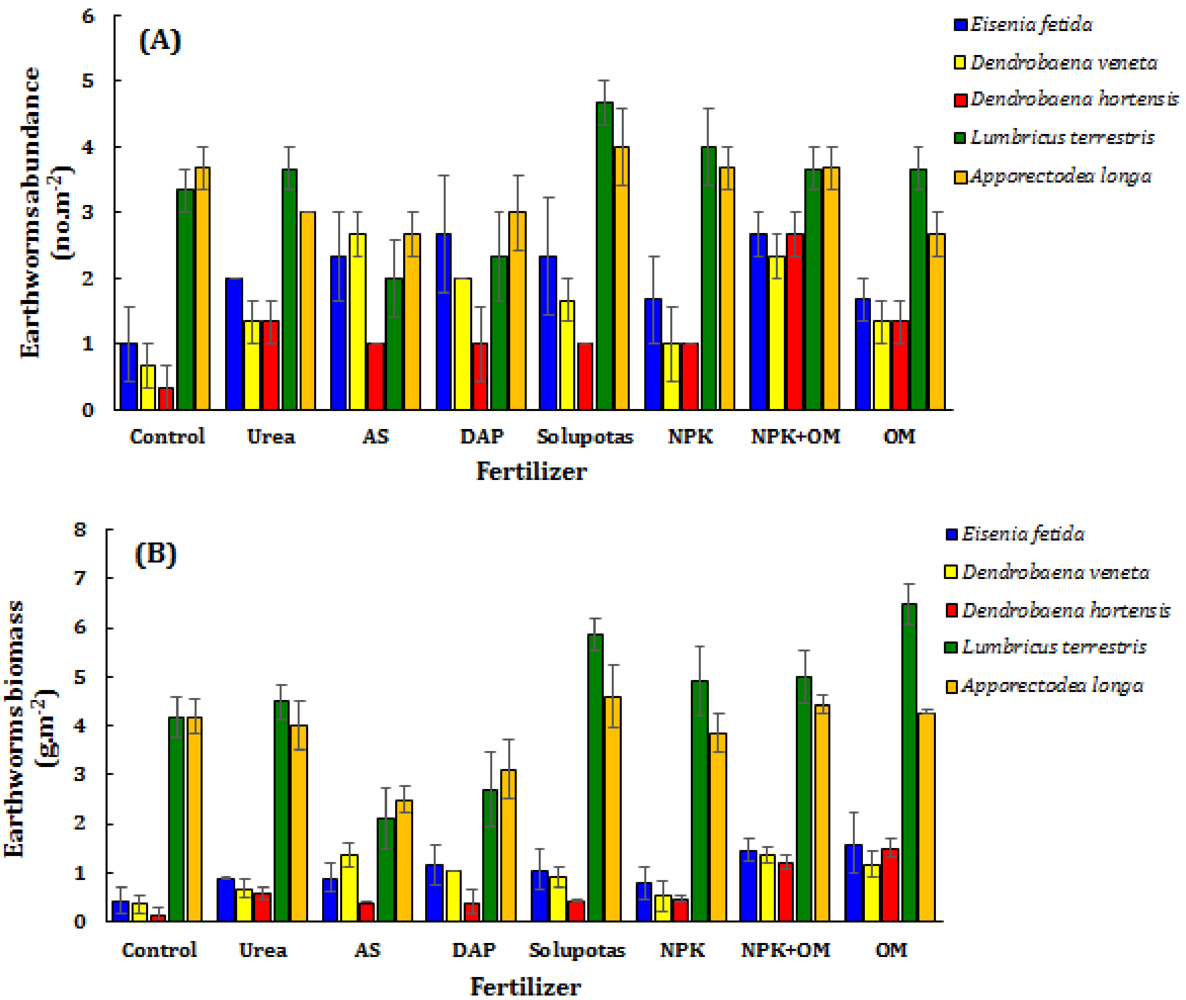

Figure 2. Means' comparisons of (A) earthworms species' abundance and (B) earthworms species' biomass in plots receiving different fertilizer amendments on 20th day at depth of 20-40 cm. P<0.05 (LSD).

60th day, depth of 0-20 cm

60 days after adding fertilizers, epigeic *D. veneta* and *E. fetida* were the most populous species and *A. longa* species was the least populous species at depth of 0-20 cm. Comparison of means by species showed that number of *E. fetida* species was decreased drastically in AS treatment compared to control plot (Figure 3A). Several authors have attempted to define that endogeic species of earthworms such as *Aporrectodea* spp. were more strongly affected than the epigeic group of *Lumbricus* spp., although an exception was noted for A. caliginosa tuberculata (Ma et al., 1990). At the same time, applying NPK+OM treatment significantly increased the number of D. veneta and E. fetida species compared to control. Meanwhile, the studied species did not indicate any significant difference in AS and urea treatments, however, number of *E.fetida* and *D. veneta* species in NPK+OM containing plots was more than in NPK containing plots. In most treatments, the population of *D. veneta* was more than other species, indicating the adaptation of this species to the environment. Measuring the biomass of different species at 0-20 cm depth showed that the highest biomass belonged to *L. terrestris* and *D. veneta* species. In NPK+OM treatment, the biomass of *E. fetida* increased significantly with respect to control treatment. Also, biomass of *E. fetida* species increased significantly in OM compared to similar species in control plot (Figure 3B). Guo et al. (2016), demonstrated that applying merely chemical fertilizers resulted in negative effects on earthworm activity, while cattle manure alleviated such negative effects, after applying cattle manure compost combined with chemical fertilizer to a wheat–maize rotation field. Unexpectedly, the five identified species did not show significant differences in AS and Urea treatments, which appeared that after 60 days, chemical conditions of the soil have reached a balance and earthworms have been able to withstand the initial stress. The presence of organic matter (OM) in experimental plots led to a significant increase in biomass of *E. fetida*, *L. terrestris* and *A. longa* than similar species in NPK treatment. The organic fertilizers probably act directly by providing food for the earthworms. This was most obvious for populations of *L. terrestris*, which increased more than those of other species did probably because it feeds directly on surface organic matter.

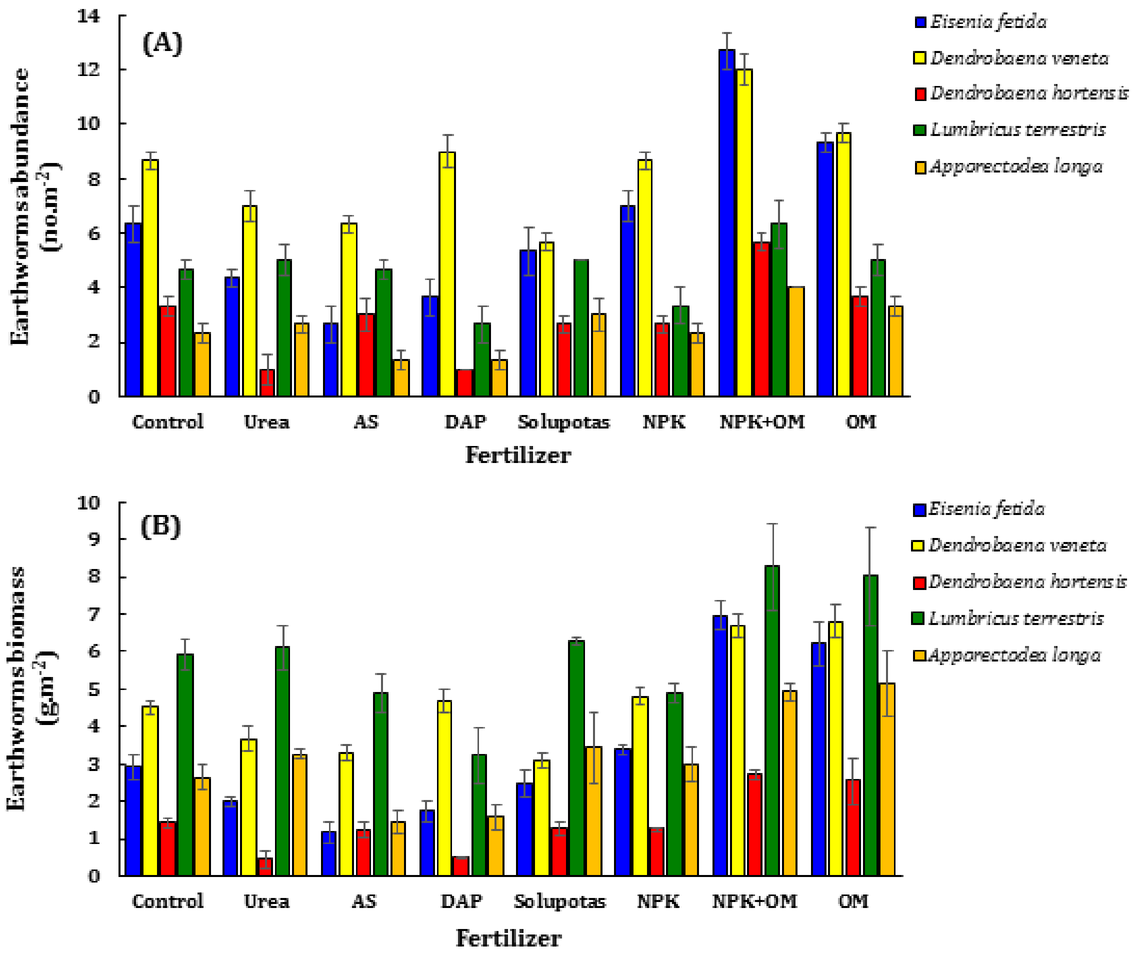

Figure 3. Means' comparisons of (A) earthworms species' abundance and (B) earthworms species' biomass in plots receiving different fertilizer amendments on 60th day at depth of 0-20 cm. P<0.05 (LSD).

60th day, depth of 20-40 cm

At depth of 20-40 cm, 60 days after adding fertilizers, the highest number of earthworms belonged to anecic *A. longa* and *L. terrestris* and the lowest number of earthworms referenced to epigeic *D. hortensis* and *E. fetida* (Figure 4A). Surprisingly the only significant change in worm populations was the increase in the number of *L. terrestris* species in plots containing AS and Urea treatments compared to the same species in control plot. It is less clear how these inorganic nitrogenous fertilizers favour the build-up of earthworm populations. It seems that 60 days after using of chemical fertilizers, these compounds have undergone chemical changes and their destructive effects have diminished. Moreover, the highest biomass in this depth was related to *A. longa* and *L. terrestris* species. Under those circumstances, the biomass of *L. terrestris* in all plots showed a significant increase ($p<0.05$) compared to the same species in the control plot (Figure 4B).

Conclusion

Results obtained in this study indicate that among the epigeic group of earthworms, *D. Veneta* had the most resistance or compatibility with chemical fertilizers and in anecic group; *L. terrestris* was able to withstand the condition of inorganic fertilizers. Yet, it is impossible to give a definitive and clear-cut recommendation on the effect of chemical fertilizers on earthworms. On the other hand, the effects of mineral fertilizer on earthworms are variable. Some inorganic fertilizers that are recommended by the soil test may be below the critical level for worms and found to be safe for them. However, there is higher possibility of having sub-lethal effect of these chemical amendments on earthworm. This is because; all the agrochemical go through bioaccumulation in the animal and plants tissues. It is also evident that the effects of various inorganic fertilizers on earthworms apparently vary from site to site and depth to depth as well. We concluded that ammonium sulfate caused a sharp reduction in the number of worms in the soil, especially in the depths of the surface of the soil. Epigeic earthworms are very sensitive in this regard because of their low drilling power. If it is necessary to use these fertilizers, it is advisable to use them in deep soil depth. It is also appropriate to use organic fertilizers along with inorganic fertilizers such as urea or NPK. The adverse influence of chemical fertilizers could be alleviated by application of organic and natural inputs. Our results confirm these findings and provide a basis for speculation on the ways in which inorganic fertilizers increase earthworm populations in deeper depth of soils regardless of types of these amendments.

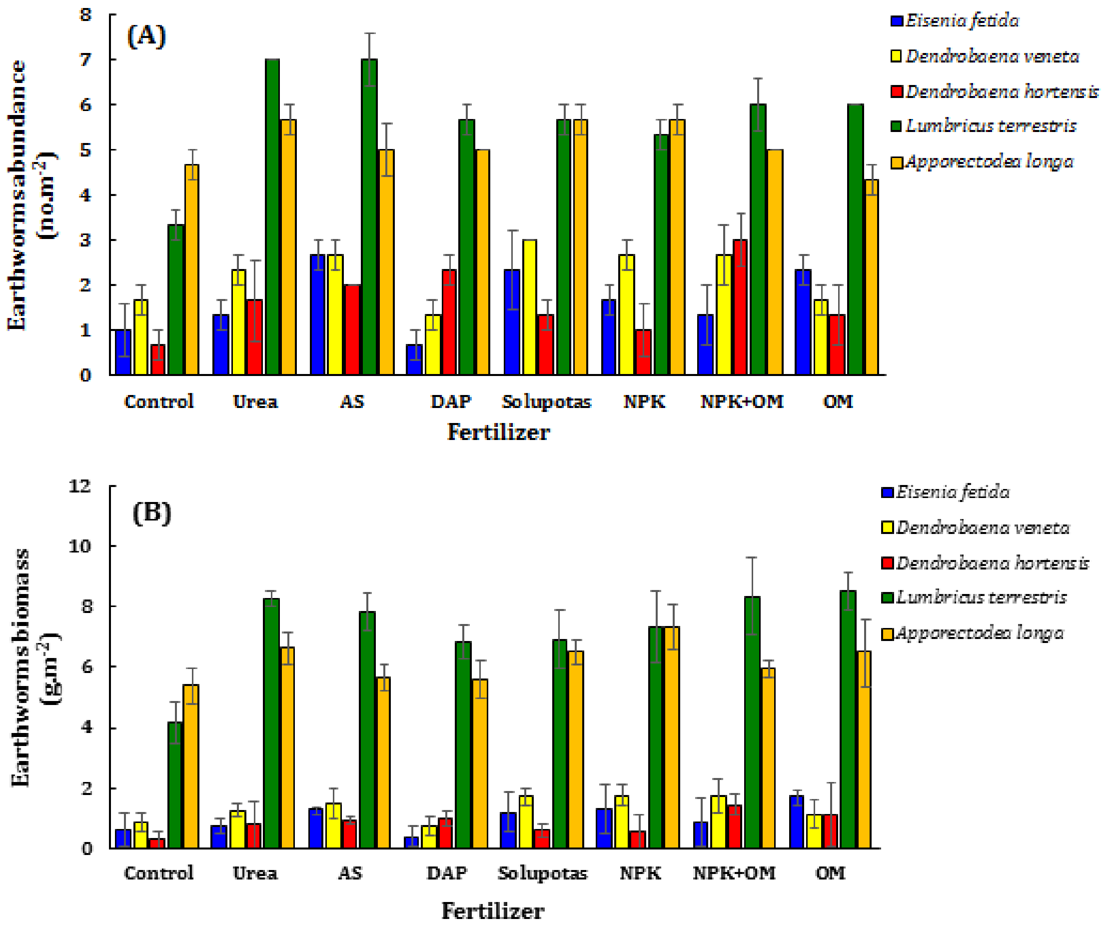

Figure 4. Means' comparisons of (A) earthworms species' abundance and (B) earthworms species' biomass in plots receiving different fertilizer amendments on 60th day at depth of 20-40 cm. P<0.05 (LSD).

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References

Anderson, JR., 1978. Pesticide effects on non-target soil microorganisms. In: Pesticides Microbiology, Hill, I.R., Wright, S.J.L. (Eds.). Academic Press, London, UK. pp. 313-33.

Bhattacharya, A., Sahu, SK., 2014. Lethal effect of urea on soil biota: a laboratory study on earthworm (Drawida willsi). *Journal of Biodiversity and Environmental Sciences* 4(6): 64-72.

Blair, J.M., Parmelee, R.W., Lavelle, P., 1995. Influences of earthworms on biogeochemistry. In: Hendrix, P.F. (Ed.), Earthworm Ecology and Biogeography in North America. Lewis Publishers, Boca Raton, USA. pp. 128–154.

Blakemore, R. J., 2008. Cosmopolitan Earthworms –an Eco-Taxonomic Guide to the Species. (3rd Edition). VermEcology, Yokohama, Japan. 757p.

Brown, G.G., Pashanasi, B., Villenave, C., Patron, J.C., Senapti, B.K., Giri, S., Barois, I., Lavelle, P., Blanchart, E., Blakemore, R.J., Spain, A.V., Boyer, J., 1999. Effects of earthworms on plant production in the tropics. In: Lavelle P., Brussaard, L., Hendrix, P. (Eds), Earthworm Management in Tropical agroecosystems. CABI Publishing, New York, USA. pp. 87-147.

Bunemann, E.K., Schwenke, G.D., Van Zwieten, L., 2006. Impacts of agricultural inputs on soil organisms - a review. *Australian Journal of Soil Research* 44(4): 379-406.

Curry, J.P., 1976. Some effects of animal manures on earthworms in grassland. *Pedobiologica* 16: 425-438.

Curry, J.P., 2004. Factors affecting the abundance of earthworms in soils. In: Earthworm Ecology. Edwards, C.A. (Ed.), CRC press LLC, Boca Raton, Florida, USA. pp. 91–114.

Curry, J.P., Doherty, P., Purvis, G., Schmidt, O., 2008. Relationships between earthworm populations and management intensity in cattle-grazed pastures in Ireland. *Applied Soil Ecology* 39(1): 58-64.

Edwards, C.A., Bohlen, P.J., 1992. The effects of toxic chemicals on earthworms. *Reviews of Environmental Contamination and Toxicology* 125: 23-99.

Edwards, C.A., Bohlen, P.J., 1996. Biology and Ecology of Earthworms. Chapman & Hall, London, UK. 426p.

Edwards, C.A., Bohlen, P.J., Linden, D.R., Subler, S., 1995. Earthworms and sustainable land use. In: Earthworm Ecology and Biogeography in North America. Hendrix, P.F. (Ed.), CRC Press, Boca Raton, Florida, USA. pp. 215–231.

Edwards, C.A., Lofty, J.R., 1982. Nitrogenous fertilizers and earthworm populations in agricultural soils. *Soil Biology and Biochemistry* 14(5): 515-521.

Eijsackers, H., 2004. Earthworms in environmental research. In: Earthworms Ecology, C.A. Edwards (Ed.), CRC Press, Boca Raton, Florida, USA. pp. 103-122.

Ernst, G., Emmerling, C., 2009. Impact of five different tillage systems on soil organic carbon content and the density, biomass and community composition of earthworms after a ten-year period. *European Journal of Soil Biology* 45(3): 247-251.

Estevez, B., N'Dayegamiye, A., Coderre, D., 1996. The effect on earthworm abundance and selected soil properties after 14 years of solid cattle manure and NPKMg fertilizer application. *Canadian Journal of Soil Science* 76(3): 351-355.

Gerard, B.M., Hay, R.K.M., 1979. The effect on earthworms of ploughing, tined cultivation, direct drilling and nitrogen in a barley monoculture system. *The Journal of Agricultural Science* 93(1): 147-155.

Guo, L., Wu, G., Li, Y., Li, C., Liu, W., Meng, J., Liu, H., Yu, X., Jiang, G., 2016. Effects of cattle manure compost combined with chemical fertilizer on topsoil organic matter, bulk density and earthworm activity in a wheat–maize rotation system in Eastern China. *Soil and Tillage Research* 156: 140–147.

Hendrix, P.F., Mueller, B.R., Bruce, R.R., Langdale, G.W., Parmelee, R.W., 1992. Abundance and distribution of earthworms in relation to landscape factors on the Georgia Piedmont, USA. *Soil Biology and Biochemistry* 24(12): 1357–1361.

Iordache, M., Borza, I., 2010. Relation between chemical indices of soil and earthworm abundance under chemical fertilization. *Plant, Soil and Environment* 56(9): 401-407.

Jordan, D., Miles, R.J., Hubbard, V.C., Lorenz, T., 2004. Effect of management practices and cropping systems on earthworm abundance and microbial activity in Sanborn Field: a 115-year-old agricultural field. *Pedobiologia* 48(2): 99–110.

Lee, K.E., 1985. Earthworms: Their ecology and relationships with soils and land use. Academic Press, Sydney, Australia. 411p.

Lofs-Holmin, A., 1983. Influence of agricultural practices on earthworms (Lumbricidae). *Acta Agriculturae Scandinavica* 33(3): 225-334.

Ma, W.C., Brussarrd, L., de Ridder, J.A., 1990. Long term effects of nitrogenous fertilizers on earthworms and their relation to soil acidification. *Agriculture, Ecosystems & Environment* 30(1-2): 71-80.

Marhan, S., Scheu, S., 2005. The influence of mineral and organic fertilisers on the growth of the endogeic earthworm *Octolasion tyrtaeum* (Savigny). *Pedobiologia* 49(3): 239-249.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Koppen-Geiger climate classification. *Hydrology and Earth System Sciences* 11: 1633–1644.

Rai, N., Ashya, P., Rathore, D.S., 2014. Comparative study of the effect of chemical fertilizers and organic fertilizers on *Eisenia foetida*. *International Journal of Innovative Research in Science Engineering and Technology* 3(5): 12991-12998.

Romig, D.E., Garlynd, M.J., Harris, R.F., 1996. Farmer-based assessment of soil quality: a soil health scorecard. In: Methods for Assessing Soil Quality. Doran, J.W., Jones, A.J. (Eds.), Soil Science Society of America, Madison, Wisconsin, USA. pp. 39–59.

Sims, R.W., Gerard, B.M., 1999. Earthworms: Notes for the Identification of British Species. Linnean Society of London and the Estuarine and Coastal Sciences Association, London, USA. pp. 169.

Soil Survey Staff, 2010. Keys to Soil Taxonomy, 11th Edition. U.S. Department of Agriculture, USA. pp. 539–579.

Syers, J.K., Springett, J.A., 1984. Earthworms and soil fertility. *Plant and Soil* 76(1-3): 93-104.

Timmerman, A., Bos, D., Ouwehand, J., de Goede, R.G.M., 2006. Long-term effects of fertilisation regime on earthworm abundance in a semi-natural grassland area. *Pedobiologia* 50(5): 427-432.

Tindaon, F., Benckiser, G., Ottow, J.C.G., 2011. Side effects of nitrification inhibitors on non target microbial processes in soils. *Journal of Tropical Soils* 16(1): 7-16.

Whalen, J.K., Parmelee, R.W., Edwards C.A., 1998. Population dynamics of earthworm communities in corn agroecosystems receiving organic or inorganic fertilizer amendments. *Biology and Fertility of Soils* 27(4): 400–407.

Zajonc, I., 1975. Variation in meadow associations of earthworms caused by the influence of nitrogen fertilizers and liquid manure irrigation. In: Proceedings 5th Int. Colloquium in soil zoology, Prague, Czech Republic. pp. 497-503.

Zar, J.H., 1996. Biostatistical Analysis. 3rd Edition, Prentice-Hall, Upper Saddle River, New Jersey, USA. 663p.

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Relation of reactive solute-transport parameters to basic soil properties

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Abstract

Solute-transport parameters are needed to assess the pollution risks of soil and groundwater resources. A reliable estimate of these parameters from easily measurable soil properties is therefore important. So, the correlations of the transport parameters for one metalloid compound ($NaAsO_2$), six heavy metal compounds ($Cd(NO_3)_2$, $Pb(NO_3)_2$, $Ni(NO_3)_2$, $ZnCl_2$, $CuSO_4$ and $Co(NO_3)_2$), two pesticides (cartap and carbendazim) and one inert salt ($CaCl_2$) with some basic properties of eight agricultural soils of Bangladesh were investigated. The purpose of this study was to generate information for development of non-parametric pedo-transfer functions for reactive solute transport through soils. The transport experiments with the solutes were done in repacked soil columns under unsaturated steady-state water flow conditions. The major solute-transport parameters – velocity of transport (V), dispersion coefficient (D), dispersivity (λ), retardation factor (R) and Peclet number (P) – were determined by analysing solute breakthrough curves (BTCs). The basic soil properties pertinent to solute transport: clay content, median grain diameter (D_{50}), pore-size distribution index (n), bulk density (ρ), organic carbon content (C) and pH were determined. The associations of the solute-transport parameters with these soil properties were investigated and evaluated. Both the solute dispersivity and retardation factor increased significantly ($p<0.05$) (λ linearly and R following power law) with the increase in soil clay content. Dispersivity significantly decreased with the increase in median grain diameter following power law. The V, D, λ and P values were weakly and negatively correlated with the soil bulk density. Retardation factor, R, was moderately and positively correlated with the ratio of clay content to organic carbon content. Dispersivity decreased but P increased, both significantly, with increasing pore-size distribution index, n. V, D and P were positively correlated with soil pH, while R and λ were negatively correlated with it. The correlation of the solute-transport parameters with soil properties being significant ($p < 0.05$), in most cases, provides strong possibility of predicting solute-transport parameters from the basic soil properties through the development of pedo-transfer functions.

Article Info

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Introduction

Intensive agriculture with increased use of agrochemicals and other hazardous chemicals (Thawornchaisit and Polprasert, 2009) is continuously raising the pollution level of soils (Muchuweti et al., 2006) and groundwater, especially in the developing countries like Bangladesh. Tannery industries discharge chromium (Cr), silver (Ag), cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), while dye effluents contain

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Cd, Cu, Zn, Cr and iron (Fe). Applications of some chemical fertilizers and pesticides, and contamination of irrigation water by industry may cause soil pollution by heavy metals and pesticide residues. Increasing use of wastewater and sewage sludge, containing various heavy metals, in irrigation is worsening the problems. Islam et al. (2004) reported elevated concentrations of As, Cr, Cu, Ni, Pb and Zn in many agricultural soils of Bangladesh. As-contaminated groundwater, used for drinking and irrigation, is also a severe problem in large part of Bangladesh.

Solute transport through porous media is important for a wide range of applications, such as groundwater and soil remediation, salt water intrusion, drinking water purification, and wastewater treatment (Pugliese et al., 2015). It is also important for plant growth, chemical reactions (such as sorption, precipitation and redox) and for understanding the environmental impact of waste dumping sites and surface-applied chemicals, such as pesticides and fertilizers (Karup et al., 2016). So, characterization of the solute-transport process through soils is an important aspect, specifically for assessing the pollution of soil and groundwater resources. For an accurate assessment, solute-transport parameters, such as velocity of transport, dispersion coefficient, dispersivity and retardation factor need to be determined. These parameters are needed for modelling of water and solute movement in field soils and aquifers. These models can guide both future research efforts and current management practices in an objective and quantitative manner. They are also needed for the design of waste disposal sites (industrial and municipal), long-term management of various harmful substances (e.g., radioactive waste) (Filipović et al., 2016), optimum application of agrochemicals in the field, selection and design of suitable leaching methods, and monitoring quality of soil and groundwater resources over time. The success of these models, however, depends on the ability to quantify properly the solute-transport parameters to be used in the models.

Practically, it is not possible to measure the solute-transport parameters for a large number of soils under nearly infinite variety of field conditions since their direct measurement is time consuming, cumbersome and costly. Often, the use of field technologies is not a suitable option to study solute transport in soil due to their temporal and spatial limitations and high cost. Laboratory experiments and modelling can be good alternatives (Filipović et al., 2016). However, temporal and spatial variability in soil physical properties has a considerable effect on model results. So, it is necessary to know the transport behaviour of different solutes through various soil types. But, because of large time and high cost, the majority of the techniques for direct measurement of solute-transport parameters are restricted to small scales (Darcy scale and smaller) only. So, it is not possible to map solute-transport properties at larger scales by direct measurements. However, Koestel et al. (2013), through a comprehensive review of 733 breakthrough curves, reported the possibility of a way out by using proxy variables like soil texture, bulk density, or land use to estimate soil solute-transport properties. The essence of this possibility is that good predictions, instead of direct measurements, may be accurate enough for many practical applications.

The transport behaviour of solutes in soils is governed by a variety of complex and dynamic physical, chemical and biological processes. Particle size distribution, bulk density, structure and pH of the soils also greatly influence solute transport (Karup et al., 2016). Li et al. (2009) reported weak negative relation between velocity of solutes and bulk density of soils, while Montoya et al. (2006) reported a strong positive correlation (r = 0.91) between velocity of solutes and clay content for soil columns from non-tillage land. Li et al. (2009) and Tabarzad et al. (2011) reported positive relationship between solute dispersion coefficient and bulk density. But, contrasting result was observed by Bromly et al. (2007) that was supported by Montoya et al. (2006) and Okada et al. (2014); they observed a strong positive correlation (r = 0.80) between dispersion coefficient and clay content in well-structured soil samples under no-tillage condition. Bromly et al. (2007) reported significant negative correlation between dispersivity and bulk density, while Xu and Eckstein (1997) reported a directly related dispersivity with median grain size, D_{50}, for uniform classic materials with a uniformity coefficient <2. Hussein (2009), on the other hand, obtained linear relation between D_{50} and effective molecular diffusion coefficient of solutes. Nemeth-Konda et al. (2002) observed positive correlations of adsorption coefficients with soil clay content and organic carbon for carbendazim. The ratio between the clay content and organic carbon content was also hypothesized as a fundamental control of the structure of agricultural topsoil and consequently for the solute transport properties (de Jonge et al., 2009).

Despite substantial amount of field and laboratory data on the transport of solutes in soils obtained in the recent decades in different countries, the methods for assessing the chemical parameters from the physical properties of soils remain poorly developed (Raymundo-Raymundo et al., 2012). In the comprehensive review, Koestel et al. (2012) analysed information on 733 BTCs, all of which were for inert/conservative tracers, mostly, on undisturbed soil samples and a smaller number on columns filled with glass beads, clean sands, or sieved and repacked soil. But, the transport behaviour of the inert solutes in soils is markedly different from the reactive solutes (Mojid and Vereecken, 2005a,b). For example, because of the adsorption of reactive solutes by the soil particles, their transport velocity is slower than the inert solute (Taran et al., 2015). Models to estimate solute transport in soils are often soil-specific and simply cannot be extrapolated to soils with a different texture. Furthermore, for establishing relationships between soil properties and solute-transport properties, it is important to focus on small scales since the small-scale relationships are very likely fundamental to corresponding relationships at larger scales (Vogel and Roth, 2003). Such relationships for soils, especially agricultural soils of Bangladesh, are yet to be investigated. So, the objective of this study was to investigate relationships of some soil properties with solute-transport parameters. The main motivation for this work was to create a dataset of reactive solute-transport properties to enable the future development of non-parametric pedo-transfer functions, especially for reactive solute transport.

Material and Methods

Site selection and soil sampling

Soil samples were collected from seven administrative districts of Bangladesh - Mymensingh, Gazipur, Comilla, Satkhira, Bogra, Rajshahi and Dinajpur, the corresponding Agro-Ecological Zone (AEZ) being 9, 28, 19, 13, 25, 11 and 3 (BARC, 2008). Total eight soil samples, taking two samples from Mymensingh and one from each of the other districts, were collected. As ploughing upper soil layers (≈15 cm) is a common practice at the selected locations and soil structure is affected during irrigation and rainfall, repacked soil columns were used to determine solute-transport parameters to reduce variability due to heterogeneity. Soil samples were collected from 0–15 cm top soil layer covering an area of one square meter. The soils were air dried and passed through a 2-mm mesh sieve after crushing; soils with aggregate size of ≈ 2 mm are regarded representative for characterizing reliable physical quality indicators (Stavi et al., 2011). Sub-samples of the soils were analysed for texture, grain size, electrical conductivity (EC), pH and organic carbon (C) following standard methods (Page et al., 1982).

Selection of solutes

Based on composition of the most frequently used agrochemicals and waste products discharged by industry, and problem of groundwater contamination by arsenic (As) in Bangladesh, one metalloid (As), six heavy metals (Cd, Ni, Pb, Co, Zn and Cu) and, for comparison, laboratory grade calcium chloride ($CaCl_2$) were used for the transport experiments. In addition, cartap and carbendazim, extensively used as insecticide and fungicide, respectively, were selected as organic solutes. Tables 1 and 2 provide some properties of the selected chemicals.

Table 1. Chemical formula, molecular weight, electrical conductivity (EC) and form of $CaCl_2$, $NaAsO_2$, $Pb(NO_3)_2$, $Cd(NO_3)_2$, $ZnCl_2$, $CuSO_4$, $Ni(NO_3)_2$ and $Co(NO_3)_2$

Sl. No	Solute	Metal salt	Formula	Mol.wt. (g mol^{-1})	*EC (mS m^{-1})	Form
1	Ca	Calcium chloride	$CaCl_2$. $2H_2O$	147.02	166	Powder
2	As	Sodium arsenite	$NaAsO_2$	312.01	236	Granular
3	Pb	Lead nitrate	Pb $(NO_3)_2$	331.21	213	Powder
4	Cd	Cadmium nitrate	$Cd(NO_3)_2.4H_2O$	308.47	207	Crystal
5	Zn	Zinc chloride	$ZnCl_2$	136.28	152	Powder
6	Cu	Copper sulphate	$CuSO_4.5H_2O$	249.68	116	Crystal
7	Ni	Nickel nitrate	Ni $(NO_3)_2.6H_2O$	290.81	211	Crystal
8	Co	Cobalt nitrate	Co $(NO_3)_2.6H_2O$	291.03	153	Crystal

* EC was measured at concentration 5 mM l^{-1}.

Table 2. Molecular weight, solubility, electrical conductivity (EC) and form of cartap and carbendazim pesticides

Active ingredient	Chemical group	Commercial name	Mol. wt. (g mol^{-1})	Solubility (water) (mg l^{-1})	*EC (mS m^{-1})	Form
Cartap	Cartap hydrochloride	Bravo	273.8	2.0×10^5	241	Powder
Cabendazim	Carbamate-benzimidazole	Bavistin	191.2	8.0	77	Granular

Source: Shanghai Skyblue Chemical Co. Ltd., China

* EC was measured at concentration 5 mM.

Solute-transport experiments

The experimental set-up and conduction of solute-transport experiments were described in Mojid et al. (2016); only a summary is provided here. Four PVC columns (each 1.2 m high, 0.2 m in diameter and with the bottom closed) were set on a wooden pallet and uniformly filled with a sandy loam soil. These columns, to be used for supporting experimental soil columns, were allowed to attain stable structure by alternate wetting and drying over one year. Following Mojid et al. (2004), four additional PVC columns (each 34 cm long and 15 cm in inner diameter) were filled uniformly and compactly up to 32 cm depth with air-dried and sieved soils to be used for solute-transport experiments. Tap water (EC = 17 mS m^{-1}) was applied from the bottom upwards by placing the soil columns in a large flat-bottom plastic bowl. After settlement and forming structure in six months, sufficient quantity of tap water was leached through the soil columns following six wetting and drying cycles in the next three months. The columns were then transferred to the top of the 1.2-m supporting soil columns and placed vertically. The remaining four soils were used in the second batch of similar experiments.

Two 3-rod TDR sensors (10 cm long, 3 cm spacing of centre to centre of the outer rods and 0.2 cm rod diameter) were inserted horizontally to each column and glued to make water proof. One sensor was at 8 cm and the other at 28 cm below the top of the upper columns. Measuring concentrations between the two sensors within a sample rather than from the top of the sample to one sensor provided several advantages (Mojid et al., 2006). A cartridge pump applied tap water at a constant rate (0.32 ± 0.02 cm h^{-1}), which was lesser than the saturated hydraulic conductivities of the soils, ensuring unsaturated flow. At steady-state condition, a pulse of 5 ml $CaCl_2$ solution (250 g l^{-1}) was introduced uniformly on each column by a syringe. A TDR100 and CR10X datalogger recorded water content and bulk EC of the soils at pre-selected intervals; the EC is a proxy of breakthrough concentration of the solutes. The measurements continued until whole of the applied solute leached out from the upper columns. Measurements of water content and bulk EC were conducted sequentially for the ten solutes (Table 1 and 2) in the same soil column according to the order: Ca, cartap, Ni, Cu, Zn, Pb, carbendazim, Cd, Co and As. The pulse volume and concentration for all the solutes were the same as that for $CaCl_2$ (5 ml). After completion of the experiments with the eight soils in two batches, six soil samples were collected from the top 5 cm of each column using 5-cm diameter core samplers.

Soil analysis

Soil particle size distribution was determined by Hydrometer Method (Page et al., 1982) and textures of the soils were determined there from. The EC and pH of the soils were determined by a glass electrode pH meter, and organic matter was determined by Walkey-Black method as outlined by Jackson (1962). Gradation tests of the soils were done on the samples by a typical sieve analysis involving a nested column of sieves with wire mesh screen and a round pan at the base. For each soil, 500-g air dry sample was poured in the top sieve; each lower sieve in the column had smaller openings than the one above. After shaking the sieves with an electrical shaker, the soil particles retained on each sieve were weighed separately. This test was done in accordance with the British Standards, BS 1377 (1990) (Code of Practice) for the eight soils. The effective grain size (D_{10}), median grain diameter (D_{50}), grain diameter at 60% passing (D_{60}) and uniformity coefficient (C_u) were calculated from the particle size distribution curves of the soils. The C_u, considered as a shape parameter, was calculated by

$$C_u = \frac{D_{60}}{D_{10}} \tag{1}$$

The bulk densities of the soils (ρ) in the experimental columns were determined by core cutter method (BS 1377 (1990)). Three of the soil samples in the core samplers from each column were dried in oven at 105 ^{0}C for 24 h. The bulk densities of the soils were determined by dividing the oven dry weights of the soils by the volume of the cores.

Soil-water retention

Soil-water retention data were measured on the remaining three soil samples in the core samplers for each column. A sandbox (Eijkelkamp, The Netherlands) was used to measure water retention data at low matric suction (<100 cm). Water retention data at higher matric suctions (200, 300, 500, 1000, 1700, 3000, 8000, 12000 and 15000 cm) were determined by using a pressure plate apparatus (Soil Moisture Equipment Corp., Santa Barbara, CA-850-964-3525). The samples used for the sandbox and pressure plate apparatus were weighed after they reached equilibrium at each suctions. Finally, the soil samples were dried in oven at 105 ^{0}C for 24 h. From the difference in weights of the samples at the end of different suctions and those after drying in oven, the water contents of the samples against the applied suctions were calculated. By plotting the water contents against the corresponding matric suctions, the soil-water retention curves for the samples were obtained.

Soil-water retention model of van Genuchten (1980) was fitted to the soil-water retention curves by using nonlinear least-squares optimization approach. The model is given by

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha h)^n]^m} \tag{2}$$

where θ_s and θ_r are the saturated and residual soil-water contents, respectively, θ is the gravimetric water content (g g^{-1}), *h* is the matric suction (cm), α is the inverse of matric suction at the inflection point of the retention curves, and *m* and *n* are parameters that govern shape of the fitted curves. The van Genuchten's *n* (Eq.2) is a measure of pore-size distribution index and considers the slope of desaturation zone of the soil-water retention curve (Mosaddeghi et al., 2008). However, Guber et al. (2004) suggested that the physical correlate of *n* is the impact content of small aggregates in a soil. A large *n* indicates dominancy of small pores in the total porosity. So, *n* can be treated as a measure of the increase or decrease of micro-porosity in soils. The minimization function is expressed by

$$F(\alpha, n, m) = \sum_{i=1}^{m_1} \left(\theta_{meas,i} - \theta_i\right)^2 \tag{3}$$

where m_1 is the number of measured points on the water retention curve, $\theta_{meas,i}$ is the measured and θ_i is the corresponding estimated value calculated by Eq. 2.

Breakthrough curve analysis

The analysis of TDR-measured EC is based on the relation between the concentration of a solute in soil water and the EC of soil water, which is linearly related to the EC of bulk soil for constant soil-water content (Ward et al., 1994). Thus, solute BTCs were constructed from the time series of TDR-measured bulk soil EC. For the details of BTC analysis, the readers are referred to Mojid et al. (2016). In brief, the mean travel time (τ), mass-dispersion number (N), and retardation factor, *R*, of the solutes were optimized from the BTCs by a transfer-function method (Mojid et al., 2004; their Equations 5 and 7). For $CaCl_2$, *R* was fixed at unity considering it to be a non-reactive solute. The other solute-transport parameters – *V*, *D* and λ – were calculated from τ, N and the distance, Z, between the input and response BTCs that were measured at the top and bottom TDR sensors. *P* was calculated by Z*V*/*D*. For the physical meaning of *V* and *R* for the reactive solutes (all solutes in this study except $CaCl_2$), the readers are referred to Mojid and Vereecken (2005b). Pearson correlation coefficients, along with their significance (for $p < 0.05$), were calculated to evaluate relationships among the solute-transport parameters and basic soil properties.

Results and Discussion

Basic soil properties

The sand, silt and clay content of the soils (Table 3) ranged over 4.92 –79.48%, 14.48 – 77.96% and 6.04 – 19.12%, respectively. Five of the eight soils were silt loam; one was loamy sand, one sandy loam and one silt. The dry bulk density, ρ, of the repacked soils in the experimental columns varied from 1.29 to 1.40 g cm^{-3} (Table 3); the variation of bulk density was due to the soil textural variation, not due to variation in compaction. The narrow range of bulk density in the soils was due to the closer textural classes of the soils.

Table 3. Textural class, clay content, bulk density, organic carbon content and pH of soils

Locations	Textural class	USDA classification (1978)	Clay content (%)	Bulk density (g cm^{-3})	Organic carbon (%)	pH
Mymensingh (1)	Loamy sand	Aeric Haplaquepts	6.04	1.36	0.767	7.36
Mymensingh (2)	Silt loam	Aeric Haplaquepts	11.44	1.33	0.686	7.45
Dinajpur	Sandy loam	Udic Ustochrepts	8.50	1.33	0.452	7.58
Bogra	Silt loam	Aeric Fluvaquents	10.68	1.29	0.753	7.38
Gazipur	Silt loam	Aeric Fluvaquents	12.68	1.40	0.523	7.01
Rajshahi	Silt	Aquic Eutrochrepts	13.36	1.34	0.787	7.07
Comilla	Silt loam	Aquic Udifluvents	15.48	1.37	0.372	6.32
Satkhira	Silt loam	Aquic Eutrochrepts	19.12	1.32	0.840	6.85

For soils with similar textures, ρ is regarded as a strong predictor for structural variation in the soils (Norgaard et al., 2013). The bulk density was weakly and negatively correlated (r = -0.014) with %clay of the soils. It decreased insignificantly (r = - 0.51; $p < 0.05$) with the increase in organic carbon, C. Relatively low and narrow range of organic carbon (0.37 to 0.84%) and clay content (6.04 – 19.12%) of the soils might limit complete exposure of their roles in solute transport through the soils. Soil pH ranged from slightly acidic (6.32) to slightly alkaline (7.58). It was strongly and negatively correlated (r = -0.71) with clay content of the soils. The effective grain diameter (D_{10}), median grain diameter (D_{50}) and grain diameter at D_{60} of the soils ranged from 0.028 to 0.085 mm, 0.062 to 0.235 mm and 0.079 to 0.278 mm, respectively (Table 4). The uniformity coefficient (C_u) of the soils was within 2.63–3.86, implying that the soils were well-graded (C_u > 2.0; Arora, 2000) with a good drainage environment.

Table 4. Effective grain size (D_{10}), median grain diameter (D_{50}), grain diameter at 60% passing (D_{60}) and uniformity coefficient (C_u) (n = 8)

Locations	D_{10} (mm)	D_{50} (mm)	D_{60} (mm)	C_u (-)
Mymensingh (1)	0.085	0.235	0.278	3.27
Mymensingh (2)	0.048	0.101	0.157	3.26
Dinajpur	0.073	0.200	0.261	3.58
Bogra	0.052	0.112	0.173	3.30
Gazipur	0.035	0.095	0.135	3.86
Rajshahi	0.029	0.069	0.085	2.98
Comilla	0.031	0.066	0.082	2.63
Satkhira	0.028	0.062	0.079	2.78

Solute transport as affected by soil properties

Transport velocity as affected by soil bulk density and clay

The velocity of the solutes, V, through the unsaturated soil columns varied inversely with bulk density, ρ, of the soils, revealing that soil clay enhanced solute movement through the soils. The correlation between V and ρ (r = -0.047 to – 0.101) was insignificant ($p < 0.05$). It is noted that although the correlation matrices were determined and tabulated with the Pearson correlation coefficients for all the solutes under investigation, only that for $NaAsO_2$ is provided in Table 5 as an example. During conditioning of our repacked soil columns by alternate wetting and drying, the soils attained structure, the level of which varied on the quantity of clay content; the soil with higher clay content attained better structure than the one with lower clay content. Over the narrow range of clay content (6.04 – 19.12%) in the soils, the movement of the solutes was dominantly governed by the level of soil structural development than by the texture of the soils. The observed velocity of the solutes suggests that clay content in soils under conservational tillage would favour the transport of solutes since it augments solute velocity through soil structural improvement.

Table 5. Correlation matrices (Pearson correlation coefficients) of velocity (V), dispersion coefficient (D), dispersivity (λ), retardation factor (R) and Peclet number (P) of $NaAsO_2$ and bulk density (ρ), organic carbon content (C), clay content, pH, effective grain size (D_{50}) and uniformity coefficient (C_u) of eight soils

Parameters	V (cm h^{-1})	D (cm^2 h^{-1})	λ (cm)	R	P	ρ (g cm^{-3})	C (%)	Clay (%)	pH	D_{50} (%)	C_u
V	1										
D	0.93*	1									
λ	-0.99*	-0.88*	1								
R	-0.98*	-0.88*	0.99*	1							
P	0.98*	0.85*	1.00*	-0.98*	1						
ρ	-0.05	0.04	0.12	0.10	-0.10	1					
C	0.02	-0.11	-0.09	0.05	0.09	-0.51	1				
Clay	-0.99*	-0.95*	0.96*	0.97*	-0.95*	-0.01	0.07	1			
pH	0.76*	0.72*	-0.79*	-0.73*	0.74*	-0.51	0.40	-0.71	1		
D_{50}	0.93*	0.75*	0.95*	-0.96*	0.97*	0.01	-0.05	-0.89*	0.59	1	
C_u	0.59	0.67	-0.58	-0.54	0.53	0.24	-0.18	-0.59	0.61	0.47	1

* Correlation is significant for $p < 0.05$ (2-tailed).

Dispersion coefficient as affected by bulk density and clay content

Solute dispersion coefficient, D, was mostly independent of soil bulk density, ρ, providing insignificant relationship between them (r = 0.02 – 0.17). Several contrasting results were, however, reported regarding the role of ρ on D: Li et al. (2009) observed power law relation between D and ρ, Bromly et al. (2007)

observed significant negative correlation between them, while Tabarzad et al. (2011) reported a decrease in *D* in clay loam soils compared to sandy loam and silt loam, implying a linear relation between *D* and ρ. The later observation is similar to our observation. Okada et al. (2014), on the other hand, found positive correlation between *D* and clay content in no till samples; they did not observe such relation in conventional tillage samples. As mentioned before that because of closer textural classes of the soils under investigation, the bulk density variation was relatively small (1.29 to 1.40 g cm^{-3}, Table 3). But, using soils with large textural variation and hence with a wide bulk density range would probably reveal the complete role of ρ on *D*.

Dispersivity as affected by clay content and median grain diameter

Figure 1 illustrates that dispersivity of the reactive solutes, λ, is strongly and significantly ($p<0.05$) correlated with clay content of the soils (r = 0.91 – 0.98) following power law; for non-reactive $CaCl_2$, the correlation (r = 0.37) is insignificant. Such correlation between λ and %clay reveals that soil clay can be a promising predictor of solute dispersivity. This proposition is also substantiated by Bromly et al. (2007) who reported clay content as the most important controlling factor of λ. Soil bulk density plays only insignificant role on λ. Figure 2 depicts power law decrease of λ with the increase in median grain diameter (D_{50}) of the soils except for $CaCl_2$. Similar to Xu and Eckstein (1997), the effect of D_{50} on λ gradually decreased in relatively heterogeneous materials ($C_u>2$). The correlation (r = 0.88–0.97) between λ and D_{50} was significant ($p<0.05$), which exposed that D_{50} could be an important predictor of solute dispersivity. Dispersivity also decreased linearly with the increase in pore-size distribution index, *n* (Figure 3). The significant correlations between λ and *n* (r = 0.89–0.99) implied that *n* could also be a potential predictor of λ. It is noted that since organic carbon improves soil aggregation and structure, the relationship between dispersivity and soil properties might become obscured by perturbations due to its presence in the soils. However, the organic carbon contents in the soils under investigation being low (0.37–0.84) might not cause considerable perturbations in the observed results.

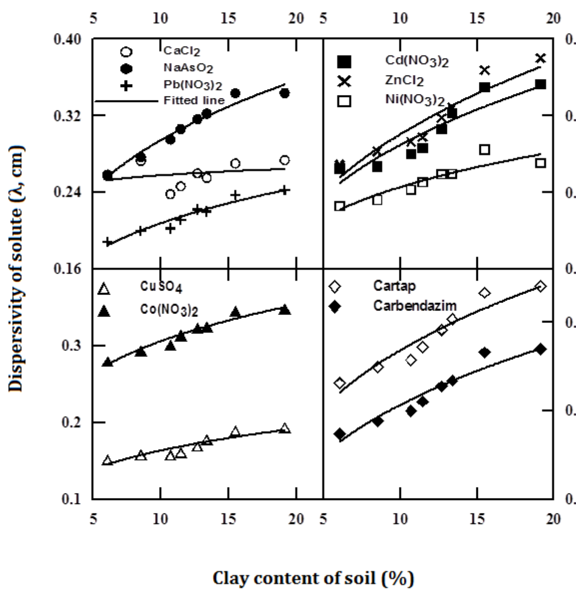

Figure 1. Effects of clay content on the dispersivity of different solutes through different soils at average water flux of 0.32 cm h^{-1}.

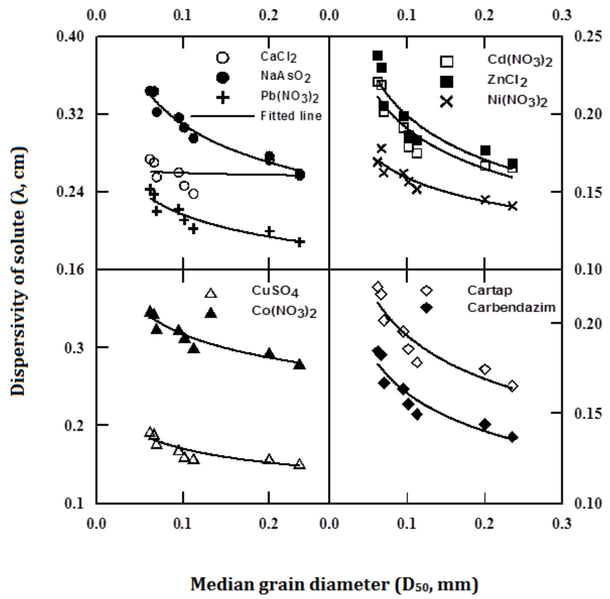

Figure 2. Relationship between dispersivities (λ, cm) and median grain diameters (D_{50}) of different textured soils for different solutes at average water flux of 0.32 cm h^{-1}.

Peclet number and retardation factor as affected by soil properties

Pore-size distribution index, *n*, strongly influenced *P*, which increased linearly with the increase in *n* (Figure 4). The significant correlations between *P* and *n* (r = 0.82–0.99) implied that *n* could be a reliable predictor of *P*. The clay content of the soils, by enhancing solute adsorption in the soils, considerably augmented the retardation factors. Figure 5 illustrates the increase in *R* with the increase in %clay content following power law with significant correlation (r=0.92–0.98). Calcium chloride is an inert solute having an ideal retardation factor of unity.

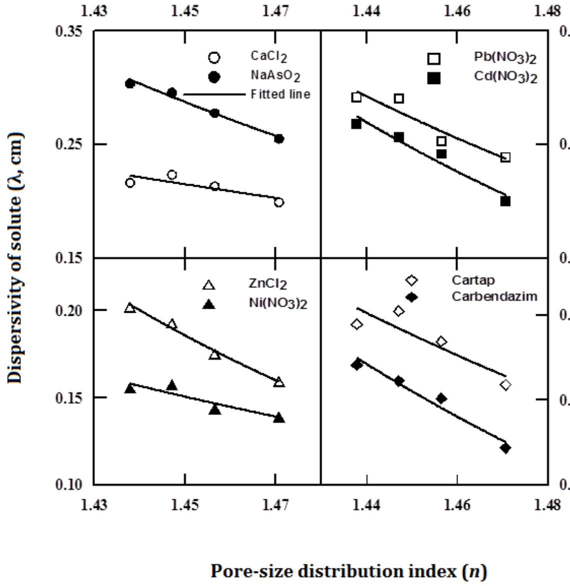

Figure 3. Decrease in dispersivity (λ) of different solutes in soils due to increase pore size distribution index (n) after treatment with wastewater at average water flux of 0.33 cm h^{-1}

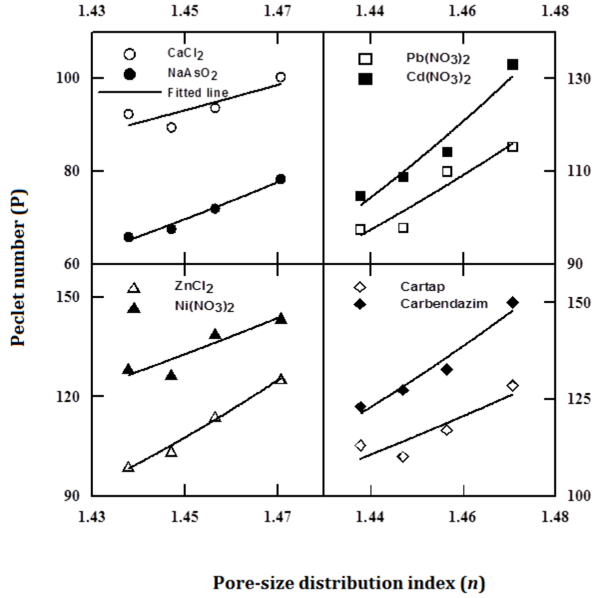

Figure 4. Variation of Peclet number (P) with pore size distribution index (n) for different soils treated with fresh water and wastewater at average water flux of 0.33 cm h^{-1}

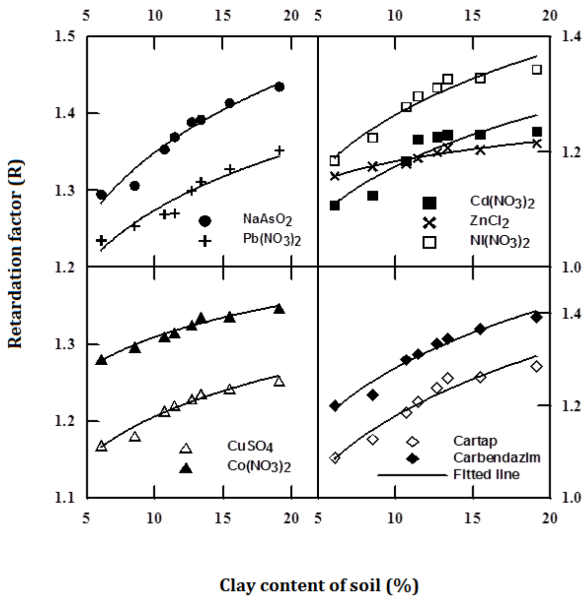

Figure 5. Variation of retardation factor (R) with the clay content for different solutes through different textured soils at average water flux of 0.32 cm h^{-1}

Effect of pH on solute-transport parameters

Soil pH contributed positively to velocity of solute, V, dispersion coefficient, D, and Peclet number, P. The correlations of V and P with pH were significant for the solute under investigation except for $CaCl_2$ in case of P. But, the correlation of D with pH was significant only for As, Pb and Co. The correlation of dispersivity, λ, and retardation factor, R, with soil pH was negative; the correlation of λ with pH was significant except for $CaCl_2$. Soil pH is one of the most important parameters affecting adsorption and ion-exchange properties of clay minerals. It partly determines the degree of surface charge on colloidal-sized soil particles. At high pH, negatively charged surfaces develop, while at low pH, positively charged surfaces occur. Consequently, the tendency for sorption of anions or cations is dependent on soil-water pH. Soil pH also controls the accumulation, mobility and bio-availability of heavy metals and pesticides in soils. A decrease in pH elevates adsorption capacity of soils by which accumulation of heavy metals or pesticides is enhanced. The soils at Satkhira and Comilla with relatively low pH (6.85 and 6.32; Table 3) were characterized by higher level of adsorption than the other soils; the higher adsorption was manifested by higher values of the solute retardation factors in these soils. The adsorption of metals on the soils was high at pH below 7, but it dropped considerably with the increase in pH above 7. Consequently, soil pH (>7.0 for six soils) contributed positively to the velocity of the solutes. As pH increased, the portion of positively charged surface sites on soil particles decreased with a consequent increased repulsion of anionic solute species and reduction of adsorption. Under this condition, adsorption of metals does not occur by electrostatic interaction, but can occur by specific chemical interaction between the negatively charged soil surface and the solute ions (Jain et al., 1999).

Effects of organic carbon on solute-transport parameters

Organic carbon, C, in the soils improved structure of the repacked soils by enhancing soil aggregation, which enhanced solute movement through the soils. Consequently, velocity of the solutes, *V*, increased, to some extent, with the increase in C; the correlation between *V* and C was however insignificant (r = 0.013–0.048). The solute dispersion coefficient, *D*, and dispersivity, λ, were negatively and insignificantly correlated with C. This result agreed well with Hussein (2009), who reported smaller λ in well-structured soils than in weakly structured soils. In the soils under investigation, the more C-containing soils having more stable structures than the less C-containing soils provided smaller λ values. Our result was also very similar to that of Koestel et al. (2012), who observed no correlation between organic carbon content and dispersivity; in our case, the r value was -0.034 to 0.234.

Adsorption of solutes with soil minerals that depends on the type of solutes, and clay and organic matter contents of the soils govern solute retardation factor, *R*. Soil organic matter, due to its extensive surface area (Arthur et al., 2015; Jensen et al., 2015), surface properties and functional group, can serve as a buffer, an ion exchanger, a surfactant, a chelating agent and a general sorbent. All these properties of the organic matter played important role in the attenuation of the solutes in the soils. It is noted that the metal adsorption in the soils was related to soil organic matter content only at low metal loadings (Gao et al., 1997). Clay content of the soils played a more prominent role in accumulating heavy metals and pesticides in the soils. The relative importance of organic matter and clay in the adsorption of solutes in a soil depends on the ratio of clay content to organic carbon content (RCO) of the soil.

Conclusion

The dispersivity, λ, of one metalloid compound ($NaAsO_2$), six heavy metal compounds ($Cd(NO_3)_2$, $Pb(NO_3)_2$, $Ni(NO_3)_2$, $ZnCl_2$, $CuSO_4$ and $Co(NO_3)_2$) and two pesticides (cartap and carbendazim) in eight agricultural soils of Bangladesh was significantly ($p < 0.05$) and positively correlated with clay content (r = 0.91–0.98) but negatively correlated (r = 0.88–0.97) with median grain diameter of the soils; both functional relations were governed by power law. Solute retardation factor, *R*, also exhibited significant positive correlation (r = 0.92–0.98) with clay content following power law variation. Column Peclet number, *P*, and solute velocity, *V*, had insignificant negative correlation with soil bulk density, ρ, while dispersion coefficient, *D*, and λ were weakly and positively correlated with ρ. An increasing pore-size distribution index, *n*, proportionately reduced λ but augmented *P* with corresponding correlation range of r = 0.89 to 0.99 and r = 0.82 to 0.99; the correlation was significant ($p<0.05$) in both cases. *V* and *P* were positively and significantly correlated with soil pH, while *R* and λ were negatively correlated with soil pH; the correlation of λ with pH was significant. Thus, the clay content, median grain diameter, pore-size distribution index, bulk density, organic carbon content and pH of the soils are the major factors that govern solute-transport parameters, mostly significantly, through the soils. The significant functional relations between the solute-transport parameters and governing soil properties demonstrate strong prospects of predicting solute-transport parameters from basic soil properties. The results described herein can thus serve as a dataset of transport experiments to develop more general pedo-transfer functions for solute-transport parameters that can significantly enhance prediction of pollution transport through soils.

References

Arora, K.R., 2000. Soil Mechanics and Foundation Engineering (Geotechnical Engineering). Standard Publishers, 5th Edition, 953p.

Arthur, E., Tuller, M., Moldrup, P., Jensen, D.K., De Jonge, L.W., 2015. Prediction of clay content from water vapour sorption isotherms considering hysteresis and soil organic matter content. *European Journal of Soil Science* 66(1): 206–217.

BARC (Bangladesh Agricultural Research Council), 2008. National Agricultural Technology Project (NATP), Bangladesh. Phase-1 (IDA Credit # 4386).

Bromly M., Hinz, C., Aylmore, L.A.G., 2007. Relation of dispersivity to properties of homogeneous saturated repacked soil columns. *European Journal of Soil Science* 58(1): 293–301.

BS 1377, 1990. Methods of test for soils for civil engineering purposes. Classification Tests. Parts 2 and 5. BS EN ISO 17892-5:2017.

de Jonge, L.W., Moldrup, P., Schjønning, P., 2009. Soil infrastructure, interfaces & translocation processes in inner space ("Soil-it-is"): towards a road map for the constraints and crossroads of soil architecture and biophysical processes. *Hydrology and Earth System Sciences* 13(8): 1485–1502.

Filipović, V., Ondrašek, G., Filipović, L., 2016. Modelling water dynamics, transport processes and biogeochemical reactions in soil vadose zone. In: Groundwater - Contaminant and Resource Management. Javaid, M.S. (Ed.). InTech. pp. 133-167.

Gao, S., Walker, R.A., Dahlgren, W.J., Bold, J., 1997. Simultaneous sorption of Cd, Cu, Ni, Zn, Pb, and Cr on soils treated with sewage sludge supernatant. *Water, Air & Soil Pollution* 93(1-4): 331–345.

Guber, A., Pachepsky, Ya., Shein, E., Rawls, W.J., 2004. Soil aggregates and water retention. In: Development of Pedotransfer Functions in Soil Hydrology. Pachepsky, Y., Rawls, W.J. (Eds.). Elsevier, Amsterdam, The Netherlands. pp.143-152.

Hussein M.F., 2009. BTC solute-transport parameters for three sediments. 4th Conference on recent technologies in Agriculture, 3 November 2009. Cairo, Egypt.

Islam, M.R., Islam, S., Jahiruddin, M., Islam, M.A., 2004. Effects of irrigation water arsenic in the rice-rice cropping system. *Journal of Biological Sciences* 4(4): 542–546.

Jackson, M.L., 1962. Soil Chemical Analysis. Prentice Hall, Inc. Englewood Chiffs, New York, USA 498p.

Jain, A., Raven, K.P., Loeppert, R.H., 1999. Arsenite and arsenate adsorption on ferrihydrite: Surface charge reduction and net OH- release stoichiometry. *Environmental Science & Technology* 33(8): 1179–1184.

Jensen, D.K., Tuller, M., de Jonge, L.W., Arthur, E., Moldrup, P., 2015. A New two-stage approach to predicting the soil water characteristic from saturation to oven-dryness. *Journal of Hydrology* 521: 498–507.

Karup, D., Moldrup, P., Paradelo, M., Katuwal, S., Norgaard, T., Greve, M.H., de Jonge, L.W., 2016. Water and solute transport in agricultural soils predicted by volumetric clay and silt contents. *Journal of Contaminant Hydrology* 192: 194–202.

Koestel, J.K., Moeys, J., Jarvis, N.J., 2012. Meta-analysis of the effects of soil properties, site factors and experimental conditions on solute transport. *Hydrology and Earth System Sciences* 16(6): 1647–1665.

Koestel, J.K., Norgaard, T., Luong, N.M., Vendelboe, A.L., Moldrup, P., Jarvis, N.J., Lamandé, M., Iversen, B.V., de Jonge. L.W., 2013. Links between soil properties and steady-state solute transport through cultivated topsoil at the field scale. *Water Resources Research* 49(2): 790–807.

Mojid, M.A., Rose, D.A., Wyseure, G.C.L., 2004. A transfer-function method for analysing breakthrough data in the time domain of the transport process. *European Journal of Soil Science* 55(4): 699–711.

Mojid, M.A., Hossain, A.B.M.Z., Cappuyns, V., Wyseure, G., 2016. Transport characteristics of heavy metals, metalloids and pesticides through major agricultural soils of Bangladesh as determined by TDR. *Soil Research* 54(8): 970–984.

Mojid, M.A., Rose, D.A., Wyseure, G.C.L., 2006. Analysis of partial breakthrough data by a transfer-function method. *Soil Research* 44(2): 175–182.

Mojid, M.A., Vereecken, H. 2005a. Modelling velocity and retardation factor of a nonlinearly sorbing solute plume. Soil Research 43(6): 735–743.

Mojid, M.A., Vereecken, H., 2005b. On the physical meaning of retardation factor and velocity of a nonlinearly sorbing solute. *Journal of Hydrology* 302(1-4): 127–136.

Montoya, J.C., Costa, J.L., Liedl, R., Bedmar, F., Daniel, P., 2006. Effects of soil type and tillage practice on atrazine transport through intact soil cores. *Geoderma* 137(1-2): 161–173.

Mosaddeghi M.R., Khatar, M., Dexter, A.R., Mahboubi, A.A., 2008. Water characteristic curve and physical quality of soil as influenced by water salinity and sodicity. 2nd International Salinity Forum Salinity, water and society–global issues, local action, Adelaide Convention Centre Adelaide, 31 March – 3 April 2008, South Australia.

Muchuweti, A., Birkett, J.W., Chinyanga, E., Zvauya, R., Scrimshaw, M.D., Lester, J.N., 2006. Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health. *Agriculture, Ecosystems & Environment* 112(1): 41–48.

Nemeth-Konda, L., Fuleky, G., Morovjan, G., Csokan, P., 2002. Sorption behaviour of acetochlor, atrazine, carbendazim, diazinon, imidacloprid and isoproturon on Hungarian agricultural soil. *Chemosphere* 48(5): 545–552.

Norgaard, T., Moldrup, P., Olsen, P., Vendelboe, A.L., Iversen, B.V., Greve, M.H., Kjaer, de Jonge, L.W., 2013. Comparative mapping of soil physical–chemical and structural parameters at field scale to ıdentify zones of enhanced leaching risk. *Journal of Environmental Quality* 42(1): 271–283.

Okada, E., Costa, J.L., Bedmar, F., Barbagelata, P., Irizar, A., Rampoldi, E.A., 2014. Effect of conventional and no-till practices on solute transport in long term field trials. *Soil and Tillage Research* 142: 8–14.

Page, A.L., Miller, R.H., Keeney, D.R., Baker, D.E., Ellis, R., Rhoades, J.D., 1982. Methods of Soil Analysis. eds (No. 631.41 MET 9-2 1982. CIMMYT.).

Pugliese, L., Straface, S., Trujillo, B.M., Poulsen, T.G., 2015. Relating non-equilibrium solute transport and porous media physical characteristics. *Water, Air & Soil Pollution* 226, 59.

Raymundo-Raymundo, E., Nikolskii, Y.N., Guber, A.K., Landeros-Sanchez, C., 2012. Adequacy of transport parameters obtained in soil column experiments for selected chemicals. *Eurasian Soil Science* 45(7): 675–683.

Stavi, I., Ungar, E.D., Lavee, H., Sarah, P., 2011. Soil aggregate fraction 1–5 mm: An indicator for soil quality in rangelands. *Journal of Arid Environments* 75(11): 1050–1055.

Tabarzad, A., Sepaskhah, A.R., Farnoud, T., 2011. Determination of chemical transport properties for different textures of undisturbed soils. *Archives of Agronomy and Soil Science* 57(8): 915–930.

Taran, F., Nazemi, A.H., Sadraddini, A.A., Dinpazhuh, Y., 2015. Investigation of conservative and non-conservative solute transport in soil and comparison of three adsorption models using HYDRUS-2D. *Journal of Materials and Environmental Science* 7(6): 2082–2093.

Thawornchaisit, U., Polprasert, C., 2009. Evaluation of phosphate fertilizers for the stabilization of cadmium in highly contaminated soils. *Journal of Hazardous Materials* 165(1-3): 1109–1113.

van Genuchten, M.Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* 44(5): 892–898.

Vogel, H.J., Roth, K., 2003. Moving through scales of flow and transport in soil. *Journal of Hydrology* 272(1–4): 95–106.

Ward, A.L., Elrick, D.E., Kachanoski, R.G., 1994. Laboratory measurements of solute transport using time domain reflectometry. *Soil Science Society of America Journal* 58(4): 1031–1039.

Xu, M., Eckstein, Y., 1997. Statistical analysis of the relationships between dispersivity and other physical properties of porous media. *Hydrogeology Journal* 5(4): 4–20.

Li, Z.M., Zhou, Q., Wang, H., Lu, X., 2009. Influence of bulk density on the characteristic of water solute transport in red soil. *Journal of Soil and Water Conservation* 23: 101–103.

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Assessing soil quality issues for crop production function based on farmers' perception: An experience from Itapaji Watershed in Southwestern Nigeria

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Abstract

To successfully manage soil quality for sustainable crop production, there is need to identify issues affecting it. These are problems facing the capacity of soil to perform its functions and thus reducing its productivity. In addition, the similarities and differences between farmers' perception of soil quality issues and that of soil scientist are very pertinent. This study, which was carried out at Itapaji watershed in Ikole local government area of Ekiti state, aims at identifying soil quality issues using participatory approach and conventional method. Diagnostic survey was carried out using participatory approach involving farmers' judgement using questionaires. . The resultswere analysed to identify the soil quality issues from farmers' perspectives. For conventional method, major soil types were identified and soil quality issues were identified using soil management assessment framework. The relationship between the soil issues from farmers' interview and soil analysis were established by correlation analysis at α0.05. Soil quality issues identified by farmers are soil compaction, low soil fertility, termite infestation, crop wilt, hardpan formation, erosion, poor drainage and land use intensification. Low soil fertility is the most prominent with about 36.2 % impact on crop production in the watershed. Conventionally from soil analysis, CEC and organic matter are low which indicate low soil fertility; there is high acidity, shallow soil depth with presence of plinthite and hard pan. The farmers' perception of soil quality and that of soil scientists correlate well (r = 0.70). There is therefore need for promotion of farmers' participation by providing a forum for articulation of their opinions in mitigating low soil quality.

Keywords: Soil quality issues, participatory, conventional, watershed.

Introduction

The persistent imbalance between population and food growth rate is a serious challenge facing most nations of Sub Saharan Africa (SSA); a good example is Nigeria (Rosegrant et al. 2001; USDA, 2006). This has made attainment of food sufficiency difficult in these nations. Nigeria by virtue of its prominent position as the most populous nation in the region is currently depending on food importation and this can only be eradicated by increase in domestic food production. Previous attempts to increase food production in Nigeria were tailored mainly to expansion of areas under arable cultivation rather than increasing the productivity of the arable lands. This has however led to the decline in Nigerian agricultural land area, degradation and desertification (Brown, 2005). Land use intensification is a way of increasing food

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production without extending the quantity of land under cultivation. However, this has to be accompanied with the use of modern inputs and sustainable farming practices otherwise it could also lead to continuous depletion of soil fertility, decline in productivity, loss of soil structure, soil erosion and general land degradation.

Soil is a dynamic resource that provides several essential functions to support plant, animal and human life. Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Enhanced soil quality will reduce soil erosion, improve water and nutrient use efficiencies, and ensure that the soil is sustained for future use. Assessing soil quality can be likened to a medical examination of humans in which measurements of certain issues are taken. These issues are those that can affect the capacity of soils to function effectively and efficiently at present and in the future (Doran and Parkin, 1994). There are two major approaches to identifying soil quality issues: The farmers' perception and soil scientist perception. To successfully monitor and manage soil quality for sustainable crop production, there is need to identify such issues.

Itapaji watershed, located in intensive farming communities of Ekiti State, is one of the many watersheds in Nigeria with perennial water flows. The area is endowed with enormous potential for irrigation farming which makes high level of intensification possible.

This study aims at identifying soil issues in Itapaji watershed in southwestern Nigeria using participatory approach and conventional methods so as to enhance good management while intensifying land use for increased productivity.

Material and Methods

Study site

The study was carried out in Itapaji watershed in Ikole local government area (Figure 1). Ikole local government area is in Ekiti State (7.40–8.00 N and 5.20 to 5.40 E). The Itapaji watershed is in the Benin-Owena hydrological basin with agro- ecology varying from humid forest to derived savannah. The watershed is primarily agricultural and is majorly drained by the Itapaji River. The southern part of the watershed is forest ecology with cash crops and primary forest while the northern part is derived savannah with arable crops cultivation being the major occupation of the farmers. The drainage network in the watershed is not dense; aside the Itapaji river, the basins of the other rivers like Arinkin Ako, Oke Ako, Ayan and other streams have high potential for dry season agricultural activities.

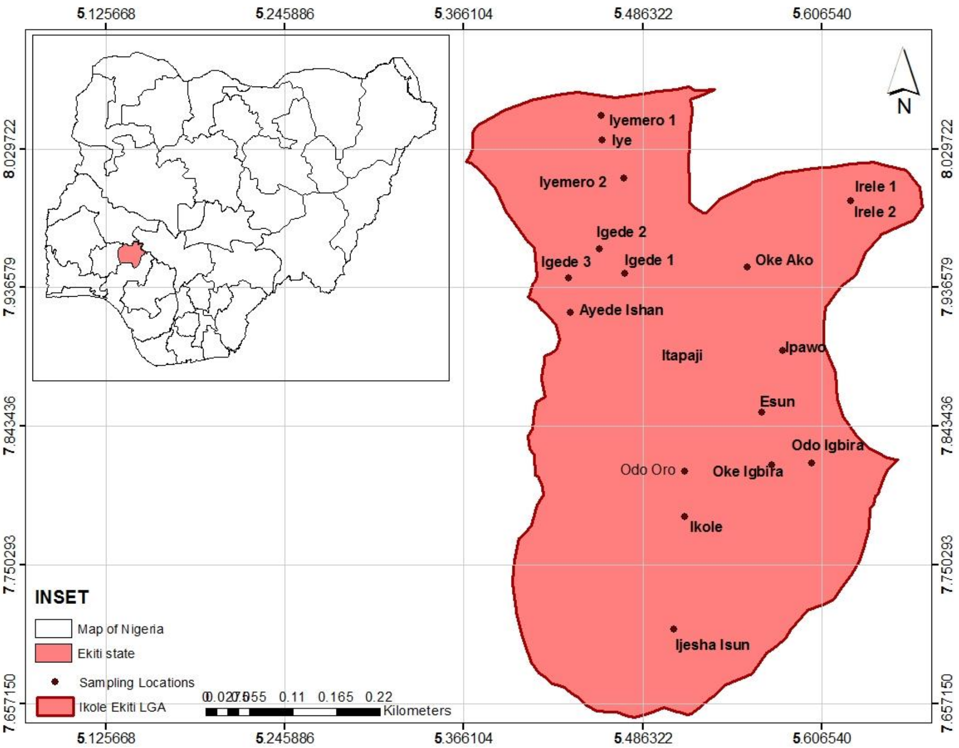

Figure 1. Map of Ikole Local Government showing the study sites

The temperature across Itapaji watershed ranged between 28.8 ^{0}C – 35.1^{0}C while minimum temperature of 19.5 ^{0}C is possible during the dry harmattan season. Average rainfall within the watershed is 1234±74.7mm with a bi-modal peak observed in the month of June and September. Reference evapotranspiration (ETo) within the watershed is highest in March (5.11mm/day) and lowest in August (3.41mm/day) (Ayoade, 2002; NIMET, 2007). The soils are formed on Crystalline Basement Complex rocks with granite gneiss as the dominant parent rock. There is a very strong geological and geomorphological influence on the pattern of soil distribution in the study sites. Vegetation also contributes to the pattern of soil development in the area. The farming system is mainly yam-based. Other crops include African yam bean, pepper, maize, sorghum, tomatoes, cowpea, cassava, leafy vegetable and groundnut. The most prominent crop combination in the watershed is maize/cassava/yam.

Field work

A farm survey was conducted in farming communities located within the watershed. A total of 200 farmers were selected through multi-stage sampling technique from Ikole Local Government Areas (LGA) identified as the location of the watershed. The list of villages located along the course of the main water bodies were obtained from the Agricultural Development Programmes in the state while the list of farmers in each of the villages were obtained from the village head and contact farmers. Ten villages were randomly selected from the list of villages located along the main water bodies in the states. Twenty (20) farmers were randomly selected from the list of farmers in each of the villages. Personal interview was conducted with the aid of structured interview schedule designed to elicit information on the soil quality issues being faced by farmers. Also, information were obtained on crop production practices, crop combination, land use pattern, soil fertility maintenance and conservation practices, water bodies available for farm production and their uses, water management practices, crop yield, production constraints and the training needs. These were analysed to identify the soil quality issues from the farmers' perspectives.

For the conventional method, major soil types in the watershed were identified through site and soil characterization. Free survey method was employed for mapping of the area. As movements were made along the road and footpaths, incursions were also made into the land to examine the soil for identification of soil types, characterization, classification and soil type boundary placement. Changes in vegetation cover, land use, physiography, soil surface form and stoniness, micro-relief, etc. were noted and also used as clues to arrive at changes in soil types and establishment of soil boundaries. Placements of boundaries were further achieved by grouping similar auger examination points and modal soil profile pits were dug based on the most representative auger examination points for each of the identified soil types. On the whole, eight (8) major soil types were identified. All necessary environmental information relating to the site characteristics and the soil morphology were recorded. The soil profiles were described according to the FAO guideline (FAO, 2014) and soil samples were collected. Soil samples collected were analyzed in the laboratory, classified using Murdoch et al. (1976) and Soil Survey Staff (2014); and soil quality issues (as well as their impacts on crop production) were identified by modifying the approach of Andrews et al. (2004) known as soil management assessment framework. This is based on critical values of each parameter and the level of importance of each parameter (relative weight) to crop production. Any indicator that is not able to meet the critical value is scored less and thus becomes soil issue affecting crop production. The level of importance (i.e. the relative weight) of the indicator indicate the level of impact of the issue on crop production (Table 1 and 2). Digital soil map of the site was produced in GIS environment.

The relationship between the soil issues from farmers' interview and soil analysis were established by rank correlation analysis at $\alpha_{0.05}$.

Table 1. Soil quality ındicators, their critical values/range and their relative weight

Indicator	Critical Value/Range	Relative Weight
Available Phosphorus	10 – 15mg/kg	0.085
Total Nitrogen	1.6 – 2.4g/kg	0.10
Available Water Capacity	8 – 20 %	0.08
Organic Carbon	10 – 20g/kg	0.15
pH(H_2O)	5.5 – 6.5	0.085
Cation Exchange Capacity	6 – 8 cmol/kg	0.145
Exchangeable Sodium Percentage	13 %	0.065
Bulk Density	1.3 – 1.5g/cm^3	0.112
Total Porosity	0.15 – 0.18m^3/m^3	0.062
Texture	Sandy clay loam	0.05
Effective Soil Depth	100 – 150 cm	0.066

Table 2. Soil quality indicators values and their scoring

Indicators	Average Actual Values	Scoring (%)	Critical Value
Availaple Phosphorus (mg/kg)	13.16	60	10 – 15
Organic Carbon (g/kg)	14.10	60	10 – 20
Total Nitrogen (g/kg)	1.00	40	1.6 – 2.4
pH	6.83	40	5.5 – 6.5
Exchangeable Sodium Percentage	13.49	40	13
Cation Exchange capacity (cmol/kg)	4.46	40	6 – 8
Bulk Density (g/cm^3)	1.29	50	1.3 – 1.5
Total Porosity (m^3/m^3)	0.47	40	0.15 – 0.18
Available Water Capacity (%)	14.40	50	8 – 20
Texture	Sandy Loam	50	Sandy clay loam
Effective Soil Depth (cm)	119	50	100 - 150

Results

The soil types encountered at the watershed are shown on Figure 2. The soils are Egbeda series (Typic Kandiudalf), Eruwa series (Typic Paleudalf), Fashola series (Oxic Haplustept), Matako series (Udic Kanhapludalf), Ofiki series (Arenic Paleudalf), Olorunda series (Dystric Eutrudept), Shante series (Arenic Eutrudept) and Temidire series (Oxic Paleudalf). Table 3 shows the chemical properties of the soils encountered at the watershed. The soils are moderately acidic with pH in water and KCl ranging from 4.21 to 6.88 and 5.31 to 7.14 respectively. The basic cations are adequate and this is reflected in the high values of base saturation indicating that the exchange sites are adequately occupied by basic cations. Organic carbon is very low and decreases down the profile in all the soils encountered. Total Nitrogen is also very low and follows the same trend as organic carbon. Cation Exchange Capacity (CEC) is also very low indicating low rate of ion exchange. Available phosphorus is low to moderate. Exchangeable sodium percentage (ESP) is moderate and tending towards high indicating that the soils may be tending towards sodicity. The physical properties of the soils encountered are shown on Table 3. The soils are sandy in texture with clay fraction increasing down the profiles. Bulk density is high in some of the soil profiles (1.56 to 1.80 mg/m^3) which is an indication of soil compaction. Available water capacity and porosity are also low.

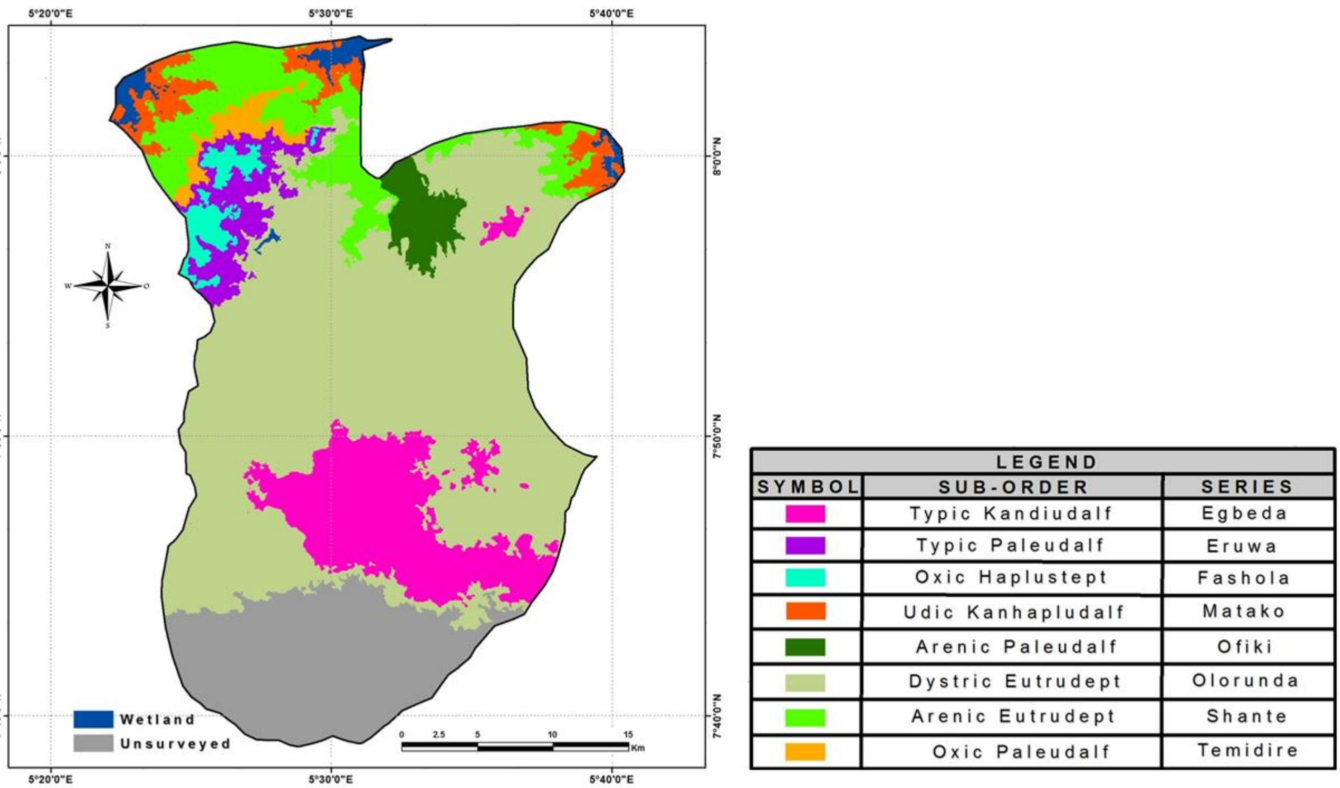

Figure 2. Soil Map of Itapaji Watershed, Nigeria

Table 3. Chemical and Physical properties of the soils encountered in the area

Horizon Design	Depth (cm)	Exchangeable bases (cmol/kg) Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	pH (H_2O)	pH (KCl)	BS (%)	ESP (%)	CEC	OC (g/kg)	T.N (g/kg)	CEC Clay	Av.P (mg/kg)
Olorunda Series (Dystric Eutrudept)															
A	0-17	0.37	2.31	0.24	0.53	2.03	5.64	6.06	62.96	6.66	5.48	13.0	1.10	29.5	10.04
B1	17-31	0.16	1.86	0.14	0.46	0.13	5.54	5.53	95.14	5.81	2.76	5.0	0.45	12.7	11.32
B2	31-54	0.14	1.65	0.14	0.50	0.15	5.81	5.26	94.28	5.25	2.57	8.0	0.78	15.1	14.43
B31	54-105	0.11	1.80	0.18	0.43	0.15	5.42	5.31	94.55	3.95	2.66	5.0	0.40	11.0	0.73
B32	105-140	0.09	1.77	0.18	0.46	0.12	5.02	5.85	95.50	3.44	2.62	4.0	3.80	11.0	11.96
Eruwa Series (Typic Paleudalf)															
A	0-21	0.46	2.56	0.48	0.63	0.09	5.78	6.23	97.66	10.9	4.23	15.5	1.50	19.2	68.84
B1	21-43	0.12	2.01	0.36	0.53	0.10	5.06	6.13	96.68	3.83	3.13	10.7	0.90	14.9	26.48
B2	43-66	0.07	1.42	0.36	0.53	0.11	4.97	5.95	95.46	2.61	2.49	16.1	1.50	11.7	13.79
B3	66-94	0.12	1.97	0.46	0.59	0.12	4.87	5.86	96.42	3.52	3.27	26.1	2.50	16.7	11.05
B4	94-148	0.15	2.17	0.38	0.56	0.09	4.21	6.29	97.15	4.46	3.36	4.1	0.38	12.0	8.58
Fashola Series (Oxic Haplustept)															
A	0-15	0.31	2.60	0.32	0.56	0.09	5.87	6.35	97.61	7.85	3.88	12.2	1.20	24.6	10.32
B1	15-40	0.03	1.47	0.20	0.50	0.06	6.03	6.88	97.08	1.33	2.26	3.8	0.35	23.3	8.34
B2	>40	0.04	1.87	0.69	0.66	0.08	5.78	6.45	97.33	1.05	3.34	3.4	0.30	24.0	19.63
Matako Series (Udic Kanhapludalf)															
A	0-19	0.44	2.54	0.36	0.59	0.09	6.13	6.31	97.65	10.90	4.04	14.1	1.40	49.2	48.98
Bt	19-50	0.07	1.68	0.30	0.53	0.13	5.97	5.62	95.23	2.41	2.70	5.8	0.45	23.9	9.04
B1	50-80	0.02	0.83	0.24	0.50	0.07	4.97	6.74	95.62	1.20	1.67	3.7	0.34	14.7	6.85
B2	>80	0.05	1.40	0.26	0.50	0.08	4.85	6.41	96.12	2.18	2.29	3.4	0.30	21.4	9.04
Shante Series (Arenic Eutrudept)															
A	0-13	0.69	2.65	0.48	0.59	0.13	6.57	5.53	97.06	15.20	4.55	13.8	1.35	45.1	61.91
B1	13-42	0.63	2.58	0.36	0.53	0.08	6.72	6.57	98.04	15.10	4.18	9.8	0.95	32.2	29.49
B2	42-71	0.06	1.92	0.28	0.50	0.11	6.71	6.07	96.26	1.92	2.86	2.3	0.20	25.3	9.95
B3	71-135	0.08	1.39	0.36	0.53	0.10	6.58	6.11	95.73	3.05	2.46	4.1	0.38	136.6	10.59
B4	>135	0.11	1.48	0.30	0.46	0.09	6.88	6.27	96.03	4.29	2.45	0.8	0.20	52.0	19.45
Temidire Series (Oxic Paleudalf)															
A	0-19	0.33	2.44	0.30	0.59	0.11	5.96	5.86	96.91	8.59	3.78	12.2	1.20	37.8	11.61
B1	19-43	0.01	0.53	0.26	0.46	0.11	4.59	5.88	91.59	0.72	1.38	6.1	0.58	11.9	9.95
B2	43-84	0.02	0.51	0.26	0.43	0.09	5.08	6.21	92.49	1.14	1.32	5.6	0.52	18.8	6.31
B3	84-109	0.03	0.59	0.20	0.40	0.10	5.82	6.15	92.18	2.28	1.32	5.7	0.50	19.1	6.66
B4	>109	0.04	0.94	0.18	0.40	0.09	5.98	6.34	94.36	2.12	1.65	2.4	0.20	22.0	6.03
Egbeda Series (Typic Kandiudalf)															
A	0-21	0.82	2.65	0.51	0.53	0.09	6.12	6.22	97.85	17.70	4.60	23.8	0.24	28.7	58.52
AB	21-47	0.40	2.22	0.26	0.40	0.12	5.87	5.67	96.24	11.70	3.41	10.5	1.00	60.9	44.01
Bt	47-65	0.44	2.35	0.32	0.43	0.13	5.91	5.56	96.41	11.80	3.67	19.8	1.96	20.2	25.56
B1	65-76	0.36	2.17	0.32	0.40	0.08	5.96	6.59	97.57	10.80	3.33	11.2	1.10	18.5	11.78
B2	76-113	0.27	2.11	0.26	0.40	0.08	5.81	6.45	97.18	8.65	3.12	5.1	0.48	16.6	10.13
B3	113-156	0.21	1.88	0.20	0.36	0.07	5.75	6.79	97.31	7.52	2.27	10.1	0.98	14.5	23.01
Ofiki Series (Arenic Eutrudept)															
A	0-15	0.94	2.82	0.75	0.56	0.08	6.42	6.67	98.48	18.30	5.14	33.6	2.90	25.7	7.94
B11	15-33	0.61	2.76	0.59	0.50	0.05	6.13	7.14	98.82	13.60	4.50	16.7	1.55	88.3	18.53
B12	33-61	0.63	2.76	0.51	0.43	0.06	6.04	6.93	98.54	14.40	4.39	17.7	1.60	78.3	18.53
B2	61-143	0.63	2.69	0.32	0.36	0.07	6.27	6.87	98.35	15.40	4.07	5.1	0.48	42.4	5.84

Conventionally, Most of the soil quality indicators assessed were scored below 50 % when their actual average values were compared with the critical values (Table 2). This is an indication their values are low and will result into overall low quality and this automatically makes them become issues that will affect crop productivity. Soil quality issues identified from the physical and chemical indicators of the soils assessed are low CEC, low organic matter, low soil fertility, high acidity, high bulk density, high rate of compaction, shallow soil depth with presence of plinthite and hard pan (Table 3). Out of all these, low soil fertility (which encompasses low available P, low Nitrogen and available water) has the greatest impact on crop production based on their relative importance (wieght) to crop production.

Soil quality issues identified by farmers in the watershed are also shown on Table 4. The issues include soil compaction by cattle overgrazing, low soil fertility, termite infestation, crop wilt, hardpan formation, erosion, poor drainage, flooding, decreased crop yield and high land use intensity. Among all these issues, low soil fertility is the most prominent with about 36.2% impact on crop production in the watershed. There is a high positive relationship (r=0.70) between farmers' perception of soil quality and the conventional method. This is an indication that the methods can be used interchangeably in the watershed.

Discussion

The soil, in addition to providing anchorage for plant roots, stores water and nutrients required for plant growth. Healthy soil is essential for the production of crops and perceptions of what constitute a good soil vary and depend on the requirement of individual crops or land use. While intensive agriculture can cause nutrient depletion and wide-scale soil erosion, over-application of fertilizers and pesticides leads to soil and water contamination. However, many farmers are choosing sustainable agricultural techniques such as conservation tillage, crop rotation and organic fertilizer application in order to protect this valuable soil resource.

Table 3. (continue)

Horizon Design	Depth (cm)	Particle size (g/kg)					Bulk density (mg/m³)	AWC	Total Porosity	Textural Class
		Gravel	CS	FS	Silt	Clay				
Olorunda Series (Dystric Eutrudept)										
A	0-17	133	614	180	20	186	1.50	0.155	0.39	SandyLoam
B1	17-31	154	633	130	20	217	1.49	0.185	0.35	SandyClayLoam
B2	31-54	500	620	170	40	170	1.53	0.159	0.32	SandyLoam
B31	54-105	529	449	180	130	241	1.62	0.165	0.31	SandyClayLoam
B32	105-140	375	221	340	200	239	1.65	0.166	0.34	SandyClayLoam
Eruwa Series (Typic Paleudalf)										
A	0-21	60	540	220	20	220	1.56	0.119	0.48	SandyClayLoam
B1	21-43	56	490	260	40	210	1.69	0.022	0.35	SandyClayLoam
B2	43-66	39	438	280	70	212	1.80	0.023	0.30	SandyClayLoam
B3	66-94	400	364	390	50	196	1.79	0.072	0.44	SandyLoam
B4	94-148	200	340	300	80	280		0.067	0.40	SandyClayLoam
Fashola Series (Oxic Haplustept)										
A	0-15		562	160	30	158	1.31	0.118	0.47	SandyLoam
B1	15-40	562	653	190	30	97	1.36	0.112	0.39	LoamySand
B2	>40	154	561	240	60	139		0.124	0.40	SandyLoam
Matako (Udic Kanhapludalf)										
A	0-19	72	778	120	20	82	1.40	0.118	0.42	Sand
Bt	19-50	200	737	120	30	113	1.42	0.114	0.39	LoamySand
B1	50-80	182	617	220	50	113	1.61	0.112	0.33	LoamySand
B2	>80	83	533	240	120	107		0.114	0.35	SandyLoam
Shante Series (Arenic Eutrudept)										
A	0-13		769	110	20	101	1.08	0.206	0.46	LoamySand
B1	13-42		710	150	10	130	1.37	0.145	0.45	LoamySand
B2	42-71	77	697	170	20	113	1.45	0.108	0.39	LoamySand
B3	71-135	36	642	260	80	18	1.48	0.115	0.37	Sand
B4	>135	39	678	235	40	47		0.143	0.42	Sand
Temidire Series (Oxic Paleudalf)										
A	0-19		740	150	10	100	1.27	0.123	0.40	LoamySand
B1	19-43	23	704	150	30	116	1.41	0.129	0.45	LoamySand
B2	43-84	13	655	215	60	70	1.51	0.116	0.33	LoamySand
B3	84-109	71	711	160	60	69	1.60	0.123	0.35	LoamySand
B4	>109	167	695	190	40	75	1.76	0.123	0.38	Sand
Egbeda Series (Typic Kandiudalf)										
A	0-21	231	590	240	10	160	1.13	0.129	0.50	SandyLoam
AB	21-47	286	409	400	135	56	1.59	0.073	0.37	LoamySand
Bt	47-65	643	277	161	380	182	1.80	0.063	0.33	Loam
B1	65-76	550	346	184	290	180	1.76	0.082	0.33	SandyLoam
B2	76-113	333	161	391	260	188	1.43	0.007	0.45	SandyLoam
B3	113-156	182	182	350	280	188	1.26	0.017	0.51	SandyLoam
Ofiki Series (Arenic Paleudalf)										
A	0-15	143	590	190	20	200	1.14	0.184	0.63	SandyLoam
B11	15-33	167	419	400	130	51	1.44	0.134	0.43	LoamySand
B12	33-61	111	474	360	110	56	1.53	0.167	0.38	LoamySand
B2	61-143	21	704	160	40	96	1.85	0.216	0.31	LoamySand

The essence of this study is to identify issues that can affect the capacity of soils to function effectively at present and in the future. Using the farmers' perception, the issues identified are compaction, erosion, low soil fertility as a result of low nutrient availability and retention, termite infestation, crop wilt, hardpan formation, poor drainage, flooding, high land use intensity without proper management and all these have resultant effect of decreased crop yield or low roductivity. According to Adeyolanu and Ogunkunle (2017), compaction, alkalinity, soil dryness, acidity, salinity/sodicity and low organic matter are six of the major soil problems affecting productivity. Similarly, NRCS (2005) identified erosion and compaction as two serious problems facing urban soil quality. According to them, erosion is accelerated when soil is disturbed or left bare and exposed to wind and/or water. Compaction occurs when soil particles are compressed, causing soil bulk density to increase and pore space for air and water are reduced. Apart from causing reduction in water intake and movement through the soil, compaction also limits root growth and the biological diversity of the soil. These problems are compounded with low soil organic matter content.

Table 4. Conventional and Farmers' identified soil quality issues and their impacts on crop production

Conventional Method		Participatory Method	
Soil quality issues	% impact on productivity	Soil quality issues	% impact on productivity
Low CEC	14.5	Over grazing	6.9
Low Organic matter	15.0	Gravelly Hardpan	6.9
High Acidity	8.5	Insect pests	8.6
High bulk density	11.2	Crop wilt	8.6
Compaction	11.2	Low Soil Fertility	36.2
Shallow depth	6.6	Termite Infestation	8.6
Low soil fertility	26.5	High Land use Intensity	17.8
Sodicity	6.5	Poor drainage, flood and erosion	6.4

Among the soil issues identified by farmers, low soil fertility is the most prominent with about 36.2 % impact on crop production in the watershed. For conventional method also, low soil fertility has major impact on crop production with low CEC and low organic matter content as the major cause. CEC and organic matter are indicators that are relevant to nutrient availability/retention process for crop production function in the soil. Therefore, with their low values, other soil quality indicators will be severely affected and crop productivity will be impaired. Soil organic matter plays key roles in soil function; determining soil nutrient status, water holding capacity and susceptibility of soil to degradation (Giller and Cadisch, 1997; Feller et al., 2001). Negassa (2001), Solomon et al. (2002) and Merrington et al. (2006) also reported that a change in organic matter content of the surface soil significantly influenced other key soil properties. In addition, soil organic matter may serve as a source or sink of atmospheric CO_2 and an increase in the soil carbon content is indicated by a higher microbial biomass and elevated respiration (Sparling et al., 2003). It is also the principal reserve of nutrients such as N in the soil and some tropical soils may contain large quantities of mineral N in the top 2m depth (Havlin et al., 2005). Chen et al. (1998) found that soil organic matter is a primary factor affecting topsoil bulk density for a range of cultivated soils. Increased soil organic carbon levels improved soil structure by decreasing bulk density, improving aggregate stability, pore size and air-filled pore space. In terms of biological indicators, any decline in soil structure is also frequently associated with decreases in microbial biomass and activity as a result of low organic matter (Neves et al., 2003).

With high intensity and crop combination that comprises of crops that are great nutrient miners (maize/cassava/yam), the soil fertility depletion is the expected consequence. High land-use intensity with crop combination devoid of legume in the rotation provides for no soil nutrient replenishment through, for instance, nitrogen fixation.

The high positive relationship (r=0.70) between farmers' perception of soil quality and the conventional method is an indication that the two methods can be used interchangeably in the watershed. In soil quality assessment, two major approaches (qualitative and quantitative) have been established. Qualitative approach makes use of descriptive indicators and is farmers-oriented while quantitative approach makes use of laboratory data. Also, high positive relationship has been established between the two approaches (Aikore, 2002; Adeyolanu and Ogunkunle, 2016). Those authors also submitted that the approaches of soil quality assessment can be used interchangeably depending on the level of information required from soil quality assessment and the soil function of interest. Therefore, if methods of soil quality assessment of farmers and scientists are used interchangeably, their perception of soil issues can also be used interchangeably since soil issues occur as a result of depletion or deterioration in the level of soil quality indicators.

Soil degradation is better prevented than 'cured', so there is need to be pro-active by assessing and monitoring soil quality before land use and management is imposed so as to have a reference point. Chen and Hseu (1997), submitted that the most effective way to maintain soil quality is to maintain high soil organic matter, or soil organic carbon pool in the soil. Planting of cover crops or green manuring is a way of improving organic matter in the soil. Cover crops usually provide a canopy for seasonal soil protection from erosion and improvement of soil fertility for the production of main crops. Leguminous cover crops have the additional benefit of fixing atmospheric nitrogen for the benefit of crop that follows (Ibewiro et al., 2000). Other benefits from cover crops include protection of the soil from water and wind erosion, improved soil tilth and suppression of soil-borne pathogens (Gugino et al., 2007). Are et al. (2011) also submitted that vegetative cover crop is necessary to protect the soil surface from raindrop impact, runoff, erosion and rapid desiccation. Another way of soil protection or organic matter build-up is by plantation crops in form of agroforestry where food crops are grown with permanent tree crops before the canopy is closed up. The tree crops naturally produce relatively large amount of above and below ground biomass, and because of their perennial nature, there is continuous addition of organic matter and biomass to the soil. Paudel et al. (2011) found out that perennial vegetation enhances soil organic matter accumulation, has minimum disturbance to the soil and has positive impact on the soil quality and ecosystem at large. To further support this, an experiment conducted to assess soil quality under intensive cultivation and tree orchards showed that soil quality indicators (organic carbon, enzymatic activities, microbial biomass, functional and bacteria diversity, electrical conductivity) were negatively impacted by intensive cultivation while tree orchards positively impacted the levels of these indicators (Bonanomi et al., 2011).

Traditional cropping system has been found to be effective in maintaining soil quality and needs to be emphasized in our farming systems. Due to the method of land preparation which encourages minimum tillage, observations have shown a reduced erosion incidence, improved soil structure, increase in microbial activities, improved organic matter content, as well as infiltration rate and reduced bulk density (Adesodun et al., 2007).

Conclusion

From this study, it was shown that crop production in Itapaji watershed takes place under high land-use intensity characterized by shortened fallow period. Also the crop combination is devoid of legume rotation and this depicts opportunity for soil nutrient replenishment through natural process of nitrogen fixation. For enhanced soil intensification and increased productivity without damaging the resource base, there is need to incorporate legume rotation in the cropping system. The farmers' perception of soil quality and that of soil scientists correlate well. There is therefore need for promotion of farmers' participation so as to provide a forum for articulation of their opinions in mitigating low fertility and soil quality. Also, traditional cropping system has been found to be effective in maintaining soil quality and needs to be emphasized in our farming systems.

References

Adesodun, J.K., Adeyemi, E.F., Oyegoke, C.O., 2007. Distribution of nutrient elements within water-stable aggregates of two tropical agro-ecological soils under different land uses. *Soil and Tillage Research* 92(1-2): 190-197.

Adeyolanu, O.D., Ogunkunle, A.O., 2016. Comparison of qualitative and quantitative approaches to soil quality assessment for agricultural purposes in Southwestern Nigeria. *Cogent Food and Agriculture* 2: 1149914

Adeyolanu, O.D., Ogunkunle, A.O., 2017. Soil quality assessment for sustainable land use and management. *International Journal of Plant & Soil Science* 13(6): 1 – 11.

Aikore, O.D., 2002. A comparison of qualitative and quantitative approaches to soil quality assessment. M.Sc. Dissertation. Agronomy Department, University of Ibadan, Ibadan, Nigeria. 50 – 52.

Andrews, S.S., Karlen, D.L., Cambardella, C.A., 2004. The soil management assessment framework: A quantitative soil quality evaluation method. *Soil Science Society of America Journal* 68(6): 1945-1962.

Are, K.S., Babalola, O., Oke, A.O., Oluwatosin, G.A., Adelana, A.O., Ojo, O.A., Adeyolanu, O.D., 2011. Conservation strategies for effective management of eroded landform: Soil structural quality, enrichment ratio and runoff water quality. *Soil Science* 176(5): 252-263.

Ayoade, J.O., 2002. Introduction to climatology for the tropics. John Willey and Son. Chicherter, UK. 210p.

Bonanomi, G., D'Ascoli, R., Antignani, V., Capodilupo, M., Cozzolino, L., Marzaioli, R., Puopolo, G., Rutigliano, F.A., Scelza, R., Scotti, R., Rao, M.A., Zoina, A., 2011. Assessing soil quality under intensive cultivation and tree orchards in Southern Italy. *Applied Soil Ecology* 47(3): 184-194.

Brown, L.E., 2005. Outgrowing the Earth: The Food Security Challenge in an Age of Falling Water Tables and Rising Temperatures. Earthscan, Earth policy Institute, London, UK. 239p.

Chen, Z.S., Hseu, Z.Y., 1997. Total organic carbon pool in soils of Taiwan. Proceedings of National Science Council ROC Part B: Life Sciences 21: 120 – 127.

Chen, Z.S., Hseu, Z.Y., Tsai, C.C., 1998. Total organic carbon pools in Taiwan rural soils and its application in sustainable soil management system. *Soil and Environment* 1: 295 – 306. [in Chinese]

Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Defining and assessing soil quality for a sustainable environment. Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.). SSSA Special Publication No 35, Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin, USA pp.1 – 21.

FAO, 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192p. Available at [Access date: 31.10.2017]: http://www.fao.org/3/a-i3794e.pdf

Feller, C., Balesdent, J., Nicolardot, B., Cerri, C., 2001. Approaching functional soil organic matter pools through particle-size fractionation. Examples for tropical soils. In: Assessment methods for soil carbon. Lal, R., Kimble, K.M., Follet, R.F. (Eds). Lewis Publishers, Boca Raton, USA. pp. 53-67.

Giller, K.E., Cadisch, G., 1997. Driven by nature: a sense of arrival or departure. In: Driven by nature: Plant litter quality and decomposition. Cadisch, G., Giller, K.E., (Eds.). CAB International, Wallingford, UK. pp.393 – 399.

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., Van Es, H.M., Wolf, D.W., Thies, J.E., Abawi, G.S., 2007. Cornel soil health assessment training manual. Edition 1.2. Cornel University, Geneva, New York, USA. 51 p.

Havlin, J.L., Beaton, J.D., Tisdale, S.L., Nelson, W.L., 2005. Soil fertility and nutrient management: An introduction to nutrient management. 7th edition. Pearson/Prentice Hall. Upper Saddle River, New Jersey, USA. 515p.

Ibewiro, B., Sanginga, N., Vanlauwe, B., Merckx, R., 2000. Nitrogen contribution from decomposing cover crop residues to maize in a tropical derived savanna. *Nutrient Cycling in Agroecosystems* 57(2): 131-140.

Merrington, G., Fishwick, S., Barraclough, D., Morris, J., Preedy, N., Boucard, T., Reeve, M., Smith, P., Fang, C., 2006. The development and use of soil quality indicators for assessing the role of soil in environmental interactions. Environment Agency. Science Report SC030265, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol. 241p.

Mudorch, G. Ojo-Atere, J.O., Colborne, G., Olomu, E.I., Odugbesan, E.M., 1976. Soils of the Western State Savanna in Nigeria, Volume 4. Land Resources Division, Ministry of Overseas Development, Tolworth Tower, England. CTBI Publications, 145 pp.

Negassa, W., 2001. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako area, Western Ethiopia. Alemaya University, School of Graduate Studies, (McS Thesis), Ethiopia. 93p.

Neves, C.S.V.J., Feller, C., Guimarães, M.F., Medina, C.C., Filho, J.T., Fortier, M., 2003. Soil bulk density and porosity of homogeneous morphological units identified by the Cropping Profile Method in clayey Oxisols in Brazil. *Soil and Tillage Research* 71(2): 109-119.

Nigerian Meteorological Agency (NIMET), 2007. 2007 Seasonal Rainfall Predictions (SRP)/Nigerian Meteorological Agency. Available at [Access date: 31.10.2017]: http://www.nimet.gov.ng/seasonal-rainfall-predictions

Paudel, B.R., Udawatta, R.P., Anderson, S.H., 2011. Agroforestry and grass buffer effects on soil quality parameters for grazed pasture and row-crop systems. *Applied Soil Ecology* 48(2): 125-132.

Rosegrant, M.W., Paisner, M.S., Meijer, S., Witcover, J., 2001. 2020 global food outlook: trends, alternatives and choices. International Food Policy Research Institute, Washington,D.C., USA. 18p. Available at [Access date: 31.10.2017]: https://www.staff.ncl.ac.uk/david.harvey/AEF811/Development/IFPRI2020Food.pdf

Soil Survey Staff, 2014. Keys to soil taxonomy. 12th Edition. U.S. Department of Agriculture, Natural Resources Conservation Service. Washington DC, USA. 372 pp.

Solomon, D.F., Fritzsche, F., Tekalign, M., Lehmann, J., Zech, W., 2002. Soil organic matter composition in the subhumid Ethiopian highlands as ınfluenced by deforestation and agricultural management. *Soil Science Society of America Journal* 66(1): 68-82.

Sparling, G., Liburne, L., Vojvodic-Vukovic, M., 2003. Provisional target for soil quality indicators in New Zealand. Landcare Research, Palmerston North, New Zealand. 224 p

USDA, 2006. Food Security Assessment 2005. United State Department of Agriculture (USDA), Economic Resrarch Service, GFA-17, USA.

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Morphological, mineralogical and geochemical features of topomorphic vertisols used for sorghum production in North Cameroon

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Abstract

In the present study, two topomorphic vertisols profiles used for sorghum production were described and characterized. After macroscopic characterization, physicochemical, mineralogical and geochemical analyses were made. Physicochemical analyses were made by standard methods while mineralogy was determined on clay fraction (<2µm) by X-ray diffraction coupled to Fourier transform infrared spectroscopy. Geochemical analysis was determined on 180µm fraction by inductively coupled plasma- Atomic Emission Spectroscopy (ICP-AES) and mass spectrometry (ICP-MS). Results revealed that studied vertisols were average deep, less differentiated with desiccations cracks and gilgai micro relief. The angular blocky structure and clayey texture were observed. They were alkaline ($7.3 \leq pH_{water} \leq 8.4$) and recorded a low to moderate organic matter and nitrogen contents. Cation exchange capacity was high reaching 52.24 meq $100g^{-1}$ and exchangeable cations were moderates with Ca^{2+} (3.69- 29.6 meq $100g^{-1}$) the most represented cation. Vertisols were made of smectites associated to kaolinite and a lesser content of quartz. Illites and calcite were also identified in some horizons. On the geochemical point of view, Si02 (55.87- 83.64%), Al_2O_3 (6.08-20.25%), Fe_2O_3 (2.09-6.39%) and K_2O (1.43-2.24 %) were the dominant oxides. Traces elements were represented essentially by Ba (518-1202 mg kg^{-1}), Zr (334-685 mg kg^{-1}) and Sr (71-190 mg kg^{-1}). The overall features are suitable to dry season sorghum production. The amount of smectites seemed to be an important factor affecting their water holding capacity on which dry season sorghum production depends. Improved cropping systems have to be developed to sustain productivity in vertisols with low smectites and where annual rainfall is lesser.

Keywords: Topomorphic vertisols, clay, smectites, dry season sorghum, North Cameroon.

Introduction

Vertisols are defined as clayey dark soils typical of tropical area which enjoy contrasting climate alternating wet and dry seasons. They also occurred in humid and temperate regions (Dudal, 1965; Coulombe et al., 1996). Morphology is the major feature used to distinguish them from the other soils type (Dudal, 1965; Wilding, 2004; Tamfuh et al., 2011; Temga et al., 2015; Rahim et al., 2015). The gilgai micro relief, the desiccation cracks and slickensides were dominant features common to vertisols over the world (Dudal, 1965; Dudal and Eswaran, 1988; Wilding, 2004; Kovda and Wilding, 2004; Tamfuh et al., 2011; Rahim et al., 2015). These features are due to their high clay content and the predominance of expanding clay minerals

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which controls the swelling and shrinking pattern (Dudal and Eswaran, 1988; Tamfuh et al., 2011; Adjia et al., 2013; Rahim et al., 2015).

In Cameroon, vertisols were found in sudano sahelian zone globally between 8° and 13° N and between 12° and 16° E (Brabant and Gavaud, 1985; Raunet, 2003; Nguetnkam, 2004; Tamfuh et al., 2011; Temga et al., 2015). These soils which were very widespread, covering about 1 200 000 ha were used for brick production and for agricultural purposes (Brabant and Gavaud, 1985; Coulombe et al., 1996; Raunet, 2003; Tamfuh et al., 2011; Temga et al., 2015). They were considered as very fertile with respect to their physicochemical properties. They were used to grown annual crops such as sorghum, rice and cotton (Coulombe et al., 1996; Ambassa-Kiki et al., 1996; Ben Hassine, 2006; Tamfuh et al., 2011). An important part of vertisols was subjected to dry season sorghum production (Mathieu, 2005). But, due to their heavy texture, they were difficult to manage (Coulombe et al., 1996; Ambassa-Kiki et al., 1996; Azinwi et al., 2011). The management problems were related to their extreme stickiness when wet and their hardness when dry (Tamfuh, 2012). The seasonal flooding pattern constitutes another important constraint to their cropping in rainy season because it limits the growing period. According to Tamfuh (2012), the vertisols physical properties and moisture regime constitute serious management constraints to their use in agriculture. For instance, large areas of vertisols were left on fallow or used for grazing and as earth crude materials in house building (Ambassa-Kiki et al., 1996; Temga et al., 2015).

Two major types of vertisols were observed in North Cameroon in regard to their parent materials (Brabant and Gavaud, 1985; Raunet, 2003; Nguetnkam, 2004; Tamfuh et al., 2011; Temga et al., 2015). The lithomorphic vertisols were developed on a wide range of rocks mainly igneous and metamorphic (Nguetnkam, 2004; Tamfuh et al., 2011). The topomorphic vertisols were more widespread than lithomorphic. They were formed on alluvial and colluvial materials generally in low landscape positions notably in rivers valleys and floodplains poorly or imperfectly drained, suitable to bases accumulation and bisiallitisation process (Blanchart et al., 2000; Raunet, 2003; Tamfuh et al., 2011; Temga et al., 2015).

Soils distribution in Northern Cameroon is governed by climate, parent material and the topography (Brabant and Gavaud, 1985; Raunet, 2003; Tamfuh et al., 2011). Thus, the same soils type can differ from one area to another. This is the case of soils developed on alluvial material specifically topomorphic vertisols. The dry season sorghum cultivation was concerned only vertisols. However, due to demographic pressure observed these last years, it production was extended to others clayey soils units (Coulombe et al., 1996; Mathieu et al., 2002, Mathieu, 2005). Nowadays, topomorphic vertisols used for sorghum production were not well known. The aim of this study is to describe these topomorphic vertisols on the morphological, mineralogical and geochemical point of view. It also, focuses on the influence of vertisols features on dry season sorghum productivity.

Material and Methods

Study site

The study was investigated in the sudano-sahelian zone of Cameroon especially in Mayo Danay division. Two localities were considered mainly Bougaye and Velé (Figure 1) for their contribution to sorghum production. This part of North Cameroon experiences the tropical climate type with a pronounced dry season which was about height months extending from October to May. The mean annual rainfall and the mean annual air temperature in the area are 800 mm and 29°C respectively. On the geomorphological point of view, the study site is dominated by plains with altitude less than 400m above the sea level and a few gentle dune slopes. An important part of these plain called yaere is sometimes flooded during the wet season. The natural vegetation is dry savannah with rare tree species notably in yaere where grassland dominated. The only tree species observed were *Balanites aegyptiaca, Ziziphus mauritiana, Faidherbia albida, Combretum sp* and *Bombax costatum*. The study area was covered mainly by vertisols and arenosols (WRB, 2014). Vertisols were observed in low altitude notably in alluvial depressions while the relative high altitudes were globally occupied by arenosols (Brabant and Gavaud, 1985; Raunet, 2003).

Methods

Field work consisted of direct observations, description of environmental settings and soil survey in order to choose the position of pits. One pit was dug in each site and described in detail according to the standard procedure. The main search characters were colour, thickness of horizons, coarse elements, texture, structure, porosity, consistency and boundaries between horizons. The Munsell Soil Color Chart (2014) was used for color appreciation. Soils samples were thereafter collected from any horizon and packaged in plastic bags, labeled and sent to the laboratory for soil analyses.

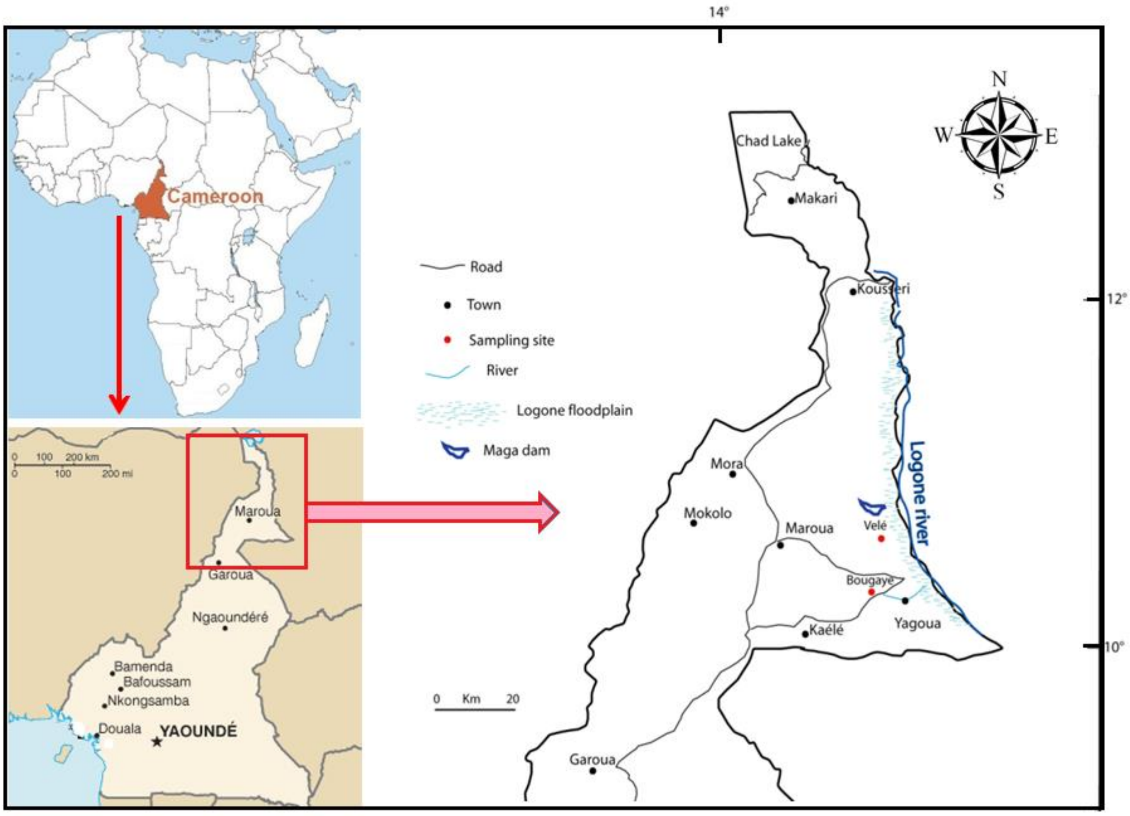


Figure 1. Location of the sampled sites

In the laboratory, bulk soil samples were air-dried at room temperature and then sieved (2 mm) to discard coarse fragments. The pipette method was used for particle size distribution analysis after dispersion with sodium hexametaphosphate $(NaPO_3)_6$ and organic matter destruction by hydrogen peroxide (H_2O_2). Soil pH was measured in water and KCl via pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. The soil organic carbon (OC) was determined by the wet oxidation method (Walkley and Black, 1934). The content in organic matter was calculated by multiplying the organic carbon values by the factor 1.72. The total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined according to Bray II procedure. Exchangeable cations were dosed by ammonium acetate extraction method at pH 7 and Cation Exchange Capacity (CEC) was determined using the sodium saturation method.

Soil mineralogy was determined on oriented clay samples by X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) at the Institute of soil sciences of Leibniz University in Germany. The clay fraction (< 2µm) was separated first by dispersing in deionized water and sedimentation according to Stoke's law. The resulting clay suspension was freeze-dried. The D8 Bruker diffractometer with CoKα1 radiation (λ = 1,789Å) was used for XRD data recording. IR spectra were recorded using Fourier transform spectrometer Bruker IFS 55 type.

The inductively coupled plasma source (ICP) was performed on 180µm fraction for geochemical analyses. The major elements were determined by atomic emission spectroscopy (ICP-AES) while trace elements by mass spectrometry (ICP-MS) after fusion in LiBO2 and dissolution in nitric acid (HNO_3). The detection limit was 1% for major elements. For trace elements, it was 5 mg kg^{-1} (Ba, Zr, Nb), 20 mg kg^{-1} (Ni) and 4 mg kg^{-1} (Y, Sc, Sr).

Results

Morphology, texture and chemical characteristics of soils

In velé, vertisol profile (10°29'96'' N; 15°10'92'' E; 321m above sea level) presented six different horizons with some desiccation cracks at surface. From the top to the bottom, following horizons were observed:

0 -35 cm: A_1 horizon; gray (2.5Y 5/1); polyhedral macrostructure; sandy clay; compact; gradual boundary with the underlying horizon;

35 - 140 cm: B_{1t} horizon; dark gray (2.5Y 6/1); angular blocky to sub angular structure; heavy clayey; too compact; presence of quartz fragments; gradual boundary with the underlying horizon;
140 - 240 cm: B_{21tCa} horizon; gray (2.5Y 5/1); angular blocky; clayey; calcareous nodules; presence of slickensides; gradual boundary with the underlying horizon;
240 - 345 cm: B_{22Ca} horizon; dark gray (2.5Y 6/1); angular blocky; clayey; calcareous nodules; yellowish spots (10YR 7/6); gradual boundary with the underlying horizon;
345 - 380 cm: B_{23Cag} horizon; gray (2.5Y 5/1); angular blocky; clayey; calcareous nodules; too compact; few (5%) yellow spots (5YR 6/6); plastic; gradual boundary with the underlying horizon;
380 - 405 cm: B_{3G} horizon; light gray (2.5Y 7/2); angular blocky; clayey; brownish spots (7.5YR 5/6); humid; plastic.

Pit from Bougaye (10°15'92'' N; 15°06'06'' E; 334m above sea level) was opened in the flooded depression where dry season sorghum field were installed. Some desiccations cracks and gilgai micro relief were observed at the surface soil. From the top to the bottom, following horizons were observed:

0 - 16 cm: A_p horizon, gray (2.5Y 5/1), angular blocky; sandy clay; porous; desiccations cracks; hard and too compact; gradual boundary with the underlying horizon;

16-35 cm: B_{1t} horizon, gray (2.5Y 6/1); angular blocky; clayey; compact; gradual boundary with the underlying horizon;

35-100 cm: B_{21tCa} horizon; brownish gray (2.5Y 6/2); angular blocky; clayey; calcareous nodules (3 to 4 mm^3) which diminish from the top to the bottom of the horizon; too compact; gradual boundary with the underlying horizon;

100- 190 cm: B_{22tCa} horizon; light gray (2.5Y 7/2); angular blocky; more calcareous nodules; clayey; plastic; gradual boundary with the underlying horizon;

190-270 cm: B_{3t} horizon; light gray (2.5Y 7/1); sub angular blocky; sandy clay; compact; plastic.

Particle size distribution revealed that studied vertisols were ranged from clayey to sandy clay. Clay content quite decreases from the top to the bottom of the profile (Table 1). In contrast, sand proportion displayed an opposite trend. The organic carbon (OC) and total nitrogen (TN) were globally moderate and uniformly distributed throughout the profiles. Relative higher OM values were observed at the bottom of the profiles (Table 1).

Table 1. Physico-chemicals characteristics of the studied vertisols

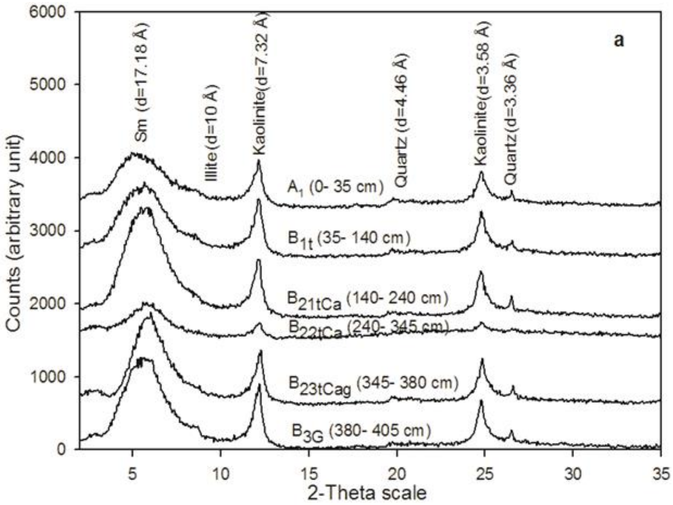
Depth (cm)	Particle size distribution (%)				OC, %	TN, %	Cations, meq100g^{-1}				CEC, meq100g^{-1}	Av P mgkg^{-1}	pH	
Horizon	Clay	Silt	Sand	Class			Ca^{2+}	Mg^{2+}	K^+	Na^+			in H_2O	in KCl
Velé profile														
A_1 (0-35)	38	25	37	C	2.06	1.05	5.47	1.08	0.019	0.018	22.40	38.96	7.5	6.3
B_{1t} (35-140)	47	30	23	C	2.34	0.78	7.80	1.06	0.024	0.016	24.80	16.06	8	6.7
B_{21tCa} (140-240)	50	28	22	HC	1.46	1.34	7.73	0.84	0.087	0.012	27.76	20.64	8.2	7
B_{22tCa} (240-345)	41	25	34	C	2.62	0.49	10.22	0.93	0.101	0.021	16.00	7.23	8.1	7.1
B_{23tCag} (345-380)	44	26	30	C	3.47	1.10	5.66	0.72	0.113	0.02	20.80	17.2	8.4	7.2
B_{3G} (380 -405)	50	20	30	HC	1.26	0.62	3.69	0.91	0.191	0.025	22.00	7.87	8.1	6.6
Bougaye profile														
A_1 (0-16)	26	24	50	CSS	1.07	0.58	26.1	0.5	0.040	0.012	37.84	8.26	7.3	5.6
B_{1tCa} (16-35)	29	22	49	SC	1.92	0.42	27.1	0.25	0.036	0.045	49.12	8.51	7.4	5.7
B_{21tCa} (35-100)	32	21	47	SC	0.74	0.46	29.1	1.02	0.037	0.058	50.72	8.44	7.8	6.3
B_{22tCa} (100-190)	35	25	40	C	1.60	0.50	29.6	0.69	0.036	0.007	52.24	17.55	8.2	7
B_{3t} (190-270)	40	24	36	C	0.50	0.81	27.6	0.56	0.036	0.024	45.36	21.68	8.4	6.7

C=Clay; HC=Heavy Clay; SC=Sandy Clay; CSS=Clayey Sandy Silt; OC=Organic Carbon; TN=Total Nitrogen; Av P= available phosphorus

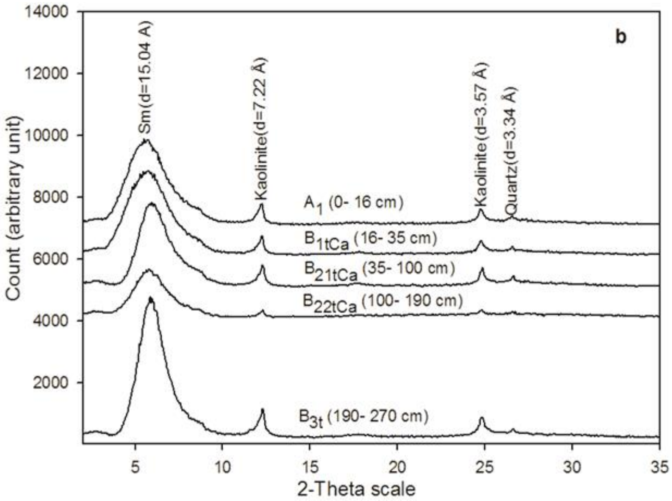
Vertisols were slightly alkaline to alkaline with pH H_2O ranged between 7.3 and 8.4. Ca^{2+} (3.6929.6 meq $100g^{-1}$) was the most represented cation on the exchangeable sites accounting for more than 80% of the total of exchangeable bases. The CEC (16.00-52.24 meq $100g^{-1}$) is high with the highest values in Bougaye vertisols even if their clay content were relatively lesser. In both profiles, CEC increased from the top towards the bottom of the profile. Available phosphorus ranged between 8.26 and 38.96 mg kg^{-1} indicating low to high available phosphorus contents. The relative higher contents were recorded in Velé in which content decreased from the top to the bottom of the profile. An opposite behavior was observed in Bougaye profile (Table 1).

Mineralogical and geochemical composition

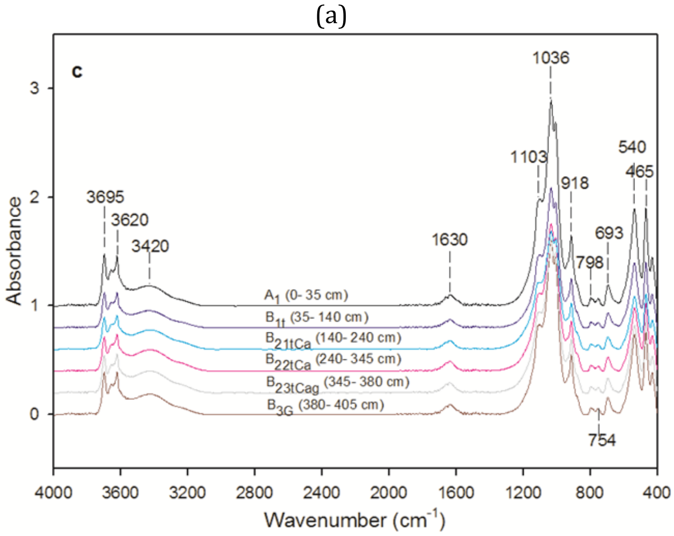
The XRD patterns of the vertisols clay fraction showed the presence of smectites, kaolinite and quartz. The high peak intensities at 15.04 Å and 17.18 Å indicated relative high amount of smectites (Figure 2). The high peaks at 7.32 Å and 3.57 Å in Velé vertisols compared to those from Bougaye suggests relative higher amount of kaolinite. The sharp character of these peaks compared to those from smectites indicate that kaolinite is well-crystallized than smectites. Also, illites were detected in vertisols from Velé mainly by the peak at 10 Å. Quartz occurs in little amount in Bougaye vertisols (Table 2). The presence of smectites was confirmed in IR spectra by the strong band at 3420 cm^{-1} which expresses the swelling rate of 2:1 minerals and assigned to OH- stretching vibration (Figure 2). Calcite not observed in XRD-pattern was identified in FT-IR by the band located at 1429 cm^{-1} and 875 cm^{-1} attributed to C-O stretching vibrations (Farmer, 1979; Nzeukou Nzeugang et al., 2013). Feldspars commonly observed in vertisols in North Cameroon (Tamfuh et al., 2011; Temga et al., 2015) were not found. It was observed that vertisols from Bougaye displayed higher amount of 2:1 clays minerals than those from Velé. Further, calcite was not found in Velé profile despite the fact that calcareous nodules were observed.



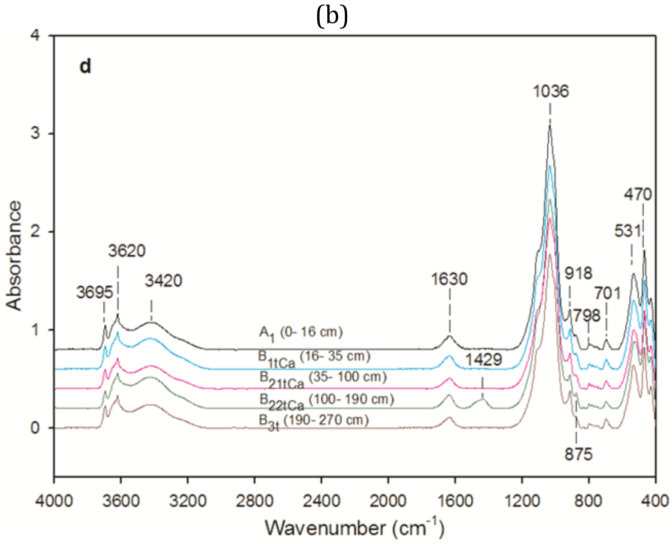
(a)



(b)



(c)



(d)

Figure 2. XRD pattern (a- Velé, b- Bougaye, Sm smectites) and IR spectra (c- Velé, d- Bougaye) of the clay fraction of studied vertisols

The table 3 shows chemical composition of vertisols samples. The major elements were constituted mainly by $Si0_2$ (55.87-83.64%) followed by Al_2O_3 (6.08-20.25%), Fe_2O_3 (2.09- 6.39%) and K_2O (1.43-2.24). Except CaO for which proportion in horizons contained calcareous nodules reached to 3.53%, the others major elements were globally less than 1%. The traces elements were dominated by Ba (518-1202 mg kg^{-1}), followed by Zr (334-685 mg kg^{-1}) and Sr (71-190 mg kg^{-1}) (Table 3).

Table 2. Minerals and their relative abundance in different vertisols samples

Samples	Smectites	Kaolinite	Quartz	Illite	Calcite
Velé profile					
A_1 (0-35 cm)	+++	+++	++	++	/
B_{1t} (35-140 cm)	++++	+++	++	+	/
B_{21tCa} (140-240 cm)	+++++	++++	+++	++	/
B_{22tCa} (240-345 cm)	+++	++	++	+	/
B_{23tCag} (345-380 cm)	++++	+++	++	++	/
B_{3G} (380 -405 cm)	++++	+++	++	++	/
Bougaye profile					
A_1 (0-16 cm)	++++	+++	++	/	/
B_{1tCa} (16-35 cm)	++++	+++	++	/	/
B_{21tCa} (35-100 cm)	++++	+++	++	/	/
B_{22tCa} (100-190 cm)	+++	++	++	/	++
B_{3t} (190-270 cm)	+++++	++++	++	/	/

++++ very abundant +++ abundant ++ lightly abundant + traces / none

Table 3. Major and selected traces elements in studied vertisols (LOI= loss on ignition)

Profiles	Velé						Bougaye				
Horizon	A_1	B_{1t}	B_{21tCa}	B_{22tCa}	B_{23tCag}	B_{3G}	A_1	B_{1tCa}	B_{21tCa}	B_{22tCa}	B_{3t}
Depth (cm)	(0-35)	(35-140)	(140-240)	(240-345)	(345-380)	(380 -405)	(0-16)	(16-35)	(35-100)	(100-190)	(190-270)
SiO_2 (%)	56.93	55.87	61.55	75.88	66.43	65.96	83.64	80.65	82.21	75.44	64.12
Al_2O_3 (%)	19.45	20.25	16.72	10.61	14.83	14.96	6.08	7.12	6.83	6.83	17.17
Fe_2O_3 (%)	6.39	6.23	5.45	3.11	4.72	5.26	2.09	2.92	2.47	2.46	4.16
MgO (%)	0.79	0.93	0.93	0.41	0.66	0.42	0.38	0.56	0.55	0.81	0.5
CaO (%)	0.69	0.7	0.92	0.43	1.18	0.53	0.36	0.48	0.48	3.53	0.55
Na_2O (%)	0.42	0.28	0.21	0.23	0.31	1.01	0.17	0.17	0.18	0.19	0.8
K_2O (%)	1.85	1.43	1.47	1.67	1.88	2.24	2.03	1.99	1.95	2.03	2.12
TiO_2 (%)	1.17	1.12	0.98	0.75	0.98	0.98	0.55	0.55	0.55	0.54	1.06
P_2O_5 (%)	0.10	0.05	0.03	0.02	0.02	0.10	0.02	0.01	0.02	0.02	0.06
MnO (%)	0.05	0.04	0.04	0.04	0.03	0.04	0.05	0.12	0.07	0.05	0.02
LOI (%)	11.90	12.90	11.50	6.70	8.70	8.20	4.50	5.30	4.60	7.90	9.20
Total (%)	99.95	99.96	99.97	100.00	99.97	99.97	100.01	100.00	100.01	99.99	99.96
Ba, mg kg^{-1}	1202	856	841	589	791	848	533	558	518	592	823
Ni, mg kg^{-1}	50	52	37	22	34	34	<20	<20	<20	<20	36
Sr, mg kg^{-1}	187	184	160	104	153	190	71	71	71	140	185
Zr, mg kg^{-1}	424	334	408	513	519	588	685	566	610	633	558
Y, mg kg^{-1}	30	32	22	20	27	34	14	16	16	26	23
Nb, mg kg^{-1}	25	29	21	14	20	18	10	12	10	10	21
Sc, mg kg^{-1}	15	16	12	8	11	11	4	5	5	5	13

Suitability to sorghum productivity

Heavy clay soils poorly drained were usually not submitted to millet, maize, leguminous and cotton cultivation in North Cameroon. Due to the annual flood pattern in rainy season, the studied vertisols were not used for rainy sorghum production. However, they were subjected to dry season sorghum cultivation and sorghum-sorghum system was regularly practiced.

Based on the soil requirement of the dry season sorghum, physicochemical properties of the studied vertisols are suitable. The sorghum has a high capacity to tolerate waterlogging period subsequent to poor drainage and the drought conditions in dry season. Soil water retention capacity is fundamental to dry season sorghum growth. The pH, the phosphorus level, calcium and magnesium reached the required content (Memento de l'Agronome, 1991). The only element less than the required amount is potassium which is highly less than the needed. Globally, for dry season sorghum the fertility status of studied vertisols is appreciable.

According to the data collected from farmers, the mean yield by hectare was about 2tha^{-1} of sorghum grain on Bougaye vertisols while it was about 1.5t ha^{-1} at Velé. It appeared that the nature of the clay fraction was more affecting dry season sorghum productivity than the proportion of clay. It also noted that the vertisols with the high CEC recorded the high sorghum productivity. So, the content of smectites was a key factor promoting the dry season sorghum productivity on vertisols.

Globally, the two studied vertisols are suitable to dry season sorghum cultivation because of their mineralogical and physicochemical characteristics.

Discussion

The studied vertisols were globally average deep with surficial desiccation cracks during the dry season in both sites. This feature is common to all clayey soils which alternates dry and wet seasons (Dudal, 1965; Wilding, 2004; Coulombe et al., 1996; Tamfuh et al., 2011; Temga et al., 2015). The micro-relief called gilgai were the most pronounced geomorphology associated to vertisols fields. The dark color characteristic of vertisols was observed in all horizons and regularly throughout the profiles. It was noted that vertisols can have a range of colors depending on the climate, the drainage behavior, the parent material and the topography (Coulombe et al., 1996; Tamfuh et al., 2011; Temga et al., 2015). The constancy of the same color throughout the profile is due to regular homogenization through the vertic movements which mix the entire profile (Tamfuh et al., 2011). Red and yellowish spots observed are the result of poor drainage which promotes temporal hydromorphy. The slickensides are the dominant morphological feature associated to vertisols (Dudal, 1965; Coulombe et al., 1996; Wilding, 2004; Nguetnkam, 2004; Tamfuh et al., 2011; Temga et al., 2015). Globally, the profiles had less horizons differentiation which according Tamfuh et al. (2011) was due to the shrink-swell movements. This fact can be assigned to regular homogenization of the entire profile by pedoturbation process (Coulombe et al., 1996; Nguetnkam, 2004; Tamfuh, 2012; Temga et al., 2015).

On the physical point of view, the studied vertisols were characterized by their heavy texture and their hardness when dried. It was always reported that clay proportion in vertisols was more than 30% to a depth of 50 cm or more (Dudal, 1965; Coulombe et al., 1996). The high clay content is responsible for their properties which promotes their suitability for dry season sorghum cultivation (Brabant and Gavaud, 1985; Coulombe et al., 1996; Kenga et al., 2005; Mathieu, 2005; Tamfuh et al., 2011). The both profiles were also marked by the presence of calcareous nodules which is characteristics of flooded and poorly drained environments promoting calcium precipitation. It was reported that carbonates were a common mineral in neutral and alkaline vertisols in which they occurred as calcite (Coulombe et al., 1996).

The different horizons were slightly alkaline to alkaline and not differ significantly along the profiles. The alkaline character of vertisols was sometimes attributed to the calcareous or base-rich parent materials from which they were developed (Nguetnkam, 2004; Moustakas, 2012). Relative higher vertisols pH in the current study compared to those from others part of North Cameroon (Coulombe et al., 1996; Mathieu, 2005; Tamfuh et al., 2011; Temga et al., 2015) could be attributed to the presence of calcareous nodules described. The high cation exchange capacity obtained is more consistent with the predominance of smectites (Table 1) than the high clay content (Table 2). In fact, smectites were recognized to have a high CEC (Caillère et al., 1982). This is one of the factors which classify vertisols as one of the fertile soils from the Northern Cameroon. Topomorphic vertisols are formed on low landscape positions in which poor drainage limit bases leaching promoting bisiallitisation process responsible of smectites synthesis (Blanchart et al., 2000; Nguetnkam et al., 2007; Tamfuh et al., 2011; Temga et al., 2015). Also, weathering process in dry areas with pronounced dry season and low water-flow condition leads to conservation of a part of silica, bases and thus, to neoformation of smectites (Pedro, 1968; Blanchart et al., 2000; Nguetnkam et al., 2007). This class of vertisols was well known in North Cameroon by farmers who called them *baleewal* because of their dark color. Their high clay content and water retention capacity were appreciated by farmers (Mathieu, 2005). An occurrence of calcite is consistent with the presence of calcareous nodules.

Geochemically, the studied vertisols were dominated by silica (SiO_2), aluminum (Al_2O_3) and iron (Fe_2O_3). Also, alkali and alkalino-earth elements were observed throughout the profiles. According to Tamfuh et al. (2011), the low landscape positions and the strongly contrasted climate is favorable to accumulation of these constituents. This is also consistent with the mineralogy dominated by aluminosilicates (smectites and kaolinite). The high content of K_2O and CaO are in agreement respectively with the presence of illites and calcite as well as calcareous nodules. The fact that Ba and Sr were the most represented traces elements could be attributed to the low landscape positions and their low mobility (Abbaslou et al., 2014).

The heavy texture of the vertisols coupled to the predominance of smectites on the clay fraction was the features promoting their use for dry season sorghum cultivation. Tamfuh (2012) noted that adaptability of sorghum to vertisols is due to his well-developed and finely branching roots system which could not be damaged by the desiccation cracks. In addition, his very small leaves limit evapotranspiration in dry season. An important factor contributing to vertisols productivity in semi-arid zones is their high water holding capacity. For instance, it is well known that the *Muskwari* (dry season sorghum) production depends on the soil water reserve accumulated during the rainy season which is conditioned by the poorly drainage of the soil subsequent to his high content in 2:1 clay minerals (Tabo et al., 2002; Mathieu et al., 2002; Mathieu, 2005; Tamfuh et al., 2011). So, the water retention capacity of the soil which is associated to the content in swelling clays is fundamental to obtaining high yield. This is why vertisols from Bougaye had relative higher sorghum yield than those from Velé. However, the main problems associated to cropping these soils are the difficulty inherent to their management because of their swelling/shrinking behavior. In order to sustain soil productivity, crop has to be rotated in order to improve their hydro physical status.

Conclusion

This study was focused on the description of vertisols features used for sorghum production in North Cameroon. Studied vertisols were developed on alluvial materials and were globally average thin showing desiccation cracks at surface. The structure was globally angular blocky with calcareous nodules towards the bottom of the profiles. They were clayey, alkaline and displayed a high CEC. Smectites were the main minerals; they were associated to kaolinite and a lesser amount of quartz. Calcite was also observed in some horizons mainly at Bougaye profile. SiO_2, Al_2O_3, and Fe_2O_3 were the dominant oxides. Globally, based on their features, studied vertisols were suitable to dry season sorghum cultivation. However, the yield of this crop seemed to be more dependent on smectites content than the textural class (clay proportion) of the vertisols.

References

Abbaslou, H., Martin, F., Abtahi, A., Moore, F., 2014. Traces elements concentrations and background values in the arid soils of Hormozgan province of southern Iran. *Archives of Agronomy and Soil Science* 60(8): 1125-1143.

Adjia, H.Z., Villiéras, F., Kamga, R., Thomas, F., 2013. Mineralogy and physic-chemical properties of alluvial clays from far-north Cameroon: A tool for an environmental problem. *International Journal of Water Resources and Environmental Engineering* 5(1): 54-66.

Ambassa-Kiki, R., Aboubakar, Y., Boulama, T., 1996. Zero-tillage for rice production on Cameroonian vertisols. *Soil and Tillage Research* 39(1-2): 75–84.

Ben Hassine, H., 2006. Mineralogical nature and nutritional role of cereal soil clays in subhumid and semi-arid zones (Tunisia). *Comptes Rendus Geoscience* 338(5): 329-340.

Blanchart, E., Achouak, W., Albrecht, A., Barakat, M., Bellier, G., Cabidoche, Y.M., Hartmann, C., Heulin, T., Lané-Larrouy, C., Laurent, J.Y., Mathieu, M., Thomas, F., Villemin, G., Watteau, F., 2000. Déterminants biologiques de l'agrégation dans les vertisols des petites Antilles. Conséquences sur l'érodibilité. *Etude et Gestion des Sols* 7(4): 309- 328. [in French]

Brabant, P., Gavaud, M., 1985. Soils and land resources of North Cameroon (North and Far North Provinces). Paris, ORSTOM-MESRES-IRA. [in French]

Caillère, S., Henin, S., Rautureau, M., 1982. Minéralogie des argiles : Classification et nomenclature (Tome 2). Masson (éd). 189p. [in French]

Coulombe, C.E., Wilding, L.P., Dixon, J.B., 1996. Overviews of vertisols: Characteristics and impacts on society. *Advances in Agronomy* 57: 289-375.

Dudal, R., 1965. Dark clay soils of tropical and subtropical regions. Food and Agriculture Organization of the United Nations (FAO), Agricultural Development. Paper No 83, Rome, Italy, 172 p.

Dudal, R., Eswaran, H., 1988. Distribution, properties and classification of vertisols. In: Vertisols: their distribution, properties, classification and management. Wilding, L.P., Puentes, R. (Eds.). Texas A&M University, Printing Centre, College Station, Texas, USA. pp. 1-22.

Farmer, V.C., 1979. Infrared spectroscopy. In: Data handbook for clay materials and other non-metallic minerals. Van Olphen, H., Fripiat, J.J. (Eds.). Perganon Press, Oxford, UK. pp. 285-330.

Kenga, R., Njoya A., M'biandoun, M., 2005. Analysis of constraints to agricultural production in the sudano savanna zone of Cameroon and implication for research priority setting. *Tropicultura* 23(2): 91-99.

Kovda, I.V., Wilding L.P., 2004. Vertisols: problems of classification, evolution and spatial self-organization. *Eurasian Soil Science* 37(12): 1341-1351.

Mathieu, B., 2005. Une démarche agronomique pour accompagner le changement technique : cas de l'emploi des herbicides dans les systèmes de culture à sorgho repiqué au Nord-Cameroun. Thèse de Doctorat; Institut National Agronomique Paris Grignon, 234p. [in French]

Mathieu, B., Fotsing, E., Gautier, D., 2002. L'extension récente du muskuwaari au Nord-Cameroun : Dynamique endogène et nouveaux besoins de recherche. In: Savanes africaines : des espaces en mutation, des acteurs face à de nouveaux défis. Jamin J.Y., Seiny Boukar, L., Floret, C. (Eds.). Actes du colloque, mai 2002, Garoua, Cameroun. Prasac, N'Djamena, Tchad - Cirad, Montpellier, France. [in French]

Mémento de l'Agronome. 1991. République Française, Ministère de la Coopération et du Développement 1635 p. [in French]

Moustakas, N.K., 2012. A study of vertisol genesis in North Eastern Greece. *Catena* 92: 208-215.

Munsell Soil Color Chart, 2014. Available at [Access date: 13.02.2018]: https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-soil-color-charts/

Nguetnkam, J.P., 2004. Les argiles des vertisols et des sols fersiallitiques de l'Extrême Nord du Cameroun: genèse, propriétés cristallochimiques et texturales, typologie et application à la décoloration des huiles végétales. Thèse Doct., Univ. Yaoundé I, Cameroon. 216p. [in French]

Nguetnkam, J.P., Kamga, R., Villiéras, F., Ekodeck, G.E., Yvon, J., 2007. Altération du granite en zones tropicales. Exemple de deux séquences étudiées au Cameroun (Afrique centrale). *Etude et Gestion des Sols* 14(1): 31-41. [in French]

Nzeukou Nzeugang, A., Medjo, E.R., Fagel, N., Kamgang, K.B., Njoya, A., Balo M.A., Mache, J.R., Melo, C.U., 2013. Characterization of clay deposits of Nanga-Eboko (Central Cameroon): suitability for the production of building materials. *Clay Minerals* 48(4): 655-662.

Pedro, G., 1968. Distribution des principaux types d'altération chimique a la surface du globe. *Revue de Géographie Physique et Géologie Dynamique* 10(5): 457–470. [in French]

Rahim, I.S., Wahba, M.M., Amal, M.A., 2015. Micromorphological characteristics of vertisols in Egypt. *International Journal of Research in Management* 5(6): 1-7.

Raunet, M., 2003. Quelques clés morpho-pédologiques pour le Nord Cameroun à l'usage des agronomes. CIRAD, Montpellier, 24 p. [in French]

Tabo, R., Olabanji, O.G., Ajayi, O., Flower, D.J., 2002. Effect of plant population density on the growth and yield of sorghum varieties grown on vertisols. *African Crop Science Journal* 10(1): 31-38.

Tamfuh, P.A., 2012. Petrological, physico-chemical and mechanical study of the Benue watershed vertisols (North Cameroon): spatial analysis and agricultural potential evaluation. Ph.D Thesis, University of Yaoundé 1; Yaoundé, Cameroon. 172p.

Tamfuh, P.A., Woumfo, E.D., Bitom, D., Njopwouo, D., 2011. Petrological, physico-chemical and mechanical characterization of the topomorphic vertisols from the Sudano-sahelian region of North Cameroon. *The Open Geology Journal* 5: 33-55.

Temga, J.P., Nguetnkam, J.P., Balo, M.A., Basga, S.D., Bitom, D.L., 2015. Morphological, physico chemical, mineralogical and geochemical properties of vertisols used in bricks production in the Logone Valley (Cameroon, Central Africa). *International Research Journal of Geology and Mining* 5(2): 20-30.

Walkley, A., Black, C.A., 1934. An examination of Digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-38.

Wilding, L.P., 2004. Advancement in the knowledge base of vertisols genesis, classification, distribution and management. *Revista Científica Agropecuaria* 8(1): 45-54.

WRB, 2014. World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports 106. Food and Agriculture Organization of the United Nations. Rome, Italy. Available at [access date: 13.02.2018]: http://www.fao.org/3/a-i3794e.pdf

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Spatial variability pattern and mapping of selected soil properties in hilly areas of Hindukush range northern, Pakistan

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Abstract

Soil samples at 0-20 cm depth were collected from major crop areas of Hindukush mountainous range, District Chitral, extreme Northwestern Pakistan, during April 2014 to assess their physico-chemical properties and spatial distribution pattern. 103 soil samples were analyzed and maps were created by geostatistical technique of inverse distance weighting and kriging techniques using GIS and GS win-7 computer software. The soil texture ranged from silt loam to dominantly sandy loam, slightly acidic to alkaline and moderate to highly calcareous but with no salinity indication. Soil organic matter was higher than 2 % in about 75 % of samples. Soil pH, EC and lime showed slight dependence on each other with r values from 0.4 to 0.5 while OM varied independently as indicated by their lower correlation values. Semivariogram analysis showed that soil pH, lime, OM had strong spatial dependence (nugget-sill ratio, <25%) while silt, sand, EC had moderately (nugget-sill ratio, 25-75%) and clay had weakly distributed in the area. Linear, Gaussian and exponential models were used for different soil parameter based on nugget, mean prediction error and root mean square standardize prediction error values and maps were developed through extension techniques to cover all the area outside the sampling points.

Keywords: Spatial variability, soil mapping, kriging, Chitral district, geostatistics.

Introduction

District Chitral is undoubtedly the most important and captivating place in the majestic Hindukush Range. It is a mountainous area in the extreme north of Pakistan about 330 kilometers away from Peshawar, the capital of Khyber Pakhtunkhwa province. The valley of Chitral lies at an elevation of 1494 m from the sea level. The total area of Chitral is 14,850 km^2 situated between 35.12 – 36.50^0 N latitude (North) and 71.20 – 74.55^0 E longitude (East). According to 2004 population census, the total population of district Chitral was about 320,000 and according to latest estimate it has reached the mark of 500,000 (Chitral today). Chitral has semi-arid climate with almost no rainfall during the very hot summers. The total cultivable land is 23000 ha which is only 4% of the total area. Farmers hold very limited farming land and hence reliance on food such as cereals and fodder crops for animal remains high. The common crops grown in district Chitral are maize, rice, wheat and potato.

Soil properties change temporally and spatially from field to large area. They are influenced by different soil forming factors like climate, parent materials, relief, time and organisms. Besides these natural process some other agronomic practices like fertilization, crop rotation also influences these properties at greater extent. Variation in soil properties affect crop growth though reduction in effectiveness of uniformly applied

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fertilizer to the field as described by Mulla et al. (1990). In past, variation in properties of soil has been determined through field experiments such as Rothamsted Classical Experiments by Johnston et al. (1986) and Ecological Research Program by Risser (1991). But this method was very time-consuming and in most of the cases too much expensive to be affordable. Spatial variability of soil properties can be used for prediction the value of soil at un-sampled location by using experimentally analyzed data of sampled location. Geostatistics can be regarded as a collection of numerical techniques that deal with the characterization of spatial attributes, employing primarily random models in a manner similar to the way in which time series analysis characterizes temporal data by Olea (1999). Using geostatistics is not only related to soil physico-chemical properties, but it is also applicable for the determination of spatial pattern of soil microorganisms described by Wollum and Cassel (1984).

The present study was conducted to evaluate the soil physical and chemical properties of district Chitral collected randomly from various parts of the district. Arc GIS 9.3 and other statistical software were used for assessing variability, spatial pattern, mapping and classification of various soil properties determined in these soil samples. The prepared maps, chart and tables of various soil physico-chemical properties were thought to have good use for soil resource management, enhancing agriculture production and for as guide line for further research in the area. The main objective of this research was to determine various soil physico-chemical properties of district Chitral, to develop their maps and to delineate problem soil of district Chitral for future planning and management.

Material and Methods

Site description and sample collection

Soil samples were collected from different locations in district Chitral of Khyber Pakhtunkhwa province of Pakistan to determine the soil physico-chemical properties and their mapping by using geostatistical techniques and mapping tool (ArcGIS 9.3). For this purpose a total number of 103 soil samples were randomly collected from 0-20cm depth from different areas of the district (Figure 1). Samples were collected from major agricultural growing areas including Garam Chashma valley, Bumburate valley, upper Boni areas, Chitral Township, Agricultural Research Station, and Drosh valley lying in the south western part of the district. Extreme hilly area seldom used for patchy agricultural activities were excluded from the study. Extensive samples were collected from Chitral Agricultural Research Station and were analyzed separately. Each sampling location was recorded by using Global Positioning System (GPS). These soil samples were collected, labeled properly and then further analyzed.

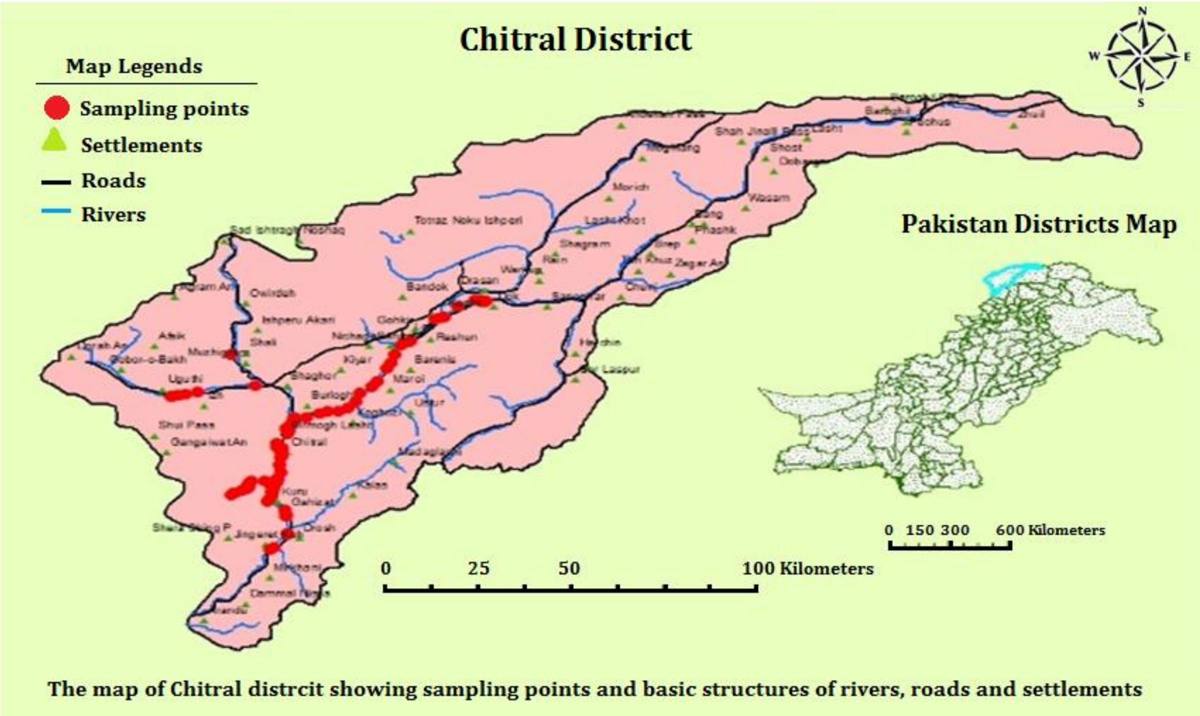

Figure 1. Boundaries of Pakistan and northern district Chitral showing sampling sites, settlements, roads and rivers

Sample analysis and data interpolation

Collected soil samples were ground and sieved with the help of 2 mm mesh after air drying and were analyzed in the laboratory for soil physico-chemical properties like soil pH by Mclean (1982), electrical conductivity by Richards (1954), soil texture by Bouyoucos (1936), organic matter by Nelson and Sommer (1982), lime content by Richards (1954). The reading of each location was taken by GPS in degrees and minutes and was then changed to decimal degrees. ArcGIS 9.3 and ArcGIS Geostatistical Analyst were used for mapping. To determine spatial structure of various soil properties, geostatistical techniques of semivariogram analysis by Bhatti et al. (1991) were used. Soil test of un-sampled location were analyzed by using geostatistical techniques (Kriging and Inverse Distance Weighting) and then map were prepared at smaller grid spacing by Rashid and Bhatti (2005). Inverse Distance Weighting (IDW) and Kriging were used to interpolate the values of unsampled locations as also suggested by Caers (2005). IDW can estimates or predict the values of unsampled location by using distance and the values of sampled location. It decreases the contribution of known values to predicted values. The weight of every sample point is an inversely proportional to the distance. Kriging is commonly used for interpolation or prediction of spatial data of unknown points through data from surrounding known points. The following formula was used for kriging:

$$Z(x_0) = \sum_{1=i}^{n(h)} \lambda_i Z(x_i)$$

Xo represent locations of un-sampled areas, λi are the weighting factors, Xi is the samples position and Z represent the measured value of soil property. Based on best fit, the IDW technique was used for district Chitral while kriging was used for interpolation of data acquired from Agricultural Research Station.

Variogram and semivariogram play an important role in kriging. It was used to produce spatial distribution and map of soil properties of Agriculture Research Station of district Chitral.

Semivariogram analysis

Semivariogram analysis is a key method to interpolate spatial variability. It was developed to interpolate the degree of spatial continuity among data points and to find a range of spatial dependence for soil physico-chemical property. It is used to measure the spatial correlation between two samples. It depends upon the distance between the samples points. Semivariance has a direct relationship to the distance. If the distance between the samples points are small then there will be smaller semivariance and if the distance is large then it yield larger semivariance. It was developed to evaluate and to analyze the degree of spatial continuity among sample points and to generate a range of spatial dependence for each soil parameters. Some of the characteristics of semivariogram are sill, range and nugget. Sill is the semivariance value at which the variogram levels off. Range is the lag distance at which the semivariogram or component of semivariogram reaches the sill value or it is the critical distance. Theoretically the value of semivariogram at the origin should be zero. It is very close to zero or different from zero then this semivariogram value is said to be nugget. Different variogram models were used for the quantitative description of soil properties. The most common and widely used variogram models include spherical, exponential and linear models and Gaussian.

Linear model :$\gamma(h) = Co + Bh$

Spherical model : $\gamma(h) = Co + [(\frac{3}{2})(\frac{h}{a}) - (\frac{1}{2})(\frac{h}{a3})]$ $0<h<a$

Exponential model : $\gamma(h) = Co + C_1\ [1\text{-}\exp(-\frac{h}{ao})]$

Gaussian model : $\gamma(h) = C_0 + C\ [1\text{-}\exp(\frac{h2}{a2})]$ $h>0$ and if $\gamma(0) = 0$

Results

Descriptive statistics

Soil separates showed that most of the soils in the Chitral district varied from silt loam to sandy loam. Sand fraction ranged from 36.40 to 78.40% with mean value of 59.04%, silt from 15.40 to 55.40% with mean value of 32.18% and clay from 4.20 to 14.20% with mean value of 8.76%, (Table 1). In hilly areas such coarse texture soils are common where most of fine materials prone to runoff losses. In contrast to low lying areas or flood plain, these areas are not expected to receive any soil depositions. The textural classes in the area are close to the reports of Nazif et al. (2006).

Table 1. Statistical analysis of soil fractions

Parameters	%Clay	%Silt	%Sand
Minimum	4.20	15.40	36.40
Maximum	14.20	55.40	78.40
Mean	8.76	32.18	59.04
1st Quartile	8.20	27.40	54.40
Median	8.20	31.40	60.40
3rd Quartile	10.20	37.40	64.40
Sum	903.0	3315.4	6081.6
SD	1.76	8.29	8.82
C.V	20.15	25.76	14.94
Variance	3.12	68.76	77.89
SE Mean	0.17	0.81	0.86
Skewness	-0.08	0.53	-0.39
Kurtosis	0.31	0.44	0.01

Table 2. Valley wise analysis of soil fractions

Valleys Name	Clay (%) ± SD	Silt (%) ± SD	Sand (%) ± SD
Garam Chashma	7.80 ± 1.11	21.31 ± 5.83	71.02 ± 5.91
ARS, Chitral	7.41 ± 1.54	30.41 ± 4.73	62.30 ± 5.66
Chitral Town	9.58 ± 2.16	35.69 ± 8.29	54.99 ± 9.47
Kaari to Jenalikoch	8.96 ± 1.38	29.47 ± 6.91	61.48 ± 6.70
Boni Areas	9.69 ± 1.68	31.18 ± 3.47	58.92 ± 3.62
Chumurkone to Drosh	9.11 ± 1.11	39.10 ± 8.85	51.93 ± 8.94
Ayun	9.34 ± 1.96	38.40 ± 8.82	52.42 ± 9.09
Bumburate	7.80 ± 1.62	32.84 ± 5.74	59.27 ± 5.64

The soils in the area ranged from slightly acidic (6.12) to alkaline pH (8.35) with mean value of 7.59±0.36 in 1:5 soil water suspensions (Table 3). The alkaline pH could be associated to calcareousness of soil and low vegetation. About > 90 % samples were alkaline in soil reaction while only 10% samples had pH <7.0. Garam Chashma valley had comparatively lower soil pH with mean value of 6.91±0.51 while the higher pH value with mean value of 7.86±0.22 was noted in areas lying between Karri to Jenalikoch situated on Boni road. The upper lying Garam Chashma valley is cooler and at higher altitude with more vegetation than other areas that could be associated to its lower pH. This valley is commonly used for offseason potato production in summer due to its cooler climate and good soil conditions. The low lying areas have comparatively higher pH and higher lime content than upper areas.

Table 3. Statistical analysis of selected soil chemical properties

Parameters	pH (1:5)	EC (1:5) dSm^{-1}	Lime (%)	O.M (%)
Minimum	6.12	0.06	3.30	0.87
Maximum	8.35	0.30	22.48	3.98
Mean	7.59	0.16	10.79	2.44
1st Quartile	7.48	0.14	8.34	1.97
Median	7.70	0.17	9.88	2.42
3rd Quartile	7.81	0.19	13.24	2.94
Sum	782.17	17.49	1111.9	251.93
SD	0.36	0.04	3.77	0.68
C.V	4.83	24.18	34.98	28.15
Variance	0.13	1.68	14.26	0.47
SE Mean	0.03	4.04	0.37	0.06
Skewness	-1.58	0.50	0.84	0.03
Kurtosis	3.17	1.55	0.70	-0.37

Electrical conductivity (EC) as measured in 1:5 soil water suspension ranged from 0.06 to 0.30 dS m^{-1} with mean value of 0.16 dS m^{-1} (Table 3) indicating that the study area had no salinity problem (<4 dS m^{-1}). The northern hilly areas posing with frequent and extensive run off losses are rather low in basic salt requirements like Ca and S instead of any salinity problem. The values are in close consistency with Baber et al. (2004).

District Chitral ranged from moderate to strongly calcareous nature, ranged from 3.30 to 22.48% with mean value of 10.79% in the analyzed soil samples (Table 3). This range in % lime in the area was in agreement with reports of Wasiullah and Bhatti (2007). When averaged with reports of Rashid (1994) about >87% soil samples were moderately calcareous with lime 3-15% while 13% samples were strongly calcareous having lime >15%. Comparatively higher lime content with mean value of 14.69%±4.28 was observed in low lying Kaari to Jenalikoch areas than upper lying Garam Chashma areas with mean value of 6.25±1.43%. It includes all the materials of plants, animals or microbial origin produced in the soil or added to the soil.

Organic matter in soils of the area was comparatively more than other plain areas of Pakistan as discussed by Sarwar et al. (2008). It ranged from 0.87 to 3.98% with mean value of 2.44% in the whole soil samples (Table 3). When compared with standard values as described by Rashid et al. (1994), about >94% soil samples were high in organic matter with values above 1.29% while only <6% soil samples were low in organic matter. The higher organic matter in the areas could be attributed to colder weather conditions as compared to other parts of the country. Plant leaves and dry matter decomposition reduces significantly with decrease in soil temperature as reported by Hood (2001).

Table 4. Valley wise analysis of selected soil chemical properties

Valleys Name	pH ± SD	EC (dS m^{-1}) ± SD	Lime (%) ± SD	OM (%) ± SD
Garam Chashma	6.91 ± 0.51	0.13 ± 0.04	6.25 ± 1.43	2.41 ± 0.60
ARS, Chitral	7.58 ± 0.18	0.18 ± 0.03	9.64 ± 1.94	1.93 ± 0.46
Chitral Town	7.79 ± 0.10	0.18 ± 0.04	11.11 ± 2.44	2.31 ± 0.46
Kaari to Jenalikoch	7.86 ± 0.22	0.20 ± 0.03	14.69 ± 4.28	2.47 ± 0.57
Boni Areas	7.73 ± 0.10	0.20 ± 0.05	12.33 ± 3.40	2.51 ± 0.67
Chumurkone to Drosh	7.64 ± 0.24	0.16 ± 0.04	11.28 ± 3.58	2.27 ± 0.80
Ayun	7.46 ± 0.35	0.13 ± 0.03	9.18 ± 2.63	2.82 ± 0.43
Bumburate	7.41 ± 0.35	0.16 ± 0.02	8.90 ± 2.26	2.87 ± 1.01

Correlation analysis

Soil pH, EC and lime contents showed significant correlation with each other. Increasing the lime contents in soil, pH and EC increased with r2 values of 0.333 and 0.193. Similarly with increasing the EC the soil pH increased with r2 value of 0.285 (Figure 2). However, r2 values were lower and can suggest only the trends. Such weak correlations are not unusual in field conditions where any characteristics of soil could be influenced by many factors. For example, besides lime content and soluble salts, the pH of soil could be influenced by vegetation, parent materials, rainfall and soil texture. Soil sand and silt showed strong influence on each other advocating that these were the two main soil separates and that the increase of one decreased the other as revealed by their strong negative correlation with each other with r2 value of -0.98.

Table 5. Correlation analysis among soil parameters

	EC	Lime	OM	Clay	Silt	Sand
pH	0.45	0.54	0.00	0.11	0.22	-0.23
EC	1.00	0.41	-0.07	0.20	0.03	-0.07
Lime	-	-	0.10	0.27	0.12	-0.17
OM	-	-	-	0.05	0.08	-0.09
Clay	-	-	-	-	0.20	-0.39
Silt	-	-	-	-	-	-0.98

Spatial variability and geostatistical analysis

The strength of spatial variability is measured by semivariogram analysis. In this the data is analyzed and fit into different models like Linear, Exponential and Gaussian. For best fit model and measuring the strength, different geostatistical results are made as criteria such as the mean prediction error close to 0, root mean square standardize prediction error close to 1 and smallest nugget value. Similarly, the nugget-sill ratio of <25% is considered as strong spatial dependence, 25-75% is considered as moderate spatial dependence and >75% is considered as weak spatial dependence as described by Cambardella et al. (1994).

Table 6. Models and parameters of spatial distribution of soil physico-chemical properties

Soil parameters	C_0 (Nugget)	C_0+C (Sill)	C_0/C+C_0 Nugget-Sill ratio (%)	A_0(m) (Range)	Models	r^2	RSS
%Clay	3.01575	3.01	100.0	46463	Linear	0.284	3.41
%Silt	51.4	103.7	49.57	31470	Gaussian	0.663	1963
%Sand	53.8	134.8	39.91	46080	Exponential	0.622	2089
Soil pH	0.047	0.196	24.0	32071	Gaussian	0.631	0.0237
Soil EC	0.00117	0.003	44.49	40250	Gaussian	0.640	1.135
Lime	5.12	36.34	14.08	101100	Exponential	0.302	412
OM	0.094	0.48	19.58	1320	Gaussian	0.160	0.106

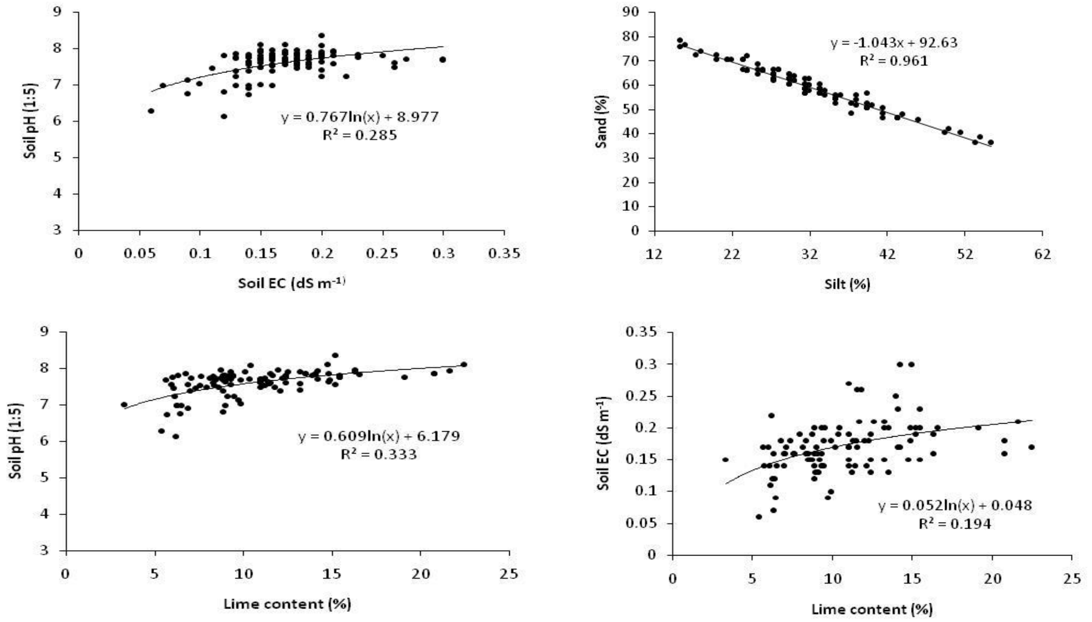

Figure 2. Correlation among soil parameters

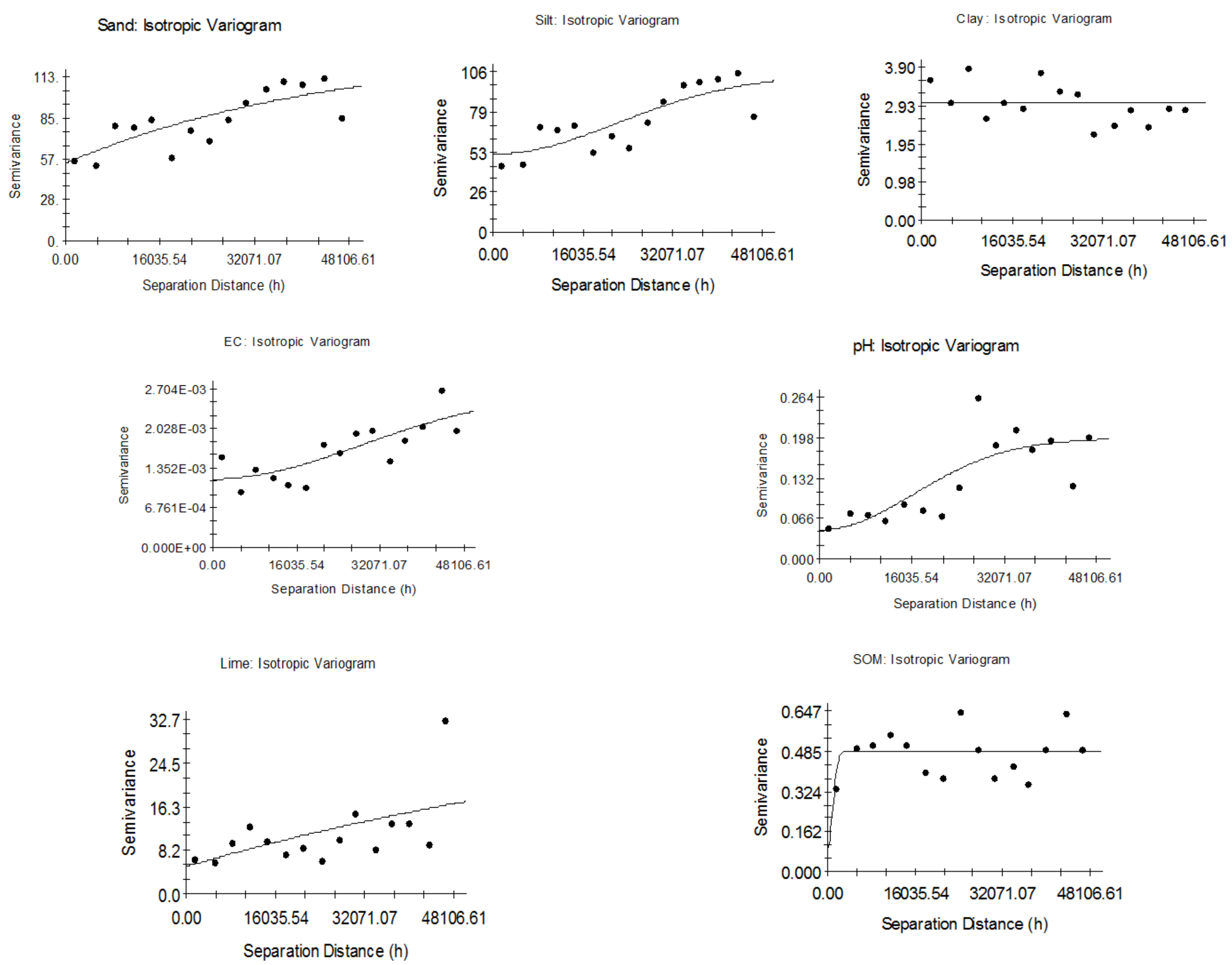

Figure 3. Spatial distribution pattern of soil properties across the sampling sites

Interpolation and mapping of selected soil properties

The following maps shows sampling points of the whole district and Agriculture Research Station, Chitral (Figure 4). Soil sample were collected from 103 selected areas started from April to May 2014. Arc GIS 9.3 and other necessary statistical software were used for evaluating spatial variability pattern, mapping and classification of various soil parameters.

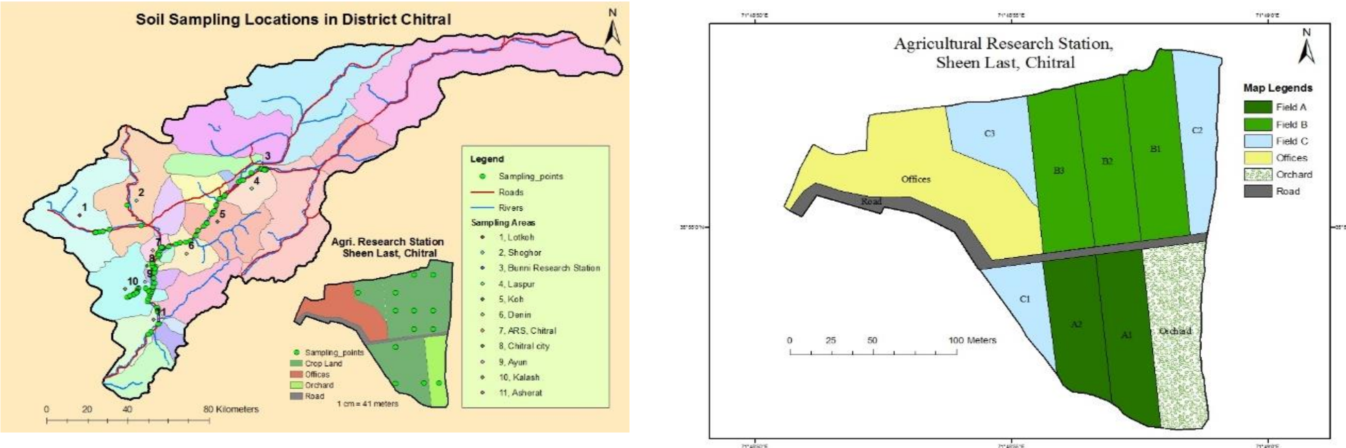

Figure 4. Maps showing sampling points in Agriculture Research Station and whole district including various rivers, settlement and roads

Map distribution regarding soil fractions in the areas shows that comparatively high clay was found in northern and north eastern parts of the district while low were found in northwestern parts (Figure 5). Sands contents was comparatively high in northwestern parts while comparatively low northeastern parts which could be associated to high altitude and slope lands.

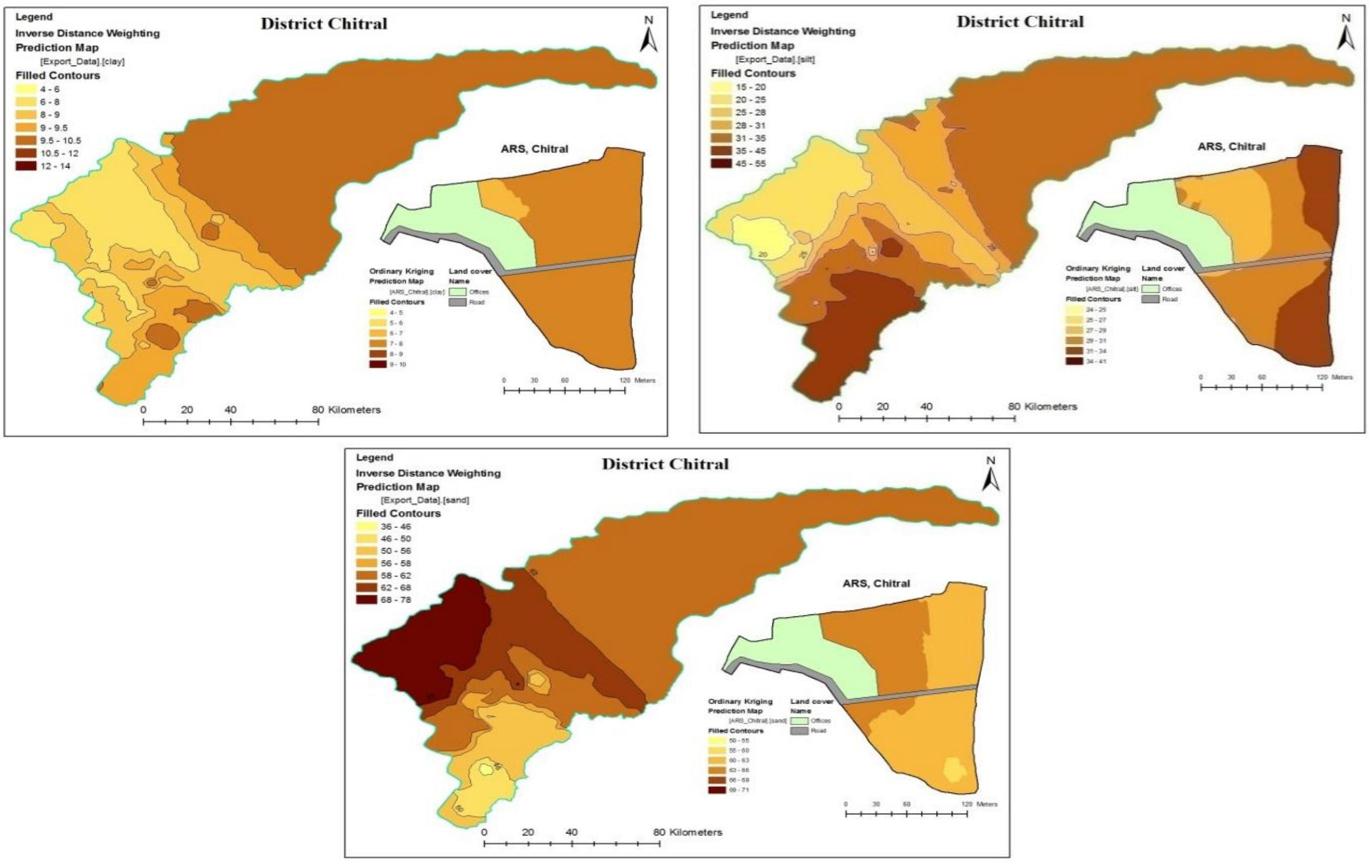

Figure 5. Map showing of soil fractions (clay, silt and sand)

Town and central areas are mostly alkaline in nature. On basis of valleys, Garam Chashma and south-western parts had low pH comparatively to the lower lands, which could be attributed to higher rainfall at higher altitude. The higher pH in a range of > 8.0 was found in the across the mid line and near to the city. Similarly, Orchard field in ARS, shows comparatively higher pH than the other fields. Most of the areas did not show salinity problem but comparatively higher values were found in central and north-eastern parts of the districts while minimum in extreme north-western side (Figure 6).

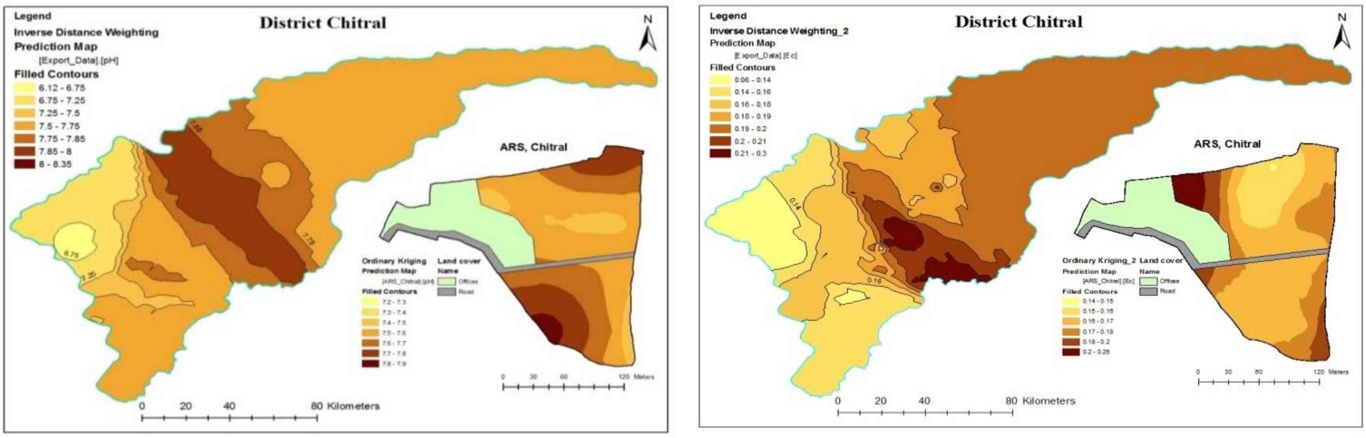

Figure 6. Map showing soil pH and EC (dSm^{-1})

Lime and organic matter content are comparatively high in central parts and northern areas than the other sitess (Figure 7). Lime content was low in north-western areas of district Chitral. In ARS the lime was higher in central areas while the soil organic matter was high in orchard while low in crop land area.

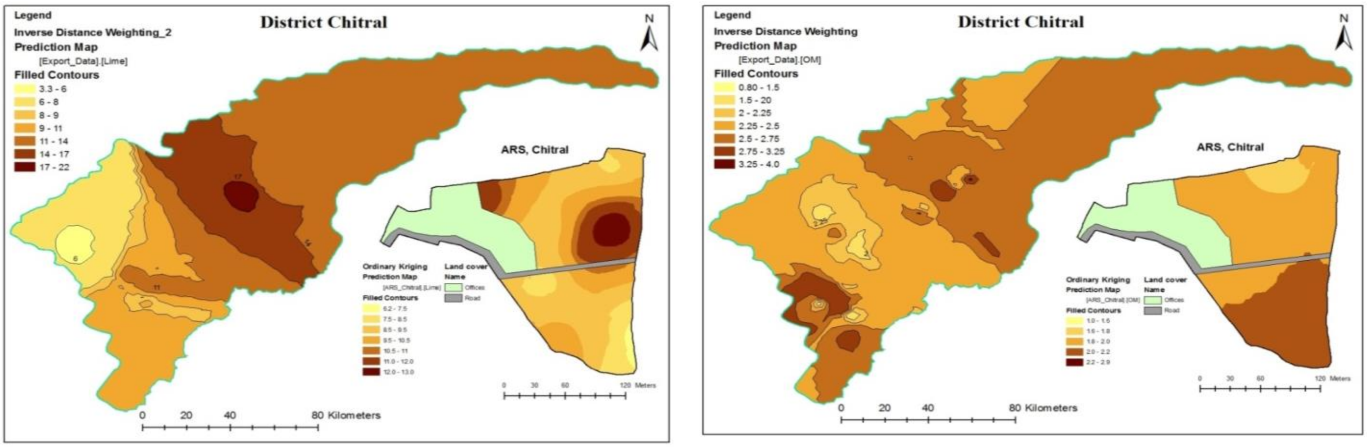

Figure 7. Map showing soil lime and organic matter (%) contents

Discussion

Descriptive statistical analysis of soil properties

Comparing the variation in different valleys of the area, upper areas like Garam Chashma valley had coarser soils than the lower areas like Chitral Town, Ayun and Drosh. The drift from coarser to fineness in soil separate toward down the slope in hilly areas was reported by Charan et al. (2013) whereby the clay and silt fraction showed negative while sand showed positive correlation with altitude. However, this variation between the upper and lower areas in the valley was smaller and all the soils in the area irrespective of location were coarser in nature. Such soils are prone to runoff losses and hence measures should be taken to control both water and wind erosion.

The soil pH may vary with soil organic matter, lime content, precipitation and natures of parent soil materials as discussed by Mellbye (1988) and Rastija (2007), which are influenced by the elevation and climatic conditions of the area and as such not a single factor could be responsible for pH changes in the given area. For examples, Boni which is also at higher altitude but still have alkaline pH which could be associated to higher lime and low rainfall in the area as compare to Garam Chashma or Bumburate areas.

Low electrical conductivity in the area would be due to sandy soil and high leaching process that removed the salts from surface soil. Low saline soil would also be due to irrigation of field with good quality of water that could wash away the surface salts into deeper zones as discussed by Friedman (2005). Again the Garam Chashma had lower EC than low lying areas that showed close correlation with soil fraction. However other factors like irrigation water and precipitation could also affect. The Ayun area which is finer in texture than other areas and also is low lying area but because of frequent irrigation with good quality water most of salts leach down from root zone and hence had lower EC than upper lying Boni area in contrast. It is common phenomenon that, high temperature and dry regions lead to accumulation of salts in surface soil.

The natural factors governing variation in soil lime content include evaporation, precipitation, runoff and leaching losses and parent material (Ou et al., 2017; McLean., 1982) and as such a single pattern could not assign to its variation in the study areas. The high lime content is useful to maintain basic salts concentration in these areas and also may act as cementing agent to coagulate soil materials and help them to resist losses with runoff water. However on other hand, this high lime content is responsible for alkaline pH in the area.

The decrease in temperature reduces the oxidation rate and as a result whatever the organic materials added to soils stays in the soil for longer periods and hence shows comparatively more organic matter than other similar but hot areas. This was corroborated by the fact that organic matter increased with altitude. Comparing the different valleys, Bumburate valley showed higher organic matter content with mean value of 2.87%. This valley is at high altitude with cooler climate and more vegetation than other parts of the district. However only the altitude could not be responsible for higher organic matter other factors like addition of organic fertilizers to soils and agronomic practice also largely influence the organic matter content of soil. For example Ayun area which is comparatively plain and is down hill area but had higher organic matter contents than Boni and Garam Chashma valleys that might be associated with agricultural practices.

Spatial variability and geostatistical analysis

Soil separates showed weak to moderate spatial pattern indicating that they varied independently at each location. The weakest was among the clay contents with nugget-sill ratio of 100 % whereas the sand and silt showed moderate spatial distribution with nugget-sill ratio of 39.91 and 49.57% and r^2 of 0.622 and 0.663, respectively. Clay, silt and sand were best expressed by linear, Gaussian and Exponential models, respectively. Soil pH was best fit by Gaussian model and it was strongly spatially distributed with nugget-sill ratio of 24%. EC was also expressed by best fit of Gaussian model but it was moderately spatially distributed with nugget-sill ration of 44.49 %. Lime showed strong spatial distribution among the sites in district Chitral having nugget-sill ratio of 14.08%. Such strong spatial distribution of lime could be associated with soil formation factors and parent materials that remain comparatively similar for adjoining sampling sites. Organic matter also showed strong spatial distribution with best fit to Gaussian model and nugget-sill ratio of 19.58 %. The range for spatial distribution for lime was comparatively higher than organic matter.

Interpolation and mapping

The prepared maps, classified tables and figures for various physico-chemical properties were thought to have a good use for soil resource management, enhancing agriculture production and for as guide line for further research in the area.

Higher amount of sand contents in higher altitude could be attributed to rapid weathering and disintegration of rocks such as shale, granite and limestone etc. The rainwater might run away the surface soils to the lower lands. Continuous cultivation and application of fertilizer in ARS, farm made the soil very productive. Moderate calcareous and low pH in higher altitude like Garam Chashma valley could be associated with climatic condition like high rainfall, low temperature and high organic matter contents. As shown in the map that low electrical conductivity in most of the area would be due to sandy soil and high leaching process that removed the salts from surface soil. In plain areas, low saline soil would also be due to irrigation of field with good quality of water that could wash away the surface salts into deeper zones. It was further confirmed that areas at higher altitude were low EC than lower lands due to coarse texture soil. It is common phenomenon that, high temperature and dry regions lead to accumulation of salts in surface soil. Maps were prepared that visually described the distribution of each parameter that could be easily understood and used by researcher, farming community and policy makers and other stack holders.

Conclusion

From the analysis it is concluded that soils of district Chitral were dominantly coarse in texture, alkaline in reaction, non-saline, moderate to highly calcareous and contained comparatively highly higher organic matter than other low lying areas of the country. Clay had poor but silt and sand had moderate spatial dependence (nugget-sill ratio, 25-75%). Soil lime, organic matter content, pH and EC had strong spatial dependence (nugget-sill ratio, <25%). These distributions were fit into different models including linear, exponential and Gaussian based on smallest nugget value, MPE close to 0 and RMSSPE close to 1. Maps were developed that visually described the distribution of each parameter that could be easily understood and used by researcher, farming community and policy makers and other stack holders. Such maps should be developed for other areas of the country with focus on more other parameters to manage and safeguard food and environment security.

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References

Baber, K., Khattak, R.H., Hakeem., 2004. Physico-chemical characteristics and fertility status of Gilgit soils. *Journal of Agricultural Research* 42 (3-4): 305-312.

Bhatti, A.U., Mulla, D.J., Frazier, B.E., 1991. Estimation of soil properties and wheat yields on complex eroded hills using geostatistics and thematic mapper images. *Remote Sensing of Environmen*t 37(3): 181-191.

Bouyoucos, G.J., 1936. Directions for making mechanical analysis of soils by the hydrometer method. Soil Science 42(3): 225–230.

Caers, J., 2005, Petroleum Geostatistics, Society of Petroleum Engineers. 88p.

Cambardella, C.A., Moorman, T.B., Parkin, D.L., Karlen, J.M., Novak, Turco, R.F., Konopka, A.E., 1994. Field-scale variability of soil properties in central Iowa soils. *Soil Science Society American Journal* 58 (5): 1501–1511.

Charan, G., Bharti, V.K., Jadhav, S.E., Kumar, S., Acharya., Kumar, P., Gogoi, D., Srivastava, R.B., 2013. Altitudinal variations in soil physico-chemical properties at cold desert high altitude. *Journal Soil Science and Plant Nutrition* 13(2): 267-277.

Friedman, S.P., 2005. Soil properties influencing apparent electrical conductivity: a review. *Computers and Electronics in Agriculture* 46(1-3): 45-70.

Hood, R.C., 2001. The effect of soil temperature and moisture on organic matter decomposition and plant growth. *Isotopes in Environmental and Health Studies* 37(1): 25-41.

Johnston, A.E., Goulding, K.W.T., Poulton. P.R., 1986. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. *Journal of Soil Use Management* 2 (1): 3-10.

McLean, E.O., 1982. Soil pH and lime requirement. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp.199-224.

Mellbye, M., 1988. The effect of surface liming on soil pH and calcium. Handout, Soil Acidity and Liming Symposium, Oregon State University, Corvallis, USA.

Mulla, D.J., Bhatti, A.U., Kunkel, R., 1990. Methods for removing spatial variability from field research trials. In: Advances in Soil Science, Singh R.P., Parr J.F., Stewart B.A. (Eds.). Vol 13, Springer, New York, USA. pp. 201-213.

Nazif, W., Perveen, S., Saleem, I., 2006. Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). *Journal of Agriculture and Biological Science* 1(2): 35-40.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, A.L. Page, R.H. Miller, D.R. Keeney (Eds.), 2nd Ed. Agronomy Monograph No. 9, ASA-SSSA, Madison, Wisconsin, USA. pp.539–573.

Olea, R.A., 1999. Geostatistics for Engineers and Earth Scientists. Kluwer Academic Publishers 324p.

Ou, Y., Rousseau, N.A., Wang, L., Yan, B., 2017. Spatio-temporal patterns of soil organic carbon and pH in relation to environmental factors—A case study of the Black Soil Region of Northeastern China. *Agriculture, Ecosystem and Environment* 245: 22-31.

Rashid, A., Rafique, E., Bughio, N., 1994. Diagnosing boron deficiency in rapeseed and mustard by plant analysis and soil testing. *Communication in Soil Science and Plant Analysis* 25(17-18): 2883-2897.

Rashid, M., Bhatti, A.U., 2005. Mapping of spatial variability of macro and micronutrients for site specific management. *Soil and Environment* 24 (1): 34-52.

Rastija, M., Banaj, D., Markoviš, M., 2007. Influences of liming on nutritional status of soil. *Cereal Research Communications* 35 (2): 981-984.

Richards, L.A., 1954. Diagnosis and improvement of saline and alkali soil. U.S. Salinity Lab. Staff, U.S. Department of Agriculture, Agricultural Research Service, Handbook 60. Washington D.C. USA. 160p.

Risser, P.G., 1991. Long-term Ecological Research: An International Perspective. Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). Wiley, New York. USA. 294p.

Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M., Safdar, E., 2008. Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany* 40 (1): 275-282.

Wasiullah, Bhatii, A.U., 2007. Physico-chemical properties of soils of Kohat and Bannu Districts NWFP Pakistan. *Journal of the Chemical Society of Pakistan* 29(1): 20-25

Wollum, A.G., Cassel, D.K., 1984. Spatial variability of Rhizobium japonicum in two North Carolina soils. *Soil Science Society of American Journal* 48(5): 1082-1086.

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An investigation of mercury distribution in the soils around gold mining area at Dar-Mali locality, river Nile State, Sudan

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Abstract

An artisanal gold mining region located in North of Atbara (Dar-Mali locality), River Nile State, Sudan (17.82289 to 17.82389N and 33.99974 to 34.02127E) has been studied with the aim to evaluate the soil contamination with mercury (Hg) using two parameters; (i) Comparison of the Hg concentration with the mean concentrations in world soils, (ii) Enrichment Factor (EF). The results revealed that, the concentrations of the Hg are varying in the studied area and the highest concentrations were obtained inside the mining basins used for gold extraction (2.62 mg kg^{-1} soil) it is around 29 times more than mean Hg concentration in world soils, while the lower concentrations are found at recent Nile River terrace (0.10 mg kg^{-1} soil). The results also indicated that the soil samples collected from inside mining basins had a highest E.F value (352.84) that means, this site must be closed and remediation process should be started immediately. While the E.F value of recent Nile River terrace site was 8.74, means, all studied sites have significant contamination with Hg. The mobility of Hg may have influenced by northeast wind, or water runoff from mining zone to nearest areas at same wind direction or water flow direction.

Keywords: Sudan, River Nile State, Hg concentration, gold mining, enrichment factor, mining basins.

Introduction

Soil is not only a medium for plants growth or waste disposal but also a transmitter of many pollutants to surface water, ground water, atmosphere and food. Soil pollution may threaten human health not only through its effect on hygiene quality of food and drinking water, but also through its effect on air quality (Wong, 1996).

Informal gold mining constitutes an important source of income for many people in Africa, Southeast Asia and China. this growing industry employs more than 10 million people around the world, and there is a generalized environmental menace to human health because most of the gold is extracted by Hg amalgamation, leading to Hg contamination of the ecosystems by releasing more than 650.000 tons of Hg annually (Olivero and Solano, 1998; Guedron et al., 2009).

Mining has been identified as one of human activities, which can have a negative impact on the environment quality (Donkor et al., 2005). It causes the destruction of natural ecosystems through removal of soil and vegetation and burial beneath waste disposal sites funeral (Cooke and Johnson, 2002). Mining waste can be divided into two categories: (i) mine tailings, generated during processing of the ore, and (ii) waste rock produced when uncovering the ore body (Ledin and Pederse, 1996).

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Mercury (Hg) is consider an important pollutant due to its global distribution, bioaccumulation and toxicity (Yin et al., 2014), soils can accumulate up to 75% of the Hg present in the biosphere (Mason and Sheu, 2002), mostly as a result of the affinity of Hg for soil organic matter and Al and Fe (Schuster, 1991; Skyllberg et al., 2006). Hg is a very toxic and insignificant element of life. Nevertheless, elemental Hg and its compounds are highly volatile and can easily migrate to environments that enter the food chain, which can cause irreversible damage to people and animal life, the risk for mercury exposure is significant, elemental mercury exposure can be toxic to multiple organ systems, including the nervous and dermatologic systems (Fernandes et al., 2012).

The Hg is widely used for the gold extraction in our study area, so, a high concentration of it are expected will be found in the mining zone and other adjacent areas at same wind direction or water flow direction in the study area. The main objectives of this study were to assessing the distribution of Hg in soils around gold mining area with the hypothesis that it could be leaching from tailings and deposition at mining area to nearest locations at Dar-Mali locality, River Nile State, Sudan, this study also aim to investigate the effect of vicinity and distance from mining zone on concentration of Hg in the study area.

Material and Methods

The investigated area is located at North of Atbara city, River Nile State, Sudan, with an altitude of (336-358 meters) above sea level. The studied area covered around 10.0 km^2 and it is located within coordinates of 17.82289 to 17.82389N and 33.99974 to 34.02127E Fig1 The study area falls within the arid climatic zone. The average annual rainfall varies from 0 to 100 mm. the mean maximum temperature of the hottest months (May and June) is 43˚C. The mean minimum temperature of the coldest month (January) was less than 13˚C. The mean annual relative humidity ranges between 15 to 21% (January to February), and less than 15% (March to June). The predominant natural vegetation consists of the following species; Tundub (*Capparis decidua*), Seyal (*Acacia tortilis*), Usher, Musket (*Prosopischilensis*), Heglig (*Balanitesaegypiaca*) and Seder (*Zizyphusspina-christi*). The calculated soil temperature regime is hyperthermic and soil moisture regime is aridic (Elfaki et al., 2015). The soils of the study area belong within Entisols and Aridisols orders (USDA, 2014a).

Twenty soil samples were collected from different sites around gold mining area at Dar-Mali locality, (Table 1). At each site, approximately 5kg of soil sample was collected from the depth of 0-30cm using an auger and kept in a cloth bag. Each sample was labeled with; collected data, site coordinates, sample number, then, subjected to physical and chemical analyses at the soil laboratories.

Table 1. Geographical coordinates, elevation, and texture class of the study sites

No	Descriptive Locations	Geographical coordinates		Elevation	Texture
		N	E	(m ASL)	Class
1	Instructional farm (Nile Valley University)	17.82289	34.02127	356	Silt loam
2	Instructional farm, Nile Valley University	17.82283	34.02044	354	Silt loam
3	Instructional farm, Nile Valley University	17.82062	34.0203	351	Silt loam
4	Instructional farm, Nile Valley University	17.82044	34.02142	353	Silt loam
5	Near wells of the instructional farm	17.82214	34.02237	358	Loamy sand
6	Farm near mining mills	17.82503	34.01473	354	Loamy sand
7	Outside the farm in the mining zone	17.82503	34.01473	354	Sandy Loam
8	Outside the mills in mining zone	17.82578	34.01468	356	Sand
9	Outside washing basin and the gold extraction	17.82288	34.01498	352	Sandy Loam
10	Outside washing basin and the gold extraction	17.82288	34.01498	352	Loamy sand
11	Outside washing basin (red color)	17.82145	34.01407	351	Sandy Loam
12	Inside washing basin (red color)	17.82145	34.01407	351	Loamy sand
13	Middle of mining zone	17.82167	34.01612	357	Sandy Loam
14	Farm near mining zone	17.82483	34.00957	351	Sandy Loam
15	Recent Nile River terrace	17.81779	33.99229	349	Sandy Loam
16	Recent Nile River terrace	17.81779	33.99229	349	Silt loam
17	Inside Residential zone	17.81763	33.99478	351	Sandy Loam
18	Inside Residential zone	17.82344	33.99523	352	Sandy Loam
19	Inside Agric. College (Nile Valley Uni.)	17.82389	33.99974	356	Sand
20	Inside Agric. College (Nile Valley Uni.)	17.82389	33.99974	356	Sand

In order to calculate to the distances between mining zone and other studied areas which may affected by Hg pollution which used in mining zone for extraction of gold, Sinnott, (1984) equation Eq. (1) was used to convert the longitudes and latitudes coordination to distances. Then, the Sigma plot v12 software was used to draw the distribution of Hg concentration to all studied areas.

$$\Delta\hat{\sigma} = 2\arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\phi}{2}\right) + \cos\phi_s\cos\phi_f\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right)$$

Where	$\Delta\sigma$	Interior Spherical Angle
	$\Delta\phi$	Latitude1 - Latitude2
	ϕ_s	Latitude1
	ϕ_f	Latitude2
	$\Delta\lambda$	Longitude1 - Longitude2

Eq. (1) Sinnott, (1984) equation used to calculate the distance between two points.

Enrichment factor (EF)

The enrichment factor (EF) was calculated using Dragovic et al. (2008) formula

$$EF = (\left(\frac{C_x}{C_{Fe}}\right) sediment)/(\left(\frac{C_x}{C_{Fe}}\right) Earth's crust)$$

Eq. (2) Dragovic et al. (2008) Enrichment factor formula

Where;

(C_x/C_{Fe}) sediment = the concentration of an element / the concentration of Fe in the sample (C_x/C_{Fe}) earth's crust = concentration of a metal in the earth crust /the concentration of Fe in the earth crust.

Dragovic et al. (2008) classified the EF in to classes as the following scale; EF (2-5) is moderate contamination, EF (5-20) means significant contamination, EF (20-40) high contamination and EF (>40) classified as very high contamination.

Figure 1. Google map image of study area

Determination of soil properties

In the laboratory, soil samples were air-dried (25± 2°C) and passed through 2 mm mesh sieve to obtain the fine earth fraction. The particles-size distribution of the soil samples was determined using pipette method which was recommended by Elfaki et al. (2016b), and the textural class was obtained by using the USDA textural triangle according to (USDA, 2014b). Soil pH was measured in 1:5 soil suspensions using a digital pH meter Jenway Model 3510, The electrical conductivity (EC dS/m at 25˚C) was determined in 1:5 soil extract using a conductivity meter Jenway (Model 4510), Calcium carbonate percent was estimated by Calcimeter which recommend by Elfaki et al. (2016a).

Determination of Hg in the soil samples

Microwave digestion oven model (CEM Mars 5) was used to digest soil samples, 1gram of air-dried soil was used after a well-milling, and then placed in a microwave oven pipes. A 10ml aliquot of nitric acid was added to each pipe containing soil sample and well closed, then placed into the microwave oven, and digested using (EPA-3051A) method described by (Link et al., 1997). After samples digestion, extracted samples were transferred quantitatively into 100 ml volumetric flask and the volume was completed by deionized water to the mark. All digested samples were filtered using filter paper (Whatman No. 42) and then transferred to

(Perkin Elmer 350D ICP mass spectrometer) after standard curve was prepared from different concentrations (1 ppb, 5 ppb, 10 ppb, 25 ppb, 50 ppb, 100 ppb) of Hg in order to achieve accurate results of Hg concentration at ppb levels.

Results and Discussion

General characteristics and topography of the study area

Highest elevation in the study area was recorded at the instructional farm for Agricultural College (358m ASL) and lowest elevation recorded at recent Nile River terrace (349m ASL), which means the study area was completely slopes towards the River Nile. That may increase the risk of pollutants to transfer from mining zone towards the River Nile (especially at raining season) or via wind through transition and sedimentation processes. The descriptive and geographical locations, textural classes, calcium carbonate percentage of all sites were presented in (Table 2). The soil texture ranged from sandy loam at the recent terrace, silt loam at the second instructional farm - Nile Valley University (NVU).

Table 2. Some soil physico-chemical properties of the study area

Site	Rate	pH	EC, dS m^{-1}	$CaCO_3$, %	Sand, %	Silt, %	Clay, %	Dominant Textural Class
Instructional farm (NVU)	Max	8.73	4.57	7.4	52.57	61.14	6.66	
	Min	7.86	0.15	2.75	32.61	41.57	5.49	Silt loam
	Average	8.26	1.06	4.78	39.44	54.61	5.95	
Faculty of Agriculture (NVU)	Max	8.80	0.57	3.44	87.99	12.13	1.75	
	Min	8.35	0.46	2.58	86.12	11.78	0.23	Sand
	Average	8.58	0.51	3.01	87.06	11.96	0.99	
Inside Residential area	Max	8.80	4.64	4.64	58.07	37.78	12.00	
	Min	8.15	2.58	2.58	56.00	32.0	4.16	Sandy loam
	Average	8.48	3.61	3.61	57.04	34.89	8.08	
Mining area	Max	8.68	0.19	10.32	86.79	49.96	64.33	
	Min	8.19	0.09	3.44	7.32	13.24	5.74	Sandy loam
	Average	8.48	0.13	5.59	52.38	30.87	20.95	
Recent Nile River terrace	Max	8.42	0.25	5.5	48.38	62.98	31.41	
	Min	8.01	0.23	4.47	5.61	47.77	3.85	Silt loam
	Average	8.22	0.24	4.98	26.99	55.38	17.63	
Outside gold extraction basins	Max	8.76	20.9	6.02	77.8	37.21	9.85	
	Min	7.46	0.14	2.58	57.21	20.53	1.66	Sandy loam
	Average	8.15	7.43	4.3	62.65	31.55	5.80	
Inside gold extraction basins	Max	8.11	0.41	ND	81.48	20.53	1.66	
	Min	-	-	ND	77.8	18.28	0.24	Loamy sand
	Average	-	-	ND	79.6	19.41	0.95	

Soil properties of study area

Table 2 shows the soil physio-chemical properties, the soil reaction at the study area was varied from alkaline to strongly alkaline according to Marx and Stevens (1999), with a pH values ranged from 7.46 to 8.8. The composite sample taken from outside washing basin showed least value of soil reaction (pH 7.46). This could be due to the washing of soil bases through mining process and their later removal during gold extraction. The EC values ranged from 0.13 to 20.9 dS m^{-1}, suggesting non-saline to extremely saline conditions at different sites according to Rhoades (1996). The content of the calcium carbonate (%$CaCO_3$) was varied in all sites from non-calcareous to moderately calcareous according to FAO (2006) guidelines, while $CaCO_3$ was disappeared inside gold extraction basin (Figure 2), this could be due to possibility of dissolution and transportation of $CaCO_3$ inside soil depths via washing water. the dominant texture of the studied sites was sand fraction (up to 87.99 %).

Mobility and distribution of Hg in soils of the study area:

According to table3, which present the maximum, minimum, and mean of Hg concentrations (mg kg^{-1} soil) in the soils of the study area. The highest concentrations were obtained at the mining zone particularly inside gold extraction basins (2.62 mg kg^{-1} soil), and the minimum concentrations were found at recent Nile River terrace (0.10 mg kg^{-1} soil). Generally, the Hg concentration in the study area were rated as to following sequences; Inside gold extraction basin s> Outside gold extraction basins > around gold mining zone > Instructional farm (Nile Valley University) > Inside residential zone> Agricultural college (Nile Valley University) > Recent Nile River terrace.

Figure 2. Gold extraction basin

Table 3. Maximum, minimum and mean concentrations of Hg in the study area

Sites		Hg Concentrations (mg kg^{-1} soil)
Instructional farm (Nile Valley University)	Max	0.10
	Min	0.21
	Mean	0.16
Agricultural College (Nile Valley University)	Max	0.31
	Min	0.26
	Mean	0.29
Inside Residential zone	Max	0.65
	Min	0.13
	Mean	0.39
Around gold mining zone	Max	1.32
	Min	0.31
	Mean	0.90
Recent Nile River terrace	Max	0.21
	Min	0.10
	Mean	0.16
Outside gold extraction basins	Max	1.52
	Min	0.65
	Mean	0.97
Inside gold extraction basins	Max	2.62
	Min	1.02
	Mean	1.82

Comparing the mean of Hg concentrations in studied sites with the mean of Hg concentrations in world soils (0.09 mg kg^{-1} soil), all studied sites are above of Hg concentration in the world soils even in recent terrace site (0.16 mg kg^{-1} soil) it is near to couple times more. While comparing between Hg concentrations inside gold extraction basins at mining zone (1.82 mg kg^{-1} soil) with the mean concentrations in world soils, it is more than 20 times more! That means that site must be closed and remediation process should be started immediately. However, the average concentration of total Hg in study area was lower than concentrations found in some gold mines around the world such as Almadén (Spain). Where Hg soil concentrations were found ranging between 0.13 and 2695 mg kg^{-1} (Molina et al., 2006); Idrija (Slovenia) and in alluvial soils range between 0.595 and 1970 mg kg^{-1} (Gosar and Žibret, 2011) or Wanshan (China) with total Hg contents in soils ranging between 5.1 and 790 mg kg^{-1} (Horvat et al., 2003). This may be attributed due to the fact the gold mining in the study area was started recently before 5 years ago.

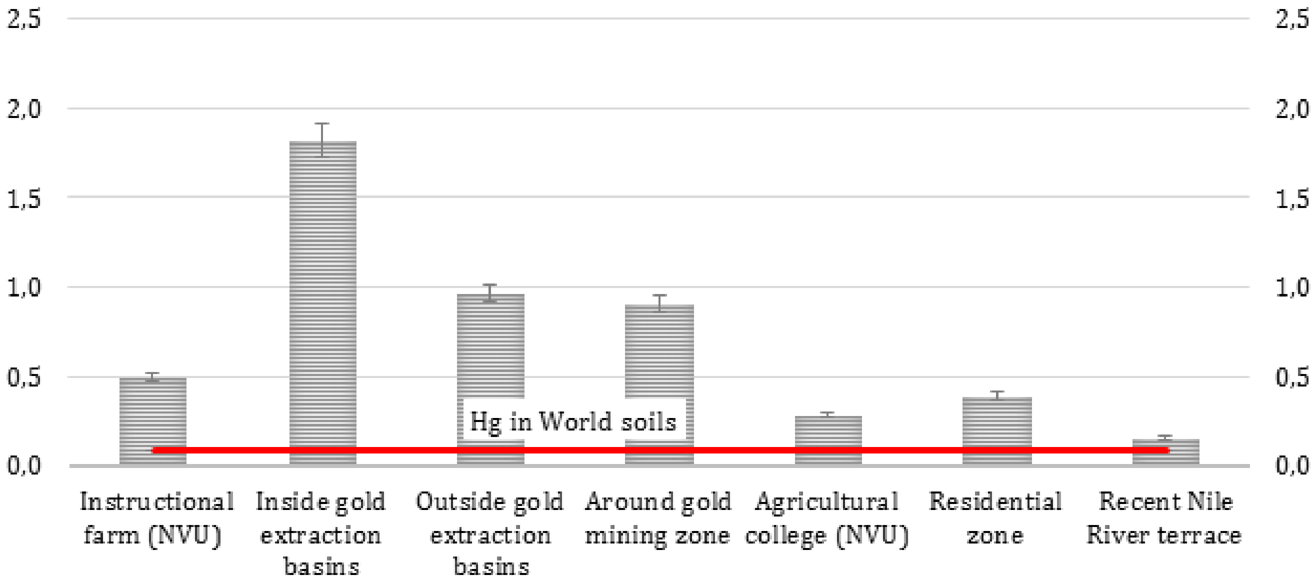

Figure 3. Hg concentrations (mg kg^{-1}) in studied sites comparing with world soils

Use of Enrichment factor (EF) to assess the Hg concentration in the study sites:

According to Dragovic et al. (2008) classification, the EF value at studied sites were ranged from 8.7 – 352.8 (Table 4), that means there is a significant contamination even at the recent Nile River terrace site (E.F 8.74) although, this area are renewed annually by transition and precipitation process from Nile River. The high contamination are classified in %71 of studied sites, whereas the highest EF value are observed inside gold extraction basins (E.F 352.84).

Table 4. EF values in studied sites

Studied sites	EF
Recent Nile River terrace	8.740273
Residential zone	33.22241
Agricultural college (NVU)	23.63295
Around gold mining zone	83.44194
Outside gold extraction basins	107.1644
Inside gold extraction basins	352.8417
Instructional farm (NVU)	41.15672

When distribution of Hg in studied sites was drawn using sigmaplot v12 software (Figure 4). We found that the distribution of Hg ranged from mining zone (highest concentration of Hg) to southwest sites, this agreed by Ali et al. (2017) when studied the distributions of heavy metals in the same area, they interpreted that this was due to transition of pollutants via northeast wind, from mining zone to nearest areas at same wind direction.

On other hand, the distribution of Hg in our study looks like the distribution of the lead (Pb) in Ali et al. (2017) study (Figure 5), where they studied the distribution of some heavy metals in the same area, this may be due to non-purity of Hg which used in gold extraction Figure 6, this hypothesis was supported by the ability of Hg to dissolve other metals like lead. This will be done by rubbing lead filings with Hg in a mortar or by pouring molten lead into Hg; this amalgam has no definite composition. It possesses a brilliant gray color and remains liquid with as much as 33% of lead and 67% Hg although, lead is less dense than Hg (density of Pb is 11.340 kg/m^3 and density of Hg is 13.534 kg/m^3) (Mortazavi and Mortazavi, 2015). Finally, it was noticed that the appearance of Hg which using by miners it is seem mixed by other minerals, the one of it might be Pb.

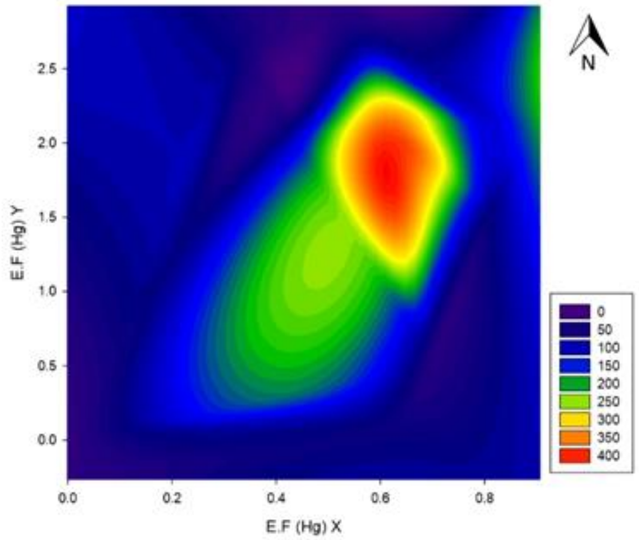

Figure 4. Hg distribution in studied area based on EF values (red color is the center of mining zone).

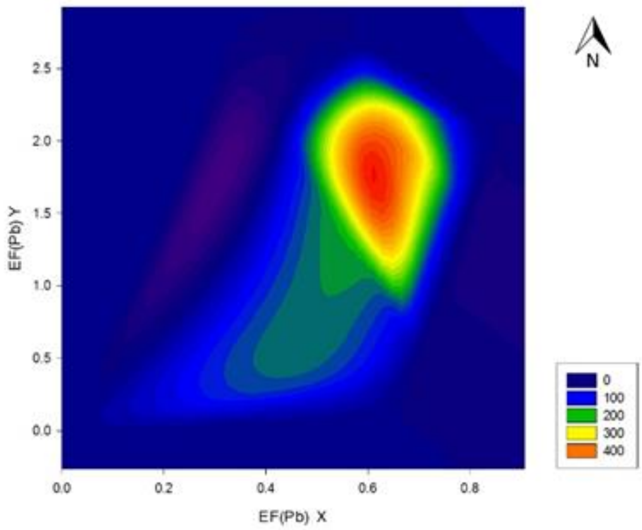

Figure 5. Distribution of Pb pollution in the study area based on EF values (red color is the center of mining area).

Figure 6. Utilization of Hg in gold extraction processes in the mining area.

Conclusion

After studied the mobility and distribution of Hg in soils around gold mining area at Dar-Mali Locality, River Nile State, it can be concluded that the Hg concentration in all sites are above the mean concentration of Hg in world soils. In addition, the distribution of Hg concentrations around the studied sites dispersed via northeast wind, from mining zone to nearest areas at same wind direction. Finally, the Hg concentrations inside gold extraction basins at mining zone (1.82 mg kg^{-1} soil) about 20 times more the mean Hg concentration in world soils! That means this site must be close and remediation possess should be stat immediately.

References

Ali, M., Elhagwa, A., Elfaki, J., Sulieman, M., 2017. Influence of the artisanal gold mining on soil contamination with heavy metals: A case study from Dar-Mali locality, North of Atbara, River Nile State, Sudan. *Eurasian Journal of Soil Science* 6(1): 28-36.

Cooke, J.A., Johnson, M.S., 2002. Ecological restoration of land with particular reference to the mining of metals and industrial minerals: a review of theory and practice. *Environmental Reviews* 10(1): 41-71.

Donkor, A.K., Bonzongo, J.J.C., Nartey, V.K., Adotey, D.K., 2005. Heavy metals in sediments of the gold mining ımpacted Pra River Basin, Ghana, West Africa. *Soil and Sediment Contamination* 14(6): 479-503.

Dragović, S., Mihailović, N., Gajić, B., 2008. Heavy metals in soils: Distribution, relationship with soil characteristics and radionuclides and multivariate assessment of contamination sources. *Chemosphere* 72(3): 491-495.

Elfaki, J.T., Gafer, M.A., Sulieman, M.M., Ali, M.E., 2016b. Hydrometer method against pipette method for estimating soil particle size distribution in some soil types selected from Central Sudan. *International Journal of Engineering Research and Advanced Technology* 2(2): 25-41.

Elfaki, J.T., Gafer, M.O., Sulieman, M.M., Ali, M.E., 2016a. Assessment of calcimetric and titrimetric methods for calcium carbonate estimation of five soil types in central Sudan. *Journal of Geoscience and Environment Protection* 4(1): 120-127.

Elfaki, J.T., Sulieman, M.M., Nour, A.M., Ali, M.E., 2015. Short-term changes in ınorganic nitrogen concentrations during storage at different temperatures of three different soils of the Nile River terraces, North of Sudan. *Advances in Environmental Biology* 9(24):397-402.

FAO, 2006. Guidelines for soil description, Fourth edition. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at [access date: 14.12.2017]: http://www.fao.org/3/a-a0541e.pdf

Fernandes, A.B., Barros, F.L., Peçanha, F.M., Wiggers, G.A., Frizera, V.P., Ronacher, S.M., Stefanon, I., 2012. Toxic effects of mercury on the cardiovascular and central nervous systems. *Journal of Biomedicine and Biotechnology* Article ID 949048

Gosar, M., Žibret, G., 2011. Mercury contents in the vertical profiles through alluvial sediments as a reflection of mining in Idrija (Slovenia). *Journal of Geochemical Exploration* 110(2): 81–91.

Guedron, S., Grangeon, S., Lanson, B., Grimaldi, B., 2009. Mercury speciation in a tropical soil association; consequence of gold mining on Hg distribution in French Guyana. *Geoderma* 153(3-4): 331-346.

Horvat, M., Nolde, N., Fajon, V., Jereb, V., Logar, M., Lojen, S., Jacimovic, R., Falnago, I., Liya, Q., Faganeli, J., Drobne, D., 2003. Total mercury, methylmercury and selenium in mercury polluted areas in the province Guizhou, China. *Science of The Total Environment* 304 (1-3): 231–256.

Ledin, M., Pedersen, K., 1996. The environmental impact of mine wastes – Roles of microorganisms and their significance in treatment of mine wastes. *Earth-Science Reviews* 41(1–2): 67–108.

Link, D.D., Walter, P.J., Kingston, H.M., 1997. EPA Methods 3015A and 3051A: Validation studies for updated microwave leach methods. Waste Testing & Quality Assurance Symposium (WTQA '97). July 6-9, 1997, Arlington, VA, USA. pp. 55-60.

Marx, E.S., Hart, J., Stevens, R.G., 1999. Soil test interpretation guide. Oregon State University Extension Service circular EC-1478. OR: Oregon State University. Corvallis, USA. Available at [access date: 14.12.2017]: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/14361/ec1478.pdf?sequence=3

Mason, R.P., Sheu, G., 2002. Role of the ocean in the global mercury cycle. *Global Biogeochemical Cycles* 16(4): 40–1-40-14.

Molina, J.A., Oyarzun, R., Esbrí, J.M., Higueras, P., 2006. Mercury accumulation in soils and plants in the Almaden mining district, Spain: one of the most contaminated sites on Earth. *Environmental Geochemistry and Health* 28(5): 487–498.

Mortazavi, G., Mortazavi. S.M.J., 2015. Increased mercury release from dental amalgam restorations after exposure to electromagnetic fields as a potential hazard for hypersensitive people and pregnant women. *Reviews on Environmental Health* 30(4): 287-292.

Olivero, J., Solano, B., 1998. Mercury in environmental samples from a waterbody contaminated by gold mining in Colombia, South America. *Science of The Total Environment* 217(1-2): 83-89.

Rhoades, J.D., 1996. Salinity: Electrical conductivity and total dissolved solids. In: Methods of Soil Analysis Part 3—Chemical Methods. Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H.(Eds.). SSSA Book Series 5.3. Soil Science Society of America, American Society of Agronomy, Madison, WI, USA. pp. 417-435.

Schuster, E., 1991. The behavior of mercury in the soil with special emphasis on complexation and adsorption processes - a review of the literature. *Water Air & Soil Pollution* 56(1): 667–680.

Sinnott, R.W., 1984. Virtues of the Haversine. *Sky and Telescope* 68(2): 159.

Skyllberg, U., Bloom, P.R., Qian, J., Lin, C.M., Bleam, W.F., 2006. Complexation of Mercury(II) in soil organic matter: EXAFS evidence for linear two-coordination with reduced sulfur groups. *Environmental Science and Technology* 40(13): 4174–4180.

USDA, 2014a. Keys to Soil Taxonomy. United States Department of Agriculture, Natural Resources Conservation Service, Available at [access date: 14.12.2017]: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1252094&ext=pdf

USDA, 2014b. Kellogg Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42, Version 5.0, United States Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Kellogg Soil Survey Laboratory, USA. Available at [access date: 14.12.2017]: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1253872.pdf

Wong, J.W.C., 1996. Heavy metal contents in vegetables and market garden soils in Hong Kong. *Environmental Technology* 17(4): 407-410.

Yin, R., Feng, X., Li, X., Yu, B., Du, B., 2014. Trends and advances in mercury stable isotopes as a geochemical tracer. *Trends in Environmental Analytical Chemistry* 2: 1–10.