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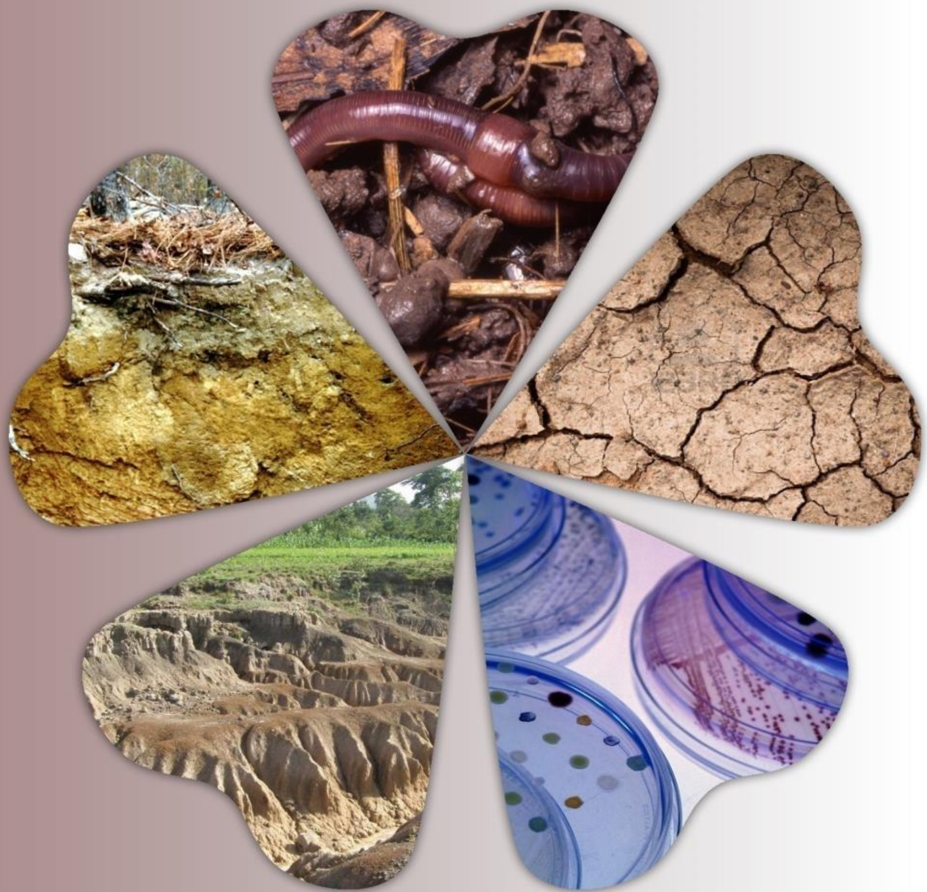

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Roles of soil biota and biodiversity in soil environment – A concise communication

Suleiman Usman [a]*, Yakubu Muhammad [b], Alhaji Maigana Chiroman [c]

[a] Department of Soil Science, Faculty of Agriculture, Federal University Dutse (FUD), Jigawa State, Nigeria
[b] Department of Soil Science, IBB University of Science and Technology, Lapai, Niger State, Nigeria
[c] Department of Soil Science, University of Maiduguri (Unimaid), Borno State Nigeria

Abstract

Soil biota (the living organisms in soil) plays an important role in soil development and soil formation. They are the most important component of soil organic matter decomposition and behave efficiently in the development and formation of soil structure and soil aggregate. Their biodiversity provides many functional services to soil and soil components. They help in dissolving verities of plant and animal materials, which could left as decayed organic matter at the surface soil. Understanding the vital role of soil organisms would undoubtedly helps to increase food production and reduces poverty, hunger and malnutrition. Soil biota and biodiversity research in sub-Saharan Africa would play an important role in sustaining food security, environmental health, water quality and forest regeneration. This paper, briefly highlighted some of the biological functions of soil biota and suggests that proper understandings of biota and their biodiversity in soil environment would provide ways to get better understanding of soil health, soil function, soil quality and soil fertility under sustainable soil management activities in agricultural production.

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Introduction

Soils and soil environmental studies require awareness about the immediate environment within the magnitude of the biological organisms' presence (Ritz et al., 2010). These studies may include the subject themes relevant to soil science and its components, crop science and sustainable economic developments, animal science and its husbandries, forestry and forest managements, fishery and its managements as well as environmental risk assessment. Therefore, knowledge of biological organisms is needed in many aspects of agricultural and environmental assessments (De Bello et al., 2010). Lack of access to this knowledge is a clear determinant of limited sound knowledge on what our global ecosystem is all about, and also a scientific challenge for new agricultural developments (Brussaard et al., 2010). These organisms or soil biota include the bacteria, actinomycetes, fungi and algae (the micro-flora); the protozoa and nematode (the micro-fauna); the collembolan, mites, termites, ants and other associated micro-organisms and meso-fauna and flora (Usman, 2013). They play a vital role in the soil and represent large function of global biodiversity and global ecosystem (FAO, 2005; Petchey and Gaston, 2006). Thus, providing a better understanding of the linkages

* Corresponding author.
Department of Soil Science, Faculty of Agriculture, Federal University Dutse (FUD), Jigawa State PMB 7156 Nigeria
Tel.: +2347034233241 E-mail address: labboallugu@yahoo.com
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between soil parent materials, plant community composition, forest regeneration, organic matter and diverse organisms in wider contrasting environments (Eskelinen et al., 2009; Loreau, 2010).

Generally, without vital recycling processes of soil organisms, the soil would become a stockpile of dead plant and animal materials with no facilities to reprocess essential nutrients such as carbon, nitrogen and phosphorus in soil ecosystem (Eskelinen et al., 2009). Thus, the conditions and maintenance of soil environment together with proper understanding of soil biota and their biodiversity are central to the role played by various microorganisms that live in agricultural soil environment (Brussaard et al., 2007). The role of these organisms in soil formation and development has been well documented (Jenny, 2009). However, their activities in soil environment and soil ecosystem functions have been considered the most important component of nutrient recycling and soil quality managements (Kramer and Gleixner, 2008; Culman et al., 2010; Usman, 2013). This indicates that the role of soil microbial community requires a vast understanding and an expanding study into proper appreciation of many aspects of soil environment. Therefore, the objectives of this paper are to provide a concise elucidation of the roles of soil biota and their biodiversity in the global soil development and soil transformation.

Soil biota and biodiversity – a way forward

From the perspective of soil scientists, soil biota is a general term refers to all soil organisms living and communicating in soil environment. Ritz et al. (2004) considered soil biota as the 'biological engine of the earth', – driving and transforming physical, chemical, biological and ecological processes in global soils. Soil biota are described as micro-, macro- and meso-biota. Bacteria and fungi are the major group of micro-biota and exist in numerous number in agricultural soil and grassland areas (Riesenfeld et al., 2004; De Vries et al., 2006). Their ranges were identified as the smallest in different sizes, extremely abundant and diverse, and able to decompose almost any existing natural material in soil (Figure 1).

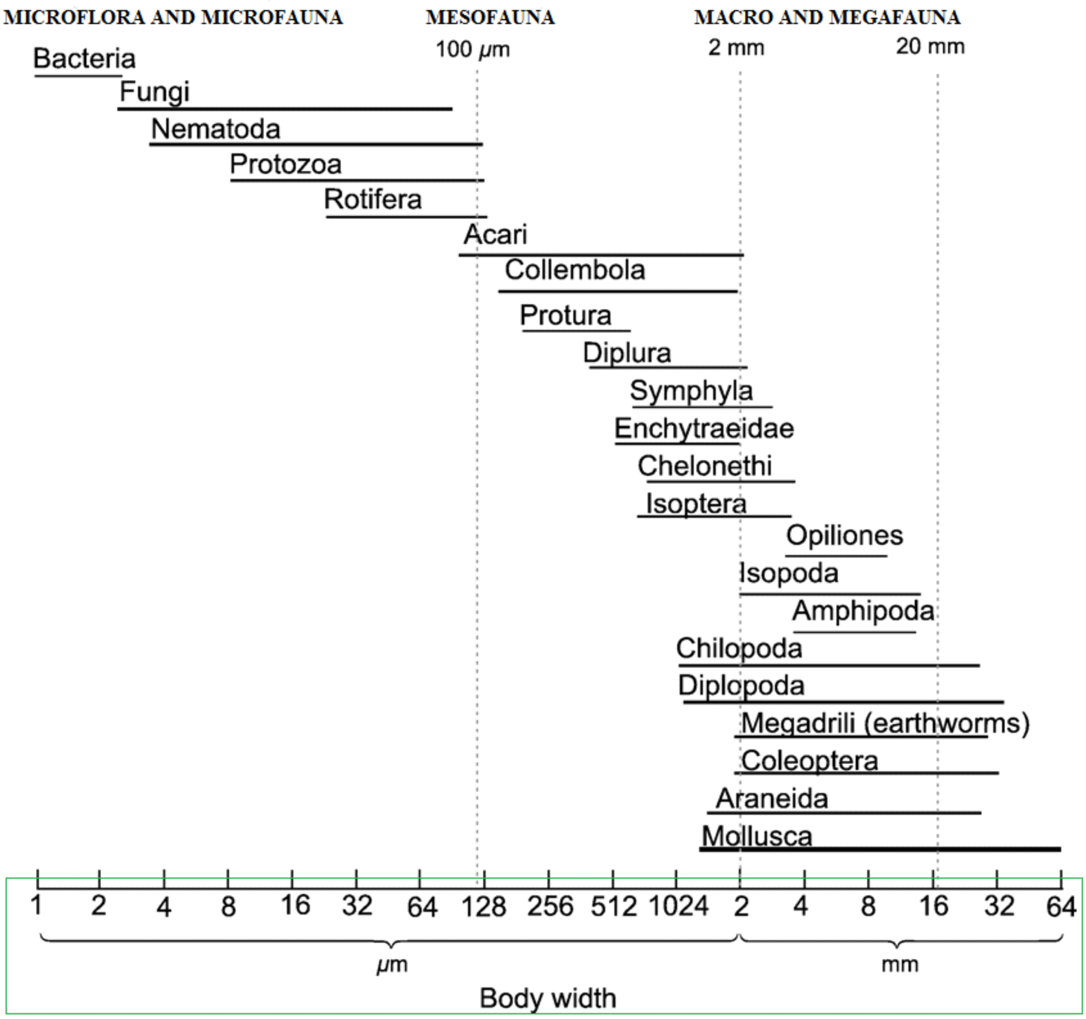
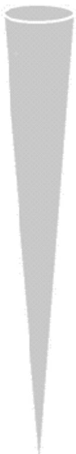


Figure 1. Size classification of soil organisms according to body width (Adapted and modified after Swift et al., 1979)

Soil macro and meso fauna are groups of biota that are also very important in soil medium. These organisms include the earthworms, termites, arthropods, millipeds, ants, moles, protozoa and nematodes (Coleman, 2001). They play a vital role in moving soil particles, transforming soil structure and enhancing soil moisture (Ritz et al., 2004). Earthworms are considered numerous and grouped into 23 families, 700 genera and many species (Usman, 2013). Termites are described as grass harvester, surface litter feeders, wood feeders and soil feeders 'humivores' (FAO, 2005); probably up to 10,000 species exist in soil medium (Coleman, 2001). Arthropods are grouped into Coleoptera which believe to cover 48% of the population followed by Acari and Formicidae species (FAO, 2005). Nematodes are considered the major consumers classified as bacteria feeders, fungal feeders, plant feeders, predators and omnivores (Usman, 2013). These groups of nematodes were identified to range between 0.15 to 5 mm long and 2 to 100 µm wide (FAO, 2005). Also, about 40,000 species of soil protozoa have been described, with as many as 50 individuals in a single soil medium (Coleman, 2001). Generally, the sustainable function of natural and agricultural soil ecosystems is dependent on the contribution that these groups of biota and their biodiversity offer (Barrios, 2007). Table 1 describes an estimated number of species of these groups of biota according there body structure and sizes.

Table 1. Estimated number of species of plants and of soil organisms organized according to body size (After Wall et al., 2001)

Size	Group	Known species	Estimated total species	% Known
	Vascular plants	270.000	300.000	90
	Macrofauna			
	Ants	8.800	15.000	58.7
	Termites	1.600	3.000	53.3
	Earthworms	3.600	No estimate	No estimate
	Mesofauna			
	Mites	20.000-30.000	900.000	2.2-3.3
	Collembola	6.500	24.000	27.1
	Microfauna			
	Protozoa	1.500	200.000	7.5%
	Nematodes	5.000	400.000	1.3
	Microflora			
	Bacteria	13.000	1.000.000	1%
	Fungi	18.000-35.000	1.500.000	1-2%

[a] Estimates for vascular plants (UNEP, 1995)

On the other hand, soil biodiversity is comprised of the organisms that spend all or a portion of their life cycles within the soil or on its immediate surface (Coleman, 2008). This reflects complexity and diversity of the species of living organisms in the soil (invisible microbes to visible macro-biota) (Wall et al., 2001). Thus, soil biota must be selectively studied because of their high diversity and wide distribution in the composite and heterogeneous soil medium at scales ranging from microns to meters (Barrios, 2007). This means that the biodiversity of soil biota is an industry with diverse components that worked together to transform the soils into lively and functional environment. And, as such make up the diversity of life that represents a large fraction of global terrestrial biodiversity in soil (Bardgett, 2005).

Soil biota interacts and communicates with each other forming a food web within soils (FAO, 2005). This interaction indicates how their activities are vital in providing many essential services to our global soil ecosystem (Table 2).

Table 2. Ecosystem services provided by soil biota (adapted after modifications made by Brussaard, 2012 from the work of Kibblewhite et al., 2008)

Ecosystem services	**Ecosystem functions**
1. Water quality and supply	Soil structure maintenance Nutrient cycling
2. Erosion control	Soil structure maintenance
3. Atmospheric composition and climate (greenhouse gas) regulation	SOM dynamics
4. Pollutant attenuation and degradation	Decomposition
5. Pest and disease control	Nutrient cycling
6. Biodiversity conservation	Biological population regulation Biological population regulation

Soil biota: functional and taxonomic concept

Soil biota can be distinguished by considering their functional services and taxonomic classification. This concept is quite very important because of the need to note that not all the groups of biota are connected with agricultural soil functions. The 21st Century technologies related to DNA sequences revealed that some members of soil biota have no direct or weak relationship with providing functional services to soil medium (Riesenfeld et al., 2004; Bardgett, 2005; Barrios, 2007). This effort helps soil biologists to expand their understanding into many aspects of soil biota, and also to determine how these organisms behave very well in soil environment (Coleman, 2008; Ritz et al., 2010; Castro-Huerta et al., 2015). Taxonomic soil biota provides a linkage to identify some species of soil organisms that are only presence in soil without much support to soil quality and soil management (Riesenfeld et al., 2004). These organisms could be silent when speaking about the role of biota in soil environment, because their biodiversity and contributions are very weak unlike with those organisms that have a very strong functional diversity (Petchey and Gaston, 2006).

Soil biota: an environmental issues of the 21st Century

Environmental issues related to agricultural soils and food security are quite very important in determining and understanding the role of soil biota and their biodiversity (Wall et al., 2001). For example, agricultural soil management, environmental pollution, global warming, soil degradation and climate change are directly and indirectly connected with the existence and biodiversity of many soil organisms (de Bello et al., 2010). These environmental issues were considered the major threat to soil and its biological components including the biota and their biodiversity (UNEP, 2006). Their physical and chemical deteriorations have put agricultural production at stake while decline soil quality has affected many functional services of million soil organisms as well as their presence and existence/population in agricultural soils (Bai et al., 2008). This indicates the need of constant understanding of how these organisms behave and contribute to the global ecosystem development particularly in the aspect of agriculture or food security (Ritz et al., 2010).

Role of soil biota in soil environment – a brief guide

The science of soil biology has functionally linked the populations of soil organisms of all kinds, sizes and shapes through their roles in the decomposition of various forms of plants and animal materials (FAO, 2005). Thus, the roles played by soil biota were considered vital in transforming and improving soil properties and soil quality (Lupswayi et al., 1998; Miyazawa et al., 2000). These functions of soil biota were reported to create vital activities, which are considered to be part of biological indicators of soil health (Pankhurst et al., 1997; Kibblewhite et al., 2008). Coleman (2001) noted that the soil biota is responsible to a varying degree for performing vital functions in the soil. They contribute with a wide range of essential services to the sustainable function of all ecosystems, by acting as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission; modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation, enhancing plant health and maintain soil quality (Denef et al., 2001; FAO, 2005; Wang et al., 2008; Dominguez et al., 2014; Castro-Huerta et al., 2015). FAO (2007) provides a notable digest of the essential functions performed by soil biota in our global soil environment (Table 3).

Table 3. Summarized key roles of soil biota in soil environment (After FAO, 2007)

	Role of soil biota	Key organisms involved (examples)
1.	Maintenance of soil structure	Earthworms, arthropods, soil born fungi, mycorrihizas, plant roots
2.	Regulation of soil hydrological processes	Mostly micro-organisms and plant roots
3.	Gas exchange and carbon sequestration	Mostly micro-organisms
4.	Soil detoxification	Various saparophytic, bacteria, fungi etc
5.	Decomposition of organic matter	Mycorrhizas and other fungi, nematodes, bacteria, earthworms, termites
6.	Suppression of pests and diseases	Varieties of fungi and bacteria
7.	Sources of food and medicine	Plant roots, stems and leaves; various insects, earthworms
8.	Symbiotic and asymbiotic relationship with plants and their roots	Rhizobia, mycorrhizae, actinomycetes
9.	Plant growth control (positive + negative)	Direct effects e.g. plant roots, actinomycetes, rhizobia, mycorizas; indirect: most soil biota

Physical and biological component of soil medium

Soil organisms provide many supports in the trasformation and development of soil physical and biological properties. They are exclusively part of soil formation and decomposition processes of diverse plant and animal materials (Janney, 1994). Bacteria contribute to the carbon cycle by fixation (photosynthesis) and decomposition of organic materials and hence might improve soil colour and soil quality (Darbyshire, 1994; FAO, 2005). Their activities might also help to improve the strength of soil particles and soil resilience against soil runoff and soil erosion. Fungi also help in binding soil particles and an increase water infiltration and soil water holding capacity (Alfred, 2001; Ritz et al., 2004). Generally, a ton of microscopic bacteria may be active in each acre of soil as typically indicated in Figure 2 (NRCS: www.nrcs.usda.gov720 × 475 Search by image). These active organisms fall into four functional groups – decomposers, mutualists (form partnership with plants – nitrogen-fixing bacteria), pathogens and lithotrophs or chemoautotrophs; both played a vital role in soil nutrient cycling (Coleman et al., 1983; Ingham, 2000).

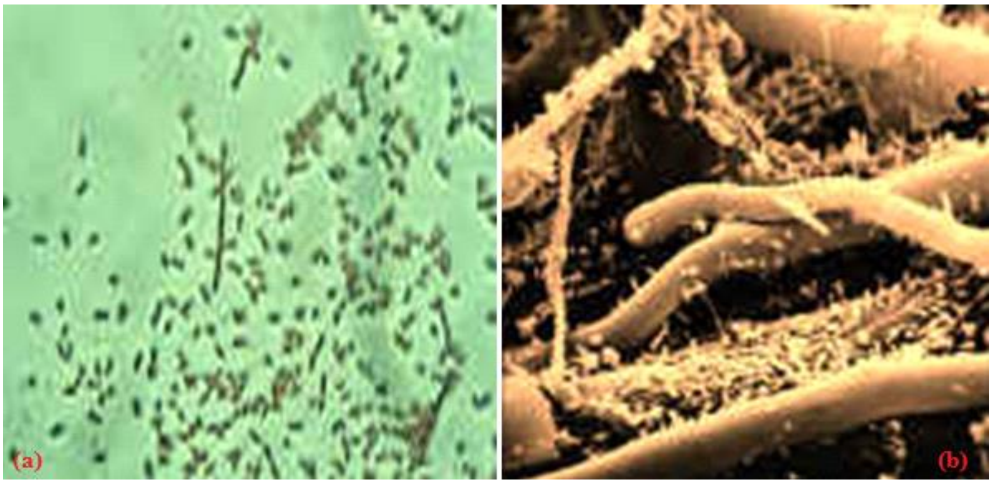


Figure 2. Microscopic representation of bacteria biodiversity in soil environment: (a) a ton of microscopic bacteria may be active in each acre of soil and (b) Bacteria dot the surface of strands of fungal hyphae [The images were used by the authors with the copyright permission of Soil and Water Conservation Society]

Earthworms play a significant role in regulating soil physical and chemical properties and soil processes (Lubbers et al., 2011). Earthworms are the major decomposers of dead organic matter and transformed soil structure, aggregate particles, soil colour and surface soil layers (Edward, 2000).Earthworms are very mobile organisms, which substantially create, inhabit, and burrow the soil particles for quite advance soil developments (Smith et al., 2008). Jongmans et al. (2003) noted that earthworms essentially change soil structure by casting and burrowing and as such improve soil aggregate stability, cohesion and adhesion in soil and pore-size division.

Another soil biota in this consideration is protozoa. These organisms move soil particles and help in the decomposition processes of soil organic matter (Corliss and Esser, 1974; Darbyshire, 1994; Song et al., 2004). Yeates and Coleman (1982) recognized nematodes in soils environment. These flexible organisms play an important role in soil health, soil function, and soil organic matter decomposition processes (Coleman et al., 1984; Bardgett, 2005; Kramer and Gleixner, 2008). Termites played an important role in modifying the soil particles into fine and stable aggregate. Termites sustain other components of soil biota in soil, and increase soil water infiltration rate (Allen, 1990). Termites are divided into three groups according to the structure of their nests (those that build mounds) (FAO, 2005): (a) above ground, (b) on the soil surface, and (c) below ground. The most notable role of these termites in soil environment is depicted in Figure 3.

Chemical and management component of soil medium

Soil organisms were considered the most important component of soil that help in the proper cyclation of nutrients availability in soil (Coleman et al., 1984; Ritz et al., 2010). Soil biota such as plants are also considered the major producers, which used solar energy to fix carbon from carbon dioxide through photosynthesis, and help to produce roots, tubers and other underground organs within soil body (Fageria et al., 2002). These plant organs have a great influence on soil properties and soil formations (Fageria et al., 2002; Dominguez et al., 2014). The root plays an important function in binding soil particles and resilience against soil erosion and unacceptable environmental changes (Castro-Huerta et al., 2015). The leaves and litter materials from the trees also add organic matter to the soils (Li et al., 2014). Overall (FAO: www.fao.org/biodiversity): soil biota and their biodiversity play a role in soil fertility, soil rehabilitation and nutrient uptake by plants, biodegradation processes, reducing hazardous waste and control of pests through natural biocontrol; enhance crop productivity through recycling the basic nutrients required for all ecosystems (nitrogen, phosphorus, potassium and calcium), breaking down organic matter into humus, increasing soil porosity and water infiltration.

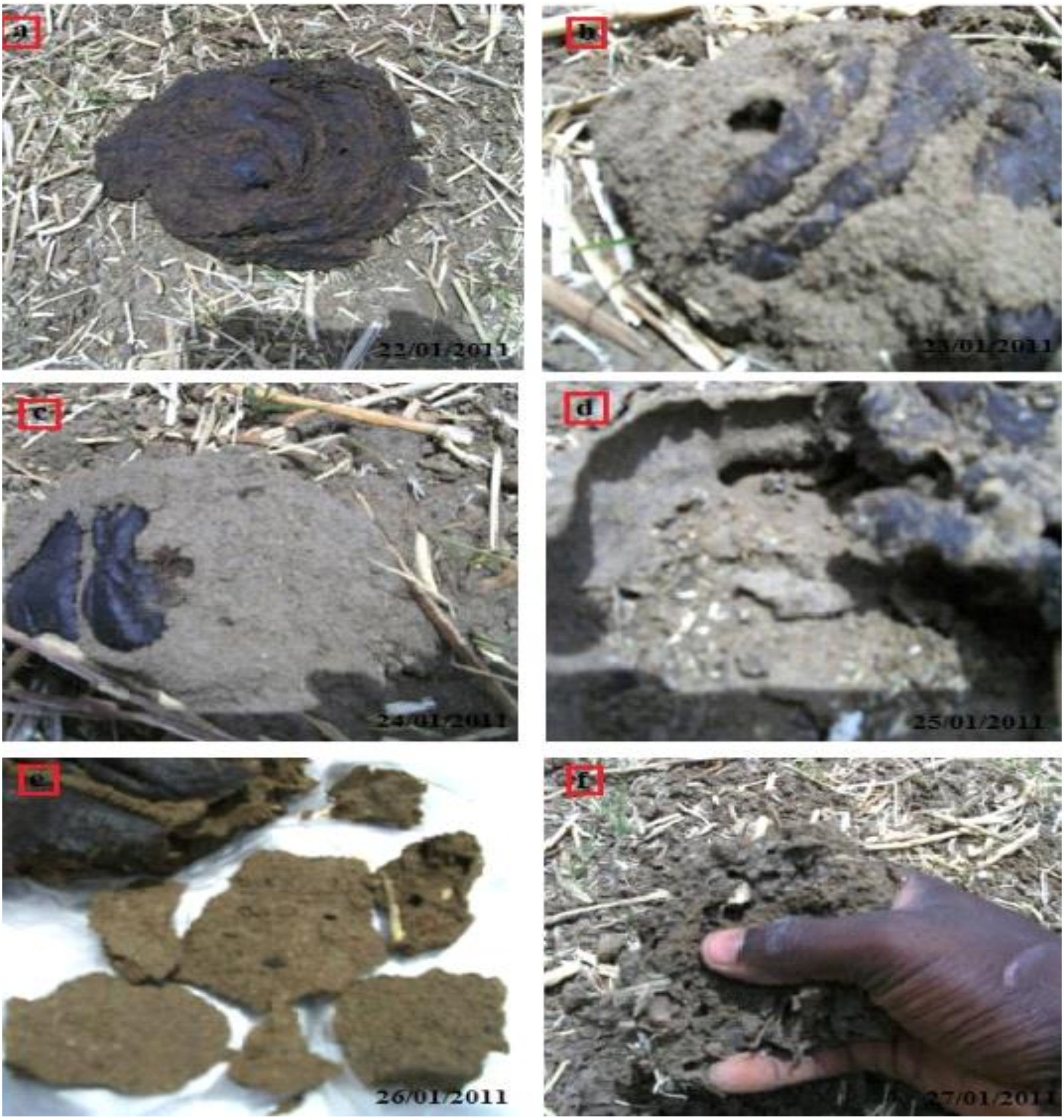


Figure 3. Typical example of physiological function of soil biota (termites) in soil environment within 6 consecutive days: (a) cow dung dropped by a cow under cattle rearing, (b) decomposition process begins after one day, (c) transformation of organic compound from complex to simple form in day 3, (d) simple organic particles are trying to become part of soil body in day 4, (e) stable aggregate soil particles in plate-like structure are produced in day 5 and (f) organic compounds completely become part of soil body produced well-granules particles in day 6. Photos by Suleiman Usman

Physiological interactions with soil aggregates

As clearly observed by Tisdall and Oades (1982), our understanding of soil biota and their role in soil environment could be transiting from analogue stage to digital level. Soil organic matter which is the vital component of soil quality development in soil environment undergoes some important decomposition processes (mineralization and humification). Mineralization is a biochemical breakdown of organic materials by soil biota whereas humification is the change of simple organic substances into larger molecules, which finally become humus (FAO, 2005). However, in the model of aggregate organization as depicted in Figure 4, it is very clear that soil biota participate fully in aggregate formation and developments. They bind soil particle together, improve the stability and cohesion of aggregate development and help in nutrients cycling within the pores of different sizes (Six et al., 2004).

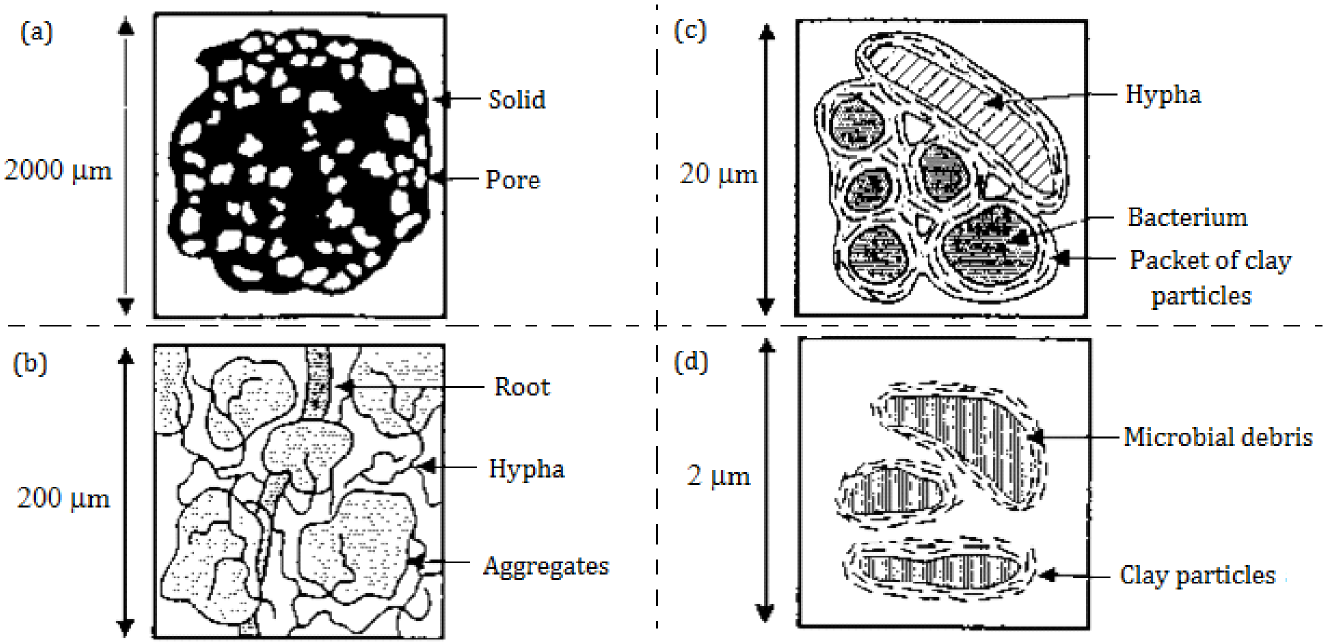


Figure 4. Model of aggregate organization with major binding agents indicated (a) Solid pore (b) Roots and hyphae (medium-term organic), (c) Plant and fungal debris encrusted with inorganics (persistent organic) and (d) Microbial and fungal debris encrusted with inorganics (persistent organic) (After Tisdall and Oades 1982)

FAO (2005) noted that numerous microbes exist in soil particles and or within the surface areas of soil micro-aggregates. Thus, soil micro-aggregates could be considered as zoological houses where millions of bacteria and fungi occupied. Riesenfeld and co-workers noted that one gram of soil may contain thousands of species and billions of individual soil microorganisms (Riesenfeld et al., 2004). Their presence provides many essential ecosystem services to soil aggregates and soil structures (Table 4).

Soil biota also makes soil to become added lively for great diversity of numerous bacteria and fungi in soil environment (Rillig and Mummey, 2006). Similarly, the arrangement of soil particles into different shapes, sizes and forms are vital to the soil formation and soil development (Jenney, 2009). Indeed, soil biota played a vital role in this process. Ritz et al. (2010) noted that soil biota produce soil structure by a number of direct and indirect processes. These processes are (Ritz et al., 2010):

a. Moving and aligning primary particles along cell or hyphal surfaces;

b. Adhering particles together by the action of adhesives involved in colony cohesion, and other exudates, such as extra-cellular polysaccharides (EPS);

c. Enmeshment and binding of aggregates by fungal hyphae and actinomycete filaments, and associated mycelia;

d. Coating pore walls with hydrophobic compounds, particularly by fungi which produce such polymers to insulate their mycelia, which have a relatively large surface area: volume ratio.

Table 4. Functional services of soil biota to soil aggregate particles (adapted after modifications made by Brussaard, 2012 from the work of Kibblewhite et al. 2008)

Aggregate ecosystem functions	Soil biota
1. Carbon transformations	Microfoodweb: a) Microflora – fungi, bacteria, b) Microfauna – prorozoa, nematodes Litter transformers: a) Mesofauna – enchytraeids, microarthropods, b) Macrofauna– earthworms, macroarthropods
2. Nutrient cycling	Microfoodweb Litter transformers Root/rhizosphere biota a) N-fixers b) Mycorhizae c) Free-living rhizosphere Microbes a) Microbial pathogens b) Root herbivores
3 Soil structure maintenance	Ecosystem engineers a) Roots b) Macrofauna c) Earthworms d) Macroarthropods e) Fungi
4. Biological population regulation	Microfoodweb Biocontrollers a) Predators b) (Hyper)parasites c) Microbial pathogens d) Root herbivores

Gaps and challenges: - sub-Saharan African context

There have been many researches carried out regarding the soil microbial communities, globally. To date, majority of these researches were based in Europe, US, UK and in China (e.g. Colleman et al., 1983; De Vries et al., 2006; Brussaard et al., 2007; Wang et al., 2008; Eskelinen et al., 2009; Ritz et al., 2010; Li et al., 2014; Castro-Huerta et al., 2015). Similarly, there are also some important researches carried out in Africa on biota and biodiversity of which Jürgens et al. (2012) provided important information on their patterns at different spatial scales, which fill gaps of critical baseline information that are missing in the region. Nonetheless, researches on soil biota and biodiversity in sub-Saharan Africa are still need to be expanded into many aspects of soil and agricultural production, environmental conservation, climate change and land degradation; because soil biota and biodiversity were considered the root of sustainable agriculture in the 21stcentury (FAO, 2007). Therefore, achieving sustainable agriculture in sub-Saharan Africa must focus on food security within its boundaries, and as such, we do believe that there must be an engagement into aspect of soil research relevant to biota and biodiversity in the region. Although, this may be a challenge due to poor research and development, findings and government contributions; however, we are of the opinion that - academic environments in the region may have the role to play in future. They need to develop and create an environment that would provide opportunity for undergraduate and post-graduate students to fully involve into different components of soil microbial studies to fill the gaps that are missing.

Conclusion

Soil biota or soil organisms are important component of soil environment and play important roles in transforming soil in varying forms. The role of soil biota is vital to soil properties and soil components. They breakdown soil particles for soil quality and soil function. Their leaves, stems and other surface organs play an important role in maintaining soil properties and improving soil organic matter. Plant debris and organic compounds in soil are largely decomposed and transformed by soil biota. They influence the stabilization and destabilization of soil organic materials for soil quality and soil fertility development. Proper understandings of soil biota and their biodiversity in soil environment would provide ways to improve soil health, soil function, soil quality, soil fertility and sustainable soil management activities in agricultural production.

The campaign to engage into the research on soil biota and biodiversity in sub-Saharan Africa will require long-term effort, and the benefits will be seen in the development of soil quality and soil fertility within a short-term course. From our mini-review of the role of soil biota here we do not have much confidence that many countries in the region are in a better commitments to fully support researches in the subject matter. However, it is significant to emphasise the needs to further expand our understanding into many aspects of soil organisms and their roles in relation to sustainable agriculture, environmental pollution, global warming, and climate change and food security. And, to target a specific research area particularly in the aspect of taxonomic soil biota, one must first understand the soil organisms' involved and the way in which they are distributed/behaved in soil medium. Also, while both the field and laboratory data requirements are quite important, we have shown that assessments and analyses are possible in the aspects of physical, chemical and biological relationships between soil biota and the role they played in soil medium. Thus, establishing a very useful approach to achieve the outline objectives could be possible under any given research subject related to the work on soil biota and biodiversity.

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Modeling cation exchange capacity and soil water holding capacity from basic soil properties

Idowu Ezekiel Olorunfemi [a,*], Johnson Toyin Fasinmirin [a], Adefemi Samuel Ojo [b]

[a] Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
[b] Department of Agricultural and Bio – Environmental Engineering, Lagos State Polytechnic, Lagos, Nigeria

Abstract

Cation exchange capacity (CEC) is a good indicator of soil productivity and is useful for making recommendations of phosphorus, potassium, and magnesium for soils of different textures. Soil water holding capacity (SWHC) defines the ability of a soil to hold water at a particular time of the season. This research predicted CEC and SWHC of soils using pedotransfer models developed (using Minitab 17 statistical software) from basic soil properties (Sand(S), Clay(C), soil pH, soil organic carbon (SOC)) and verify the model by comparing the relationship between measured and estimated (obtained by PTFs) CEC and SWHC in the Forest Vegetative Zone of Nigeria. For this study, a total of 105 sampling points in 35 different locations were sampled in the study areas. Three sampling points were randomly selected per location and three undisturbed samples were collected at each sampling point. The results showed success in predicting CEC and SWHC from basic soil properties. In this study, five linear regression models for predicting soil CEC and seven linear regression models for predicting SWHC from some soil physical and chemical properties were suggested. Model 5 [CEC = -13.93+2.645 pH +0.0446 C (%)+2.267 SOC (%)] was best for predicting CEC while model 12 [SWHC (%)=36.0- 0.215 S (%)+0.113 C (%)+10.36 SOC (%)] is the most acceptable model for predicting SWHC.

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Introduction

Cation exchange capacity (CEC) of a soil is a measurement of its ability to bind or hold exchangeable cations. In other words, it is a measure of the number of negatively-charged binding sites in soil (Rashidi and Seilsepour, 2008). The cation exchange capacity of a soil represents the total amount of exchangeable cations that a soil can retain. Cation exchange capacity helps characterize the soil type under consideration. For example, because organic matter in soil is a major source of negative electrostatic sites there is a strong correlation between CEC values, and amount of organic matter present in soil (Harada and Inoko, 1975). The CEC results provided insight into the type of soil, as well as secondary information for use in formulating a fertilizer programme. Characterization of soils' CEC is useful for making recommendations for the amounts of phosphorus, potassium, and magnesium for soils of different textures.

Soil water holding capacity (SWHC) is the amount of water retained in capillary spaces of soil after gravitational water loss into deeper layers of the soil (Senjobi and Ogunkunle, 2011). Soil water storage available for plant use is generally calculated as being between field capacity and wilting point, as water

* Corresponding author.
Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
Tel.: +234 7037986945 E-mail address: olorunfemiidowu@gmail.com
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contents higher than, while usually plant-available, are generally not sustained for long times except under specific circumstances (Sumner, 2000). The estimation of SWHC of a soil is of great value to practical agriculture, because it provides a simple means of determining moisture contents required for soils, for good plant growth, and infiltration of water into soil which is another important dynamic flow processes in the hydrological cycle (Viji and Rajesh, 2011). Knowing the soil water storage capacity allows the irrigator to determine how much water to apply at one time and how long to wait between each irrigation (Olorunfemi, 2014). Soil water holding capacity of any soil is determined by its texture, structure, and organic matter content. Soil texture influences the water retention capabilities of soils of different locations, as soils with high clay percentage or both (high clay percentage and organic matter content) tends to have high SWHC (Senjobi and Ogunkunle, 2011). Soil texture and crop rooting depth affect total amount of water stored in the soil within the plant's rooting zone. Therefore, characterizing SWHC of different locations is about defining the ability of a soil to hold water by soil and for use by a particular crop at a particular time of the season.

Cation exchange capacity and soil water holding capacity can be measured by laboratory experiments. Despite the progress made in measuring soil properties directly, laboratory analysis of some soil physical and chemical properties is still laborious and expensive to obtain. For example, CEC is often determined using laborious and time consuming laboratory tests. Also, soil properties can be highly variable spatially and temporally and measuring these properties is time consuming and difficult, but it may be more suitable, economical and essential to derive relationships that link the basic soil properties to the functional soil properties that are more difficult to measure. Recently, indirect estimation of these functional properties from widely available or more easily measured basic soil properties like; sand (S), silt (Si), clay (C), bulk density (BD), soil organic carbon (SOC) and soil organic matter (SOM) that contribute to the functional properties using pedotransfer functions (PTFs) has received considerable attention (Wösten et al., 1995; Minasny and McBratney, 2002; Minasny et al., 2004, Amini et al., 2005). According to Martel et al. (1978), Manrique et al. (1991), and Rashidi and Seilsepour (2008), soil components known to contribute to soil CEC are clay and organic matter, and to a lesser extent, silt. Several researchers: Yuan et al. 1967 (for sandy soils in Florida); Drake and Motto 1982 (for New Jersey soils); Sahrawat 1983 (for some Philippine soils) and Bell and van Keulen 1995 (for four soils in Mexico) have attempted to predict CEC from clay and organic carbon contents, while and Rashidi and Seilsepour (2008) predicted CEC from organic carbon alone for soils in Varamin, Iran, using multiple regression. Also, Krogh et al. (2000) suggested an equation based on silt, clay, organic carbon, and pH. In most of these models, CEC is assumed to be a linear function of soil organic matter and clay content (Breeuwsma et al., 1986; McBratney et al., 2002).

This study will determine relationships linking basic soil properties to CEC and SWHC thereby providing quick and easy determination of CEC and SWHC. The knowledge of these properties and process leads to better predictions of agricultural soil water management systems. In the light of the above, objectives of this research were to predict CEC and SWHC of soils using pedotransfer models developed from basic soil properties. Then, verify the model by comparing the relationship between measured and estimated (obtained by PTF) values in the forest vegetative zone of Nigeria.

Material and Methods

Experimental site and procedure

Experimental site

The study was conducted in Ekiti State in the forest vegetative zone of Nigeria (Figure1). Ekiti State is located between Latitudes 7° 15' to 8° 5' N and Longitude 4° 45' to 5° 45' E and occupies an area of about 6, 353 km^2 (EKSG, 2009). The State is mainly an upland zone, rising over 250 m above sea level. The highest contour line of 540 m above sea level is found around the North Eastern limit of the state (Simon–Oke and Jegede, 2012). It lies on an area underlain by metamorphic rock and is potentially rich in mineral deposits which include granite, kaolin, columbite, channockete, iron ore, barite, aquamine, gemstone, phosphate, limestone, gold among others largely deposited in different towns and villages within the State. The State enjoys tropical climate with two distinct seasons. These are the rainy season (April – October) and dry season (November – March). The air temperature ranges between 21° and 28° with high humidity. Ekiti State has a total annual rainfall of about 1400 mm with an average of about 112 rainy days per year (Adebayo, 1993). The dominant soils in Ekiti state are Egbeda series and Iwo series (Syrnth and Montgomery, 1962). Under the FAO/UNESCO classification, they are Orthic and Plinthic Luvisols, respectively (FAO, 1998). The vegetation of Ekiti State is guinea forest with its attendant climate, flora and fauna (EKSG, 2009).

Figure 1. Location of the study area

Experimental procedure

Soil sampling and field experiments were carried out across 35 different locations (communities) in Ekiti State. Undisturbed soil samples from the topsoil (Horizon A) were collected from each experimental site using stainless steel cylindrical cores. Soil samples were collected in depths of 0 to 30 cm. Three sampling points were randomly selected per location and three undisturbed samples were collected at each sampling point. In general, 105 soil samples were taken randomly at the different locations in Ekiti State. Soil samples collected were packed in plastic bags, and transferred to the laboratory. The samples were allowed to dry in the open air until reaching friability.

Measurements

Physico-chemical characterization of soils

Chemical characterization of the collected soil samples include the analysis of SOM, SOC, CEC at pH of 7.0, base saturation, Al^{3+} saturation and soil pH. Physical characterization consisted of particle size analysis, SWHC determination. The organic carbon was determined using Walkley - Black wet oxidation procedure and soil organic matter content was determined from organic carbon (Nelson and Sommers, 1996). The cation exchange capacity (CEC) at pH 7.0 was determined following the procedure compiled and described by Reeuwijk (2002). The exchangeable potassium (K^+) and sodium (Na^+) was extracted with HCl solution and their levels determined by flame photometry (Vogelmann et al., 2010) and exchangeable magnesium (Mg^{2+}) and calcium (Ca^{2+}) by atomic absorption spectrophotometer (Senjobi and Ogunkunle, 2010). Soil pH was determined in distilled water using the pH meter with water ratio of 1:2. Soil particle sizes were determined using the hydrometer method described in Agbede and Ojeniyi (2009). Soil water holding capacity was determined following the method described by Ibitoye (2006).

Statistical analysis

Soil properties were subjected to statistical analysis to determine the mean, standard deviation, coefficient of variation among soil samples from different locations. Each soil property was compared using Pearson correlation coefficient at 1 and 5% significant levels and the existence of inter-relationships between data set was tested by linear correlation using Minitab 17 statistical software. To predict the cation exchange capacity (CEC) of soil, pedotransfer (PTF) functions, which are multiple regression equations, among soil properties were obtained using the Minitab 17 statistical software. A paired samples t-test and the mean difference confidence interval approach were used to compare predicted and measured values of soil CEC and SWHC. Descriptive statistics such as minimum and maximum value, arithmetic mean value, standard deviation (SD), and coefficient of variation (CV) were calculated to help in providing explanations and assessing dispersion of the variables. Measure of Dispersion tells us about the variation of the data set.

Statistics such as Correlation Coefficient (R), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Relative Error (RE) were calculated using equation (1), (2), (3), and (4) respectively, where n represents the number of instances presented to the model and O_i and P_i represents measured and predicted, and O_{ave} and P_{ave} represents mean values of measured and predicted respectively.

$$R = \left[\frac{\sum_{i=1}^{n} (O_i - O_{ave})(P_i - P_{ave})}{\sqrt{\sum_{i=1}^{n} (O_i - O_{ave})^2 (P_i - P_{ave})^2}} \right] \quad (1)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n} \right]^{1/2} \quad (2)$$

$$MAE = \sum_{i=1}^{n} [|P_i - O_i|/n] \quad (3)$$

$$RE = (MAE/O_{ave})100 \quad (4)$$

Results and Discussion

Physical and chemical properties of sampled soils

Descriptive statistics of some physical and chemical properties of the soils used in this study were given in Table 1. Cation exchange capacity of all 35 sampled soils ranged from 3.43 $cmol_c.kg^{-1}$ to 11.97 $cmol_c.kg^{-1}$ with an average value of 6.53 $cmol_c.kg^{-1}$ ± 2.01. Cation exchange capacity values showed that the distribution is positively and moderately skewed with a skewness coefficient of 0.78 while values of the coefficient of kurtosis of 0.16 suggested a platykurtic behavior in their distribution. The soil water holding capacity (SWHC) ranged from 29.27% to 71.83% for all soil samples in the 35 locations with an average value of 45 %, standard deviation of 3.05 and coefficient of variation of 70 %. The skewness coefficient (1.28) of the SWHC of the sampled locations reveals a distribution that is positive and highly skewed while the kurtosis coefficient (2.57) showed that the distribution is platykurtic. Skewness and kurtosis reveal the direction of variation of the data set. It also informs about the normality of the data set.

Table 1. Descriptive statistics of physical and chemical properties of sampled soils

Statistics/Soil Properties	Sand (%)	Silt (%)	Clay (%)	Soil pH	SOC (%)	SOM (%)	SWHC (%)	CEC ($cmol+kg^{-1}$)
Minimum	24.00	4.00	20.00	4.95	0.88	1.52	29.27	3.43
Maximum	64.00	32.00	56.00	6.36	2.36	4.07	71.83	11.97
Arithmetic Mean	44.57	21.37	34.06	5.95	1.42	2.46	45.00	6.53
Standard Deviation	9.85	6.23	9.54	0.32	0.38	0.66	8.53	2.01
Coeff. of Variation	0.22	0.29	0.28	0.05	0.27	0.27	18.96	0.31
Skewness	-0.53	-0.73	0.47	-0.65	0.72	0.65	0.26	0.77
Kurtosis	-0.31	0.51	-0.70	-0.23	0.06	-0.06	1.50	0.16

Relations between CEC, SWHC, and some soil properties

Cation exchange capacity showed positive correlation with soil pH ($r = 0.441^{**}$), SOC ($r = 0.580^{**}$), SOM ($r = 0.572^{**}$), SWHC ($r = 0.580^{**}$), and clay content ($r = 0.356^{*}$) at $p \leq 0.01$ and $p \leq 0.05$ respectively amongst all the soil samples in the 35 experimental locations (Table 2). It was observed that soils with high organic matter content and clay particles demonstrated high CEC values which is due to the fact that the cation-exchange capacity (CEC) of soils is mainly due to clay minerals and soil organic matter (Martel et al. 1978; Manrique et al. 1991; Harada and Inoko, 1975) and silt to a lesser extent (Rashidi and Seilsepour, 2008). Organic matter in soil is a major source of negative electrostatic sites; therefore there is a strong correlation between CEC value and amount of organic matter present in the soil. The research findings were also in agreement with the works of Bayer and Bertol (1999); Vogelmann et al., (2010) and Fasinmirin and Olorunfemi (2012) who reported that soil samples with higher values of CEC were found to have high levels of organic matter and pH. Also in any given soil, the number of exchange sites is dependent on the soil pH; type, size and amount of clay; and amount and source of the organic material (Kamprath and Welch 1962; Miller 1970; Parfitt et al. 1995; Rashidi and Seilsepour, 2008). Soil water holding capacity correlated positively with clay content ($r = 0.539$, $p \leq 0.01$) and negatively with sand content ($r = -0.517$, $p \leq 0.01$).

Results of the correlation analysis between SWHC (%) and SOM (%) revealed a significant and positive relationship (r = 0.584, N = 35, p ≤ 0 .01). Senjobi and Ogunkunle (2011) reported that soils having high proportion of sands are associated with low SWHC. The result also shows that if clay and organic matter contents increase, water holding capacity of the soil also increases (FAO, 2005). This observation correlated with the findings of Senjobi and Ogunkunle (2011) who further stated that water holding capacity of soils increase with increase in clay content of soils in their study to assess the extent to which different land use types influences land degradation and productivity in Ogun State, Nigeria. SWHC of the soils resulted from fine texture nature of the soils.

Table 2. Pearson correlations coefficient (r) among various soil properties

	pH	Sand	Silt	Clay	SOC	SOM	SWHC	CEC
pH	1							
Sand	.088 ^{ns}	1						
Silt	.065 ^{ns}	-.366*	1					
Clay	-.134 ^{ns}	-.794**	-.275 ^{ns}	1				
SOC	.128^{ns}	-.363*	-.140 ^{ns}	.467 **	1			
SOM	.139 ^{ns}	-.339*	-.137 ^{ns}	.440**	.993**	1		
WHC	.152 ^{ns}	-.517**	-.008 ^{ns}	.539**	.610**	.584**	1	
CEC	.441**	-.281 ^{ns}	-.101 ^{ns}	.356 *	.580**	.572**	.569**	1

ns, not significant.
**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level

Prediction of soil cation exchange capacity (CEC) using pedotransfer models

Pedotransfer models to predict CEC value of soils were developed regarding the results of correlation analysis. The following models for CEC were obtained from multiple regressions on data (Model 1-5) The pedotransfer models, which were developed using some soil physical properties, to predict cation exchange capacity (CEC) were statistically significant at 1% probability level.

1) CEC = 2.17 + 3.072 SOC (%)
2) CEC = 1.77 + 0.0230 C (%) + 2.802 SOC (%)
3) CEC = -11.62 + 2.379 pH + 2.819 SOC (%)
4) CEC = -15.37 + 3.173 pH + 0.0890 C (%)
5) CEC = -13.93 + 2.645 pH + 0.0446 C (%) + 2.267 SOC (%)

Model 5 was the best model for predicting CEC with R = 0.711, RMSE = 1.39, MAE = 1.16 and RE = 17.77 (Table 3). Table 4 shows the result of Paired Samples Test used to compare the measured and predicted CEC values. Using an alpha level of 0.05, a dependent-samples t test was conducted to evaluate whether CEC values determined using two methods of laboratory test and pedotransfer function differed significantly. The results indicated that the CEC values determined using two methods of laboratory test (M = 6.53, SD = 2.01) was not significantly different from the CEC values predicted using the second method (M = 6.53, SD = 1.43), with t (34) = 2.83, p = 1.00

The 95% confidence interval for the mean difference between the two methods of determination was -0.48 to 0.48. Comparison of observed versus predicted values of CEC obtained from the models (1 - 5) were depicted in Figure 2 that indicates good match as a 1.0:1.0 scale and 45-degree angle with vertical.

Table 3. Summary of statistics of various models of soil cation exchange capacity (CEC)

Models	Statistics Parameters			
	R	RMSE	MAE	RE
1	0.580	1.61	1.28	19.54
2	0.588	1.60	1.23	18.79
3	0.687	1.44	1.22	18.74
4	0.608	1.57	1.29	19.72
5	0.711	1.39	1.16	17.77

R: Correlation Coefficient; RMSE: Root Mean Square Error; MAE: Mean Absolute Error; RE: Relative Error.

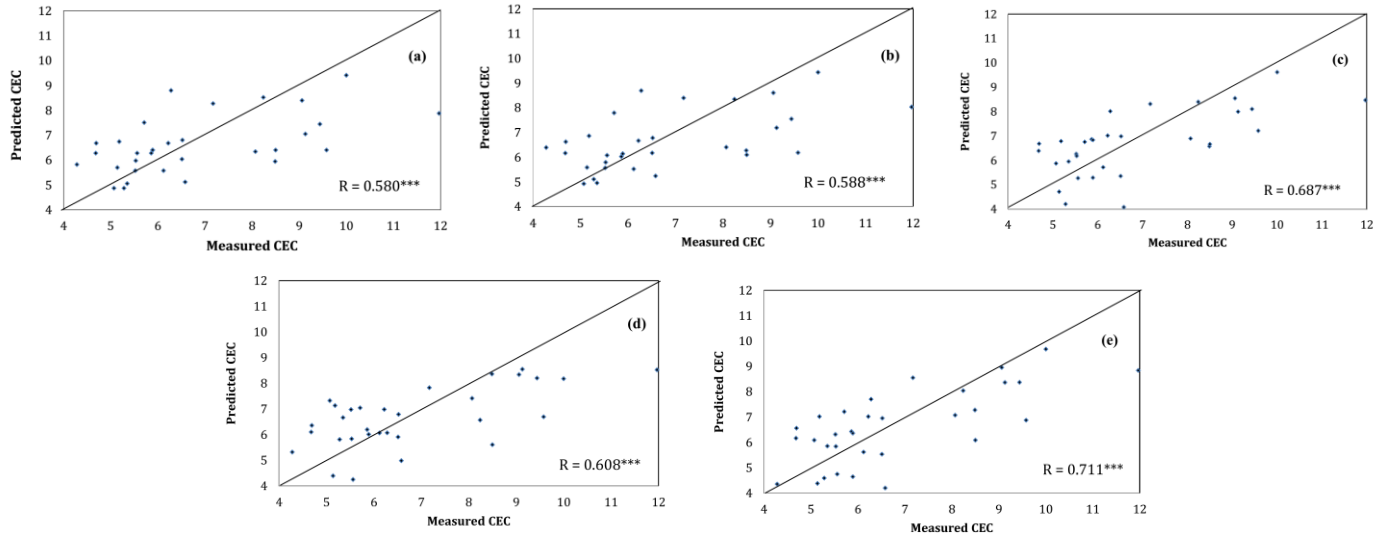

Figure 2. Comparison of measured CEC and predicted CEC for (a) model 1, (b) model 2, (c) model 3, (d) model 4, (e) model 5 with the line of equality (1.0: 1.0) (***Significant at the 0.001 level).

Table 4. Paired Samples Test analyses on comparing soil CEC determination methods

		Paired differences							
					95% confidence interval of the difference				
		Mean	SD.	SEM	Lower	Upper	t	df	Sig. (2-tailed)
Model No. 1	Measured CEC - Predicted CEC	.00	1.64	.27662	-.56215	.56215	.000	34	1.000
Model No. 2	Measured CEC - Predicted CEC	.00	1.62	.27467	-.55819	.55819	.000	34	1.000
Model No. 3	Measured CEC - Predicted CEC	.00	1.46	.24646	-.50087	.50087	.000	34	1.000
Model No. 4	Measured CEC - Predicted CEC	.00	1.59	.26944	-.54758	.54758	.000	34	1.000
Model No. 5	Measured CEC - Predicted CEC	.00	1.41	.23853	-.48475	.48475	.000	34	1.000

SD; Standard Deviation, SEM; Standard Error of the Mean

Prediction of soil water holding capacity (SWHC) using Pedotransfer models

Pedotransfer models to predict SWHC values of soils were developed regarding the results of correlation analysis (Model 6-12)

6) SWHC (%) = 64.93 - 0.447 S (%)

7) SWHC (%) = 28.57 + 0.482 C (%)

8) SWHC (%) = 25.52 + 13.72 SOC (%)

9) SWHC (%) = 43.6 - 0.207 S (%) + 0.312 C (%)

10) SWHC (%) = 42.59 - 0.294 S (%) + 10.94 SOC (%)

11) SWHC (%) = 20.46 + 0.291 C (%) + 10.30 SOC (%)

12) SWHC (%) = 36.0 - 0.215 S (%) + 0.113 C (%) + 10.36 SOC (%)

Likewise, predicted SWHC values by the models and values determined by laboratory methods were not statistically significantly different from each other. The test statistics for model 12 which is the most acceptable model was based on the mean difference between paired values of the measured and predicted SWHC (0.00) relative to the SE (Standart Error) of paired difference between sampled means (0.24). Results of the paired-samples t-test (Table 5) show that mean SWHC of the measured SWHC (M = 44.50, SD = 8.53) did not differ from predicted SWHC (M = 44.50, SD = 5.89) at the 0.05 level (t = 0.00, df = 34, n = 35, p =1.00, 95% CI for mean difference – 2.12 to 2.12). Findings therefore suggest that use of pedotransfer models could be reliable for quick assessment of soil water holding capacity and cation exchange capacity of soils with

95% confidence limit. Comparison of observed vs. predicted values of CEC obtained from the models (6 - 12) has been depicted in Figure 3 that indicates good match as a 1.0:1.0 scale and 45-degree angle with vertical.

Table 5. Summary of Statistics of Various Models of Soil water holding capacity (SWHC)

Models	Statistics Parameters			
	R	RMSE	MAE	RE
1	0.517	7.20	5.27	11.70
2	0.539	7.08	5.39	11.98
3	0.610	6.66	5.17	11.49
4	0.558	6.97	5.16	11.47
5	0.687	6.11	4.53	10.06
6	0.674	6.21	4.92	10.94
7	0.691	6.08	4.60	10.21

R: Correlation Coefficient; RMSE: Root Mean Square Error; MAE: Mean Absolute Error, RE: Relative Error

Table 6. Paired Samples Test analyses on comparing soil SWHC determination methods

		Paired Differences							
					95% confidence interval of the difference				
		Mean	SD	SEM	Lower	Upper	t	df	Sig. (2-tailed)
Model No. 1	Measured WHC - Predicted WHC	.00	7.30	1.23	-2.51	2.51	.000	34	1.000
Model No. 2	Measured WHC - Predicted WHC	.00	7.18	1.21	-2.47	2.47	.000	34	1.000
Model No. 3	Measured WHC - Predicted WHC	.00	6.76	1.14	-2.32	2.32	.000	34	1.000
Model No. 4	Measured WHC - Predicted WHC	.00	7.08	1.20	-2.43	2.43	.000	34	1.000
Model No. 5	Measured WHC - Predicted WHC	.00	6.20	1.05	-2.13	2.13	.000	34	1.000
Model No. 6	Measured WHC - Predicted WHC	.00	6.30	1.06	-2.16	2.16	.000	34	1.000
Model No. 7	Measured WHC - Predicted WHC	.00	6.17	1.04	-2.12	2.12	.000	34	1.000

SD; Standard Deviation, SEM; Standard Error of the Mean

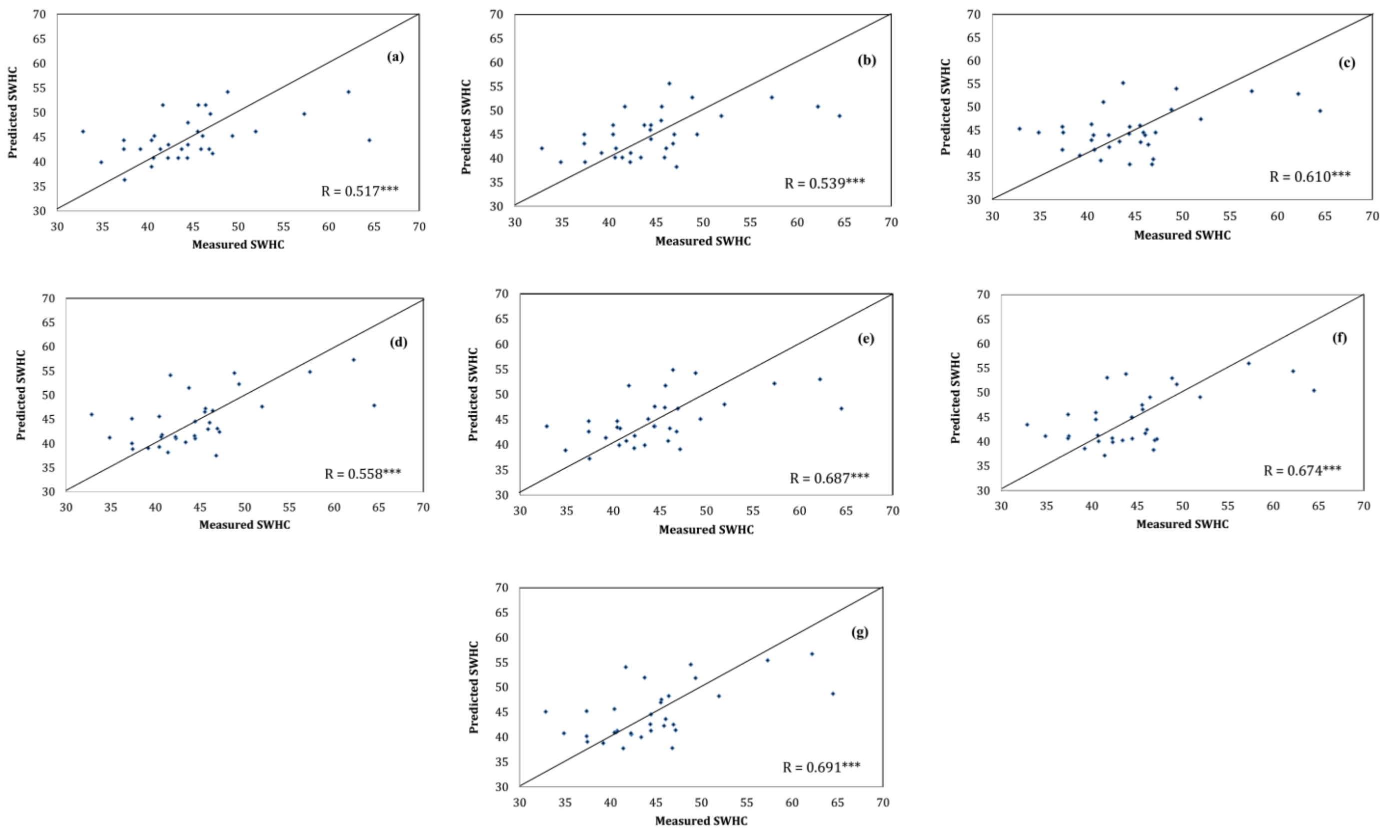

Figure 3. Comparison of measured SWHC and predicted SWHC for (a) model 1, (b) model 2, (c) model 3, (d) model 4, (e) model 5, (f) model 6, (g) model 7 with the line of equality (1.0: 1.0) (***Significant at the 0.001 level).

Conclusion

Pedotransfer models were successfully used to predict CEC and SWHC using multiple linear regression methods from basic soil properties. The paired samples t- test results indicated that the difference between predicted and measured values of the soil CEC and SWHC were not statistically significant using an alpha level of 0.05. Therefore, by using pedotransfer models, one can derive relationships that link basic soil properties to the functional soil properties that are more expensive and difficult to measure. This will result in quicker access to more expensive soil and environmental functional properties. The knowledge of these SWHC and process leads to better predictions and management of irrigation and water management systems. Likewise, CEC is a good indicator of soil productivity and a major criterion used when making soil fertilizer recommendations. Convenience in determining these properties will result in better farm management and greater agricultural productivity.

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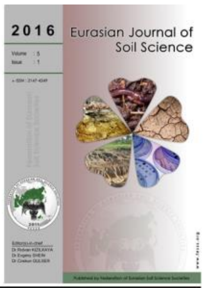

Effect of mycorrhiza on growth criteria and phosphorus nutrition of lettuce (*Lactuca sativa* L.) under different phosphorus application rates

S. Fatih Ergin, Füsun Gülser *

Yüzüncü Yıl University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Van, Turkey

Abstract

In this study, effect of mycorrhiza on growth criteria and phosphorus nutrition of lettuce (*Lactuca sativa* L.) under different phosphorus fertilization rates were investigated. Phosphorus were added into growing media as 0, 50, 100 and 200 mg P_2O_5/kg with and without mycorrhiza applications. Phosphorus applications significantly increased yield criteria of lettuce according to the control treatment statistically. Mycorrhiza application also significantly increased plant diameter, plant dry weight and phosphor uptake by plant. The highest phosphorus uptakes by plants were determined in 200 mg P_2O_5/kg treatments as 88.8 mg P/pot with mycorrhiza and 83.1 mg P/pot without mycorrhiza application. In the control at 0 doses of phosphorus with mycorrhiza treatment, phosphorus uptake (69.9 mg P/pot), edible weight (84.36 g), dry weight (8.64 g) and leaf number (28) of lettuce were higher than that (47.7 mg P/pot, 59.33 g, 6.75 g and 20, respectively) in the control without mycorrhiza application. It was determined that mycorrhiza had positive effect on growth criteria and phosphorus nutrition by lettuce plant, and this effect decreased at higher phosphorus application rates.

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Introduction

Mycorrhiza, is one of the most common symbiotic life styles in soils, occurs between plant roots and soil fungus. Arbuscular mycorrhiza within endomikorizal life style promotes plant growth in marginal soil conditions especially having critical nutrient levels (Marschner, 1995).

Mycorrhizal funguses are the basic members of soil microflora in many ecosystems and have important roles in natural ecosystems and plantations. They have important functions on nutrient uptake by plants such as; P, N, K, Ca, Zn, Cu, Mn, Fe, regulate plant-water relations and plant protection from disease and pathogens. As a result, plants having healthy and strong root system make soils more resist to erosion with improving soil structure (Brundett et al. 1996; Gülser, 2004, 2006). Arbuscular mycorrhizal funguses uptake unavailable forms of plant nutrients, especially phosphorus, from soil by micelles and supply them to plants with having symbiotic life (Papastylianou, 1993). Fitriatin et al. (2014) reported that applications of phosphorus solubilizing microbe significantly improved yield of maize on Ultisol, but had no real effect towards potential-P, available-P, phosphatase and P uptake of plants. Application of a mix inoculant of phosphorus

* Corresponding author.
Yüzüncü Yıl University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition 65080 Van, Turkey
Tel.: +90 432 2251024 E-mail address: gulserf@yahoo.com
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solubilizing microbe and phosphorus solubilizing fungi gave better effects on available-P in soil and yield of maize. Asghari and Cavagnaro (2014) studied on mycorrhizal colonization using mycorrhizal and non mycorrhizal plants, arbuscular mycorrhizal external hyphae development, plant growth, nutrient uptake and NO_3, NH_4 and available P in soil and leachate. They reported that mycorrhizal fungi highly colonized roots of arbuscular mycorrhizal plant (exotic grass *Phalaris aquatica*) and significantly increased plant growth and nutrient uptake. Columns having *Phalaris aquatica* had higher levels of arbuscular mycorrhizal external hyphae, lower levels of NO_3, NH_4 and available P in soil and leachate than non mycorrhizal plant columns.

The most researchers focused on vesicular-arbuscular mycorrhiza because of their additive effects on phosphorus uptake. Smith et al (1992) reported that vesicular-arbuscular mycorrhiza living symbiotically in more than 90% of vegetation in nature plays determinative role in phosphorus uptake by plants.

Besides their limited sources and expensive cost, excessive use of chemical fertilizers can damage soil microorganisms and cause soil pollution. Alternative approaches for chemical fertilizer use in recent years are thought due to increasing environmental pollution and decreasing phosphate rock sources. In this study, effect of mycorrhiza on growth criteria and phosphorus nutrition of lettuce (*Lactuca sativa* L.) under different phosphorus fertilization rates were investigated.

Material and Methods

This study was carried out in the greenhouse of Horticultural Department of Agricultural Faculty at Yüzüncü Yıl University, Van –Turkey. Some soil physical and chemical properties of soil were determined as follow; texture by hydrometer method (Day, 1965), available phosphorus by Olsen method, pH in 1:1 soil: water suspension by pH meter, salt content of the same suspension by EC meter, lime by Scheibler calcimeter, organic matter by modified Walkley-Black method, total nitrogen by Kjeldahl method, exchangeable potassium, calcium and magnesium by extraction of soil with 1 N neutral ammonium acetate (Kacar, 1994). The results of soil analyses belong to growing media used in this study were given in Table1. According to the results, growing media was slightly alkaline in pH, non saline, moderate in lime content, low in organic matter, total nitrogen and phosphorus contents and adequate in potassium, calcium and magnesium contents.

Table 1. Some physical and chemical properties of growing media.

Texture	Sandy clay loam	Total N, %	0.07
pH(1:1)	8.03	Available P, ppm	6.98
Salt,%	0.057	Exchangeable K, cmol/kg	1.23
Lime ($CaCO_3$),%	14.04	Exchangeable Ca, cmol/kg	24.00
Organic Matter, %	0.92	Exchangeable Mg, cmol/kg	1.84

A mixture of soil:sand:manure in 1:1:1 ratio was used as growing media. The experiment was carried out according to factorial experimental design in randomized plots with two mycorrhiza (with (M+) and without (M-) mycorrhiza) and four phosphorus (0, 50, 100 and 200 mg P_2O_5/kg) treatments. The four doses of triple super phosphate (0, 50, 100 and 200 mg P_2O_5/kg) and a basic fertilizer of 200 mg N/kg as ammonium sulphate form was added into pots. Yedikule cultivar was used as a plant material. The irrigation was made by using distilled water. The experiment was ended after four months after seed sowing. The plant diameter, leaf number, crown fresh weight and dry weight were determined according to standard methods in harvested plants. The phosphorus contents of plant samples were analyzed according to vanadomolibdo phosphoric acid method reported by Kacar (1994).

The experimental data were analyzed by SPSS statistic program and means significantly different each other were shown with LSD test.

Results and Discussion

The effects of mycorrhiza and phosphorus applications on some yield criteria and phosphorus uptake in lettuce were given in Table 2. The mycorrhiza applications have significant effects on plant diameter, dry weight and phosphorus uptake. The phosphorus applications also significantly affected on dry weight and phosphorus uptake. The phosphorus uptake was also significantly influenced by mycorrhiza x phosphorus interaction.

Mycorrhiza application into growing media generally increased plant diameter compared with growing media without mycorrhiza application (Table 3). Mean of plant diameter (19.7 cm) in mycorrhiza added (M+) media was significantly higher than that (18.2 cm) in mycorrhiza nonadded (M-) media. There is no significant effect of mycorrhiza application on leaf number at different phosphorus rates. The mean values of leaf numbers were significantly affected by different phosphorus application rates. The lowest and the highest mean values of leaf number were obtained as 24 and 31 at 0 and 50 mgP/pot application rates, respectively (Table 3).

Table 2. According to variance analysis, F values for effect of mycorrhiza and phosphorus application on yield criteria and phosphorus uptake by lettuce.

Variation Sources	df	Plant diameter	Leaf number	Fresh weight	Dry weight	Phosphorus uptake
Mycorrhiza (M)	1	4.76**	2.47	3.22	8.17**	8.84**
Phosphorus (P)	3	0.84	2.78	1.75	4.31**	36.06**
MxP	3	2.10	2.84	9.14**	31.04**	28.10**

** significant at P<0.01 level.

Table 3. Effects of mycorrhiza (M) on plant diameter and leaf number at different phosphorus rates.

Phosphorus	Plant diameter (cm)			Leaf number		
(mg P/kg)	with M+	without M-	Mean	with M+	without M-	Mean
0	19.6	17.3	18.5	28	20	24 b
50	21.6	18.0	19.8	35	27	31 a
100	18.3	19.0	18.5	27	30	29 ab
200	19.3	18.3	18.8	27	28	28 ab
Mean	19.7 a*	18.2 b		29	27	

* There are significant differences between the means shown with different letters at P<0.01 level.

The mycorrhiza applications increased crown or fresh plant weight at the control treatment (Table 4). The interaction between mycorrhiza and phosphorus significantly affected fresh plant weight (Table 2). The lowest and the highest fresh plant weight means were obtained in media without mycorrhiza application as 59.33 g/pot for control and 96.23 g/pot for 200 mg P application (Table 4). The increasing phosphorus doses upper than 50 mg/kg decreased fresh plant weight in mycorrhiza added media. On the other hand, low phosphorus doses (0 and 50 mg/kg) increased plant dry weight in mycorrhiza added growing media. However, at the higher P application rates (100 and 200 mg P/kg), fresh plant weights for mycorrhiza application decreased. The highest plant dry weight mean was obtained as 9.91 g/pot in mycorrhiza and 50 mg/kg phosphorus added media. Fitriatin et al. (2014) reported that increasing doses of P fertilizer can inhibit the activity of phosphatase. Phosphate fertilizer with 50% recommendations dose gave better effects on potential-P in soil and maize yields.

Table 4. Effects of mycorrhiza (M) on fresh and dry plant weights at different phosphorus rates.

Phosphorus	Fresh weight (g/pot)			Dry weight (g/pot)		
(mg P/kg)	with M+	without M-	Mean	with M+	without M-	Mean
0	84.36	59.33	71.85	8.64	6.75	7.69 b*
50	93.93	62.73	78.33	9.91	6.87	8.39 a
100	77.50	81.86	79.68	7.32	8.82	8.07 ab
200	74.13	96.23	85.18	8.09	9.21	8.66 a
Mean	82.48	75.04		8.49 a*	7.91 b	

*There are significant differences between the means shown with different letters at P<0.01 level.

The plant dry weight mean (8.49 g/pot) in mycorrhiza application was significantly higher than that (7.91 g/pot) in nonmycorrhiza added media. Some researchers studied on different plants such as; Welling et al. (1991) in pea, Şimşek et al. (1998) in tomato, pepper and eggplant, Çetiner et al. (1999) in sweet corn, and obtained the similar results. Mycorrhiza applications increased plant dry weight in low phosphorus doses (0 and 50 mg P/kg). These increases were occurred at high phosphorus rates of nonmycorrhiza added media.

The increasing phosphorus rates increased phosphorus uptake by lettuce (Table 5). The lowest and the highest phosphorus uptakes were obtained as 47.66 mg/kg and 88.78 mg/kg for nonmycorrhiza added media with 0 and 200 mg/kg phosphorus application rates, respectively. Also, the lowest and the highest phosphorus uptake means were obtained as 58.81 mg/kg and 85.93 mg/kg in 0 and 200 mg/kg phosphorus applications, respectively. While mycorrhiza application increased phosphorus uptake by plant in low phosphorus rates, phosphorus uptake by plant decreased in higher phosphorus rates (Table 5). Ortaş et al. (2004) reported that some plants develop the adaptation mechanism to benefit from soil phosphorus in phosphorus deficient soils. Several researchers (Li et al. 1996, Ortaş et al. 1996, Bago and Azcon-Aquilar 1997) reported that plant roots having symbiotic life with mycorrhiza play role in increasing of phosphorus uptake due to their ability in regulation of soil pH. Waterer and Coltman (1989) reported that mycorrhiza inoculation increased total fresh weight and phosphorus content of stem of onion by phosphorus applications in low doses.

Table 5. Effects of mycorrhiza (M) on phosphorus uptake by plant at different phosphorus rates.

Phosphorus (mg P/kg)	Phosphorus uptake (mg P/pot)		
	with M+	without M-	Mean
0	69.95	47.66	58.81 c*
50	82.89	61.23	72.06 b
100	64.61	80.98	72.80 b
200	83.09	88.78	85.92 a
Mean	75.14 a*	69.66 b	

*There are significant differences between the means shown with different letters at P<0.01 level.

Conclusion

As a result, it was determined that mycorrhiza application had positive effect on yield criteria and phosphorus uptake of lettuce in lower phosphorus application rates. This positive effect decreased in high doses of phosphorus application rates probably due to decreasing phosphatase activity in soil.

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Structural-functional concept of thermophysical condition of the soils of Altai Region

Sergey V. Makarychev, Andrey G. Bolotov *

Altai State Agricultural University, Barnaul, Russia

Abstract

The goal of this study was to reveal the quantitative interrelations between the thermophysical indices (thermal conductivity and thermal diffusivity) and physical soil properties such as; moisture content, density and detachability. According to the research targets, the soil samples including different genesis and soil particle size distribution were taken in different soil and climatic zones of the Altai Region. These were the sod-podzolic sandy loam soils of the dry steppes, chernozems and chestnut soils of light and medium loamy particle size distribution of temperately arid zone, and the heavy loamy gray forest soils and clayey chernozems of the Altai foothills and low mountains. The samples of undisturbed structures in different soil horizons were studied. To measure the thermophysical properties in laboratory setting, a pulse method of a two-dimensional heat source was used. The method takes into account the patterns of temperature field equalization in an unbounded medium after the heat source termination. A feature of this process is the occurrence of peak temperature at the investigated point of the medium at a given instant. The knowledge of this temperature and time enables to determine the soil thermal capacity, thermal conductivity and thermal diffusivity.

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Keywords: Soil, soil-physical factors, thermal capacity, thermal conductivity, thermal diffusivity.

Introduction

The thermophysical indices of soil such as; volumetric and specific thermal capacities, thermal conductivity and thermal diffusivity in a complex way depend on the variety of soil-physical factors suh as; temperature, density of soil profile structure, the degree of moistening of genetic horizons, particle-size composition, and the organic matter content (Gülser and Ekberli, 2004; Ekberli, 2006; Mikayilov and Shein, 2010; Arkhangelskaya, 2014).

It is known that soil moistening plays the determining role in the formation of the thermophysical condition of soil profiles. In that connection a number of authors (Nerpin and Chudnovskiy, 1970; Makarychev and Mazirov, 1996) stated that in the pattern of the soil thermal indices change depending on the moisture content the following regularities are clearly expressed: volumetric thermal capacity grows in linear fashion with the moisture content increase, thermal diffusivity has a clearly defined maximum at certain moisture content values, and soil thermal conductivity increases nonlinearly tending to “saturation”. The density and dispersion of genetic horizons render varied effect on the values of thermophysical factors and on their distribution in soil profile. The study of those interrelations enabled the development of structural-functional concept of thermophysical condition of soils of various genesis.

The goal of this study was to reveal the quantitative interrelations between the thermophysical indices (thermal conductivity and thermal diffusivity) and physical soil properties such as; moisture content, density and detachability.

* Corresponding author.
Altai State Agricultural University, Barnaul, Altai Krai 656031 Russia
Tel.: +73852628353
E-mail address: agbolotov@gmail.com
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Material and Methods

According to the research targets, the soil samples including different genesis and soil particle size distribution were taken in different soil and climatic zones of the Altai Region. These were the sod-podzolic sandy loam soils of the dry steppes, chernozems and chestnut soils of light and medium loamy particle size distribution of temperately arid zone, and the heavy loamy gray forest soils and clayey chernozems of the Altai foothills and low mountains (Makarychev and Mazirov, 1996; Bolotov and Makarychev, 2015). The samples of undisturbed structures in different soil horizons were studied.

To measure the thermophysical properties in laboratory setting, a pulse method of a two-dimensional heat source was used. The method takes into account the patterns of temperature field equalization in an unbounded medium after the heat source termination. A feature of this process is the occurrence of peak temperature at the investigated point of the medium at a given instant (Chudnovskiy, 1976). The knowledge of this temperature and time enables to determine the soil thermal capacity, thermal conductivity and thermal diffusivity. A cylindrical probe was used in the field (Makarychev and Mazirov, 1996).

Results and Discussion

It is known (Makarychev and Mazirov, 1996) that the temperature factor of soil volumetric thermal capacity depends on soil moisture content ($\beta = f(U)$) and changes according to complex law (Figure 1). It grows slowly at low moisture content values, and only in the range from maximum hygroscopic content (MHC) to capillary bond breaking moisture (CBB) its values increase dramatically, and then slow down again.

It should be noted that the soils of different dispersion have an equal temperature factor in dry conditions and at total moisture capacity. Therefore, the clearly defined change of soil temperature factor at soil's intermediate moistening is determined by the cumulative change of the physical conditions of heat transfer in the soil related to water filling the pore space, together with the change of the energy state, properties and behavior of soil moisture.

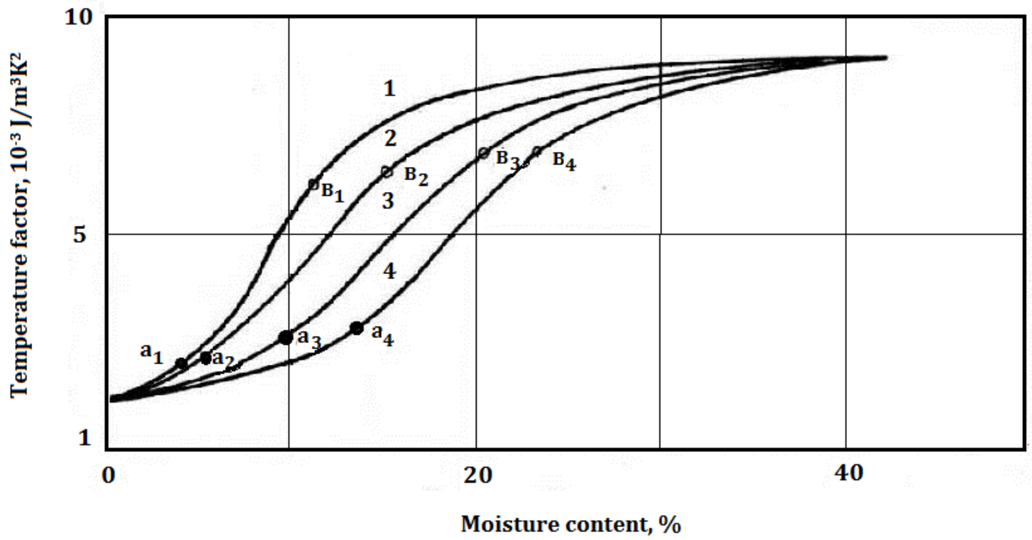

Figure 1. Temperature factor dependence of the volumetric thermal capacity of silica sand (1), sandy loam (2), loam (3) and clay (4) depending on moisture content

At the same time, with the increase of soil moisture content, the thermal diffusivity increases dramatically, reaching its maximum in medium loamy chernozem at the moisture content close to capillary bond breaking moisture. The further moistening results in the decrease of thermal diffusivity.

It is caused by the fact that in soils of different dispersion the most favourable conditions for soil air diffusion and, consequently, diffusive transfer of vapour and heat, are created at various hydrological constants when soil air is completely saturated with water vapour, and aeriferous soil pores have not been separated yet by water slugs. The further increase of soil moisture content results in water filling some of medium-sized and then large pores, and that breaks the connectivity of aeriferous pores system, and reduces the vapour permeability and thermal diffusivity of soil (Panfilov et al., 1982).

Moistening also involves the growth of thermal conductivity to some maximum value. Such run of the curves is explained by moisture gradually forcing poorly heat-conducting air out of soil pores and increasing soil thermal conductivity.

However, according to our data, dramatic increase of soil thermal conductivity clearly defined on the curves is strongly slowed down at this or that hydro-constant owing to swelling processes. As the result the contacts between solid soil particles weaken, and in the system of water-filled pores there are water-free closed pores, and that taken together results in slowing down the rate of soil thermal conductivity increase.

We also revealed quite well-defined reduction of soil thermal diffusivity with increase of soil density. At the same time the volumetric thermal capacity of dry and moistened chernozem increases linearly, and the factor of thermal diffusivity decreases exponentially. We explain those results on the basis of the concept of molecular heat transfer in disperse media and solid bodies. As it is known, gases have high thermal diffusivity. It equals 0.16×10^{-4} m/s for air, 0.13×10^{-6} m/s for water, and still less for solid bodies (Kay and Laby, 1995). Therefore, soil thermal diffusivity would strongly depend on soil compaction, soil particle-size distribution, and the degree of their air or water filled pore space.

Increasing density causes the reduction of air phase volume in soil, and the approach of the solid particles of soil skeleton. Alongside with that the total soil porosity decreases, there are fewer large and more of blind pores, in which the pressure of jammed air is higher than the atmospheric pressure.

Alltogether that causes the growth of air molecules' concentration in the pore space of soil, and the reduction of free-path length of those molecules. At constant temperature the rate of air molecule motion is constant, and the factor of thermal diffusivity is the function of free-path length only. Therefore, with soil compaction, accompanied by the change of pore space structure towards the reduction of air pores sizes, the increase of closed pores number, and the increase of molecule concentration of air contained in the pores, and, consequently, decrease of free-path length of gas molecules, soil thermal diffusivity decreases. In turn, the cumulative change of soil thermal capacity and thermal diffusivity determines the dynamics of soil thermal conductivity. It grows nonlinearly with the increase of soil structure density.

It is quite difficult to reveal the mechanism of the effect of soil particles' dispersion degree on soil thermophysical factors in their natural composition. The cumulative action of large number of factors (structure density, temperature, moisture content, etc.) enable making quality evaluation of the interrelation of thermal indices and particle-size composition only.

The dispersion degree of the horizons affects the factors of soil thermal conductivity and thermal diffusivity in a different way. So, the high content of clay and clay fraction causes the minimum values of thermal transfer factors in soil. The reason of the considered changes, in our opinion, is that the increase of dispersion involves the growth of particles number of soil solid phase, and consequently the number of aeriferous pores, but number of smaller sizes, and also the number of thermal contacts. Altogether it interferes with effective thermal exchange in soil.

Along with the considered factors, organic matter content in soil also renders significant effect on thermophysical factors. That effect is caused by the differences in thermophysical indices of both some granulometric fractions, and organic matter, as peat, for example. So, the specific thermal capacity of silica sand amounts to 821 J / (kg K), clay – 976 J / (kg K), and peat as much as 2000 J / (kg K). At the same time the thermal conductivity of silica sand amounts to 0.35 W / (m K), and peat – 0.11 W / (m K).

The experimental data shows that increasing organic matter content naturally increases both volumetric, and specific thermal capacity. But the thermal transfer factors decrease in that case. At the same time, the thermal transfer factors in the horizons with higher organic matter are considerably lower than in low humus horizons (Table 1).

Table 1. Thermophysical characteristics of some genetic horizons of chernozems with different humus content.

Horizon	Bulk Density, kg/m^3	Humus, %	Heat capacity		Thermal diffusivity, m^2/s	Thermal conductivity, W / (m K)
			Volumetric 10^{-6}, J / (m^3 K)	Specific, J / (kg K)		
A	1330	6.8	1.451	1091	0.220	0.319
AB	1380	4.9	1.501	1088	0.239	0.358
BC	1320	2.6	1.292	979	0.388	0.501

The knowledge of the interrelations of the complex of thermal and soil-physical factors enabled the development of structural-functional concept of thermophysical condition of soils.

Indeed, the thermophysical indices of the genetic horizons of a soil profile are structural-functional indices; this or that pattern of construction of aggregate-structural level of soil organization of elementary soil particles predetermines the amount and degree of variability of thermal capacity, thermal conductivity and thermal diffusivity not only of a specific horizon (horizon structural level), but also of the whole soil profile (level of a soil individual). Thus, the level hierarchy of soil structural organization is sustained (Voronin, 1984).

The structural-functional concept of thermophysical condition of soils is based on the established dependence of the thermal diffusivity maximum and the critical value of thermal conductivity of the function *a(U)* and *λ=f(U)* on the compaction degree of the soils of different particle-size composition.

It is known that the maximum of thermal diffusivity factor of loamy soils is observed at the moisture content close to capillary bond breaking moisture which is characterized by the transition of film-joint moisture into film-capillary moisture.

The moisture potential in that condition is named the potential at the maximum molecular soil moisture capacity (Voronin, 1984). At that potential the superficial forces in isothermal conditions keep the maximum amount of film moisture, and that is explained by two oppositely acting factors – the increase of the thickness and reduction of the area of the films. Thus, the thermodynamic balance between the film and capillary moisture is realized there, determined by the structure of the soil body, when not only the condition of soil capillary bond breakage develops, but also the condition of restoration of diffusive bond in the soil pore space.

In sandy loams the maximum of thermal diffusivity and the critical value of thermal conductivity are linked to the field moisture capacity (FC). Large and medium-sized pores prevail there amounting to 70% of the total porosity; that causes the discrete condition of soil moisture throughout the whole interval of natural moistening of soil. At field moisture capacity in the pores only 40-45% of pore space is water filled, while large pores and some medium-sized pores are air filled (Table 2).

Table 2. Amount of moistened pores (nominator) and air-bearing pores (denominator) in soils at FC and CBB levels, %

Soil texture	at FC		at FC	
	against total porosity	against soil volume	against total porosity	against soil volume
Medium loamy	61/39	32/21	44/56	23/30
Loamy-sandy	45/55	19/23	33/67	14/28

CBB corresponds to: a)70% FC in medium loams
b)FC in loamy sands

In those soils capillary-meniscus and capillary-film moisture movement is expressed very poorly. At the same time, at field moisture capacity the soil moisture acquires the property of capillary bonded water body revealing quite high values of contact thermal conductivity and thermal diffusivity, while the remaining free air pores support considerable thermal and vapour transfer.

In loamy soils where small pores prevail, such hydrological constant as the capillary bond breaking moisture is not expressed, and therefore, the maximum thermal diffusivity values are displaced towards the wilting moisture. At such degree of soil moistening the portion of the capillary-suspended moisture is insignificant and practically all of is presented by the osmotic form, staying in that form in unstable thermodynamic balance.

It should be noted that in the soils of various dispersion degree the change of external or internal conditions should cause the disturbance of the balance and result in the shift of thermal diffusivity maximum and the critical value of thermal conductivity relative to the degree of soil moisture content.

So, at soil compaction accompanied by destruction of large pores, the moisture transition into smaller pores is observed, where the critical potential ψ of maximum molecular soil moisture capacity is observed at lower moisture content, therefore some part of soil moisture moves into the category of capillary-suspended, capillary-supported or gravitational moisture. In that case the air-bonded condition of pore space is destructed and, as consequence, the thermal diffusivity decreases. To restore the balance some part of soil moisture should be removed.

We derived the dependences of moisture content corresponding to thermal diffusivity maximum $Ua_m=f(BD)$ for the soils of clayey (1), loamy (2) and sandy (3) particle-size composition (Figure 2). According to the dependences, the equations of linear regression are derived at the temperature of 20°C:

$$Ua_m(1) = 42.3 - 0.017BD,$$

$$Ua_m(2) = 37.9 - 0.017BD,$$

$$Ua_m(3) = 34.7 - 0.017BD,$$

where, Ua_m – soil moisture content, % of the weight; BD – soil bulk density, kg/m^3.

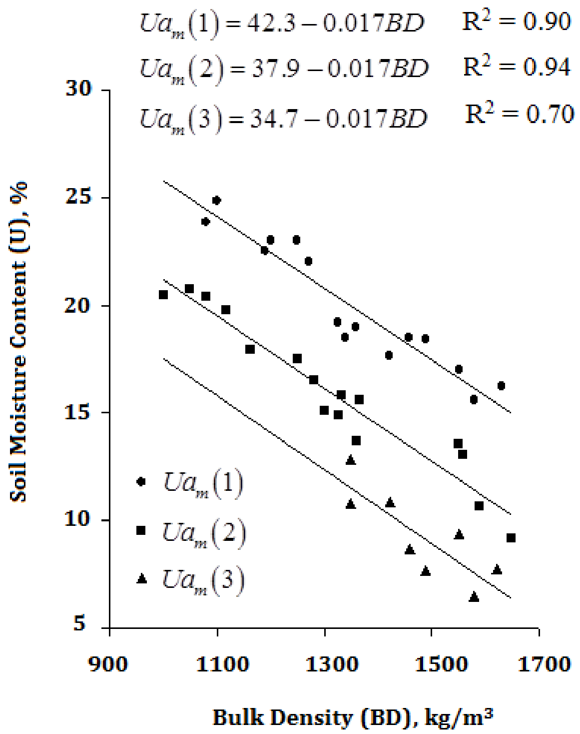

Figure 2. The moisture content corresponding to the maximum thermal diffusivity values of the soils of clayey (I), loamy (II) and sandy loam (III) particle size distribution depending on the bulk density.

The equations for clayey and loamy soils are true within the limits of 900-1600 kg/m^3, and for sandy soils – 1300-1700 kg/m^3. The relation between the composition (mechanical particles) and thermophysical indices is reflected by the equation:

$$Ua_m = -8.9 + 7.2\ln(D),$$

where D – dispersion or the number of particles less than 0.01 mm.

In that case the determination index of curvilinear correlation appears to equal 0.92 at one percent significance level, i.e., to 92% the maximum thermal diffusivity is provided by soil dispersion. The greatest rate of moisture content change, which corresponds to the maximum of thermal diffusivity, is observed in sandy soils. It is slightly less in loamy soils, and in clayey soils it decreases and tends to some limit close to 24% of soil weight (Figure 3).

Figure 3 presents the data of the dependence of the moisture change rate (moisture mobility) at which the extreme thermal diffusivity value depending on the degree of soil dispersion is observed. According to the data of the Figure 3, it follows that the moisture effect is most actively revealed in sandy soils, weaker – in loamy soils, and it is very low in clayey soils.

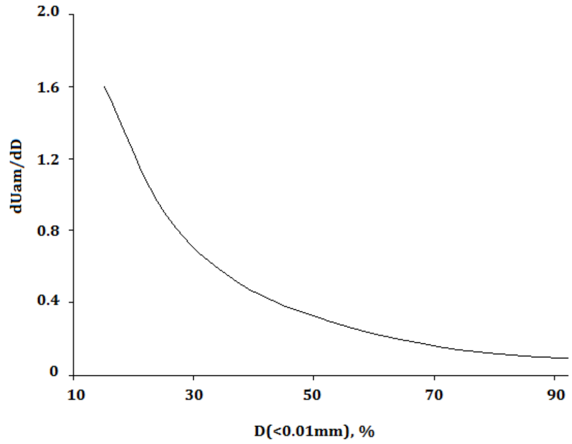

Figure 3. The change rate of moisture content (dUam/dD) depending on clay particle content in the soil.

At the same time, the bond energy of moisture with solid phase, on the contrary, is higher in more disperse soils. It is for that reason the dynamics of the thermal conductivity and thermal diffusivity factors decreases at transition from sandy to clayey particle-size composition. Thus, the structural-functional concept of thermophysical condition coordinates the quantitative interrelations between the basic soil-physical factors (*U, D* and *BD*) and the thermophysical indices (a_m, λ_K) of soils.

Conclusion

1. Soil-physical factors render many-valued effects on the character and the value of thermophysical indices of the soils of different genesis and particle-size composition. The most essential role in that belongs to the degree of soil moistening and the density of soil structure.

2. The developed structural-functional concept of thermophysical condition of soils enables revealing the quantitative interrelations between the soil moisture content, the dispersion degree, the density of structure and the factors of thermal transfer.

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Using Cesium-137 to estimate soil particle redistribution by wind in an arid region of central Iran

Fatemeh Gheysari [a], Shamsollah Ayoubi [a,*], Mohammad Reza Abdi [b]

[a] Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, Iran
[b] Department of Physics, Faculty of Science, University of Isfahan, Isfahan, Iran

Abstract

This study was conducted to estimate soil erosion and deposition rates along a transect using ^{137}Cs technique in an arid of Isfahan Province, central Iran. Sixteen sites along a northeast-southwest transect with 42 km length were used. Eighty soil samples collected from five depths (0-5, 5-10, 10-20, 20-30, 30-50 cm) were analyzed for ^{137}Cs concentration. Additional 20 soil samples were collected from the reference site for computing soil loss and deposition using ^{137}Cs measurement. The results showed that the northern part of the transect showed erosion rates ranging from12.90 to 46.86 t ha^{-1}yr^{-1}. The major factor affecting soil erosion process in northern part of the studied transect is associated dominantly with occurrence of improper gypsum mining operations and human activities. In the southern part of the transect deposition rates changed between 3.10 - 7.44 t ha^{-1}yr^{-1}, presumably influenced by increasing plant cover. Significant correlations between ^{137}Cs and magnetic susceptibility, soil organic matter (SOM), total nitrogen (TN) and particle size distributions indicated that soil redistribution by wind erosion might have modified the soil properties along the studied transect. A multiple linear regression model was developed for estimating ^{137}Cs by frequency dependence (χ_{fd}), TN, clay and sand contents which explained about 87% of the ^{137}Cs variability. This study of using ^{137}Cs to assess wind erosion is unique in the arid region of central Iran and had significant implications for further research.

Keywords: ^{137}CS inventory, oil redistribution, wind erosion.

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Introduction

Wind erosion is one of the most basic processes of land degradation and environmental concerns in the arid and semi-arid regions (Hennessy et al., 1986; Okin et al., 2001). Moreover, wind erosion is identified as one of the most serious environmental and agricultural threats in many arid regions of the world (Gomes et al., 2003; Zhao et al., 2006). Soil erosion leads to desertification and air pollution. Wind erosion like water erosion leads to coarsening soil texture by the loss of fine textured materials, decreasing of soil organic matter and degeneration of vegetation (Zhang et al., 2007).

Arid and semiarid environment is the main climatic conditions in the central Iran, as well as 80 million km^2 of Iran (> 50%) is affected by wind erosion. During the last decades the area affected by wind erosion and desertification processes has increased as a result of human activity, climate change and recent drought

* Corresponding author.
Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111 Iran
Tel.: +983133913470
E-mail address: ayoubi@cc.iut.ac.ir
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(Karimzadeh, 2001). Thus, it is crucial to control wind erosion in the arid regions of Iran as the most serious environmental problem. In this regard, the information on the rate of soil erosion is needed for developing management practices and for making strategic decisions.

Since 1930s the studies on wind erosion have been conducted to make estimates of soil loss by wind erosion. Many erosion models have been used to predict soil erosion by wind (Woodruff and Siddoway, 1965; Skidmore and Powers , 1982, Shao et al., 1996; Hagen, 1991). But, most of the developed models require a large empirical components and it has not been possible to extend them beyond the area for which they were developed. In recent years, ^{137}Cs technique has been used to estimate the rates of soil erosion by wind (Yan et al., 2002; Yan and Shi, 2004; Li et al., 2005; Zhao et al., 2006). ^{137}Cs is an artificial radionuclide with a high gamma radiation and half-life of 30.2 years, which is released into the environment as a result of nuclear weapons tests primarily during the 1950-1970. ^{137}Cs fallout reaches the earth's surface mostly as a result of precipitation and is strongly and is rapidly adsorbed by fine soil colloidal particles such as clay minerals and organic matter in the topsoil. Chemical or biological removal of ^{137}Cs from soil particles is limited and it is assumed that only physical processes that result in moving soil particles such as soil erosion and tillage particle are involved in the ^{137}Cs transport (Afshar et al., 2010; Rahimi et al., 2013).

Zhang et al. (2007) used ^{137}Cs tracer in tunnel to test the erodibility of soils in Tibet. They reported that alpine meadows have the highest resistance to wind erosion and the undamaged alpine meadow soils generally sustain only weak or no wind erosion. Yan et al. (2002) by analyzing the pattern of ^{137}Cs inventory showed that the shrub coppice dunes and semi-fixed dune fields experienced the alteration of erosion and deposition.

Although, a few studies (Afshar et al., 2010; Rahimi et al., 2013; Ayoubi et al., 2012) have been conducted in the semiarid regions of western Iran for the estimation of water erosion rate by ^{137}Cs technique, but so far no investigation has been reported in the arid region of Iran using ^{137}CS for the prediction of wind erosion till now. Therefore, as the first report, this study was performed to i) estimate soil redistribution by wind using ^{137}Cs as a tracer and (ii) explore the relationships among physicochemical and magnetic susceptibility properties with ^{137}Cs as an indicator of soil redistribution, along northeast - southwest transect across the Segzi district, east of Isfahan, central Iran.

Material and Methods

Study area

The study area is located between 32° 34' 8'' to 32° 50' 37'' N latitudes and 51° 58' 43'' to 52° 3' 4'' E longitude, 2120 m a.s.l in Segzi district, Isfahan province, central Iran (Figure 1). Mean annual precipitation is 106 mm, mean annual potential evaporation is 2201.5 mm, and the mean annual temperature is 15.2 °C. Segzi district has a desert climate and wind speed of 60 km hr^{-1}. The area predominantly included two major geomorphic surfaces of pediments and play as according to Krinsley (1970).

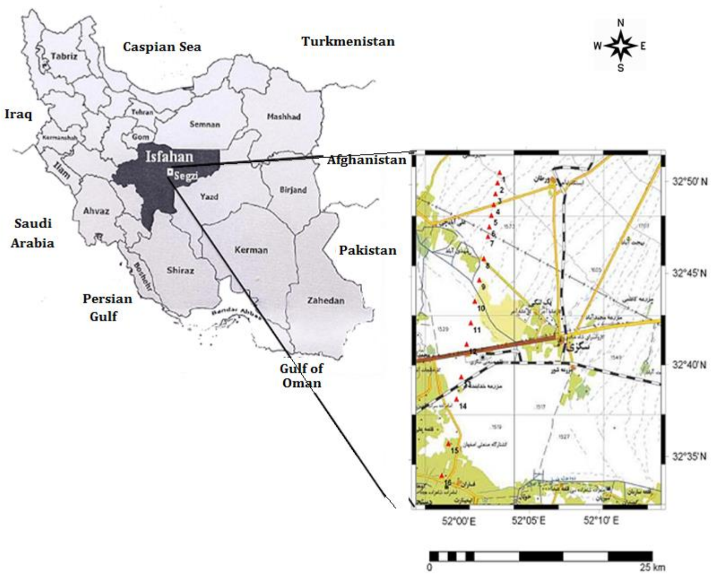

Figure 1. Location of the study site in the along northeast - southwest transect across the Segzi, east of Isfahan, central Iran

Soil sampling

Sixteen sites with 2.5 km apart in a northeast to southwest transect across the Segzi district (42 km in length) were selected (Figure 1). In each site, soil samples were taken from five depths: 0-5, 5-10, 10-20, 20-30 and 30-50 cm at the year of 2012 (total of 80 soil samples). A reference site covered by desert varnish indicating surface stability for long period of time, was selected in nearby transect. Two cores from the reference site were drilled and 20 soil samples were collected from 0 to 50 cm depth with an increment of 5 cm to evaluate the Cs-inventory and physicochemical analysis.

Laboratory analysis and ^{137}Cs measurements

Air-dried soil samples thoroughly sieved with a 2-mm sieve. Samples each of 500 g were placed in Marinelli beakers and sealed for ^{137}Cs analyses. The ^{137}Cs activity was measured at Department of Physics, University of Isfahan (Iran), from the net area under the full-energy peak at 662 KeV (ISO 11929-1, 2000), using gamma spectroscopy with a high-resolution germanium detector. Quality control of measurements was done by the reference material No: IAEA-375 from the International Atomic Energy Agency (IAEA), Analytical Quality Control Services. The count time was approximately 130 min, with counting error at <10% and 95% confidence level. The ^{137} Cs activities (Bq kg^{-1}) were converted to area activities (Bq m^{-2}) (Walling et al., 2002).

Soil bulk density was determined using the core method (Blake and Hartge, 1986). Calcium carbonate equivalent (CCE) was measured by Bernard's calcimeter method (Black et al., 1965). Soil particle size distribution was obtained by the Bouyoucos hydrometer method (Gee and Bauder, 1986). Soil pH was measured in saturated paste using pH electrode (Soil Survey Division Staff, 1993) and electrical conductivity (EC) in the extract using conductivity meter (Rhoades, 1982). Soil organic matter (SOM) was determined using a wet combustion method (Nelson and Sommers, 1982) and total nitrogen (TN) by the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Gravel content was measured volumetrically after sieving by a 2 mm sieve. $CaSO_4$ was determined by heating at 110 °C method (Porta, 1998).

Magnetic susceptibility was measured at low (0.46 kHz) and high frequency (4.6 kHz) using a Bartington MS2 dual frequency sensor. The χ value is relative to the concentration of the ferrimagnetic minerals (magnetite and maghemite) in the sample and is also sensitive to the magnetic grain size (Dearing, 1999). The percentage of frequency dependence (χfd %) was determined by the following equation:

$$\chi_{fd} = \left(\frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}}\right) \times 100 \qquad [1]$$

where, χ_{lf} and χ_{hf} are magnetic susceptibility at low and high frequencies respectively.

Computational methods

Soil particle redistribution rate at any sampling site could be assessed by establishing a quantitative relationship between the rate of deposition or erosion and the changes of ^{137}Cs inventory compared with the baseline. In this paper, a simple but empirical linear model was employed to assess soil erosion rates following the approach of Ritchie and McHenry (1990) and Walling and Quine (1993):

$$E = \frac{CPR \times BD \times D_i \times 10^4}{T} \qquad [2]$$

$$CPR = \frac{(CPI - CRI)}{CRI} \times 100 \qquad [3]$$

where *E* is the net wind erosion rate of the sample site (t ha^{-1} y^{-1}), *CPR* is the loss of ^{137}Cs (%)(Eq. 3), *BD* refers to the bulk density of sampled soil (t m^{-3}), *T* is the time period between the year of maximum ^{137}Cs fallout (1963) and the sampling year (2012); in this study, *T*= 49 year. The sampling increment, Di, was previously used as the plough depth for farmland (Ritchie and McHenry, 1990). But, for the uncultivated soils in the studied area, according to the depth distribution of ^{137}Cs activity (Figure 3), D_i was considered to be 0.2 m. In the Eq. 3, *CPR* is ^{137}Cs percentage residual at a sampling site in the field relative to the native control area (%), *CPI* is ^{137}Cs inventory (Bq m^{-2}) in the studied site, CRI represents ^{137}Cs reference inventory (Bq m^{-2}).

Data analysis

Descriptive statistics including mean, minimum, maximum, coefficient of variation (CV), standard deviation (SD), and skewness were calculated using Statistical Package for the Social Sciences (SPSS), v.16. The distribution of variables was assessed using the Kolmogorov-Smirnov test (Massey, 1951). The correlations among the variables as well as of ^{137}Cs and magnetic measures with physicochemical properties were examined using the SPSS software (Swan and Sandilands, 1995). A stepwise regression procedure was employed by regressing magnetic susceptibility on the ^{137}Cs inventory and soil physico-chemical properties. Selection of the factors for inclusion in the model was based on the probability <0.05 (Freund and Littell, 2000).

Results and Discussion

Descriptive statistics

A summary of descriptive statistics of ^{137}Cs inventory, soil magnetic and physico-chemical parameters in all sampled soils are given in Table 1. All parameters are normally distributed, except for χ_{fd}, as confirmed by the Kolmogorov-Smirnov test, and as indicated by skewness values, which varied from -1 to 1 (Table 1). The coefficient of variation (CV) of the ^{137}Cs concentration in the selected soils was 47.83 %. According to the classification proposed by Wilding (1985), ^{137}Cs in the study area was classified as highly variable (CV > 0.35). Magnetic susceptibility at high frequency, EC and silt also showed high variability with CV values of 109.87, 102.8 and 47.47%, respectively. While, SOM, TN, $CaCO_3$, clay, sand, χlf and χ_{fd} were classified as moderately variable (0.15 <CV < 0.35). Remaining variables including pH, BD and showed low variability (CV<0.15) in the studied region.

Table 1. Descriptive statistics for ^{137}Cs and physico-chemical properties along the northeast - southwest transect across the Segzi, East of Isfahan, Iran

Variable	Unit	Min	Max	Mean	SD	CV (%)	Skewness
^{137}Cs	Bq m^{-2}	255.00	1312.50	681.50	326.08	47.83	0.78
TN	%	0.10	0.31	0.17	0.05	29.41	0.78
SOM	%	0.10	0.63	0.40	0.12	30.00	-0.47
EC	dS m^{-1}	1.80	61.29	48.63	50.00	102.80	1.10
pH	-	7.30	8.51	7.94	0.36	4.53	-0.02
$CaCO_3$	%	29.40	69.50	53.71	9.67	18.00	-0.88
Clay	%	10.00	19.00	13.14	2.49	18.9	1.00
Silt	%	12.00	36.30	36.63	17.39	47.47	-0.04
Sand	%	20.00	76.30	50.23	18.66	37.14	-0.03
BD	g cm^{-3}	1.27	1.78	1.44	0.14	9.72	0.90
χlf	10^{-8} m^3/kg	36.47	85.78	63.95	14.22	22.23	-0.13
χfd	10^{-8} m^3/kg	-0.37	3.30	0.81	0.89	109.87	1.64

Min: minimum: Max: maximum: SD: Standard deviation: CV: Coefficient of variation; 137-Cs: Radioactive cesium -137 inventory; TN: Total nitrogen; SOM: Soil organic matter; EC: Electrical conductivity; pH: Soil reaction; BD: Bulk Density; χlf: Magnetic susceptibility at low frequency; χfd: Dependent frequency

These results show a high variably in ^{137}Cs distribution induced by wind erosion via soil redistribution along the transect. It seems that high variably in ^{137}Cs distribution was induced by soil erosion and deposition along the studied transect. Afshar et al. (2010) obtained similar CV value of 50% for ^{137}Cs inventory in Ardal district in west of Iran. On the contrary, Ayoubi et al. (2012) reported CV value of 103.9% for ^{137}Cs inventory in Chelgerd district in west of Iran.

^{137}Cs activity and wind erosion assessment

^{137}Cs reference inventory refers to the amount of ^{137Cs} accumulated at the study site from atmospheric ^{137}Cs fallout without any effects of wind erosion and deposition processes and human disturbance (Walling and Quine, 1993). The ^{137}Cs inventory of the two reference cores collected from the reference site had mean value of 1143.75 Bq m^{-2} (Figure 2). The mean value obtained in the present study is lower than those reported by Afshar et al. (2010), Ayoubi et al. (2012) and Rahimi et al. (2013) in some semiarid regions of Iran. The lower Cs-137 inventory at the studied site compared to the western Iran ascribes to lower precipitation in the arid region. Overall fall out of ^{137}Cs in a specific site is influenced significantly by the precipitation and rainfall (Palsson et al., 2002). In the arid selected area, annual precipitation is approx. 110 mm per year, whereas in the semiarid regions in western Iran precipitation exceeds 600 mm yr^{-1}.

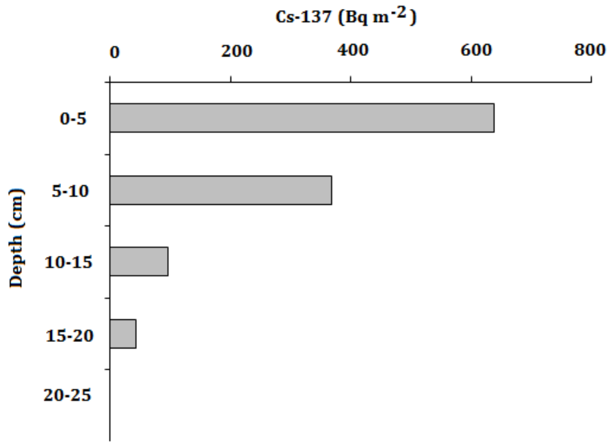

Figure 2. Vertical distribution of ^{137}Cs inventory at the reference site in the studied area

The mean values of ^{137}Cs inventory and % loss of ^{137}Cs at the studied sites as compared to the mean value of ^{137} Cs inventory at the reference site are given in Table 2. The lowest and highest values of ^{137}Cs inventory, 255 and 1312.5 Bq m^{-2} were observed in sites of X_3 and X_{11}, respectively. The concentration of ^{137} Cs in natural and undisturbed soils decreased sharply with depth and was represented by the exponential function: $Cs= ae^{-bx}$ (Figure 2) (Walling and Quine, 1990; Afshar et al., 2010). While in the disturbed soils, the ^{137}Cs activity profiles exhibited deviation to varying degrees (Figure 3). This confirmed that the ^{137}Cs inventory at different sites have been affected by erosion or/and deposition processes and human disturbances.

Through sites X_1 to X_8, in the northern side of transect, the ^{137}Cs in the 0-10 cm declined compared as the reference site, indicating the dominance of soil erosion processes. The wind soil erosion rate in this part of the transect varied from 12.90 to 46.98 t $ha^{-1}yr^{-1}$(Table 2). Ping et al (2000) assessed the average wind erosion rate in the Qinghai Tibetan Plateau using ^{137}Cs techniques to be 47.59 t ha^{-1} yr^{-1}. Yan and Shi (2004) calculated wind erosion rates using ^{137}Cs technique of 24.91 t ha^{-1} yr^{-1} in Gonghe basin, Qinghe province, China.

Table 2. Rates of ^{137}Cs loss and the estimated corresponding wind erosion rate at the sampling sites along the northeast - southwest transect across Segzi.

Sampling site	137Cs inventoryn (Bq m^{-2})	137Cs loss (%)	Soil erosion rate (t ha^{-1} yr^{-1})
X1	915	-20.00	12.90
X2	652.5	-42.95	31.19
X3	255	-77.70	41.17
X4	300	-73.77	46.98
X5	527.5	-53.88	31.17
X6	375	-67.21	40.75
X7	642.5	-43.82	29.47
X8	537.5	-53.00	31.56
X9	1300	+13.65	-7.21
X10	1209.97	+5.79	-3.10
X11	1312.5	+14.74	-7.64
X12	662.5	-42.07	23.30
X13	550	-51.91	32.02
X14	652.5	-42.95	23.39
X15	787.5	-31.15	17.93
X16	357.5	-68.74	37.71

It seems that high rate of soil erosion by wind in this part is ascribed mainly to improper management in gypsum mining around the sites X_1-X_4 by local inhabitants. Karimzadeh (2001) also in a preliminary study in determining significant factors affecting wind erosion in east of Isfahan stated that disposal of mine tailing was the most important environmental issue of desertification in this region. The plant's absence and little green cover also accelerated detachment process of fine materials (Hupy, 2004).

Enhancement of cesium-137 inventory was observed in the sites X_9, X_{10} and X_{11} which showed 13.65, 5.79 and 14.74% increasing compared to the reference site. The average soil deposition in these sites was 7.21, 3.1, and 7.64 t $ha^{-1}yr^{-1}$ (Table 2). A typical vertical distribution of cesium inventory for site 11 is illustrated in Fig. 3b. As it is seen in the profile, the lower layers (20-50 cm depth) showed a uniform distribution, but the upper layer showed non-normal (biased) distribution, indicating that deposition of enriched ^{137} Cs materials. Overall, this distribution pattern is very similar to the pattern other workers have reported for the deposition sites (Yan et al., 2002). Deposition processes in these sites might be attributed to increasing plant cover which trapped the soil particles transported from other sites. Sites X_{12} to X_{16} showed a different pattern to the previously discussed sites. These sites indicated net erosion rates ranged from 17.93 to 37.71 t ha^{-1} yr^{-1}. As seen (Figure 3c) in the 5-10 cm depth, these profiles have experienced complex deposition and erosion processes and thus they show non-normal distribution of ^{137}Cs with depth. Similar results by wind erosion were reported by Ping et al. (2000) in Qinghai-Tibet plateau, China.

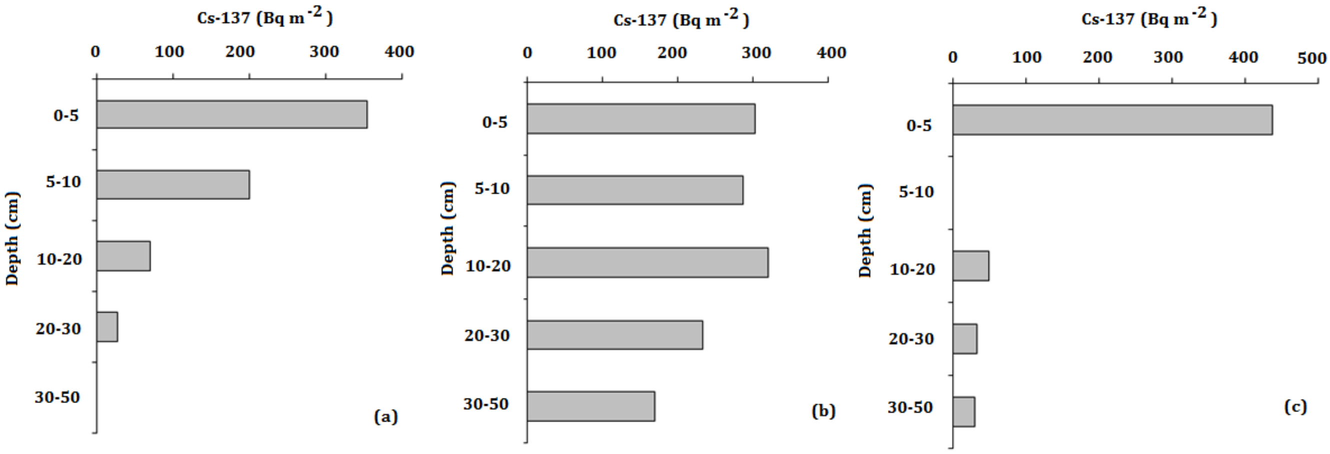

Figure 3. Vertical distribution of ^{137}Cs (Bq m^{-2}) at site X_3 (a), site X_{11}(b) and site X_{14}

Interrelations among soil properties and ^{137}Cs inventory

The linear correlation coefficients of Cs-137 inventory with the selected soil physico-chemical and magnetic parameters in all studied soil samples are given in Table 3. The results showed significant positive correlations of clay content (r = 0.63**), silt content (r = 0.50*), SOM (r = 0.63**), TN (0.83**) and EC (r = 0.62**) with ^{137}Cs inventory. Positive correlation of soil fine particles and organic matter with ^{137}Cs indicated that ^{137}Cs has been adsorbed and stabilized by clay and organic colloids. Staunton and Roubaud (1997) found a high covalent interaction between Cs and the clay surface. There were significant negative correlations of sand content (r= -0.55*), pH (r= -0.70**), and $CaCO_3$ (r= -0.53*) with ^{137}Cs inventory (Table 3). These results are agreement with the findings of Afshar et al. (2010) and Rahimi et al. (2013) in western Iran.

Table 3. Correlation coefficients among soil physico-chemical properties and radioactive ^{137}Cs at the site studied (n=80).

	^{137}Cs	TN	SOM	EC	pH	Clay	Sand	Silt	$CaCO_3$	$CaSO_4$	Gravel	BD
^{137}Cs	1											
TN	0.83**	1										
SOM	0.63**	0.55*	1									
EC	0.62**	-0.63**	0.54*	1								
pH	-0.7**	-0.52*	-0.58*	-0.76**	1							
Clay	0.63**	0.53*	0.68**	0.77**	-0.68**	1						
Sand	-0.55*	-0.14	-0.57*	-0.55*	0.54*	-0.55*	1					
Silt	0.5*	0.08	0.52*	0.68**	-0.48	0.44	-0.99**	1				
$CaCO_3$	-0.53*	-0.31	-0.26	-0.59*	-0.62*	-0.63**	0.47	-0.42	1			
$CaSO_4$	-0.1	-0.06	-0.13	0.16	-0.07	0.23	0.08	-0.13	-0.13	1		
Gravel	-0.27	0.07	-0.47	-0.6*	0.44	-0.36	0.73**	-0.73**	0.45	-0.15	1	
BD	0.029	-0.29	-0.29	0.45	0.2	-0.5*	0.53*	-0.49*	0.58*	-0.21	0.74**	1

*Significant at 95%, **significant at 99% probability level

^{137}Cs: Radioactive cesium-137; TN: total nitrogen; SOM: Soil organic matter; EC: Electrical conductivity; pH: Soil reaction BD: Bulk density.

These high statistical correlations between soil properties and ^{137}Cs inventory indicated that soil redistribution by wind likely control the variability of the selected soil properties along the studied transect. In other words, detachment and accumulation of some soil elements such as SOM, soil nutrients, and magnetic minerals and Cs-inventory associated with fine particles are regulated simultaneously along the transect.

The results of correlation analysis between ^{137}Cs inventory and magnetic parameters showed that χlf had positive significant correlation with ^{137}Cs (r= 0.64**) (Figure 4a); and also χfd had significant positive relationship with cesium-137 (r = 0.48*) in the 0-15 cm depth (Figure 4b). Rahimi et al (2013) reported positive correlation of magnetic susceptibility with ^{137}Cs inventory. It is presumably attributed to that factors affecting variability of ^{137}Cs probably (i.e. soil redistribution by wind) controlled the variability of magnetic particles associated with fine soil particles.

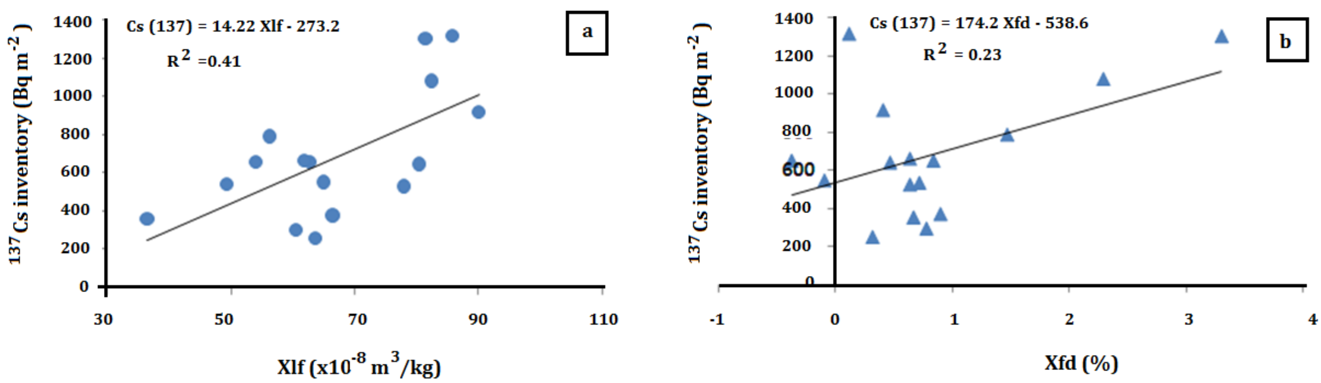

Figure 4. Linear relationships of total ^{137}Cs inventory in the studied sites with magnetic susceptibility (a) and magnetic dependency (b) and χfd: Dependent frequency in the 0-50 cm soil depth.

Also, a non-linear relationship was established to develop more powerful model between ^{137}Cs and magnetic susceptibility. In this regard, the following non-linear equation was developed between ^{137}Cs and χ_{lf} could explain 50% of total variability of ^{137}Cs in the samples along the transect.

$$137CS = 7.5 + 3.87(\chi_{lf}) + 8.04(\chi_{lf})^2 \qquad R^2=0.50,\ p<0.05 \qquad [4]$$

These results imply that soil redistribution (erosion and deposition) could likely explain the variations in magnetic susceptibly and therefore, magnetic variations have potential to be used as a proxy for soil erosion monitoring with the aim of reducing the number of ^{137}Cs analyses in the given study area affected by wind erosion processes. Mokhtari Karchegani et al. (2011) studied the efficacy magnetic measurements for assess soil redistribution in hilly regions of western Iran by water erosion. They reported that these measures could provide valuable information for soil redistribution in combined to other soil properties. Similar findings were obtained by Ayoubi et al. (2012) and Rahimi et al. (2013) in western Iran.

Moreover, a multiple linear regression (MLR) model was developed between ^{137}Cs and studied soil properties, and can be represented by the following equation.

$$^{137}Cs= 346.43 + 209.68(TN\times Clay) + 105.79\ \chi fd- 0.41\ (Sand\times Clay) \qquad R^2=0.87,\ p<0.01 \qquad [5]$$

As the equation showed, TN, clay content, χfd and sand content included in the MLR had significant effect and their combined effect could explain 87% of the total variability in the ^{137}Cs inventory along the transect. As measurement of ^{137}Cs has been identified as one of the most reliable techniques for evaluating soil redistribution, and measurement of ^{137}Cs is so time and cost consuming, therefore the above equation could provide valuable information about CS inventory using easily available soil data at the studied site. Afshar et al. (2010) reported that among the soil properties, total nitrogen, available phosphorus, and potassium explained 41% of the total variability in the ^{137}Cs inventory in western Iran.

Conclusion

The wind erosion and deposition rate was estimated along a northeast - southwest transect across the Segzi region in central Iran using the ^{137}Cs technique. The relationships between ^{137}Cs and selected soil physical and chemical properties were also examined. The ^{137}Cs inventory of sampling site ranged from 255 to 1312.5

Bq m^{-2} and wind erosion rate ranged from 3.10 to 46.98 t $ha^{-1}yr^{-1}$. In almost all of the sites studied (13 from 16 sites), soil erosion has occurred; and at the depositions sites the deposition rates varied from 3.1 to 7.64 t $ha^{-1}.yr^{-1}$. Soil erosion sites were mainly associated with gypsum mining operations and the deposition sites were mainly due to increasing plant cover.

The correlation analysis showed significant positive correlations between clay content, silt content, SOM, TN, EC, χlf, and χdf and ^{137}Cs inventory. Multiple linear regression analysis revealed that a combination of magnetic susceptibility and some easily measurable soil properties (e.g. total nitrogen, clay, sand) could explaining about 87% of total variability of ^{137}Cs, and hence these variables could be used in the future research to reduce cesium measurement to assess redistribution by wind erosion in the studied region. Overall, the results of the present study for the first time in the country show that ^{137} Cs can be used for estimating wind erosion; and this has significant implications for future research in this important area in the arid region of Iran.

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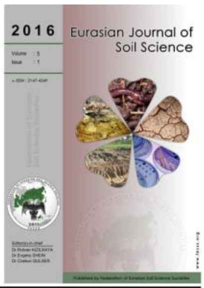

Effects of some organic materials on bicarbonate extractable phosphate content of soils having different pH

Nutullah Özdemir *, Ömrüm Tebessüm Kop Durmuş, İrem Zorba

Ondokuz Mayıs University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Samsun, Turkey

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Abstract

This study was carried out to determine the effects of rice husk compost (RC), town waste compost (TW) and tobacco waste (TB) on bicarbonate extractable phosphate content (P) in soils having different pH levels under greenhouse conditions. Soil samples used in this study were taken from surfaces (0-20 cm) of agricultural fields around Samsun, Northern Anatolia. The experiment was conducted according to split plot design with four doses of organic matterials (0, 2.5, 5.0 and 7.5, %). After a month of mixing organic matterials into soils, lettuce were grown in the medias. According to the results, RC, TW and TB applications into acidic (Tepecik), neutral (Kampüs) and alkaline (Çetinkaya) soils increased extractable P content. It was observed that effectiveness of organic matterials changed depend on soil reaction, type and dose of organic matterials. All organic wastes were more effective on increment of bicarbonate extractable phosphate content in neutral soil pH when compared the other soil pH levels.

Keywords: Compost, extractable phosphorus, organic residues, soil reaction.

Introduction

Organic matter concentration of soils is a dynamic property and affects both soil physical and chemical properties and its overall sustainability. It is known that adding organic matter to soil develop soil physical conditions and regulate chemical conditions (Anderson et al., 1990; Gajic et al., 2006; Demir and Gülser, 2015). Many studies showed that the amelioration of soil physical (Gülser and Candemir, 2006; Yakupoglu and Ozdemir, 2012) and chemical (Özdemir, 1993; Haynes, 2000) properties largley based on increaments of organic carbon in the soils with using organic wastes. Soil organic matter is an essential but transient component of the soil that controls many physical, chemical and biological properties of the soil (Carter, 1996; Kızılkaya, 2008). In the formation of fertile soil, organic substances play a direct role as sources of plant nutrients which are liberated in available form during mineralization. The incorporation of agricultural wastes such as; poultry manure and cow dung, with rock phosphate significantly improved the release phosphorus and raised crop yields (Akande et al., 2005; Akande et al., 2008; Agyarko et al., 2015).

Organic matter level of soils is mostly low in Turkey (Kızılkaya, 2004). This is a big problem especially in semi-arid regions. To increase the level of organic material, the most common approach is to apply different organic matter sources to cultivcated soils. The use of waste in agriculture, forestry and land reclamation has been increasingly identified as an important issue for soil fertility, conservation and residual disposal (Aslantas et al., 2010; Angin et al., 2013). Using waste in agriculture helps not only dispose these materials economically, but also reduces negative effects on the environment and improve soil quality parameters. Soil quality can be improved with the addition of wastes, which contains appropriate levels of organic matter (Candemir and Gülser, 2010). Organic conditioner application into soils improves not only the soil structure

* Corresponding author.
Ondokuz Mayıs University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, 55139 Samsun, Turkey
Tel.: +903623121919 E-mail address: nutullah@omu.edu.tr
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but also the nutrient quantity and availability in soils (Sahin et al., 2008; Demir and Gülser, 2015; Gülser et al., 2015).

This study was carried out to determine the effects of rice husk compost (RC), town waste compost (TW) and tobacco waste (TB) applications on extractable P content in soils having different pH levels .

Material and Methods

In this study, disturbed surface soil samples (0-20 cm depth) were taken from agricultural lands aroud Samsun, Northern Anatolia. Soil reaction was taken into account for soil sampling from neutral, acidic and alkaline soil series (Tepecik, TP; Kampus, KP Cetinkaya, CT, respectively). The rice husk compost (RC), town waste compost (TW) and tobacco waste (TB) were obtained from different institutions. Some properties of organic materials are given in Table 1.

Table 1. Some properties of organic matter sources

Organic Materials	OC, %	OM, %	N, %	C/N
Tobacco waste	38.40	66.20	1.97	19.49
Rice husk compost	9.91	17.08	0.88	11.26
Town waste compost	17.86	30.79	1.55	11.52

Soil samples were treated with four different levels of organic matterials (0, 2.5%, 5.0%, and 7.5% dry weight basis) and soil mixtures were put into plastic pots with a volume of 4500 cm^3. Each treatment was replicated two times in a split block design (3 soils x 3 organic matterials x 4 application doses x 2 replications). All pots were incubated at field capacity moisture content and 20ºC for 4 weeks under greenhouse conditions. After the one month of incubation period, lettuce plant was grown in the pots. At the end of the greenhouse study, soil samples were taken for analyses. Some physical and chemical properties of soils were determined as fallows; soil organic matter content by the modified Walkley-Black method (Nelson and Somners, 1982); soil texture by hydrometer method (Bouyoucos, 1962); pH in soil-water suspension (1/2.5 w:v) by pH meter (McLean, 1982), EC in the same soil suspension by EC meter (Rhoades, 1982), lime content by Scheibler calcimeter method (Nelson, 1982). Due to increasing soil pH after the organic matter applications, phosphate contents of soils were determined by sodium bicarbonate (0.5 M $NaHCO_3$ extractable) method (Olsen and Somners, 1982). Data analyses were done using SPSS package programe.

Results and Discussion

Soil properties

Some physical and chemical soil properties are given in Table 2. According to the results, soil properties can be summarized as; moderately fine and fine in texture, moderate in organic matter content, low in total lime content, moderately acid, neutral and moderately alkaline in pH (Soil Survey Division Staff, 1993).

Table 2. Some physical and chemical properties of the soils

Parameters	Soil series		
	Tepecik (TP)	Kampus (KP)	Cetinkaya (ÇT)
Clay, %	39.4	40.2	15.0
Silt, %	34.1	25.6	39.4
Sand, %	26.5	34.2	45.6
Texture	Clay Loam	Clay	Loam
pH (1:2.5)	5.60	7.00	8.33
EC, dS/m	0.42	2.40	0.56
$CaCO_3$, %	1.19	2.40	0.56
OM, %	2.40	1.13	1.31

Changes in soil pH values

Application of organic materials on soil pH are given in Table 3. While soil pH values in Tepecik and Kampüs soils increased by the organic waste application, soil pH values in Çetinkaya soil decreased. Mean soil pH varied between 6.53 and 6.82 in Tepecik Soil, between 7.04 and 7.37 in Kampüs Soil and between 7.45 and 7.95 in Çetinkaya Soil by the application of organic materials. Except the 2.5 % application doses in Tepecik soil, soil pH values varied around neutral and moderately alkaline after the organic waste treatments. Candemir and Gülser (2010) reported that tobacco waste application into a clay soil increased soil pH after 16, 23 and 30 months of the application in a field study. However, Demir and Gülser (2015) reported that 3, 6 and 9% applications of rice husk compost into moderately alkaline soil decreased soil pH.

Table 3. Effect of soil organic materials on soil reactions (pH).

	Dosses	Tepecik	Kampüs	Çetinkaya
Control	0	5.91	6.89	8.12
Town waste compost	2.5 %	6.48	7.38	7.96
	5.0 %	6.93	7.40	7.76
	7.5 %	6.87	7.33	7.73
Mean		6.76	7.37	7.82
Tobacco waste	2.5 %	6.46	7.00	7.61
	5.0 %	6.73	7.04	7.38
	7.5 %	7.28	7.08	7.36
Mean		6.82	7.04	7.45
Rice husk compost	2.5 %	6.38	7.11	8.03
	5.0 %	6.62	7.17	7.91
	7.5 %	6.60	7.14	7.90
Mean		6.53	7.14	7.95

Bicarbonate extractable phosphate contents of soils

The effects of amendments on the bicarbonate extractable P values changed depend on the type and rates of organic materials in each soil series (Figure 1). It was observed that the bicarbonate extractable P values of all soils increased significantly depending on soil pH and type of organic materials. Bicarbonate extractable P values in the control soils were 3.02 ppm for moderately acidic Tepecik, 11.21 ppm in neutral Kurupelit and 9.20 ppm moderately alkaline Çetinkaya soil series. (Figure 1). According to the P mean values of organic materials compared with the control, all organic treatments were more effective on neutral or Kampüs soil. The percentage increases in mean P values by the application of organic materials in moderately acidic, neutral and moderately alkaline soils over the control were found to be TB > TW > RC (69, 56 and 49 %, respectively) in Tepecik soil, TB > TW > RC (52, 43 and 29 %, respectively) in Kampüs soil and TB > TW > RC (59, 31 and 27 %, respectively) in Çetinkaya soil series. According to the control soils, bicarbonate extractable mean P contents of Tepecik, Kurupelit and Çetinkaya soil series significantly increased 57.9, 41.8 and 39.1%, respectively (Table 4). Demir and Gülser (2015) reported that application of 9 % rice husk compost into soil increased available P content from 60 to 120 ppm, significantly.

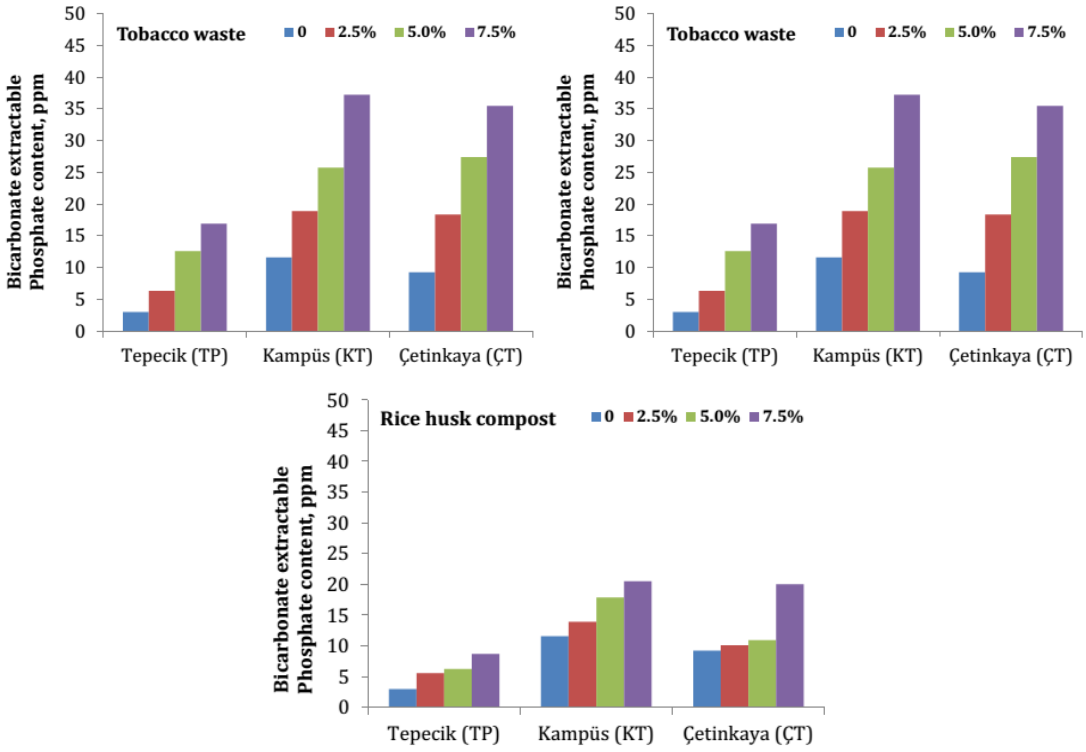

Figure 1. The effects of organic materials at different application rates on Tepecik (TP), Kurupelit (KP) and Çetinkaya (ÇT) soil series (P<0.01).

According to the statistical analysis of data given in Table 4, bicarbonate extractable P values were significantly different in soil series at 0.01 level. On the other hand, bicarbonate extractable mean P values were also significant for different organic materials and application doses at 0.01 level.

Table 4. Mean values of bicarbonate extractable phosphate content at different soil series, organic material treatments, and application rates.

Soil Series		Tepecik	Kampüs	Çetinkaya
		7.51 a*	19.79 c	16.13 b
Organic Matterials		Town waste comp.	Tobacco waste	Rice husk comp.
		13.36 b	18.57 c	11.49 a
Application Rates	0	2.5 %	5.0 %	7.5 %
	7.97 a	11.95 b	16.64 c	21.35 d

Conclusion

The results can be summarized as; organic material treatments generally increased the bicarbonate extractable P contents of soils having different pH levels. Effectiveness of the organic materials varied depends on soil reaction, type and application rates of organic materials. The effectiveness of the rice husk compost on bicarbonate extractable P content of soil had considerably lower than the other organic materials. The highest effect on the P content was obtained with the highest rate of tobacco waste application in Kurupelit soil having neutral pH. All organic wastes were more effective on the increment of P content in neutral soil pH when compared the other soil pH levels.

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Effects of different nitrogen and potassium sources on lettuce (*Lactuca sativa* L.) yield in a sandy soil

Mohamed Said Awaad *, Ragab Ali Badr, Mamoduh Ali Badr, Ahmed Hamada Abd-elrahman

Soil, Water and Environment Research Institute (SWERI), Agricultural Research Center, Giza, Egypt

Abstract

Lettuce plants were grown under sandy soil conditions in the private farm of Ahmed Orabi organization, Cairo Governorate Egypt, between 15th November 2009 and 15 January 2010. The experiment was conducted to assess the effects of different nitrogen sources, slow release N (urea-formaldehyde) and fast release N (urea) containing fertilizers at the rates of 0, 60, 90 and 120 kg N ha^{-1} applied alone or combined with potassium sulphate, on lettuce plant yield. Results indicated that application of different sources of N alone or combined with potassium sulphate gave the highest fresh dry weight per plant and total lettuce yield per hectare compared with the control. The highest dry weight of lettuce was achieved with the combination of urea and potassium sulphate. Although fertilization made with the combination of urea and potassium sulphate resulted in the highest P, K, Zn and Mn contents in lettuce plant, fertilization with urea alone gave the highest N and Fe contents. The lowest content of nitrate in lettuce plants was recorded with the fertilization of urea only or with the combination of urea and potassium sulphate. Application of the combination of urea and potassium sulphate induced the highest protein content in plants. The results indicated that application of urea-formaldehyde as a slow release nitrogen fertilizer solely or combined with potassium sulphate significantly improved yield and yield quality of lettuce plants grown in sandy soil.

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Keywords: Urea-formaldehyde, urea, potassium sulphate, *Lactuca sativa*.

Introduction

Lettuce (*Lactuca sativa* L.) is the most popular crop among the salad vegetables, which requires nitrogen (N) for growth and development. Nitrogen fertilizers such as; ammonium sulphate, ammonium nitrate or calcium nitrate positively affects fresh and dry plant weights, plant diameter and the number of total marketable leaves, whereas the yield and other yield components remained unaffected by N sources (Bozkurt et al., 2009, Gülser et al., 2010). Plants absorb N from the soil in the form of ammonium (NH_4^+) and nitrate (NO_3^-), which is converted into NH_4^+ to forms of proteins and other N containing substances in plant (Cash et al., 2002). Some vegetable crops, especially those with short lifespan such as lettuce, have the ability to accumulate proportionally nitrate. Nitrate accumulation in plant can be hazardous to human health because nitrate can be reduced to nitrite in the body and cause methemoglobinemia. Furthermore, there is a possibility of formations of N-niroso compounds from nitrite and secondary N compounds in the human stomach (Breimer, 1982). According to WHO (1995), the acceptable daily intake of nitrate is between 0 and 3.65 mg kg^{-1} of body weight. Leafy vegetables such as spinach, lettuce and celery contain nitrate at significant levels (Maynard et al., 1976). Many studies were conducted to decrease nitrite and nitrate accumulation in vegetables. Byrne et al. (2001) found that increasing rates of N in soils caused an increase in nitrate accumulation in lettuce, particularly in outer leaves. Moreover, there are evidences that the slow release N

* Corresponding author.
Soil, Water and Environment Research Institute (SWERI), Agricultural Research Center, Giza, 12112 Egypt
Tel.: +201006988461
E-mail address: moayamai@yahoo.com
e-ISSN: 2147-4249
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fertilizers increased the efficiency use of N and minimized the loss of N in form of ammonia gas (NH_3) by volatilization and leaching of NO_3^- from soils, which pollute the underground water. Hegde (1997) reported that application of slow release N fertilizers was very effective in increasing nutrient use efficiency, crop production and reducing nutrient lose.

Potassium (K) is an essential nutrient element for plant growth and taken up from the soil solution by the plant roots in the form of potassium ion (K^+). Potassium is very mobile within the plant and its deficiency symptoms in plants appear first in the old leaves (Tisdale et al., 1993). Potassium is directly involved in enzyme activation, maintenance of water status, energy relations, and translocation of assimilates and protein synthesis. K regulates cellular turgid pressure to avoid wilting, which in turn controls the stomata opening and hence greatly enhances drought tolerance (McCarty, 2005). Potassium occurs as single-valued K cation; however, K containing fertilizers differ in their accompanying anions i.e. Cl^-, SO_4^{-2} and NO_3^- which act differently on the chemical composition of plants (Nurzyński and Michałojć, 1998).

Therefore, the objectives of this study were to determine the effects of urea and urea-formaldehyde as N sources applied alone at different rates or combined with potassium sulphate, on nutrient contents, yield quantity and quality of lettuce plant, and some soil chemical properties.

Material and Methods

A field experiment was conducted on a sandy soil in the private farm of Ahmed Orabi organization, Cairo Governorate, Egypt, between 15th November 2009 and 15 January 2010. Some physical and chemical properties of the top layer of soil (up to 30 cm) were determined and given in Table 1.

Table 1. Physical and chemical properties of the studied soil

Soil properties	Value
Particle size distribution	
Coarse sand (%)	75.00
Fine sand (%)	20.00
Silt (%)	3.00
Clay (%)	2.00
Soil Texture	Sand
pH (saturated soil paste)	8.10
Ec (dSm^{-1}) in soil paste extract	1.80
Soluble ions ($mmol_cL^{-1}$) in soil paste extract:	
CO_3^{2-}	0.00
HCO_3^-	1.35
Cl^-	7.84
SO_4^{2-}	9.28
Ca^{2+}	2.67
Mg^{2+}	1.45
Na^+	14.16
K^+	0.19
Available N (mg kg^{-1})	24.85
Available P (mg kg^{-1})	4.4
Available K (mg kg^{-1})	171.6
Available Fe (mg kg^{-1})	2.00
Available Zn (mg kg^{-1})	2.30
Available Mn (mg kg^{-1})	1.20

Seeds of lettuce, Dark green cultivar, were planted in a Try, and kept at greenhouse state place and environmental conditions. The seedlings of lettuce were then transplanted in plots (3.5 x 3 m) at the field, spacing 25 cm within row and 50 cm between rows. Plants were irrigated by drip irrigation systems and received all agricultural practices needed such as weed control and pest management. Two sources of N were used, urea (46.5% N) and urea-formaldehyde (38% N) at the rates of 0, 60, 90 and 120 kg N ha^{-1}. Potassium in form of K_2SO_4 was applied at a rate of 75 kg K_2O ha^{-1} equivalent to 62.25 kg K ha^{-1}. Phosphorus was applied uniformly as calcium superphosphate at a rate of 30 kg P_2O_5 ha^{-1} equivalent to 12.5 kg P ha^{-1}. Cattle manure was added to the soil at a rate of 40 m^3 ha^{-1} before land preparation. Urea-formaldehyde as a slow N release form was applied during the land preparation. During the growing season urea as a fast N release form and K (K_2SO_4) were added to the soil at one week intervals at the rates of 20 kg N ha^{-1} and 15 kg

K ha^{-1} with irrigation water, respectively. Treatments were arranged in a randomized complete block design with three replicates.

At the harvesting date five plants were sampled from each plot. The fresh weight of each plant was determined using electronic balance. Then plant samples were dried in an oven at 70 ^{0}C for 72 h and milled.

Dry matter was used for plant nutrient content analysis in tissue. Total N content was determined by the Kjeldahl method (Nelson and Sommers, 1980). Potassium was determined by emission flame photometer, while iron (Fe), manganese (Mn) and zinc (Zn) were determined by the atomic absorption spectro photometer (Perkin Elmer Analyst 100). To obtain plant sap, complete plants were smashed until a homogenous paste was obtained. Then NO_3^- was determined based on the procedures compiled by Chapman and Pratt (1978). Protein was determined multiplying total N percentage by 6.25.

After harvesting, soil samples from each treatment were collected, mixed, air-dried, sieved by a 2-mm wire mesh sieve and used to determine soil pH and electrical conductivity (EC) (Smith and Doran, 1996). Phosphorous was determined colorimetrically using the molybdephosphoric blue colour method in sulphuric acid system as described by Jackson (1958). Potassium was extracted with neutral 1 N ammonium acetate and its amount was estimated by emission flame photometer (Jackson, 1958).

Statistical analysis

All data were subjected to statistical analysis of variance and treatment means were compared according to the Least Significant Differences (LSD) test method as described by Snedecor and Cochran (1980).

Results and Discussion

Fresh and dry weights of lettuce plants

The fresh and dry weights of lettuce increased when they were fertilized with different sources of N alone or combination with K_2SO_4 over the control (Table 2).

Table 2. Effects of different N sources and K fertilization on fresh, dry and total fresh weights of lettuce plant.

Sources of N	Rates of N applied (kg ha^{-1})	Rates of K_2O applied (kg ha^{-1})	Fresh weight (g plant^{-1})	Dry weight (g plant^{-1})	Total fresh weight (tonnes ha^{-1})
Control	0	0	245.00	28.00	7.84
Urea	60	0	294.32	45.10	9.41
	90		362.12	67.34	11.58
	120		328.11	68.32	12.73
Mean			328.18	60.25	11.24
Urea-form.	60	0	343.07	44.21	10.97
	90		426.23	78.25	13.63
	120		490.51	81.44	15.69
Mean			419.96	67.96	13.43
Urea	60	75	407.24	58.20	13.03
	90		520.03	81.23	13.44
	120		561.56	87.84	17.96
Mean			496.27	75.75	14.81
Urea-form.	60	75	483.96	99.33	15.48
	90		553.31	102.12	17.70
	120		627.09	123.14	20.06
Mean			554.78	108.19	17.74
LSD at 0.05 level			21.65	2.01	0.92

It is evidence that increasing level of N fertilizer was associated with an increase in both fresh and dry weights of lettuce plants where the highest increase was observed at 120 kg N ha^{-1}. However, the highest level of urea-formaldehyde induced significantly higher fresh and dry weights when compared with the plants fertilized with the highest rate of urea. These findings concur with the results obtained by Guertal (2009) who found that the use of slow release N fertilizers such as urea-formaldehyde or sulphur coated urea increased crop yield when compared with the standard split application of soluble N. Using slow release N fertilizers in vegetables reduces the environmental risk and production costs.

Applications of N and K at higher levels significantly increased the fresh and dry weights of the lettuce plants. When urea was combined with K, higher fresh and dry weights were achieved than that of plants fertilized with urea alone. These results are in agreement with the findings of Gülser (2005) and Stagnari et al. (2007) who indicate that the yield of spinach was increased by increasing the rates of N fertilizer. Nurzyńska-Wierdak (2009) indicated that the increase in the amounts of N and K application generally contributed to an increase in fresh leaf weight and yield. Abdel-Motagally and Osman (2010) found that increasing N and K fertilizer rates resulted to a significant increase in yield compared to the other treatments. Volterrani et al. (1999) indicated that the use of slow release N fertilizers made it possible to reduce N loss by leaching. Also, Hegde (1997) used slow release N fertilizers for some Solanaceous vegetable crops and found that these fertilizers were very effective in increasing nutrient use efficiency, crop production and reducing nutrient losses

Nutrient contents in lettuce plants

The application of different levels of N from different sources alone or combined with potassium sulphate increased the concentrations of N, P, K and Ca in the lettuce plants compared with control plants (Table 3). In general, the highest values of N concentration in lettuce plants were recorded in plants fertilized with 120 kg N ha^{-1} regardless of the sources of N, whereas, the highest values of P, K and Ca amounts in the lettuce plant were achieved in the plants received 90 kg N ha^{-1} irrespective to the form of N fertilize.

Table 3. Nutrient contents in the lettuce plants as affected by the use of different sources of nitrogen and potassium fertilizer.

Sources of N	N doses (kg ha^{-1})	K_2O doses (kg ha^{-1})	Nutrient concentration						
			N	P	K	Ca	Fe	Zn	Mn
			(%)				(mg kg^{-1})		
Control	0	0	1.11	0.21	2.88	1.14	167.23	15.92	102.00
Urea	60	0	2.57	0.25	4.02	1.68	347.21	22.98	123.00
	90		3.28	0.29	3.16	2.14	478.09	25.63	130.78
	120		3.61	0.27	3.57	1.99	578.98	28.27	145.04
Mean			3.15	0.27	3.58	1.93	468.09	25.62	132.94
Urea-formaldehyde	60	0	3.14	0.35	4.44	2.34	486.23	26.90	114.40
	90		3.92	0.31	4.76	2.91	573.98	31.67	130.40
	120		4.22	0.30	3.91	2.55	689.02	39.53	167.11
Mean			3.76	0.32	4.37	2.60	583.07	32.70	137.70
Urea	60	75	2.14	0.37	4.26	1.56	465.21	26.09	144.76
	90		3.12	0.41	4.98	2.02	564.46	28.00	152.89
	120		3.31	0.36	4.99	1.62	654.66	33.64	155.25
Mean			2.85	0.38	4.74	1.73	561.44	29.24	150.96
Urea-formaldehyde	60	75	3.00	0.44	4.75	1.88	687.93	31.17	148.38
	90		3.58	0.55	5.76	2.15	756.23	38.88	168.98
	120		4.11	0.51	5.43	2.34	869.76	43.64	189.36
Mean			3.56	0.51	5.31	2.12	771.30	37.89	168.90
LSD at 0.05			0.04	0.01	0.10	0.08	4.51	1.78	2.56

Increasing the rates of N up to 90 kg N ha^{-1} was associated with an increase in P, K and Ca concentrations in the lettuce plants. However, increasing the rates of N beyond this level was accompanied by a decrease in the contents of P, K and Ca, but this decrease was still higher than that of control, presumably due to the dilution on these nutrients in plant tissues. Similar results were obtained by Stagnari et al. (2007) who found that K content in spinach plants was decreased by increasing rates of N up to 200 kg ha^{-1}. Zarei (1995) reported that application of high rates of N decreased the absorption of P in spinach plants. Likewise, the mean values of N, P, K and Ca in N applied as urea-formaldehyde form were higher than that in N applied as urea form.

When N fertilizer was applied with potassium sulphate, the amounts of N and Ca in plants were lower than that in plants fertilized with higher rates of N alone. In contrast, higher values of P and K contents were registered in the plants received a combination of N and potassium sulphate. Results also indicated that an application of potassium sulphate + urea-formaldehyde increased the values of N, P, K and Ca contents and the mean values were 3.56%, 0.51%, 5.31% and 2.12%, respectively.

Although, the amount of Fe, Zn and Mn increased considerably in the plant tissues, when N was applied alone or combination with potassium sulphate compared with the control (Table 3). Urea-formaldehyde combined with potassium sulphate escalated the values of Fe, Zn and Mn by 771.30, 37.89 and 168.90 mg/kg, respectively. These results could be attributed to the soluble ions associated with the applied potassium which significantly increased the availability of micronutrients in sandy soil, probably due to physiological acidification of the rhizosphere. In addition, probably the apparent losses of applied N in urea-form treatment were low and the high uptakes of N promoted growth in lettuce plants, and thus stimulated more uptakes of the micronutrients. Hegde (1997) reported similar findings that the additional supply of sulphur from potassium sulphate contributed to the increase in S content in the lettuce plants. Böhme and Lua (1997) showed that K had beneficial effects on micronutrients uptake, transport and its availability in plants. Jurkowska and Rogoz (1981) reported that soil fertilization with nitrogen in the form of ammonium nitrate, calcium nitrate, urea and ammonium sulphate contributed to increased uptakes of Fe, Mn, Zn, Cu, Mo and B by barley plants. Hao et al. (2007) indicated that the transportation ability of micronutrients from root to shoot was improved with N fertilizer application.

Nitrate accumulation in lettuce

Effects of different sources and rates of N when applied alone or combined with potassium sulphate on nitrate concentration in plant tissues are given in Table 4. The application of N fertilizer increased the nitrate contents of lettuce plants compared with the control. These findings are in consistent with those of Ahmadi et al. (2010) who found that the highest nitrate content was observed at the highest fertilizer level (200 kg N ha^{-1}) compared with the control. Urea application caused greater nitrate content in lettuce plant than the urea-formaldehyde that prevented excessive accumulation of NO_3^- in the vegetables, including lettuce plants and leaching of N from the soil (Hartrath, 1986; Guertal, 2009). Lorenz (1978) suggested some methods for reducing NO_3^- content in spinach which include use of low nitrate content cultivar, appropriate N fertilizer, application of ammoniac fertilizer associated with application of nitrification inhibitor, split N application rather than basal application and utilization of slow-release fertilizer.

Table 4. The effect of different sources of N and potassium sulphate on the content of nitrate and total protein of lettuce plant.

Sources of N	Rates of N applied (kg ha^{-1})	Rates of K_2O applied (kg ha^{-1})	Nitrate content (mg kg^{-1})	Total protein (%)
Control	0	0	372.00	13.18
	60		1420.46	16.06
Urea	90	0	2729.23	20.50
	120		2987.36	22.56
Mean			2379.01	19.70
	60		930.73	19.62
Urea-formaldehyde	90	0	1080.62	24.50
	120		1730.65	26.38
Mean			1247.11	23.50
	60		1283.00	16.50
Urea	90	75	1893.75	22.00
	120		2001.78	24.44
Mean			1726.17	20.98
	60		830.91	20.25
Urea-formaldehyde	90	75	909.81	25.75
	120		1207.87	27.25
Mean			982.86	24.16
LSD at 0.05			4.88	0.14

A higher decrease in nitrate content was recorded in plants fertilized with a combination of N and potassium sulphate than plants without K (Table 4). Ahmed et al. (2000) demonstrated that application of P and K contributed to a decrease in nitrate concentration even when N was applied at a high rate. Similarly, Zong et al. (1997) proved that the increase in the rates of K fertilizer decreased nitrate accumulation in certain vegetables. Wang and Ito (1998) reported that increasing application rates of K fertilizers reduced nitrate accumulation in some vegetable crops. Moreover, Ali et al. (1985) reported that the enzyme nitrate reductase activity in the leaves and stems of rice plants supplied with K was higher than in those plants that are deficient in K. Sulphur deficiency therefore might lead to an increase in nitrate contents (Maynard et al., 1976).

Protein content in lettuce plants

The results showed that total protein contents in the lettuce plants increased as a result of application of different N forms used alone or combined with potassium sulphate compared with the control (Table 4). These findings showed that N fertilization increased absorption of N from soil and consequently increased the protein content of plant tissues. Investigation conducted by Mo et al. (1991) revealed that an application of slow release N fertilizer increased yield, amino acid and chlorophyll contents of soybean when compared with the ordinary urea.

Soil properties after crop harvesting

N fertilizer caused a reduction in the values of EC and pH of the soil compared with unfertilized soil (Table 5). When N was applied as urea-formaldehyde, EC and pH reduced slightly compared to application of urea. Utilizing N fertilizers either as urea or urea-formaldehyde elevated the amount of N, P and K in the soil when compared with control. Application of different sources of N with combination of potassium sulphate increased the EC of the soil above that of soil fertilized with slow release N fertilizer alone, application N and potassium sulphate together decreased the pH and the amounts of N and P in the soil, but increased the quantity of K.

Table 5. Some properties of the soil after harvesting the lettuce plants

Sources of N	Rates of N applied (kg ha^{-1})	Rates of K_2O applied (kg ha^{-1})	EC (dSm^{-1})	pH (1:2.5)	Available nutrients (mg kg^{-1})		
					N (NH_4+NO_3)	P	K
Control	0	0	1.22	7.88	8.34	3.20	134.21
	60		1.00	7.58	12.89	5.21	145.90
Urea	90	0	1.02	7.36	16.11	5.90	159.56
	120		1.11	7.45	18.92	6.30	160.33
Mean			1.04	7.46	15.97	5.80	155.26
	60		0.98	7.59	12.24	5.42	155.89
Urea-formaldehyde	90	0	0.85	7.37	18.90	5.90	176.90
	120		0.81	7.23	22.56	7.79	180.23
Mean			0.88	7.39	17.90	6.37	171.00
Urea	60	75	1.32	7.12	10.21	4.25	201.75
	90		1.33	7.11	13.78	4.89	223.90
	120		1.35	7.03	15.42	4.90	267.35
Mean			1.33	7.06	13.13	4.68	231.00
	60		1.01	7.10	10.34	4.90	247.94
Urea- formaldehyde	90	75	1.11	7.06	14.45	5.11	288.43
	120		1.12	7.01	16.90	5.42	297.41
Mean			1.08	7.05	13.89	5.14	277.92
LSD at 0.05			0.011	0.01	0.11	0.02	0.61

Conclusion

Slow-release nitrogen fertilizers such as urea formaldehyde can be used as a pre-plant N nutrient source. It reduces production costs and eliminates the need for multiple applications of soluble N fertilizers. Furthermore, slow-release nitrogen fertilizers were able to decrease nitrate content of plants compared with urea application.

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Salt stress-mineral nutrient relations in olive (*Olea europaea* L.) plant

Erkan Kasırğa, Mehmet Ali Demiral*

Department of Soil Science and Plant Nutrition, Faculty of Agriculture, University of Adnan Menderes, Aydın, Turkey

Abstract

In order to investigate the effect of salt stress on mineral nutrients, one year-old olive (*Olea europaea* L. cv. Gemlik) seedlings were exposed to increasing levels of NaCl salinity (4 dS m^{-1}, 8 dS m^{-1} and 12 dS m^{-1}, respectively) in pot culture and Na, K, Ca, Mg, N, P, Cl, Fe, Mn, Zn concentrations, ratios of K/Na and (K+Ca+Mg)/Na of the plants were ascertained. Sodium and Cl concentrations of plant parts increased with the salinity and the level in the aerial parts of the plants were lower than that of root. Salinity led to a general decrease in K concentrations in the all organs with the exception of subsoil trunk. Calcium concentrations of the plant parts decreased significantly by salinity with the exception of roots and subsoil trunk. Salinity affected Mg concentrations only in trunk and leaves. Treatments significantly decreased the ratios of K/Na and (K+Ca+Mg)/Na of all the plant organs. Compared to control application the highest salinity level (12 dS m^{-1}) decreased the N concentrations of all the plant organs statistically except roots. Similarly salinity increased the concentrations of P in all plant parts except trunks compared to control treatment. Concentrations of all the micronutrients detected in the study were found lower in aerial parts than the roots.

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Introduction

Salinization is the process that leads to an excessive increase of water-soluble salts in the soil. A soil is considered saline if the electrical conductivity of its saturation extract (ECe) is above 4 dS m^{-1} (US Salinity Laboratory Staff, 1954). However, the threshold value above which deleterious effects occur can vary depending on several factors including soil water regime, climate and plant type (Maas, 1986). Olive (*Olea europaea* L.) plant is considered as moderately salt tolerant (Maas, 1986) and is grown preferentially in semiarid areas where irrigation is required to produce maximum yield. Gemlik is one of the most important olive cultivar of Northern Regions of Turkey (Canözer, 1991). However the cultivar has been preferred intensively by the growers of the Southern and the Southeastern parts of Turkey in the last decade. Gemlik cultivar is selected for growing by the growers for its high rooting capacity. Since these regions have more arid climate than that of North, resources of high quality water for irrigation are limited and the use of lower quality water resources such as saline water and reclaimed sewage effluent for irrigation is implemented. Utilization of such water resources accelerate the salinisation of the soil and generally decreased crop production (Lauchli and Epstein, 1990; Maas, 1990). Previous findings demonstrated that genotypic response of olive cultivars to salt stress is variable (Tattini et al. 1992; Demiral, 2005).

An increase in soil salinity commonly results in a reduction of plant water uptake. Passive nutrient uptake of the plants is related to water uptake, and any decrease in water availability causes a reduction in uptake of nutrients such as NO_3^-, K, Zn and Ca. Additionally any imbalance in composition of saline soil solution results in uptake of some ions, such as Cl, Na or Mg, in excessive amounts. An increase in the concentration of these

* Corresponding author.
Department of Soil Science and Plant Nutrition, Faculty of Agriculture, University of Adnan Menderes, Aydın, 09100 Turkey
Tel.: +902567727023 E-mail address: mademiral@yahoo.com
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ions either has a toxic effect directly to the plants or promotes imbalance in plant nutrient metabolism (Ghafoor et al. 2004). All these processes result in lower crop yields. However, toxic effect of an ion can be controlled depending on the cationic or anionic balance especially the K/Na and (K+Ca+Mg)/Na ratios. Salt tolerant varieties of higher plant species have wider K/Na ratio than that of salt sensitive ones (Chauhan et al. 1980). The main objectives of this experiment were to investigate short-term effects of NaCl-induced salinity on chemical composition of Gemlik olive cultivar.

Material and Methods

Plant material and salinity treatments

Gemlik olive (*Olea europaea* L.) cultivar was used as test plant in the experiment. The experiment was carried out in a net-house at the University of Adnan Menderes, Aydın, Turkey from March 15 to June 15, 2007. One year-old homogeneous self-rooted plants produced through mist propagation system were planted in 18 L containers with soil/coarse sand mixture (1/1.5, w/w). Soil analysis made before planting (Westerman, 1990) showed the following soil characteristics: very low in available K (0.21 me 100 g^{-1}) (Pizer, 1967); low in total N (0.07 %), available P (4.69 mg kg^{-1}), Mg (0.05 me 100 g^{-1}) and Zn (0.60 mg kg^{-1}) (Loue, 1968; Lindsay and Norwell, 1978; Olsen and Sommers, 1982) medium in available Ca (3.05 me 100 g^{-1}), Fe (7.44 mg kg^{-1}), Mn (60.60 mg kg^{-1}) and Cu (0.68 mg kg^{-1}) (Loue, 1968, Lindsay and Norwell, 1978). Texture; sandy loam (SL) (sand 60.50%, silt 23.70% and clay 15.80%); alkaline (pH 7.99); poor in organic matter (1.01%) with high $CaCO_3$ (24.64%); and slightly-salty (251 µmhos cm^{-1}) (Soil Survey Staff, 1951; Kellogg, 1952; Thun et al. 1955; Evliya,1964).

Treatments comprised of salinized half-strength Hoagland's solution with 3 different NaCl levels (2560 mg L^{-1}, 5120 mg L^{-1} and 7680 mg L^{-1} of NaCl, which is equal to 4 dS m^{-1}, 8 dS m^{-1} and 12 dS m^{-1}, respectively). The salinity levels were adjusted by the addition of appropriate amounts of NaCl to half-strength Hoagland's solution (Hoagland and Arnon, 1950). The electrical conductivity (EC) of the solutions was measured with a hand-held EC meter (WTW-Cond 330i, Germany). Half-strength Hoagland's solution was used as control treatment. The experiment was laid out in completely randomized design. Each treatment was replicated 12 times with 1 plant per container. Seedlings (approx. 30 cm in length) were grown for a month by using half-strength Hoagland's solution then saline solutions were applied to the plants. Salinity of the solutions was increased gradually reaching to the final application levels by the end of the second month in order to prevent possible shock effect of salinity on the experimental plants. The experiment was terminated 4 months after planting.

In order to keep the salinity under control in the root area; (1) the plants were irrigated with an amount of the solutions accounting for a leaching factor of 20-25%, (2) electrical conductivity (EC) was measured throughout the entire irrigation period in the leachate obtained from the containers, (3) when the EC of the leachate exceeded the EC of the application doses about 20% the growing media was washed with fresh water and the EC was dropped to the normal levels. Additionally the containers were covered with aluminum foil to prevent evaporation that causes accumulation of salt at the surface.

Sampling and chemical analyses

For chemical analyses, all the plants were gently removed from the substrate and were divided into root, subsoil trunk, trunk and leaves. Roots were then sampled by hand from growing media and were washed with deionised water. All samples were then weighed and dried in a forced-air oven (Memmert UM 500, Schwabach, Germany) at 70 °C for 72 h. Dried samples were then prepared for analysis by grinding in a stainless steel mill (IKA A 11 Basic, Staufen, Germany). The ground samples were wet digested in a mixture of $HNO_3/HClO_4$ (4/1, v/v) solution (Westerman, 1990). Na, K and Ca concentrations were determined using flame photometry (Jenway PFP7, Staffordshire, UK); Mg, Fe, Zn and Mn concentrations by an atomic absorption spectrophotometer (Varian SpetrAA 220FS, Mulgrave, Australia), and P by the vanadomolybdophosphoric method (Westerman, 1990). Total N concentrations of dried samples were analyzed by Kjeldahl digestion method (Westerman, 1990). Cl was extracted from 0.1 g of the ground sample with 10 mL of deionized water by shaking the mixture for 2 h. Chloride concentrations of the extracts were measured by a chloridemeter (Jenway PCLM3, Staffordshire, UK) and results were expressed as % Cl in the DM (Brown and Jackson, 1955).

Statistical analyses

Analysis of variance (ANOVA) was performed for the experimental data using MSTAT statistical software (Little and Hills, 1978). Mean separation was performed with the Least Significant Difference (LSD) test at $P \leq 0.05$.

Results

Compared to control treatment, Na and Cl concentrations of plant parts increased progressively and significantly with salinity except leaves (Table 1). Elevated salinity led to a general decrease in K concentrations of the all plant organs studied, except subsoil trunks. Among the different plant parts, the highest concentration of K was found in leaves (Table 2). Salinity treatments generally led to a significant decrease in the Ca concentrations of the plant trunks and in leaves (Table 2). Salinity affected Mg concentrations only in trunk and leaves. A fluctation was observed in the Mg concentrations of aerial parts of the plants (Table 2).

Table 1. Effect of salinity on Na and Cl concentrations in different tissues of Gemlik olive cultivar

Salinity Treatment ($dS\ m^{-1}$)	Root	Subsoil Trunk	Trunk	Leaf
		Na (%)		
Control	0.20 c	0.05 d	0.13 d	0.03 c
4	0.53 b	0.17 c	0.28 c	0.13 b
8	0.58 b	0.24 b	0.42 b	0.33 a
12	1.07 a	0.31 a	0.58 a	0.38 a
		Cl (%)		
Control	0.38 c	0.12 d	0.15 d	0.19 c
4	0.93 b	0.21 c	0.26 c	0.34 b
8	0.98 b	0.30 b	0.44 b	0.56 a
12	1.40 a	0.56 a	0.68 a	0.55 a

Means with the same letter are not significantly different using LSD at $P \leq 0.05$

Table 2. Effect of salinity on K, Ca and Mg concentrations in different tissues of Gemlik olive cultivar

Salinity Treatment ($dS\ m^{-1}$)	Root	Subsoil Trunk	Trunk	Leaf
		K (%)		
Control	1.97 a	0.39 ns	1.71 a	2.53 a
4	0.70 b	0.40	1.39 b	2.32 ab
8	0.35 c	0.35	0.57 c	2.08 b
12	0.35 c	0.34	0.55 c	2.04 b
		Ca (%)		
Control	0.92 ns	0.91ns	1.35 a	1.11 a
4	0.84	0.92	1.16 b	1.03 a
8	0.85	0.87	1.22 ab	0.74 b
12	0.84	0.75	0.88 c	0.70 b
		Mg (%)		
Control	0.16 ns	0.06 ns	0.11 a	0.10 b
4.00	0.16	0.06	0.09 b	0.12 a
8.00	0.17	0.06	0.11 b	0.11 ab
12.00	0.17	0.07	0.12 a	0.12 a

Means with the same letter are not significantly different using LSD at $P \leq 0.05$; ns: nonsignificant.

Salinity decreased the ratios of K/Na and (K+Ca+Mg)/Na of the plant parts significantly. The ratios of K/Na and (K+Ca+Mg)/Na were found higher in leaves and lower in roots and subsoil trunks when compared to other plant parts (Table 3). Salinity led to a significant decrease in N concentration of the plant parts, except the roots (Table 4). Compared to control treatment, salinity significantly increased the concentrations of P in all plant parts, except in the trunk. Among different plant parts, the highest concentration of P was determined in leaves (Table 4).

Concentrations of all the micronutrients detected in the study were found lower in aerial parts of the plants compared to the roots (Table 5). Salinity treatments significantly affected the concentrations of Fe in roots and trunks of the plants. The treatments increased the root Fe concentrations in 8 $dS\ m^{-1}$ salinity level. Compared to control treatment, salinity led to a decrease in Fe concentration of trunk. Salinity affected significantly the concentration of Zn in all plant parts, except leaf. In general, root and trunk Zn concentrations decreased, and subsoil trunk Zn concentrations increased with salinity (Table 5). Compared to control treatment, salinity led to an increase in the concentrations of Mn in roots and subsoil trunk, a decrease in leaf and variable effect on trunk of the plants (Table 5).

Table 3. Effect of salinity on K/Na and (K+Ca+Mg)/Na ratios in different tissues of Gemlik olive cultivar

Salinity Treatment ($dS\ m^{-1}$)	Root	Subsoil Trunk	Trunk	Leaf
		K/Na		
Control	9.97 a	8.18 a	13.45 a	122.80 a
4	1.33 b	2.49 b	4.92 b	20.61 b
8	0.62 c	1.58 c	1.48 c	7.45 b
12	0.36 c	1.18 c	0.99 c	5.81 b
		(K+Ca+Mg)/Na		
Control	15.48 a	28.40 a	24.98 a	182.14 a
4	3.26 b	8.61 b	9.45 b	31.51 b
8	2.40 c	5.72 c	4.86 c	10.57 b
12	1.38 d	3.89 c	2.85 c	8.09 b

Means with the same letter are not significantly different using LSD at $P \leq 0.05$;

Table 4. Effect of salinity on N and P concentrations in different tissues of Gemlik olive cultivar

Salinity Treatment ($dS\ m^{-1}$)	Root	Subsoil Trunk	Trunk	Leaf
		N (%)		
Control	1.63 ns	0.53 a	0.87 a	2.31 a
4	1.63	0.54 a	0.77 b	2.31 a
8	1.65	0.51 ab	0.74 b	2.29 a
12	1.62	0.47 b	0.70 b	2.21 b
		P (%)		
Control	0.04 c	0.03 c	0.05 ns	0.12 b
4	0.08 b	0.05 a	0.06	0.14 a
8	0.10 ab	0.04 b	0.05	0.13 ab
12	0.12 a	0.05 ab	0.06	0.13 ab

Means with the same letter are not significantly different using LSD at $P \leq 0.05$; ns: nonsignificant.

Table 5. Effect of salinity on Fe, Zn and Mn concentrations in different tissues of Gemlik olive cultivar

Salinity Treatment ($dS\ m^{-1}$)	Root	Subsoil Trunk	Trunk	Leaf
		Fe ($mg\ kg^{-1}$)		
Control	362.4 b	129.9 ns	174.5 a	128.5 ns
4	367.2 b	148.0	106.1 c	126.7
8	475.6 a	152.3	125.7 bc	131.6
12	394.0 b	151.3	127.7 b	129.5
		Zn ($mg\ kg^{-1}$)		
Control	70.1 a	20.6 c	53.6 a	45.0 ns
4	67.5 a	29.3 b	49.8 ab	48.3
8	62.4 a	36.7 ab	39.0 bc	51.2
12	46.5 b	40.6 a	28.5 c	53.6
		Mn ($mg\ kg^{-1}$)		
Control	42.5 b	10.1 b	13.0 a	26.5 a
4	47.7 ab	11.3 ab	12.1 a	23.7 ab
8	45.5 ab	10.9 ab	10.0 b	20.2 c
12	56.0 a	14.1 a	12.4 a	23.2 bc

Means with the same letter are not significantly different using LSD at $P \leq 0.05$;ns: nonsignificant.

Discussion

The observation dealing with lower Na and Cl concentrations in aerial parts of the plants than that of roots may indicate that the cultivar is able to protect above ground meristematic tissues efficiently from the accumulations of Na and Cl. As reported by Demiral (2005), salt tolerant olive cultivar Barnea regulated the transport of salts from roots to aerial parts more effectively than salt sensitive olive cultivar Leccino. This ability was regarded as an essential phyto-physiological mechanism for salinity tolerance in plants (Munns, 2002) and was related to the potential growth of the plants (Ghafoor et al., 2004). Therefore, it may be speculated that Gemlik cultivar regulated the transport of to the leaves in order to maintain minimum total leaf area for photosynthesis and the production of carbohydrates crucial for the sustainable plant growth under salinity.

Probably, high K concentration of leaves represents an adaptation to salinity of the cultivar. With high K concentration in leaves, the cultivar prevented osmotically Na transport from the roots to the aerial parts of the plants (Jacoby, 1999). According to Demiral (2005), salt tolerant olive cultivar Barnea accumulated higher concentrations of K in its tissues than salt sensitive olive cultivar Leccino. On the other hand, salinity decreased concentrations of K of roots. Compared to control treatment, K concentration of the roots were 64% lower in the lowest salinity level (4.0 dS m^{-1}), and 81% lower in the 8.0 dS m^{-1} and 12.0 dS m^{-1} salinity levels. Sodium influx into root cells are partly achieved by K influx transporters (Epstein et al., 1963). Therefore, it is suggested that this reduction might be related to the antagonistic effect of Na on K influx in the plants.

Not only the concentrations of Na and K but also the ratio of K/Na can be used as a parameter giving clues about the physiological response of the plants to salt stress (de Lacerda et al., 2005). Therefore, it may be speculated that higher K/Na and (K+Ca+Mg)/Na ratios of the plant leaves can be accepted as key indicators reflecting the levels of adaptation of the cultivar to salt stress. Most likely, these findings indicate that salinity affected more efficiently K, Ca and Mg concentrations of the aerial parts than the roots. According to Ghafoor et al. (2004), passive nutrient uptake is relevant to water intake, and any decrease in water availability reduces the uptake of plant nutrients. Additionally, an imbalance in the composition of saline soil solution can cause an excessive or insufficient uptake of some ions. Calcium is supposed to be directly involved in Na exclusion and retention mechanisms regulating Na transport (Melgar et al., 2006). The results of this study agree with the aforementioned reports. In our study, all the plants survived until the end of the experiment and restricted the concentrations of Na and Cl in the aerial parts in all salinity treatments (Table 1). Therefore, the low Na and Cl and, high K and Ca concentrations of the leaves may be an evidence of the salinity tolerance ability in Gemlik olive cultivar. The low Mg concentrations of the plant parts might be one of the consequences of the competition with Ca and K. As reported by Marschner (1995), Ca is strongly competitive with Mg and the binding sites on the root plasma membrane appear to have less affinity for Mg than for Ca.

Among different plant parts, the highest concentration of N was found in the leaves. The concentration of N in the trunk was more affected than the other plant parts by salinity. Compared to the control treatment, the highest salinity treatment (12.0 dS m^{-1}) decreased N concentration by 11.3%, 19.5% and 4.3% in subsoil trunk, trunk and leaves, respectively. These results agree with previous findings (Peuke et al., 1996, Rubinigg et al., 2003). According to Rubinigg et al. (2003), a decreased rate of N translocation to the trunks could be the consequence of a general lower rate of solute flow in xylem. The authors stated that this phenomenon is a result of a reduced transpiration rate in trunk, inhibition of the xylem loading rate for NO_3^- or amino acids, a lower requirement for NO_3^- in the trunk, or a decrease NO_3^- influx in *Plantago maritima* L. growth in saline conditions.

As reported by Köhler and Raschke (2000) anion channels with similar permeability for both Cl and NO_3^- play a significant role in the xylem loading of these ions. Therefore, it may be speculated that in the presence of high Cl concentrations, the translocation of NO_3^--N from the root to the trunk decreased at the site of entrance into xylem via competition for the same channel. Our results seem to confirm this hypothesis. The accumulation of N in Gemlik olive was negatively and significantly correlated with the concentrations of Cl (r= - 0.736** for roots, r= - 0.945** for subsoil trunk, r= - 0.908**for trunk and r= – 0. 692* for leaves; ** significant at $p \leq 0.01$, * significant at $p \leq 0.05$). According to previous reports, the competition between NO_3^- and Cl^- ions uptakes across root plasma membrane are performed by various transport systems (Cerezo et al., 1997) and the internal N demand of plant was one of the properties regulating the activity of these transport systems (Forde and Clarkson, 1999). According to the authors the high N concentrations of the plant roots under salinity may have attributed to the following factors; first, the inhibition of NO_3^--N translocation from the roots to the trunk; and second, reduced transpiration rate of the plants as a result of salinity stress.

Some researchers reported that salinity induces inhibition of the high affinity mechanism in plants (Martinez and Lauchli, 1994). According to Chabra et al. (1976) salinity decreased P uptake because of the possible competition between P and Cl absorption. However, the results of some other studies indicated that salinity may increase P uptake through the low affinity system in plants under high external P concentrations

(Martinez et al. 1996). Plants have two different P uptake systems: either with a high affinity (uptake of P at low P concentrations) or low affinity (uptake of P at higher P concentrations) (Furihata et al. 1992). The low affinity system is considered constitutive (Dunlop et al. 1997) and its activity is connected with the existence of multiple transporters of P in the plasma membrane and tonoplast (Schachtman et al. 1998). The transporters are regulated by the external P concentration (Leggewie et al., 1997) and high cytosol pH (Martinez and Lauchli, 1994). In our study, the nutrient solution used in the experiment had sufficient amount of P (15.5 mg L^{-1}or 0.5 mmol P) for growing plants. Additionally, plant analysis showed that test plants accumulated sufficient amounts of P in their leaves (Jones et al., 1991). Therefore, we suggest that a Cl based limitation in uptake of P did not occur in the Gemlik cultivar.

It might be speculated that an increase in salinity and/or in salinity-induced increase in Fe and Mn concentrations led to a significant decrease in the Zn concentration of experimental plants' roots. However, as reported by Grattan and Grieve (1999), the relationships between salinity and micronutrients are complex and differences can be attributed to plant type and tissue, salinity level and composition, micronutrient concentration in the medium, growing conditions and the duration of study. Some of the possible reasons above-mentioned are beyond the scope of this study. Whatever the exact reason of the micronutrients alteration in olive plants under salinity is, we may accept that micronutrient concentrations of root of Gemlik cultivar are higher than that of micronutrient concentrations of plant parts above ground under salinity.

Conclusion

The result showed that compared to other plant parts K and Ca concentrations of the leaves were in highest concentrations under salinity. Therefore the concentrations of K and Ca, and the ratios of K/Na and (K+Ca+Mg)/Na of the leaves were regarded as an indication of adaptation to salinity in olive. In general salinity decreased N concentrations and increased P concentrations of the plant parts. Regarding the micronutrients, salinity increased root Fe and Mn concentrations, and decreased root Zn concentrations compared to control treatment. The findings of this investigation may be significant to explain the behaviour of *Olea europaea* L. under salt stress, in particular to a deeper understanding on how salinity interferes with concentration of mineral nutrients in plants.

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Relationship between soil water retention model parameters and structure stability

Amrakh I. Mamedov [a], Imanverdi Ekberli [b,*], Coşkun Gülser [b], Ilknur Gümüş [c], Ummuhan Çetin[c], Guy J. Levy [d]

[a] Institute of Soil Science and Agrochemistry and Institute of Botany, ANAS, Baku, Azerbaijan
[b] Ondokuz Mayis University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Samsun, Turkey
[c] Selcuk University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Konya, Turkey
[d] Institute of Soil, Water and Environmental Sciences, ARO, The Volcani center, Bet Dagan, Israel

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Abstract

Studying and modeling the effects of soil properties and management on soil structure and near saturation water retention is vital for the development of effective soil and water conservation practices. The contribution of soil intrinsic properties and extrinsic conditions to structure stability was inferred, in quantitative terms, from changes in water retention curves near saturation (low matric potential, 0-50 cm, macropores > 60 μm) that were obtained by the high energy moisture characteristic (HEMC) method. The S-shaped water retention curves were characterized by the modified van Genuchten model that provided: (i) the model parameters α and *n*, which represent the location of the inflection point and the steepness of the water retention curve, respectively; and (ii) the soil structure index, SI=VDP/MS, where VDP is the volume of drainable pores, and MS is the modal suction. Model parameters, claculated by the soil-HEMC model, were related to soil properties and hence soil water retention properties were linked to measured characteristics in several field and laboratory experiments. Soil SI increased exponentially with the increase in α and the decrease in *n*, while the relationship between SI and α/n was linear. An improved description of the water retention and its link to pore and apparent aggregate size distribution, by using the model parameters α and *n,* could potentially assist in the selection of management practices for obtaining the most suitable type of soil structure depending on the desired soil function.

Keywords: Structure stability, water retention, pore size, stability index, model.

Introduction

Soil structural stability is a basic property of soil health, affecting many soil properties including soil hydraulic properties, surface runoff generation and soil erosion. The formation of soil aggregates and structure is the result of biotic and abiotic factors and their interaction. The ability of aggregates to resist the dispersive and slaking processes of water is a vital property in relation to the preservation of a porous soil structure (Haynes, 2000; Levy and Mamedov, 2002; Rillig and Mummey, 2006). Incorporating organic matter (biosolids, crop residues and plants) and soil amendments in the soil favors the increase of substances (aggregation agents) involved in aggregate stability and decreases slaking and mechanical breakdown. Therefore, studying the effects of soil properties and management practices on soil structure is

* Corresponding author.
Ondokuz Mayis University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Samsun, 55139 Turkey
Tel.: +903623121919 E-mail address: iman@omu.edu.tr
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important for the development of effective soil and water conservation, and predictive soil-crop modeling tools in order to avoid risks of soil deterioration (Roger-Estrade et al., 2009).

Tillage, soil compaction, crop rotation, irrigation and amendment application can alter pore size distribution (PSD), and subsequently affect physical and chemical properties of soils, and nutrients availability. Furthermore, plant growth associated with activities of soil biota interacts with environmental variables such as dry-wet and freeze-thaw cycles to modify soil structure (Haynes 2000; Lipiec et al., 2007; Mamedov and Levy, 2013). The ability to study soil structure dynamics and affecting mechanisms are complicated by the (i) magnitude of temporal variability which in itself is affected considerably by the spatial location and growing season, (ii) effects of management practices, and (iii) difficulties involved in relating results from laboratory measurements to real field behavior (Strudley et al., 2008; Mamedov and Levy, 2013).

Structure and aggregate stability can be inferred from changes in the soil water retention curve even at the low end of the matric potential. The PSD can be derived from the water retention characteristics and is considered as a basic index for soil physical quality (Dexter and Czyz, 2007; Mamedov et al., 2010). The contribution of agricultural management to soil water retention could also be quantitatively characterized by the parameters derived from the modified van Genuchten (1980) model (e.g., α and n, the location of the inflection point and the steepness of its slope), because changes in α and n are considered to be closely related to PSD and therefore to aggregate and particle size distribution (Lipiec et al., 2006; Porebska et al., 2006). In the case of smectitic soils the α and n parameters were found useful in characterizing the contribution of both large aggregate size (> 0.25-0.5 mm, $\psi \sim 0$ to 12 cm) and small (< 0.25-0.5 mm, $\psi \sim 12$ to 50 cm) aggregates/particles, respectively, to soil structure condition (Mamedov and Levy, 2013).

The near saturation PSD and fractionation of water stable aggregates could be helpful for the better understanding of soil quality/health dynamics affected by soil management, since aggregate size distribution is more sensitive to changes in soil management than for instance organic C (Pikul et al., 2007). Soil pores affected by the suction at the range of 0–50 cm are associated with soil structural porosity (i.e. inter-particle pores, > 60 µm). These pores can be divided broadly into three subclasses (Mamedov et al., 2010) within the very fine macro-pore equivalent diameter class (75–1000 µm) with matric potential range of: (i) 0-12 cm (corresponding to pores >250 µm, herein referred to as macropores); (ii) 12–24 cm (125–250 µm, mesopores); and (iii) 24–50 cm (60-125 µm, micropores). These size-ranges of the drainable pores are accompanied by soil aggregates of comporable sizes. Hence, three apparent size classes of aggregates (e.g. apparent macro-, meso- and micro-aggregates), which correspond to the aforementioned macro-, meso- and micro-pores, respectively are defined (Mamedov and Levy, 2013).

Characterization of soil aggregate stability has commonly been used to portray structure stability, although aggregates are not necessarily a suitable proxy of soil structure. Several aggregate stability methods, utilizing diverse primary breakdown mechanisms (e.g. wet sieving, drop test, application of ultrasonic energy, etc.), are used for establishing an index of soil structure, which makes comparison between treatments difficult (Pulido Moncada et al., 2015). The recently modified high energy moisture characteristic (HEMC) method (Pierson and Mulla, 1989; Levy and Mamedov, 2002) having high reproducibility was found to be sensitive and capable of detecting even small changes in aggregate and structure stability of a range of soils from arid and humid zones (Mamedov and Levy, 2013).

The objective of this study was to examine the relationship between the soil structure stability indices and the van Genuchten model parameters (α and n) for the studied water retention curves based on already published and unpublished data of water retention curves obtained by the HEMC method.

Material and Methods

Soils

An array of samples from semi-arid cultivated soils varying in intristic soil properties and studied under differing extrinsic conditions were examined in our study: (i) effects of wetting rates (2, 8, 32, 100 and 200 mm h^{-1}) using six soils (from loamy sand to clay) (Mamedov and Levy, 2013); (ii) three soils varying in texture (loamy sand, loam and clay) treated with two biosolid amanedments (composted manure and sweage sludge, at a rate of 50 t ha^{-1} and thier components [orthophosphate, phytic acid and humic acid]) and exposed to six consequative rainfall (Mamedov et al., 2014); (iii) clay loam soil (control, rhizosphere and bulk) used under 10 various wheat types (Uyanoz et al., 2012); (iv) clay soil treated with fresh or composted poultry litter (10 t ha^{-1}), and zeolite (1.5 t ha^{-1}) under corn and wheat production (Gumus and Seker 2014). In all cases the soil samples studied were taken from the cultivated soil layer.

Water retention

We used soil samples (from various studies) water retention curves that were obtained at high energies of matric potential (HEMC, 0 to 50 cm H_2O), corresponding to drainable pores (> 60 μm). In these studies, the Soil-HEMC model (e.g., Mamedov and Levy, 2013), which enables an accurate fit of the measured water retention curves (ψ, 0 to 50 cm) was used to calculate model parameters (α and *n*) and structural index (SI=VDP/MS; VDP-volume of drainable pores, MS-modal suction) by the following equations (Pierson and Mulla, 1989; Mamedov and Levy, 2013):

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (\alpha\,\psi)^n\right]^{(1/n-1)} + A\psi^2 + B\psi + C \qquad [1]$$

$$d\theta/d\psi = (\theta_s - \theta_r)\left[1 + (\alpha\,\psi)^n\right]^{(1/n-1)} (1/n - 1)(\alpha\,\psi)^n\, n/\left[\psi(1 + (\alpha\,\psi)^n)\right] + 2A\psi + B \qquad [2]$$

where, θ_r and θ_s are the residual and saturated water content, respectively; α (cm^{-1}) and *n* represent the location of the inflection point and the steepness of the S-shaped water retention curve; A, B and C are coefficients.

Results and Discussion

Water retentions

The various attributes that were examined (contribution of soil texture, wetting rate, biosolid and its components, zeolit and poultry litter application and rhizosphere zone processes under the crops) all had considerable effects on the shape of the HEMC water retentions curves (Figures. 1-4). Increasing the wetting rate shifted the location of water retention curve (Figure 1) up-right (Mamedov and Levy, 2013). Most of the changes in pore size distribution occurred in a wide range of matric potential 0-50 cm (pore size > 60 μm). The water-retention curves of manure (and orthophosphate and phytic acid) and sludge (and humic acid) amended soil aggregates differed from the control generally in the matric potential range of 0-12 cm and 0–24 cm, corresponding to changes in macro- and mesopores (>125-250 μm) respectively (Mamedov et al., 2014). The impact of cropping of 10 wheat variety with a different root characteristics, was considerable on soil biological and chemical properties in the rhizosphere zone and around (rhizosphere and bulk) (Uyanoz et al., 2012), and also notable modified soil water retention capability. The difference between control and bulk or rhizosphere soil samples were related to the meso-and micropores (<125-250 μm) or all studied pores (> 60 μm) accordingly (Figure 3). In the field condition application of poultry litter, zeolite and their combination boosted clay soil properties, and corn and wheat production (Gumus and Seker, 2014), and sizeable enhanced soil water retention at the range of 0-24 cm (> 125 μm) (Figure 4).

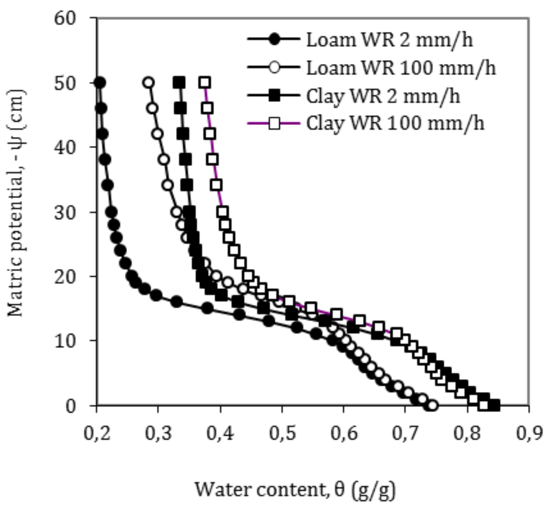

Figure 1. Soil water retention as affected by wetting rate (WR)

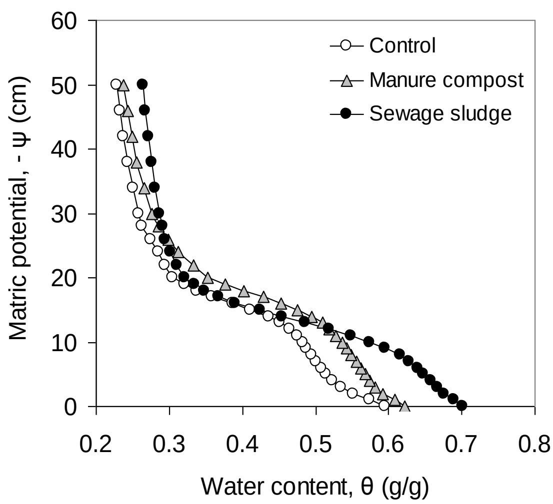

Figure 2. Loam soil water retention as affected by composted manure and sewage sludge application

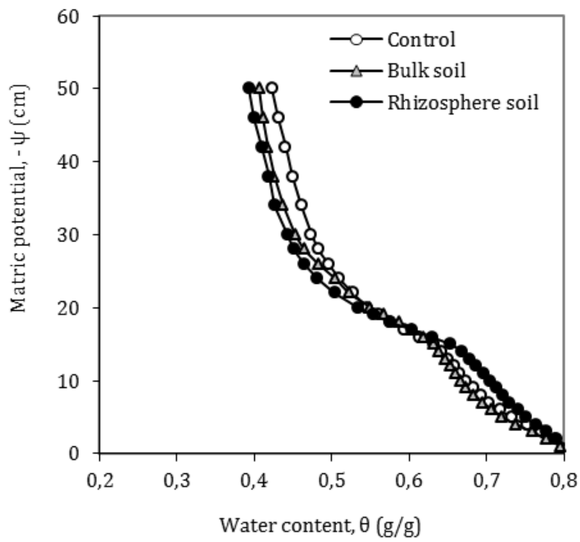

Figure 3. Clay loam soil water retention (control, bulk and rhizosphere) as affected by cropping under wheat

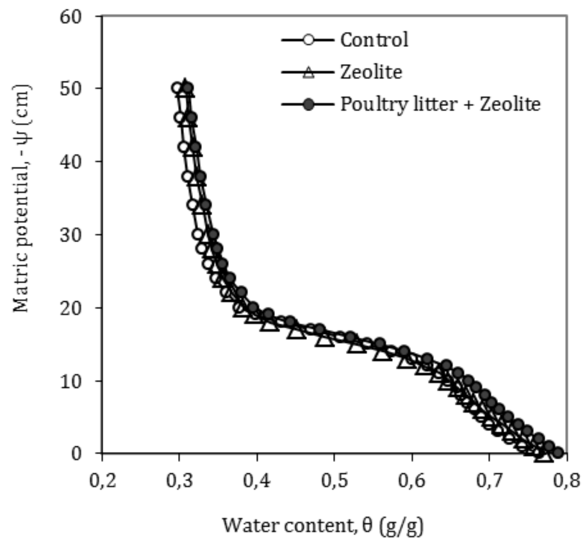

Figure 4. Clay soil water retention as affected by poultry litter and zeolite application under wheat

Wetting rate

Changes in soil structure following aggregate breakdown by fast wetting, generally resulting from formation of a larger number of aggregates or particles of smaller sizes than the original ones (leading to smaller inter-aggregate pores), affects the shape of water retentions, and hence model parameters (Mamedov and Levy, 2013). Used semi-arid soils, with low organic matter and plant residue material on soil surface, and long term cultivation history were found to be sensitive to various degree of aggregate breakdown by wetting with the effect being more pronounced in the soil with low clay content (Figure 1). Increasing the wetting rate from 2 to 200 mm h^{-1} for six soils varying in texture, increased *n*, and decreased α and hence led to wide variation in the SI (0.003-0.023). Generally the SI of soils were in the following order: loam < silty clay loam < clay. The relationship between SI and α or *n* is characterized by a strong (R^2>0.9) exponential type of relationship (Figure 5 and 6). Comparable examining the contribution of wetting rate and soil management (e.g. aggregate size distribution by tillage, irrigation, raindrop impact, crop residues) on soil PSD and structure stability could assist in simulation on surface deterioration, gas emission and N mineralization rate of semi-arid soils affected by agricultural practices (Shainberg et al., 2003; van Donk et al., 2010; Mamedov and Levy, 2013).

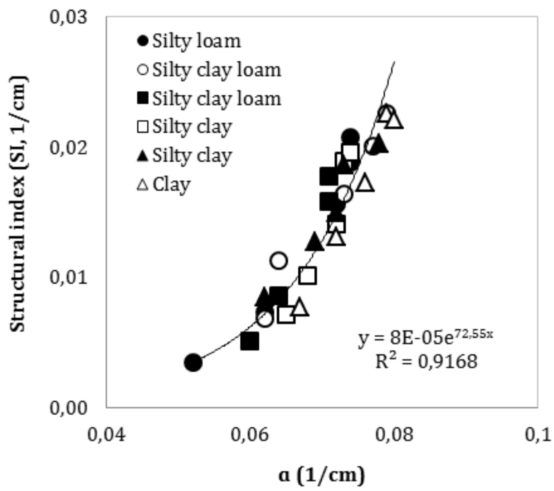

Figure 5. Soil structural index (SI) as a function of α for six soils (ranging from loamy sand to clay) saturated with five wetting rate (2, 8, 32, 100 and 200 mm h^{-1})

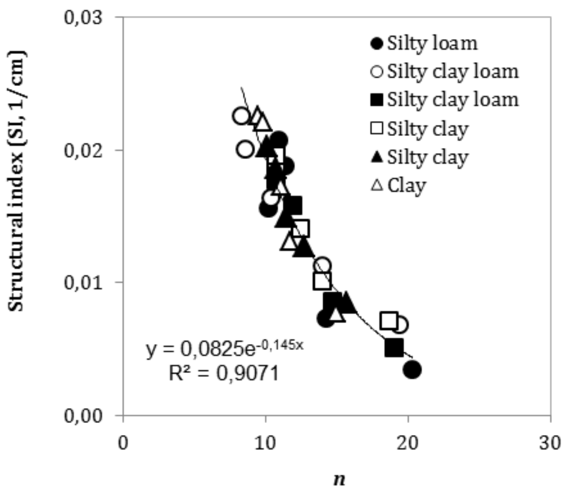

Figure 6. Soil structural index (SI) as a function of *n* for six soils (ranging from loamy sand to clay) saturated with five wetting rate (2, 8, 32, 100 and 200 mm h^{-1})

Amending with biosolids

The use of biosolids and organic wastes in agricultural soils as a nutrient resource and as a soil amendment is a common practice. The effects of the biosolid treatments on soil water retentions were soil-dependent (Figure 2) beeing in agreement with the results of previous studies that reported the effects of biosolids application on aggregate stability to be at times vague (Haynes, 2000; Mamedov et al., 2014). Amending soils with biosolids and exposing to six consecutive rainfall rates resulted in a wide range of values for the SI (0.0017-0.035), α (0.032-0.093) and *n* (6.48-21.32). The sludge and humic acid treatments contributed to an increase in macro and lesser degree on meso-pores, whereas other amendments contributed only to macro-pores, and hence the stability of apparent aggregate sizes. Amendments role was generally related to formation of adhesive films that form a bridge between soil clay platelets, and induced hydrophobic conditions, and thus increasing aggregate resistance to slaking (Haynes, 2000; Mamedov et al., 2014).

Treating soils with composted manure and sewage sludge, and their component were more notable in the coarse-textured loam and loamy sand soils than the clay soil (Mamedov et al., 2014), however the averaged SI (and α) of soils (slow and fast wetted) were in the following order: loamy sand < loam < clay (Figure 7 and 8). The exponential relationship between SI and α was much greater (R^2=0.8) than the relationship between SI and *n* (R^2=0.42), showing importance of treatments on enhancing macroaggregates. Separation of aggregates (pores), into macro- and micro-aggregates (pores), and relevant relationship between SI and model parameters, will be important for more precise evaluation and understanding of the effects organic amendments might have on aggregate stability and soil conservation planning.

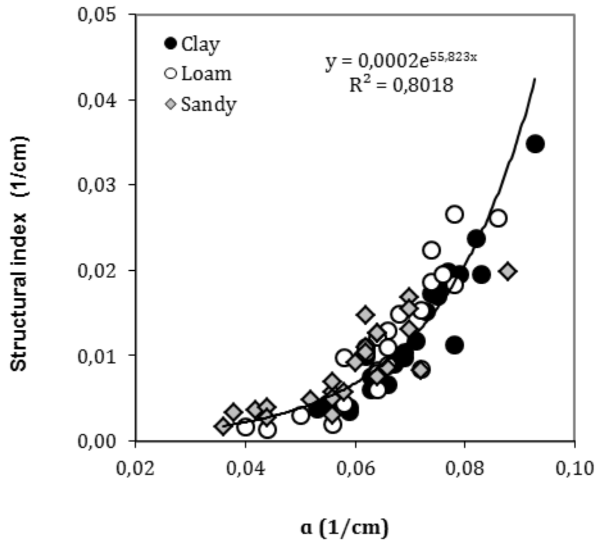

Figure 7. Soil structural index (SI) as a function of α for soils (clay, loam and loamy sand) treated with composted manure and sewage sludge and thier components (orthophosphate, phytic acid and humic acid)

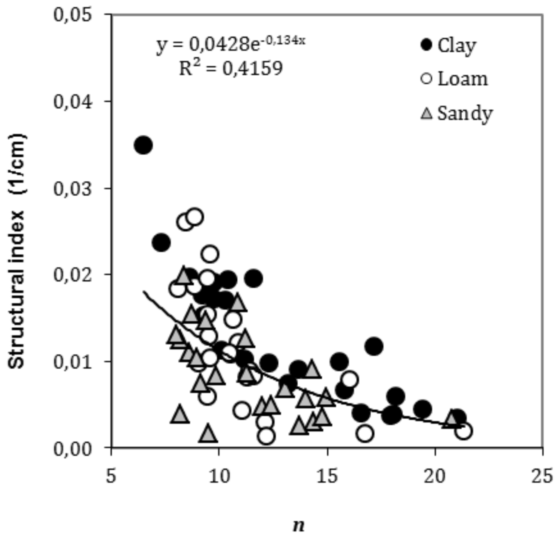

Figure 8. Soil structural index (SI) as a function of *n* for soils (clay, loam and loamy sand) treated with composted manure and sewage sludge and thier components (orthophosphate, phytic acid and humic acid)

Rhizosphere and bulk soils

The rhizosphere soil is directly influenced by the root, plant residues, root secretions and symbiotic associated microorganisms (e.g. mycorrhizal fungi). Relative to control under cropping condition the high C content, enzyme or microbial activity in the rhizosphere and bulk soil significantly increased soil SI (0.041-0.052) and α and decreased *n* (Figure 9 and 10). The SI and α of soils were in the following well defined order: rhizosphere > bulk > control. The relationship between SI and α or *n* is characterized by a strong (R^2>0. 9) exponential type relationship. Since cropping was made in same clay loam soil with a weak structure and low organic matter, the variation in SI, α and *n* in rhizosphere and bulk soil were related to wheat varieties. Soil C accounted for up to 50 % of the change of biophysical soil properties (data are not shown).

Results show that crop variety may contribute to the short-term sustainability of the agroecosystem by improving physical soil characteristics under semi-arid conditions. Main effects of rhizosphere processes on soil structure in moist conditions were orientation of clay particles around the cells, excretion of extracellular polysaccharides that induced local binding of clay particles, and a general packing effect by hyphae (Hinsinger et al, 2005). A major challenge for the future ecosystem will be to transfer new knowledge into actions that result in the beneficial management of the rhizosphere (Hinsinger et al, 2005 Rillig and Mummey, 2006). Therefore HEMC approach could be useful tool to introduce the effects of soil macroporosity on biological processes in agroecosystems models.

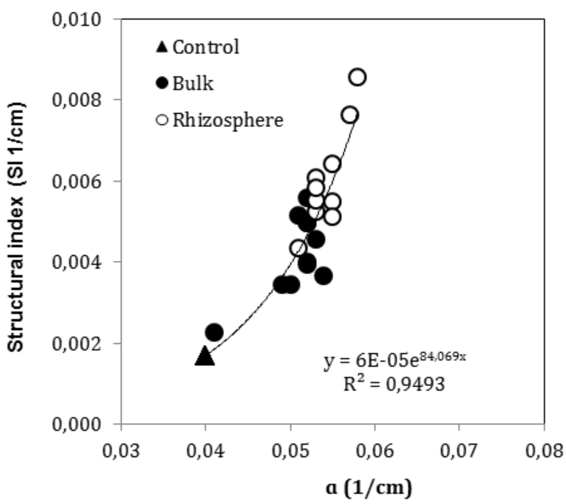

Figure 9. SI as a function of α for loam soil (control, bulk and rhizosphere soil) used under 10 varieties of wheat

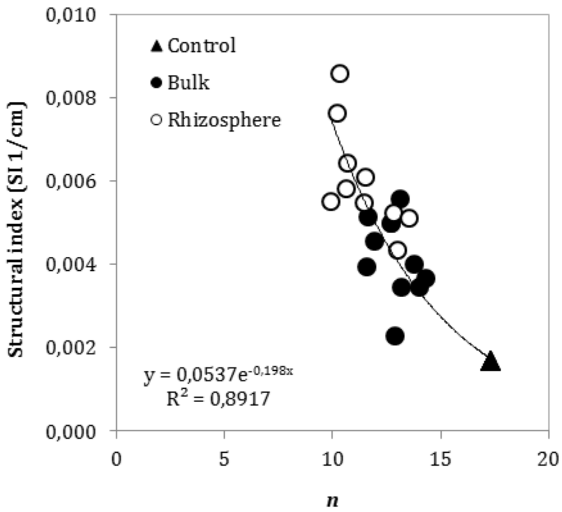

Figure 10. Soil SI as a function of *n* for loam soil (control, bulk and rhizosphere soil) used under 10 varieties of wheat

Poultry litter and zeolite application

The litter produced by the poultry industry is currently applied to agricultural land as a source of nutrients and soil amendment. However, following its application environmental pollution, resulting from nutrient and contaminant leaching may occur under certain condition (Bolan et al., 2010). Application of zeolite in combination with poultry litter may significantly improve soil physical and chemical environment, plant nutrition and yield (Gumus and Seker, 2014), and mitigate pollution issues. Contribution of poultry litter and zeolite and their combination on soil structural indices in clay soil under the wheat is characterised by a relative narrow range of SI (0.010-0.025), α (0.058-0.074) and *n* (7.6-12.2) compared with all above mentioned experiments. Yet a moderate exponential type relationships between SI and α and *n* were noted (Figure 11 and 12).

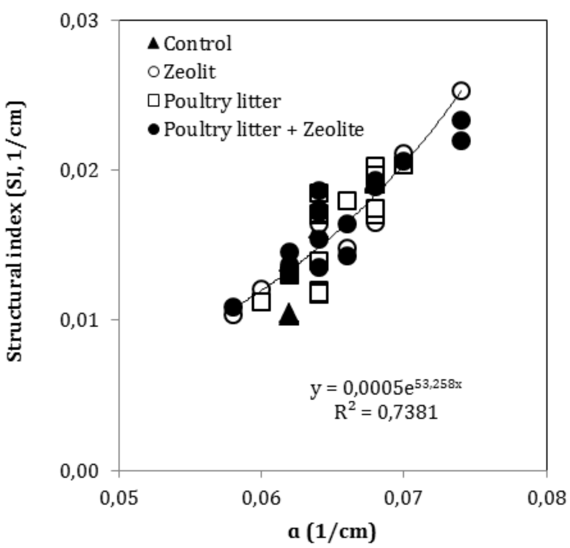

Figure 11. Soil SI as a function of α for clay soil treated with poultry litter and zeolite, and their combintion.

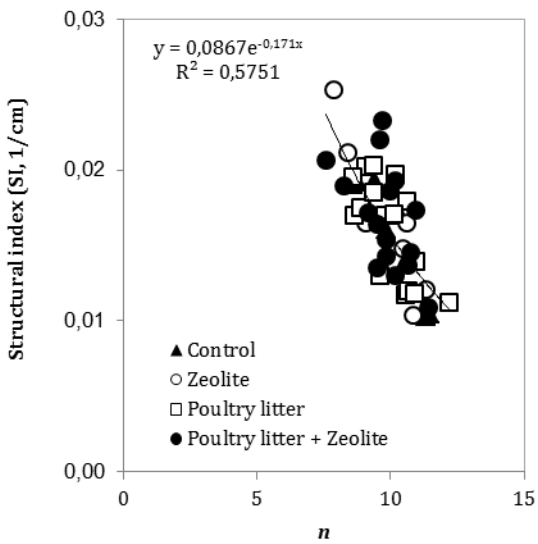

Figure 12. Soil SI as a function of *n* for clay soil treated with poultry litter and zeolite, and their combintion

In general the averaged SI and α of treatments were in the following order: Control < Poultry litter < Zeolite < Zeolite + Poultry litter; but for *n* the picture was not clear, since the value of *n* for treatments had a similar range. The results was in agreement with the results of previous studies showing that in the cultivated soil the addition of poultry manure may decrease the bulk density, and increase the organic matter content, water holding capacity, and the aggregate stability of the soils (Bolan et al., 2010).

The relationship between soil SI and model parameters (α and *n*) had, in general, a similar shape for the examined attributes. Soil SI increased exponentially with increase in α and decrease in *n*, while the parameters of the exponential equations were different (Figure 5-10). In all the above examined attributes the relationship between SI and a/n was linear (Table 1). Similar results was received by Mamedov and Levy (2013) where about 50 cultivated and irrigated semi-arid Israeli soil widely varying in texture were used (Table 1). It is suggested the exponential relationship, exponents and coefficient of the equations are related to soil texture and treatments contribution on PSD and aggregate size distribution that should be investigated in details in future studies (Mamedov and Levy, 2013).

Table 1. Relationship between soil structural index (SI) and the ratio of the water retention model parameters (α/n)

Treatments	Saoil texture	Equation SI = f (α/n)
Wetting rate	Six soil ranging from loam to clay	y = 3.1677x - 0.0044, R^2 = 0.91
Biosolid application	Loamy sand, loam, clay	y = 2.6447x - 0.0049, R^2 = 0.80
Rhizosphere and bulk soil	Clay loam	y = 1.6022x - 0.002, R^2 = 0.87
Poultry litter and zeolite	Clay	y = 2.9267x - 0.0033, R^2 = 0.73
Semi-arid soils-irrigated	50 soils ranging from loamy sand to clay	y = 3.5325x - 0.0076, R^2 = 0.92

Conclusion

Research data reporting a wide range of changes in pore size ditribution, and structure stability indices of semiarid soils widely varying in intrinsic properties and management histories were used to explore the relationships between SI and the water retention model parameters α and *n*. In all cases SI increased exponentially with an increase in α and a decrease in *n*, while the relationship between SI and α/n was linear. It is postulated that description of the water retention by soil-HEMC model and linking model parameters to soil structural index and thus pore- and aggregate size distribution, may help to select proper management practices for obtaining the most suitable type of aggregation depending on the desired soil function or soil type.

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Improved method to determine particle size distribution for some gypsiferous soils. A case study from Al-Ahsa Governorate, Saudi Arabia

Magboul Sulieman [a,b,*], Abd El-Azeem Sallam [a]

[a] Department of Soil Sciences, College of Agriculture, King Saud University, Riyadh, Saudi Arabia

[b] Department of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum, Khartoum North, Shambat, Sudan

Abstract

Until now, there is no method can be used to accurately assess the particles size distribution as well as textural classes of gypsiferous soils for proper interpretation of physical behavior of these soils, and most laboratory methods involve pretreatment to remove gypsum from the samples. Therefore, the results of the particle size distribution do not reflect the size distribution of the whole soil. This study aimed to develop an alternative method to determine particle size distribution for some gypsiferous soils selected from Al-Ahsa governorate, Saudi Arabia. Five samples from different profiles with different gypsum content were selected to evaluate the modified method. Sand fractions were separated with three disaggregation methods: 1) drying sieving, 2) shaking for 5 hours in a 7:3 ethanol: water solution, and 3) sonication for 3 minutes in a 7:3 ethanol: water solution. The statistical analysis results revealed that the sonication for 3 minutes in a 7:3 ethanol: water solution was the most effective method for separating sand fractions as compared to dry sieving and shaking. Meanwhile, there was slight difference in separating sand fractions between sonication for 3 minutes and shaking for 5 hours. The particle size distribution by the developed method showed increasing in total sand content as compared to standard particle size method. Likewise, comparison of the CEC/clay ratio between the two methods also indicated that the developed method yielded clay contents more consistent with other property data for the same horizons. Consequently, the textural classes obtained from the two methods were different. Therefore; we concluded that the determination of particle size distribution for gypsiferous soils (≤ 40% gypsum) using this developed method will improve the understanding and ability to proper interpret of physical behavior of these unique soils. We highly recommended using this developed method to separate soil particles from the gypsiferous soils.

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Introduction

Gypsiferous soils (1 to 40% gypsum) are widely scattered throughout the Kingdom of Saudi Arabia and are particularly extensive in the Eastern Region from the Kuwait/Iraq border South to the sands of the Empty Quarter. The general characteristics of these soils they are; located on plains, shallow to moderately deep with loamy texture, highly saline and are mostly unsuitable for agricultural purposes (Vincent, 2008).

According to the World Reference Base for Soil Resources (FAO, 1990), the gypsiferous soils in Saudi Arabia cover about 82.5 km^2 (approximately 0.04 % of the total area). In contrast; the general soil map of the

* Corresponding author.
Department of Soil Sciences, College of Agriculture, King Saud University, 2640, Riyadh, Saudi Arabia
Tel.: +966542995460
E-mail address: magboul@uofk.edu
e-ISSN: 2147-4249
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Kingdom of Saudi Arabia (Soil Atlas, 1984) estimated that the gypsiferous soils in Saudi Arabia cover around 1622.66 km^2 (approximately 8.5 % of total area). The reason for this significant variation is that the world map for gypsiferous soils distribution shows only area of Yermosols and Xerosols which have a gypsic or petrogypsic subsurface horizon, and the other soils which may have a gypsic horizon (e.g; Calcic units of Yermosols, Xerosols, Chernozems and Calcic Cambisols and Solonchaks) are not taken into account.

The estimation of soil texture of the gypsiferous soils under field conditions is misleading due to the presence of gypsum crystals in various sand-sized fractions. Consequently, the forms and degree of crystallization of gypsum particles influence the feel of the soil and as a result, field estimates of texture are generally coarser than indicated by laboratory methods (Soil Survey Staff, 2014b).

Until now, there is no method can be used to accurately assess the particles size distribution as well as textural classes of gypsiferous soils for proper interpretation of physical behavior of these soils (Pearson et al. 2014). However, most laboratory methods for determining particle size distribution of gypsiferous soils involve pretreatment to remove gypsum and more soluble salts as well as iron oxides (Soil Survey Staff, 2014b). Consequently, the particle size measurements by these methods indicate the size distribution of essentially insoluble, dominantly silicate minerals, and do not indicate the size distribution of the whole soil including gypsum (Porta, 1998).

Pearson et al. (2014) proposed an alternative method to determine particle size distribution in gypseous soils (≥ 40% gypsum content). The method consists of two independent measures of particle size; 1) the amount and distribution of sand-sized particles including gypsum particles, and 2) clay content of a whole soil (including gypsum) basis using the measured gypsum content of the sample.

In this study, we further develop the Pearson et al. (2014) method to determine the particle size distribution in some gypsiferous soils (≤ 40% gypsum content) selected from Al-Ahsa governorate, Saudi Arabia.

This study tried to address the following questions: (1) which disaggregation methods are most suitable to separate sand fractions for gypsiferous soils? (2) Are there significant differences in particle size distribution as well as textural class obtained by standard method and the developed method for gypsiferous soils? (3) Is this modified method suitable to determine particle size distribution for gypsiferous soils?

Material and Methods

Site description

The study area is located in the eastern part of Al-Ahsa governorate, Saudi Arabia (Figure 1). The study area falls within the arid climatic zone. The average annual rainfall varies from 0 to < 100 mm. The monthly mean maximum temperature of the hottest months (June and July) is 38˚C. Monthly mean minimum temperature of the coldest month (January) is less than 25˚C. The monthly mean relative humidity ranges between 40 to 60 % (April to August) and > 60% (January to March) and (September to December). All sampling locations were covered with natural vegetation especially *Haloxylon sallicornicum* and some area were cultivated with old date palms.

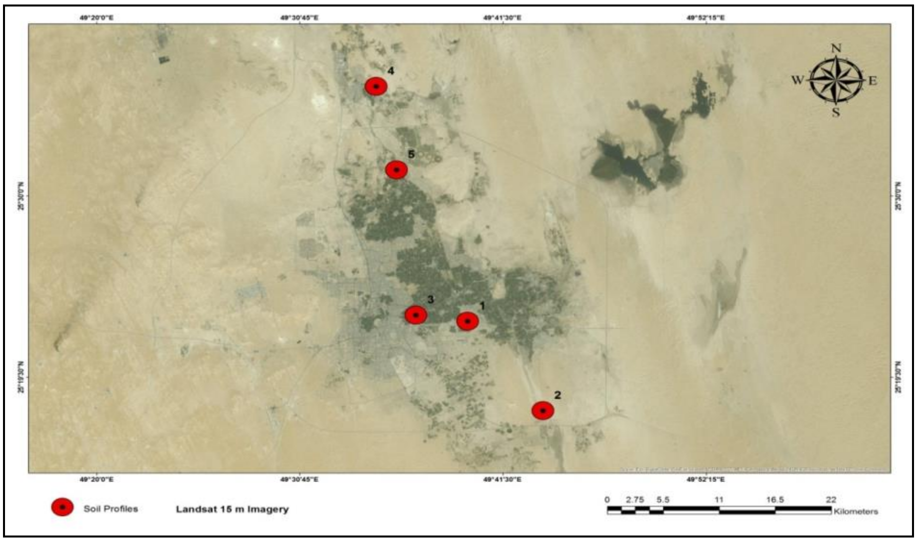

Figure 1. Location of the study area and samples sites

Table 1 presents the geographical coordinates of the sampling sites. The calculated soil temperature regime is hyperthermic and soil moisture regime is aridic. Soil samples were collected from 5 representative profiles. All soil profiles were fully described (Appendix 1) according to the FAO Guideline for Soil profile Description (FAO, 2006). According to the USDA soil taxonomy (Soil Survey Staff, 2014a), the soils of the study area belong within Aridisols and classified as gypsids suborder.

Table 1. Geographical coordinates of the sampling sites within the study area.

Profile No.	Horizon	Coordinates		Classification
		N	E	(USDA*, 2014)
Profile 1	Czy (5-25cm)	25º36'51"	49º32'54"	Typic Haplogypsids
Profile 2	Cky (5-20 cm)	25º30'32"	49º35'37"	Typic Calcigypsids
Profile 3	Czy (25-45 cm)	25º17'00"	49º43'16"	Typic Haplogypsids
Profile 4	Cky (20-80 cm)	25º17'00"	49º43'12"	Typic Calcigypsids
Profile 5	Cky (5-35 cm)	25º31'30"	49º35'52"	Typic Calcigypsids

* United State Department of Agriculture (Soil Survey Staff, 2014a,b)

Soil sampling and analysis

Five soil samples with different gypsum content were collected randomly from 5 profiles; profiles 1 and 2 were classified as Typic Haplogypsids; whereas, profiles 3, 4 and 5 were classified as Typic Calcigypsids. Selected physical and chemical properties of the samples used for the evaluation of the disaggregation methods are given in Table 2.

Table 2. Selected physical and chemical properties of the studied soil samples

Profile No.	Depth (cm)	Gypsum g kg^{-1}	pH[a]	EC[b] dS m^{-1}	CEC cmol(+) kg^{-1}	BD kg m^{-3}	$CaCO_3$ g kg^{-1}	Field texture[c]	Particle size distribution (%)			Textural class[d]
									Sand	Silt	Clay	
P 1	5-25	84.0	7.75	60.5	1.80	1.7	151	S	74.4	0.4	25.2	SCL
P 2	5-20	108.0	8.5	70.2	5.20	1.8	46.0	SCL	84.2	1.5	14.3	LS
P 3	0-25	82.0	7.72	2.65	8.25	1.7	262	SCL	72.8	4.4	22.8	SCL
P 4	20-80	53.0	7.78	4.45	7.60	1.8	70.2	SCL	89.6	3.7	6.8	S
P 5	5-35	42.0	7.67	9.50	3.40	1.9	642	SL	84.0	8.5	7.5	LS

[a] pH measured in 1:5 soil: water.
[b] Electrical conductivity of saturated paste extract.
[c d] scl: sandy clay loam, sl: sandy loam; s: sand; ls: loamy sand

Texture class by feel was evaluated in the field for different horizons and compared to those obtained by using USDA textural triangle (Soil Survey Staff, 2014b). In laboratory, samples were air-dried (20-22 °C) and passed through a 2 mm mesh sieve to obtain the fine soil fraction. The bulk density (BD) was determined in the field by using core method according to (Grossman and Reinsch, 2002). Particle size distribution was determined by using standard pipet method according to (Gee and Bauder, 1994). Soil chemical properties were determined according to the standard method (Sparks et al. 1996). Soil pH was measured potentiometrically in 1:5 soil/water suspension. Electrical conductivity (EC) was measured potentiometrically on a saturated paste extract. Gypsum percentage was evaluated by dissolution in water, precipitation in acetone, re-dissolution, and conversion of solution EC to percent gypsum. Cation exchange capacity (CEC) was determined using continuous leaching of 4 g of soil with 100 ml of 1 M NH_4OAc at pH 7 (4 g of air dry soil sample was treated three times with 1 M NaOAc, washed three times with ethanol (95 %), and then extracted three times with 1 M NH_4OAc), and concentration of the exchangeable Na^+ was determined using flame photometer (model Corning 400), and then the CEC was calcluated using the equation described by (Sparks et al. 1996). Percent calcium carbonate (% $CaCO_3$) was determined by calcimeter. The samples were treated with 0.1N HCL; the volume of CO_2 from pure calcium carbonate and samples were recorded, and the % $CaCO_3$ was then calculated according to Horváth et al. (2005).

Separation of sand fractions by the developed method

We used an alternative method described by Pearson et al. (2014) to separate sand fractions for five gypsiferous samples with gypsum content ranging from 4.2 to 10.8%. Sand fractions were separated using three disaggregation methods with fundamental changes including increasing the specimen weight and minimizing the time of the separation. Main reason for minimizing the time is that gypsum in most gypsiferous soils is present as fine sand fraction (125 -25 µm), which may be greatly affected by great energy input via sonication or shaking. As a result the fine sand may pass via sieve as silt fraction which causes a decrease in total sand content and an increase in silt content. The three disaggregation methods are as follows: (1) Dry sieving- 25 g of air dried soil sample was sieved through a set of 53 µm diameter sieves (1.0, 0.5, 0.25, 0.125, and 0.053 mm openings) on a mechanical shaker for 3 minutes (shaking model HAVER EML 200 digital, Germany) and the fraction retained on each sieve was weighed. This method did not include addition of any chemical solutions to disperse samples; thus, it can be used to compare their obtained results with the other two methods for separating sand fractions from gypsiferous soils. (2) Shaking for 5 hours in a 7:3 ethanol: water solution- 25 g of soil suspended in a 7:3 ethanol: water solution and shaken for 5 hours on a reciprocating shaker Model (SSL1, orbital shaker). The suspension was then passed through a 53µm-sieve, and sand fraction on each sieve weighted (wet weight), and left overnight to oven dry at 60°C (in order to avoid the change in gypsum contents as well as clay minerals, and which may occur if the samples have been dried at 105 °C) and then each fraction weighed for a second time (dry weight). (3) Sonication in a 7:3 ethanol: water solution- 25 g of soil was suspended in 50 ml of a 7:3 ethanol: water solution and allowed to sit for 2 minutes in a 150 mm diameter beaker. Ultrasound energy was applied for 3 minutes via a sonicator Model (Sonics & Materials Vibra-Cell VC600a, 600-Watt at 20 kHz with 20 mm horn). The suspension was then passed through a 53µm- sieve, and sand fraction on each sieve weighted (wet weight), and left overnight to oven dry at 60°C and then each fraction weighed for a second time (dry weight). Individual sand separates in the three methods were calculated as a percentage of the whole soil sample. Total sand was calculated as the sum of the sand separates.

Whole clay content measurement

The clay content was measured after gypsum removal by the standard pipet method, and then re-calculated to a whole soil (including gypsum) using the following equation described by Pearson et al. (2014):

$$\frac{\text{g clay}}{\text{g} < 2\ mm\ soil} = \frac{\text{g non gypsum separate}}{\text{g} < 2\ mm\ soil} \text{ X } \frac{\text{g clay}}{\text{g non gypsum separate}}$$

Where; (g clay/g <2 mm soil) is the calculated value of whole-soil clay content, (g non-gypsum separate/g <2 mm) soil is the content of non-gypsum residue in the sample expressed as a decimal ([100-% gypsum]/100), and (g clay/g non-gypsum separate) is the clay content of the non-gypsum residue.

Whole soil silt measurement

Whole soil silt percentage was calculated by subtracting the sand and clay percentages from 100.

Statistical analysis

The influence of the three disaggregation methods on the sand fractions as well as total sand were statistically analyzed by a one way analysis of variance with Tukey significant difference test for mean separation (P<0.05). All statistical analysis was performed using SPSS software version 21.0 (IBM Corp., 2012).

Results and Discussion

Selected physico-chemical soil properties

Selected physico-chemical properties of the studied samples are presented in Table 2. Field texture ranged from sand to sandy clay loam. Bulk density was high and ranged from 1.7 to 1.9 kg m^{-3}. The soil reaction was alkaline in all samples due to the presence of $CaCO_3$ and the pH values ranged from 7.67 to 8.50. These results are similar to those others obtained with gypsisols (Artieda, 1996; Florea and Al-Joumaa, 1998; Cantón et al. 2003). All horizons showed salinity level and the electrical conductivity (EC) values ranged from 2.65 to 60.5 dS m^{-1}. The $CaCO_3$ content ranged from 46.0 to 642 g kg^{-1}. Gypsum content varied in all samples and the values ranged from 42 to 108 g kg^{-1}. The cation exchange capacity (CEC) ranged from 1.80 to 8.25 c mol (+) kg^{-1}. The irregular distribution between CEC and gypsum/calcium carbonate may be due to the presence of different clay minerals derived from different parent materials in the study area. Recently, it has been reported that the irregular distribution of CEC and $CaSO_4$ or $CaCO_3$ may be associated with different clay minerals (Aznar et al. 2013).

Sand fractions separated by the three disaggregation methods

Figures 2 to 5 shows the sand fractions of the studied soil samples with the three disaggregation treatments. In the three soil samples from profile 1 (Czy, 5-25 cm), profile 2 (Czy, 0-25 cm) and profile 3 (Cky, 20-80 cm), the amount of very coarse sand decreased from dry sieving to shaking in a 7:3 ethanol: water solution to sonication in a 7:3 ethanol: water solution (Figure 2, 3, 4), respectively. This could be due to more complete disaggregation of the sample or fracture of primary grains if the energy input was too great. These results agreed with Pearson et al. (2014). In addition, the reduction in the amount of very coarse and coarse sand fractions has been reported in other studies of disaggregation treatments (Fuller and Goh, 1992; Imeson and Vis, 1984; Oades and Waters, 1991). In contrast, in soil samples from profile 4 (Cky, 20-80 cm), and from profile 5 (Cky, 5-35 cm), the trend was from shaking in a 7:3 ethanol solution to a dry sieving to sonication in a 7:3 ethanol: water solution (Figure 5 and 6), respectively. The reason for this trend is unknown but might be due to the presence of gypsum crystals with fine sand-sized fractions which has not been influenced by the great energy input of sonication. These findings coincide with those reported by previous authors (Al-Barrak and Rowell, 2006; Aznar et al. 2013; Poch et al. 2010). In contrast; the trends of the three disaggregation treatments for coarse sand, medium sand, fine sand and very fine sand was irregular among the soil samples. Reasons for this deviation from the trend is unknown but may be related to differences in parent materials. These results were similar to that obtained by Pearson et al. (2014).

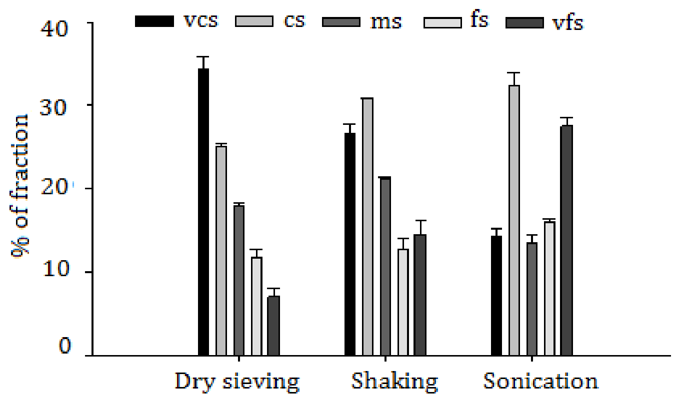

Figure 2. Sand fraction distribution after applying disaggregation methods in horizon Czy (5-25 cm) from profile 1. Shaking -15 hr shaking in 7:3 ethanol: water solution; sonication- sonication for 3 min. in 7:3 ethanol: water solution.

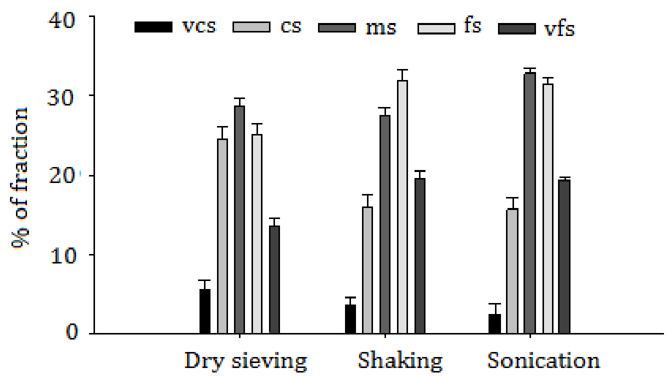

Figure 3. Sand fraction distribution after applying disaggregation methods in horizon Cky (5-20 cm) from profile 2. Shaking -15 hr shaking in 7:3 ethanol solution; sonication- sonication for 3 min. in 7:3 ethanol: water solution.

Total sand by the three disaggregation methods

Table 3 presents data for the amount of total sand measured with the three disaggregation methods. The table showed that the amount of total sand in profile 3 (Czy, 0-25 cm), profile 4 (Cky, 20-80 cm), and profile 5 (Cky, 5-35 cm) decreased from dry sieving to shaking in a 7:3 ethanol: water solution to sonication in a 7:3 ethanol: water solution. This might be due to more complete disaggregation of the sample or fracture of primary grains if the energy input was too great.

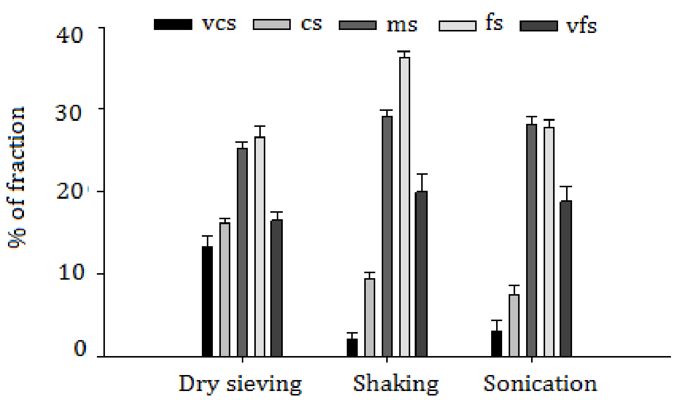

Figure 4. Sand fraction distribution after applying disaggregation methods in horizon Czy (5-25 cm) from profile 3. Shaking -15 hr shaking in 7:3 ethanol: water solution; sonication- sonication for 3 min. in 7:3 ethanol: water solution.

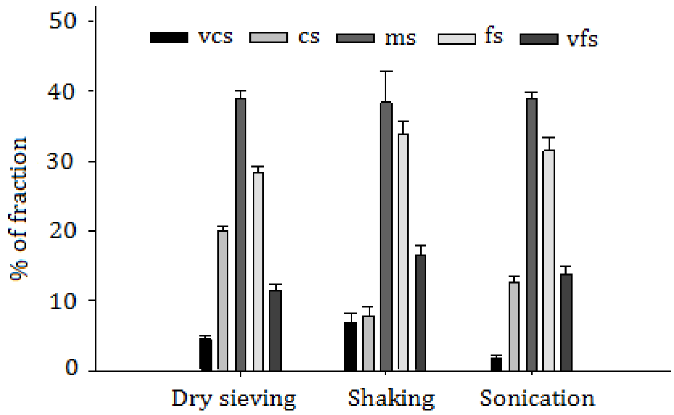

Figure 5. Sand fraction distribution after applying disaggregation methods in horizon Cky (20-80 cm) from profile 4. Shaking -15 hr shaking in 7:3 ethanol: water solution; sonication- sonication for 3 min. in 7:3 ethanol: water solution.

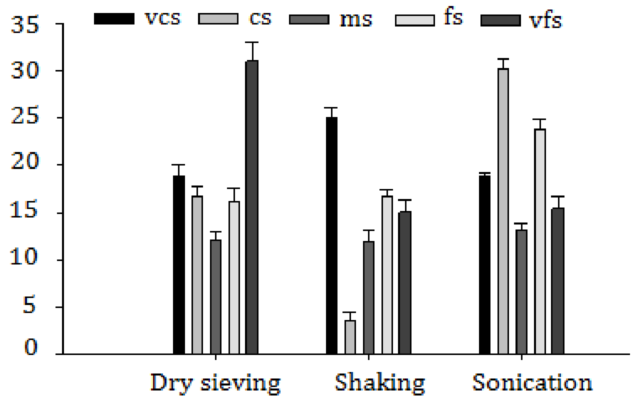

Figure 6. Sand fraction distribution after applying disaggregation methods in horizon Cky (5-35 cm) from profile 5. Shaking -15 hr shaking in 7:3 ethanol: water solution; sonication- sonication for 3 min. in 7:3 ethanol: water solution.

Similar results were obtained by Pearson et al. (2014). In contrast; the amount of total sand in profiles 1 (Czy, 5-25 cm) and profile 2 (Cky, 5-20 cm) decreased from sonication in a 7:3 ethanol: water solution to shaking in a 7:3 ethanol: water solution to dry sieving. The reasons for this deviation from the trend in profiles 3 and 4 is unknown but could be due to the presence of gypsum crystals occurring in the silt or fine sand-sized fractions which has not been affected by the great energy input of sonication or may be related to differences in parent materials. These results were agrees with Pearson et al. (2014). Additionally, Vieillefon (1979) mentioned that the presence of gypsum is mostly linked with fine sand fraction followed by the silt fraction.

Table 3. Total sand measured by the different disaggregation methods.

Profile No.	Standard PSD method %	Dry sieving %	Shaking %	Sonication %
P 1 Czy (5-25 cm)	74.4	95.99	96.0	96.0
P 2 Cky (5-20 cm)	84.2	79.26	80.28	82.0
P 3 Czy (0-25 cm)	72.8	76.91	76.69	76.62
P 4 Cky (20-80 cm)	89.6	78.5	78.2	77.8
P 5 Cky (5-35 cm)	84.0	87.3	86.8	85.5

Re-calculation of whole clay contents

Clay content measured by the standard pipet method for the non-gypsum residue ranged from 6.8 to 25.2 % (Table 4). The ratio of CEC/Clay is often used to evaluate dispersion errors in clay measurement, and its value commonly higher than 1 in most soils (Burt, 2011). CEC/clay ratios derived from clay contents measured by the standard method ranged from 0.07 to 1.12. Recalculation of the clay contents to a whole soil basis (including gypsum) ranged from 2.20 to 20.47% and resulted in CEC/clay ratios ranged from 0.40 to 0.82. In addition the clay content ranging between 2 to 50% (in gypsiferous soils) have been recorded by many researchers (e.g; Mousli, 1980; Van Alphen and de los Rios Romero, 1971; Mardoud, 1980; Dekkiche, 1976; Barzanji, 1973; Barzanji et al., 1975).

Table 4. Particle size distribution for five gypsiferous horizons by standard and modified method

Horizon	Depth (cm)	Gypsum g kg^{-1}	CEC cmol(+) kg^{-1}	Standard method				Modified method			
				Sand %	Silt %	Clay %	CEC/Clay	Sand %	Silt %	Clay %	CEC/Clay
Profile 1; Typic Haplogypsids											
Czy	5-25	84.0	1.80	74.4	0.4	25.2	0.07	96.0	1.8	2.20	0.82
Profile 2; Typic Calcigypsids											
Cky	5-20	108	5.20	84.2	1.4	14.3	0.36	82.0	5.24	12.76	0.41
Profile 3; Typic Haplogypsids											
Czy	0-25	82.0	8.25	72.8	4.4	22.8	0.36	76.62	2.91	20.47	0.40
Profile 4; Typic Calcigypsids											
Cky	20-80	53.0	7.60	89.6	3.7	6.8	1.12	77.8	4.87	17.33	0.44
Profile 5; Typic Calcigypsids											
Cky	5-35	42.0	3.40	84.0	8.5	7.5	0.45	82.5	10.31	7.19	0.47

Textural class comparison

Texture class as determined in the field by feeling disagreed with the texture class determined from the standard particle size and modified methods for 4 of 5 samples, and that about 80% of the total samples. In contrast, textural class determined by the standard pipet method disagreed with class determined by modified method for 60% of the total samples tested (Table 5). The reason for this disagreement could be due to overestimation of clay content in the field. Similar results were reported by Pearson et al. (2014). Moreover, Vieillefon (1977, 1978, 1979) in comprehensive studies on the improvement of analytical methods for gypsiferous soils, concluded that, overestimation of the clay and silt contents of gypsiferous soils occur if not corrected when done by hydrometer methods. Despite these comparisons were qualitative but they suggest that the modified method is applicable and yields particle size distribution that better reflect soil conditions observed in the field. They also suggest that the modified method shows priority in separating soil particles of the gypsiferous soils than standard pipette method.

Table 5. Comparison of textural classes obtained by feel, standard PSD method, and modified method.

Horizon	Depth	Textural class		
	(cm)	Field texture	Standard pipet method	Modified method
Profile 1, Czy	5-25	SL	SCL	S
Profile 2, Cky	5-20	SCL	LS	SL
Profile 3, Czy	0-25	SCL	SCL	SCL
Profile 4, Cky	20-80	SCL	S	SL
Profile 5, Cky	5-35	SL	LS	LS

Conclusion

The particles of gypsiferous soils in the arid regions are mainly aggregated with Ca cations (e.g; $CaCO3$) and which lead to difficult in the disaggregation of particles in these types of soils. Hence, there is a need to applying alternative techniques to properly separating the particles of these unique soils. After applying developed Pearson et al. (2014) method to determine particle size distribution for selected gypsiferous soils from Al-Ahsa governorate, Saudi Arabia, the statistical analysis results revealed that the sonication for 3 minutes in a 7:3 ethanol: water solution was the most effective for sand fractions compared to dry sieving and shaking for 5 hours in 7:3 ethanol solution. The particle size distribution by the modified method showed slight increased in total sand content as compared to standard particle size method. Additionally, the textural classes obtained from the two methods were similar. Our study suggests that use of sonication for 3 min. in a 7:3 ethanol: water solution will give accuracy in particle size measurement for gypsiferous soils. Therefore, we highly recommended using this developed method to separate sand fractions as well as to re-calculate the clay fraction for gypsiferous soils. Finally, we concluded that the determination of particle size distribution for gypsiferous soils (≤ 40% gypsum) using this developed method will improve the understanding and ability to proper interpret of physical behavior of these unique soils.

Appendix 1.

Field description of the studied gypsiferous soil profiles selected from Al-Ahsa governorate, Saudi Arabia.

Profile 1:

Classification (USDA): Typic Haplogypsids	Elevation (a.s.l): 153 m	Drainage: Poorly
Coordinates: 25º36'51" N 49º32'54" E	Slope: Nearly level	Vegetation: Null
Parent material: Residuum		

Horizon	Depth (cm)	Description
C	0-5	Very pale brown (10YR 7/3, dry), pale brown (10YR 6/3, moist), sand, single grain, non sticky, non plastic; loose, few fine roots, slightly effervescence, clear, smooth boundary.
Ckm1	5-25	Light gray (10YR 7/2, dry), light yellowish brown (2.5YR 6/4, moist), sand, massive, non sticky, non plastic; extremely hard, few fine roots, moderately effervescence, abrupt, smooth boundary.
Ckm2	25-45	White (5Y 8/2, dry), light olive gray (5Y 6/2, moist), clay, massive, very sticky, very plastic; extremely hard, some weathered rock fragments, moderately effervescence, clear, smooth boundary.
2Ck1	45-90	White (5Y 8/2, dry), pale yellow (5Y 7/3, moist), very gravely clay, very sticky, very plastic; extremely hard, some weathered rock fragments, moderately effervescence, diffuse, smooth boundary.
2Ck2	90-120	White (5Y 8/2, dry), pale yellow (5Y 7/3, moist), gravely clay, massive, very sticky, very plastic; extremely hard, some weathered rock fragments, moderately effervescence, clear, smooth boundary.
3Cm	120+	Light gray (5Y 7/2, dry), light gray (2.5Y 7/2, moist), sandy loam, massive, sticky, plastic; extremely hard, slightly effervescence, abrupt, smooth boundary.

Profile 2:

Classification (USDA): Typic Calcigypsids
Coordinates: 25º30'32" N 49º35'37" E
Parent material: Transported sand mixed with colluvial materials derived from sandstone and limestone
Elevation (a.s.l): 153 m
Slope: Nearly level
Drainage: Imperfectly drained
Vegetation: Few scattered natural vegetation (*Haloxylon licornicum*)

Horizon	Depth (cm)	Description
Cz1	0-5	Light yellowish brown (10YR 6/4, dry), brown (10YR 5/3, moist), loamy sand, slightly sticky, non plastic; soft, common fine cracks, slightly effervescence, clear, smooth boundary.
Ckz2	5-20	Very pale brown (10YR 7/3, dry), brown (10YR 5/3, moist), sandy loam, massive, slightly sticky, slightly plastic; soft, very fine roots, slightly effervescence, abrupt, smooth boundary.
C3	20-40	Very pale brown (10YR 7/3, dry), yellowish brown (10YR 5/4, moist), sand, massive, non sticky, non plastic; slightly hard, few fine decomposed organic matter, slightly effervescence, abrupt, smooth boundary.
C4	40-70	Very pale brown (10YR 7/4, dry), light yellowish brown (10Y 6/4, moist), sandy loam, slightly sticky, slightly plastic; slightly effervescence, clear, wavy boundary.
C5	70-105	Light gray (10Y 7/2, dry), pale brown (10Y 6/3, moist), sandy loam, slightly sticky, slightly plastic; few fine distinct sharp mottles, moderately effervescence, clear, smooth boundary.

Profile 3:

Classification (USDA): Typic Haplogypsids
Coordinates: 25º17'00" N 49º43'16" E
Parent material: Alluvium
Elevation (a.s.l): 150 m
Slope: Nearly level
Drainage: Well drained
Vegetation: Old farm cultivated with date palm and pomegranate trees.

Horizon	Depth (cm)	Description
Ap	0-25	Grayish brown (10YR 5/2, dry), very dark grayish brown (10YR 3/2, moist), sandy clay loam, weak fine subangular blocky, sticky, plastic; loose, very few fine lime spots, common fine and medium roots, clear, smooth boundary.
Czy	25-45	Light gray (10YR 7/2, dry) and light yellowish brown (2.5YR 6/4, moist), sand, massive, non sticky, non plastic; extremely hard, few fine roots, abrupt, smooth boundary.
C	45-80	Light brownish gray (10YR 6/2, dry), dark grayish brown (10YR 4/2, moist), sand, massive, non sticky, non plastic; hard, some hard fine lime spots, clear, smooth boundary.
Ck	80-120	Light gray (10YR 7/2, dry), grayish brown (10YR 5/2, moist), loamy sand, massive, slightly sticky, non plastic; very hard, common fine soft lime segregation, clear, smooth boundary.
2C	120-185	Light olive brown (2.55Y 5/2, dry), dark grayish brown (10YR 4/2, moist), loamy sand, massive, slightly sticky, non plastic; hard, clear, smooth boundary.

Profile 4:

Classification (USDA): Typic Calcigypsids
Coordinates: 25º17'00" N 49º43'12" E
Parent material: Alluvium
Elevation (a.s.l): 113 m
Slope: Flat
Drainage: Well drained
Vegetation: Cultivated area with palm trees

Horizon	Depth (cm)	Description
Ap1	0-20	Pale brown (10YR 6/3, dry), very dark grayish brown (10YR 3/2, moist), sandy loam, massive, non sticky, non plastic; soft, abrupt smooth boundary.
Cky	20-80	Grayish brown (10YR 5/3, dry), very dark gray (10YR 3/1, moist), sand, single grain, non sticky, non plastic; loose, abrupt, smooth boundary.
C1	80-110	Pale brown (10YR 6/3, dry), dark grayish brown (10YR 4/2, moist), sandy loam, massive, slightly sticky, slightly plastic; soft, abrupt smooth boundary.
C2	110-140	Very pale brown (10YR 8/3, dry), yellowish brown (10YR 5/4, moist), sand, single grain, slightly sticky, slightly plastic; loose, diffuse, smooth boundary.

Profile 5:

Classification (USDA): Typic Calcigypsids
Coordinates: 25º31'30" N 49º35'52" E
Parent material: Lacustrine
Elevation (a.s.l): 132 m
Slope: Flat
Drainage: Moderately well drained
Vegetation: Common scattered natural vegetation (*Phragmites australis*)

Horizon	Depth (cm)	Description
Az	0-5	Very pale brown (10YR 7/3, dry) and pale brown (10YR 6/3, moist), sand, single grain, non sticky, non plastic; loose, few fine roots, slightly effervescence, clear, smooth boundary.
Cky1	5-35	Light gray (2.5Y 7/2, dry), light brown (10YR 6/3, moist), sandy loam, weak fine subangular blocky, slightly sticky, slightly plastic; soft, few gravels, abrupt, smooth boundary.
2Ck2	35-55	Very pale brown (10YR 8/3, dry), very pale brown (10YR 7/3, moist), clay, weak fine subangular blocky, very sticky, very plastic; soft, few fine mottles, clear, smooth boundary.
2Ck3	55-90	Light brownish gray (10YR 6/2, dry), dark gray (10YR 4/1, moist), sandy clay, very sticky, very plastic; slightly hard, clear, smooth boundary.
2Ckm	90-130	White (10YR 8/2, dry), very pale brown (10YR 7/3, moist), clay, massive, very sticky, very plastic; extremely hard, few narrow channels, few fine soft lime spots, clear, smooth boundary.

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