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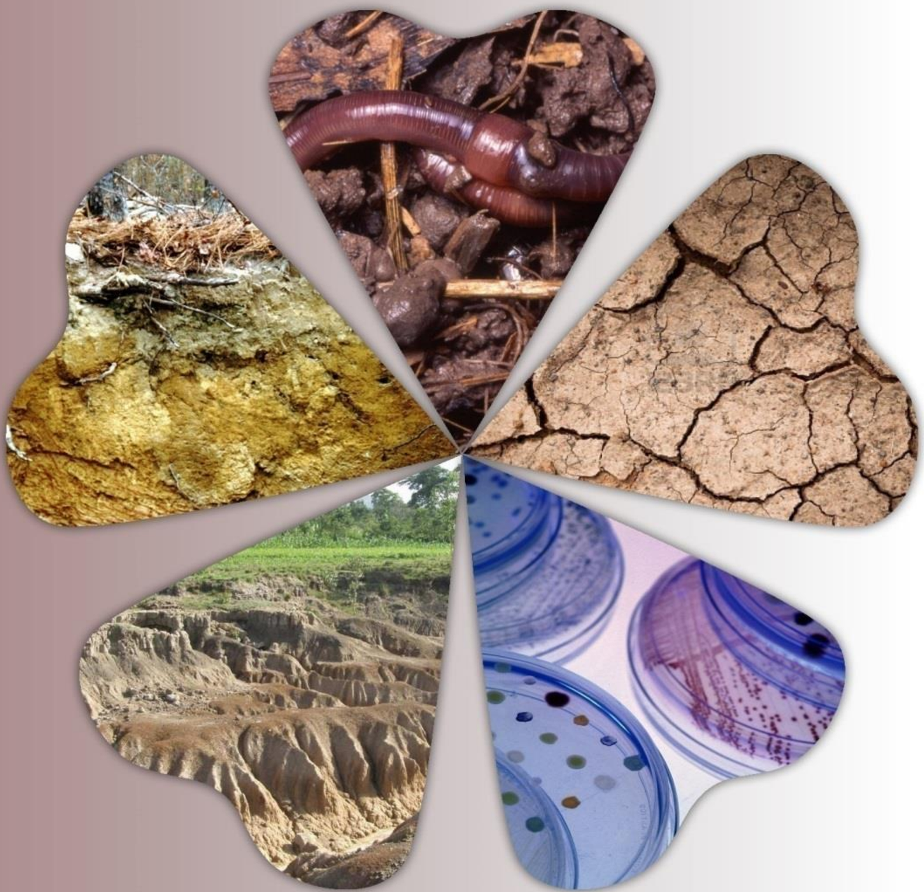

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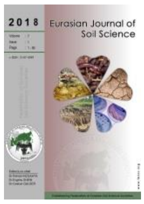

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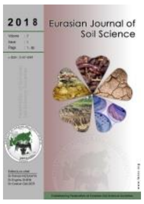

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Comparison of two different ophiolite districts in terms of some soil physical properties of grounds

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Abstract

In this study, some physical characteristics of the soils formed on the metamorphic sole and the mantle section of the ophiolitic sequence which is represented by ultramafic cumulates and tectonites located in Karacasu district in Kahramanmaraş and formed on the crustal rocks which are located around Göksun-Elbistan towns to the north of Kahramanmaraş, were investigated. In order to correlate the soil properties with the bedrocks from the different parts of the ophiolite, rock samples were collected from the same locations with 18 surface soil samples. Field capacity, permanent wilting point, liquid limit, plastic limit, coefficient of linear extensibility and volumetric shrinkage tests were performed on the soil samples. The crustal section is represented by the three different rock groups such as: cumulate gabbro (amphibole gabbro, olivine gabbro and gabbro), isotropic gabbro (gabbro) and sheeted dike complex (diabase). According to independent "t test" results; the physical properties of two fields were different from each other, except for the linear extension coefficient, (P<0.001). Statistically significant relationships were determined among the measured variables, organic matter content, and soil texture. This is attributed to the fact that the ophiolites in the Karacasu area are more altered than the ophiolites in the Göksun-Elbistan area, and this difference in the alteration affects the soil properties over the mineralogical composition.

Keywords: Coefficient of linear extensibility, ophiolite, soil water constants, volumetric shrinkage.

Introduction

Ophiolitic units are described as the remnants of the oceanic lithosphere formed on the continental margin of the ocean or on the intra-oceanic subduction zone (Miyashiro, 1975; Pearce et al., 1981; Gass, 1990). The ophiolitic bodies in the Alpine-Himalayan belt are very different in terms of their tectonic settings and all of the ophiolites in Turkey present typical characteristics of the ophiolites formed on the intra-oceanic subduction zone (Robertson, 2002; Rızaoğlu et al., 2006; Parlak et al., 2009).

The Neotethyan ophiolites in Turkey are located in five east-west trending belts. These are namely, Tauride ophiolite belt, Middle Anatolian ophiolite belt, Pontide ophiolite belt, Southeastern Anatolian ophiolite belt and Peri-Arabian ophiolite belt. The ophiolitic rocks in the south of Kahramanmaraş are located within the

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Peri-Arabian ophiolite belt while the ophiolitic units in the north (Göksun ophiolite) are located in the Southeastern Anatolian Ophiolite belt. The mantle section rocks representing the lower part of the ophiolite are located in the south, where as the rock groups representing the crustal part are cropped out in the north. In terms of rock classification, tectonitic rocks are represented by serpentinize harzburgite, dunite and serpentinite. Because of the transformations to talc and serpentine group minerals, the pyroxene and olivine group minerals are observed as lost their original properties. In addition, sub-ophiolitic metamorphic rocks with inverted metamorphic zone as a very thin slice, which are related to the thrusting of the old oceanic lithosphere on the continent are seen at the base of the tectonitic rocks, and these rocks are dominantly represented by amphibolite and amphibole schists. In mantle section and the metamorphic sole rocks just below it, the alteration level is significantly different from the crustal rocks observed in the north, and this provides a easy recognition of differences in soil formation too. In the north, the ophiolitic rocks around Göksun-Elbistan are starting with cumulate gabbro, and these rocks are represented by amphibole gabbro, olivine gabbro and gabbro. The isotropic gabbros just above them are seen in a narrow field and attracting attention with their light color. Isotropic gabbros are represented by gabbro. On the upper part, the sheeted dyke complex, which is the rocks of the uppermost section of the ophiolitic sequence in the region, and diabasic rocks are identified as rock type of this section (Parlak, 2009, 2013).

There is a close relationship between the soil properties and the origin of the parent material. Soil formation in dry and semi-arid regions, where climate and vegetation cover is inadequate, is almost controlled by the parent material. The ophiolitic units are widely seen in Kahramanmaraş region and have different geochemical and petrographic characteristics (Kısakürek, 1988; Tanirli and Rizaoglu, 2016). The influence levels of soils formed on these units from parent material carries great importance. The soils formed on the ophiolite are typically shallow, gravelly, poorly structured, with high porosity hydraulic conductivity values and low water holding capacity, generally poorly suited to plant breeding (Proctor, 1975). Baillie et al. (2000) have found that morphologically similar reddish colored, clay-textured, scattering structured soils are formed on lithologically heterogeneous ophiolite parent materials.

In this study, the differences between some physical properties of soils formed on ophiolites with different geochemical and petrographic characteristics in Elbistan-Göksun and Karacasu areas were investigated and the relationships between these differences and their levels influenced by the main materials were determined.

Material and Methods

Location of study area and general characteristics

Kahramanmaraş city is geographically composed of mountains extending from west to east with plains and valleys between these mountains. The city is located in the transection zone of Mediterranean climate and continental climate. The Mediterranean climate reaches up to the inner parts through the valleys of the Ceyhan River.

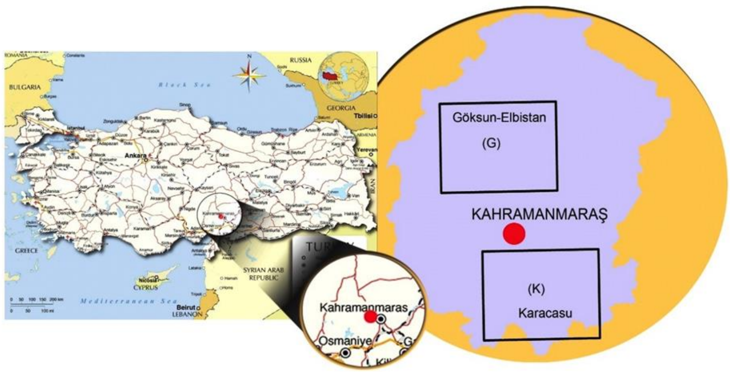

Figure 1. Location map of the study area

In the study area, mainly terrestrial climate is dominate in the north (Göksun-Elbistan) and Mediterranean climate in the South (Karacasu). According to Kahramanmaraş Meteorology Station, the total annual precipitation is 729 mm and most of the precipitation falls in winter and early spring (81%). The average annual temperature is 16.5°C, with the highest temperature in August (28 °C) and the lowest in January (4.5 °C) (TSMS, 2016). Location map of study area is given in Figure 1.

Soil sampling procedure

Disturbed soil samples were collected from each study area of 18 different points according to layered random sampling technique. When applying this method, geological differences and vegetation changes were considered. Surface soil samples were taken from 0 to15 cm depth. Coordinates of sampling points are given in Table 1. Geological and soil maps of two different locations are given in Figure 2 and Figure 3, respectively. Sampling points were shown on these maps.

Table 1. Coordinate of sampling points

No	Coordinate UTM		No	Coordinate UTM	
	East	North		East	North
G1	4212464	286303	K1	4154792	322768
G2	4212478	286300	K2	4153794	320484
G3	4217099	302196	K3	4154087	321675
G4	4220387	311866	K4	4152723	321415
G5	4221456	312444	K5	4151384	320845
G6	4221961	313142	K6	4149392	320411
G7	4222424	313221	K7	4147782	320404
G8	4227038	305804	K8	4152442	324618
G9	4229378	310415	K9	4156180	332508
G10	4223137	324724	K10	4152798	331174
G11	4195888	320864	K11	4151383	335523
G12	4197050	321670	K12	4152667	336893
G13	4199950	327037	K13	4155447	342000
G14	4200000	327603	K14	4156903	345900
G15	4202089	330123	K15	4135919	323018
G16	4202805	320038	K16	4134217	320721
G17	4204583	320717	K17	4130904	319008
G18	4205449	323168	K18	4130928	314491

G: Göksun-Elbistan district, K: Karacasu district

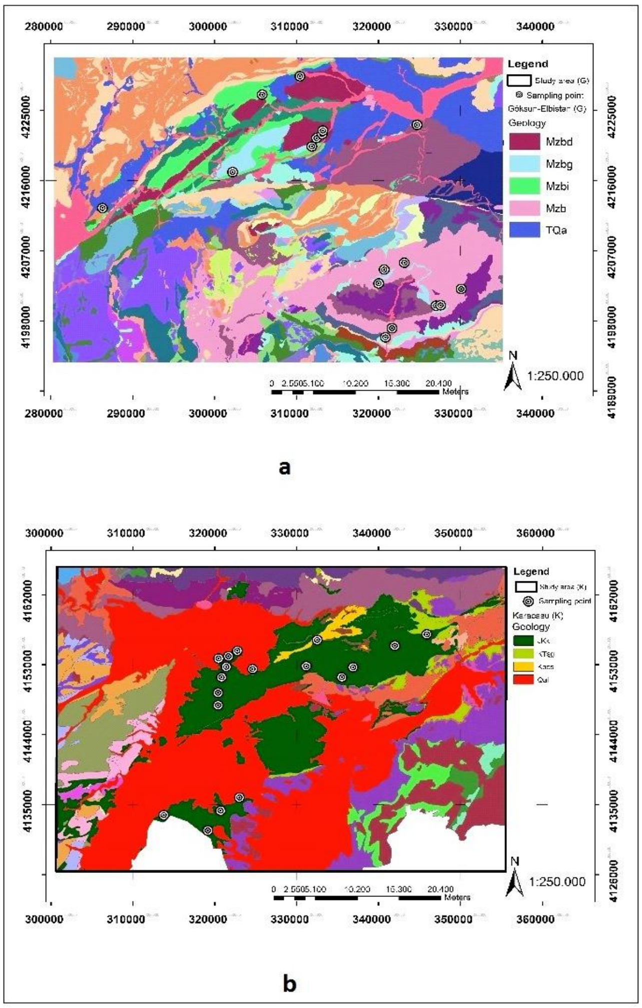

Figure 2. Geologic formation maps of study areas (a: Göksun- Elbistan district (G) and b: Karacasu district (K)), Mzbg: Layered Gabro, Mzbd: Sheeted dike complex, MzbI: Isotropic gabbro, TQa: Ahmetcik Formation, Mzb: Berit Meta Ophiolite, JKk: Kacali complex, KTşg: Germav Formation, Kbes: Sarica Marl Member, Qal: Alluvium

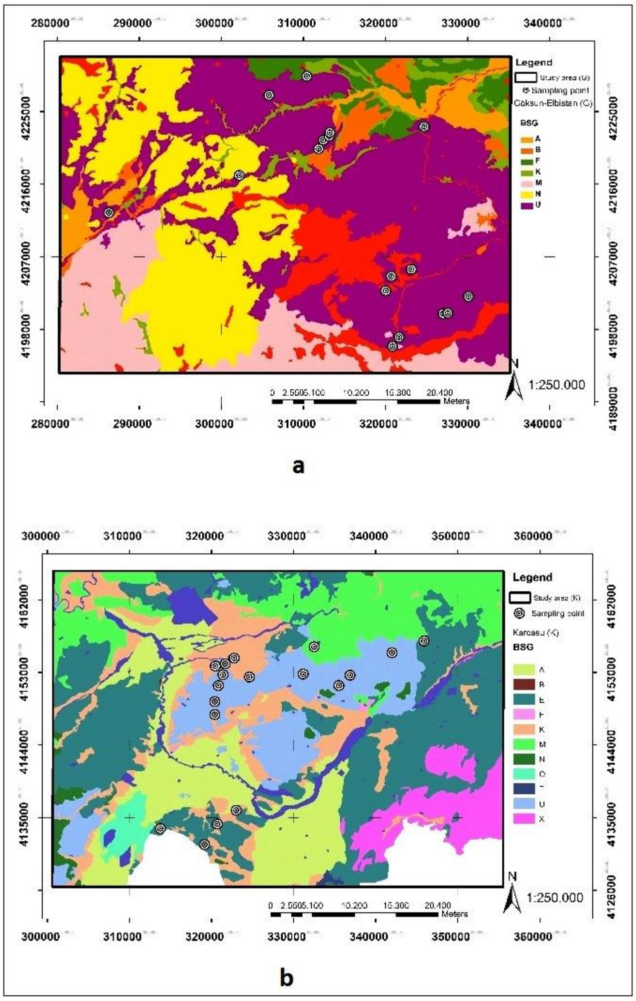

Figure 3. Soil maps of study areas (a: Göksun- Elbistan district (G) and b: Karacasu district (K)), A: Alluvial soils, B: Brownish soils, F: Reddish Brown soils, K: Colluvial soils, M: Brownish Forest soils, N: U: Lime less Brown soil, E: Terra Rosa soils, O: Organic soils, T: Reddish Mediterranean soils, X: Basaltic soils

Determination of soil properties

Some soil characteristics were determined as follows; particle size distribution by Bouyoucous' hydrometer method (Demiralay, 1993), soil organic matter content by wet digestion method (Kacar, 1994), coefficient of linear extensibility (COLE) by mud stick method (Schafer and Singer, 1976), volumetric shrinkage (SV) by standard procedure of ASTM (ASTM, 1974; Ferry and Olsen, 1975). After saturating soil samples with tap water for 24 hours, soil water content at the field capacity (FC) was measured equilibrating soil moisture for 24 hours at 33 kPa on a ceramic plate, and the permanent wilting point (PWP) was measured equilibrating soil moisture for 96 hours at 1500 kPa on a pressure plate apparatus (Gülser and Candemir, 2014). To determine liquid limit (LL), about 120 g of the soil sample passing 425-micron sieve and LL was determined according to Zerdi et al., (2016). To determine plastic limit (PL), 120 g of dry soil passed through the 425 micron IS sieve and PL was determined according to Zerdi et al. (2016).

Mineralogical evaluations in rocks

Before petrographic determinations were made on the rocks collected from the study area, a thin section of each sample was prepared. During this process, the chips obtained from the rocks were sanded and glued on a 22x48x1.5 mm lamella with Canadian balsam and the glued material was abraded and polished to the optimum thickness of 30 microns. It was then covered with thin glass laminates for easy viewing and clear images. The produced thin sections were examined under Nikon 50i pol Model polarizing microscope by means of textural and mineralogical characteristics.

Statistical evaluations

General evaluations of obtained data set were implemented on descriptive statistics. In order to compare two study areas in terms of measured variables, independent t test was used. Relations between soil characteristics were revealed by correlation tests. All statistical evaluations were made in the SPSS package (Efe et al., 2000).

Results and Discussion

Findings about ophiolit rocks

In the present study, the ophiolitic rock samples derived from the different levels of the sub-units showed far differences each other. The ophiolitic samples collected from Elbistan region belong to Göksun ophiolite and represent the crustal section of an ideal ophiolitic suite, wheras the ophiolitic samples from Karacasu region showed the typical characteristics of the mantle section.

The selected rock units in the Göksun ophiolite start at the bottom with the gabbroic cumulates. The mafic cumulate rocks are represented by amphibole gabbro, olivine gabbro and gabbro. The amphibole gabbro displays granular to poikilitic textures: it comprises amphibole (hornblende), plagioclase and Fe-Ti oxide minerals (Figure 4a). The olivine gabbro displays granular to poikilitic textures: it comprises olivine, plagioclase, clinopyroxene, orthopyroxene, chromite and Fe-Ti oxide minerals. All the mafic cumulates show poikilitic texture. Serpentine, chlorite, talc, epidote, and amphibole are secondary phases (Figure 4b). The gabbro shows granular to poikilitic textures comprises Plagioclace, clinopyroxene and Fe-Ti oxide minerals. The minor amount of epidote and chlorite represent the secondary mineral formation (Figure 4c). The gabbroic cumulate rocks directly pass into the isotropic gabbros which is dominated by gabbros. Gabbros show a non-cumulus granular to poikilitic texture and characterized by primary plagioclase, clinopyroxene, orthopyroxene and opaque (Fe-Ti oxide) minerals (Figure 4d). The investigated section of the Göksun ophiolite reaches to the sheeted dikes at the top. The dykes exhibit intergranular, doleritic and microgranular textures. The main mineral phases are plagioclase, pyroxene, amphibole, quartz and magnetite. The sheeted dyke rocks are often associated with secondary calcite, amphibole, chlorite and epidote (Figure 4e). On the other hand, the rock units from Karacasu region start at the bottom with thin sheet of metamorphic sole unit tectonically underlies the mantle tectonites to the South-southeast of Kahramanmaraş. The metamorphic sole is represented by amphibolites and plagioclase- amphibole schist. The plagioclase-amphibole schists display nematoblastic textures and comprise amphibole, epidote, plagioclase and secondary chlorite and magnetite (Figure 4f). The amphibolites exhibit granoblastic texture and comprise coarse-grained hornblendes as the main mineral phase (Figure 4g). The tectonitic section of the mantle is characterized by serpentinized peridotitic rocks such as harzburgite, dunite and serpentinite. Harzburgitic and dunitic rocks show granular to mesh texture and harzburgites are mainly composed of olivine and orthopyroxene, dunitic rocks are dominated by olivine (Figure 4h and 4i). Serpentinites display mesh texture (Figure 4j). All the ultramafic rocks include chromite as the opaque mineral.

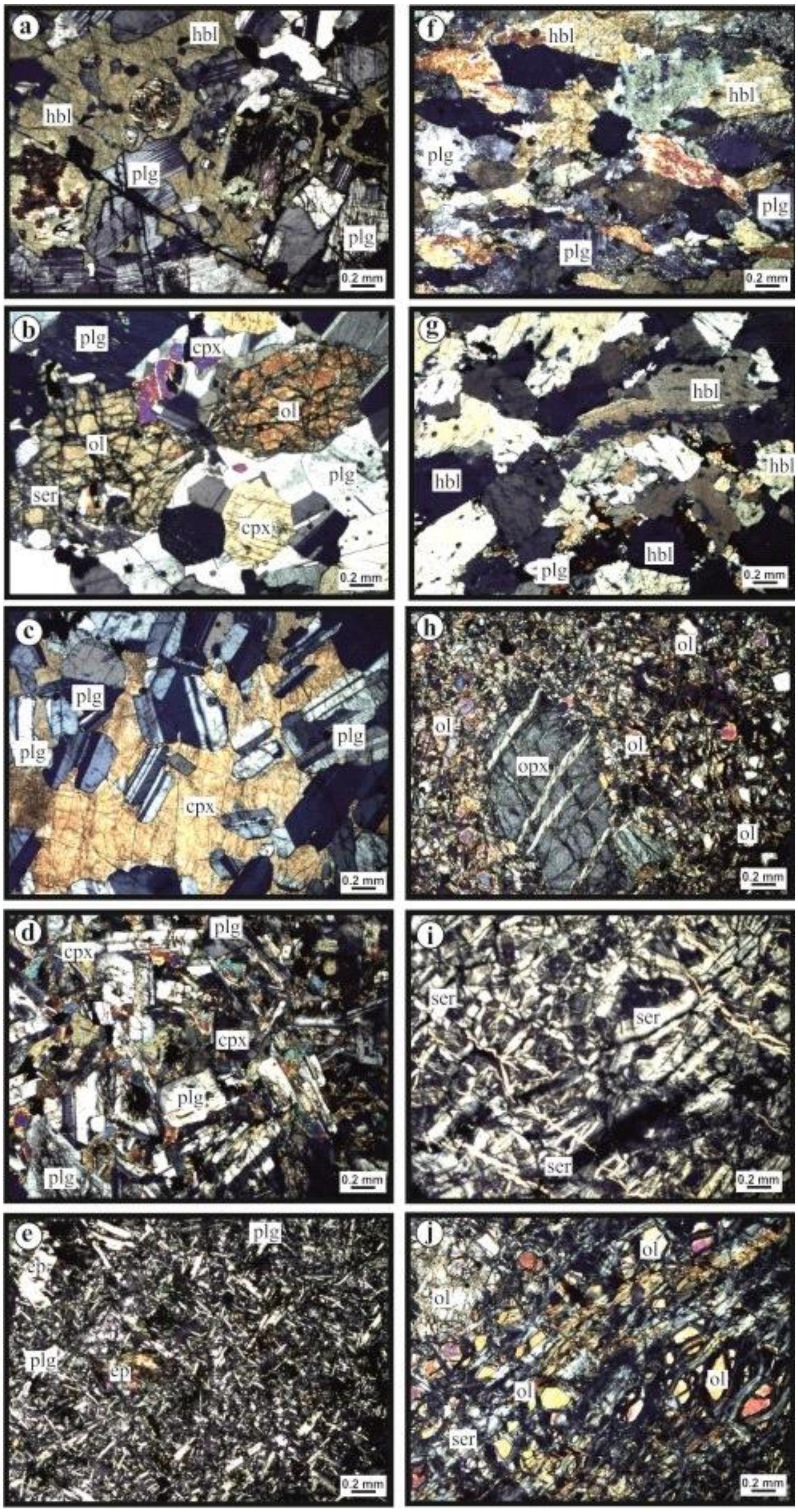

Figure 4. Electron microscopic images. a) Poikilitic texture in amphibole gabbro from cumulate gabbroic section b) Poikilitic texture in olivine gabbro from cumulate gabbroic section c) Poikilitic texture in gabbro from cumulate gabbro section d) Granular texture from isotropic gabbro e) Intergranular texture in diabase from sheeted dike section f) Nematoblastic texture in plagioclase-amphibole schist from metamorphic sole g) Granoblastic texture in amphibolite from metamorphic sole h) Mesh and Granular texture in serpentinized harzburgite from tectonite unit i) Mesh texture in serpentinite from tectonite unit j) Granular and Mesh texture in dunite from tectonite unit. Abbreviations: *ol* olivine, *kf* k-feldspar, *opx* orthopyroxene, *cpx* clinopyroxene, *ser*: serpentine group minerals, *plg* plagioclase, *q:* quartz, *hbl* hornblende, *ep* epidote, *chl*: chlorite, *cal*: calcite, *mag*: magnetite.

Findings about soils

Descriptive statistics of soils are given in Table 2. As shown in this table, LL values of Göksun-Elbistan soils were found between 17.33-54.96% and that of soils of Karacasu location between 27.54-57.54%. In the same order, for two locations, mean PL values were measured as 24.98 and 37.59%. On the Göksun-Elbistan soils, mean while COLE was determined as 0.055 this value was determined as 0.062 on the Karacasu soils. Mean SV value of Göksun-Elbistan district was measured as 5.21% and the same variable was measured as 14.30 for Karacasu soils. When examining this table in terms of soil moisture constants, it was seen that FC value of Göksun Elbistan soils were between 7.50-29.33% and that of soils of Karacasu location were between 11.82-38.57%. Minimum and maximum PWP values of Göksun-Elbistan soils were measured as 4.19-18.31%, and these values were determined as 7.91-30.13% for Karacasu soils (Table 2).

Table 2. Descriptive statistics

Location	Statistical term	Variables					
		LL	PL	COLE	SV	FC	PWP
Göksun-Elbistan location	Mean	30.94	24.98	0.055	5.21	17.58	9.79
	Standart error	8.15	7.32	0.053	5.42	5.92	3.84
	Median	28.69	24.22	0.035	3.30	17.47	9.34
	Minimum	17.33	7.69	0.008	0.01	7.50	4.19
	Maximum	54.96	45.62	0.195	20.80	29.33	18.31
	Kurtosis	2.054	1.85	0.286	1.70	-0.43	-0.51
	Skewness	1.19	0.30	1.087	1.59	0.25	0.556
	Harmonic mean	29.12	22.19	0.019	4.17	15.47	8.36
	Geometric mean	29.99	23.77	0.032	6.11	16.55	9.06
Karacasu location	Mean	45.26	37.59	0.062	14.30	28.49	20.62
	Standart error	10.09	7.79	0.035	6.60	8.04	6.78
	Median	48.91	40.48	0.067	16.0	31.19	21.29
	Minimum	27.54	24.44	0.011	3.30	11.82	7.91
	Maximum	57.54	53.78	0.132	24.6	38.57	30.13
	Kurtosis	-1.27	-0.71	-1.090	-1.10	-0.55	-1.11
	Skewness	-0.543	-0.05	0.092	-0.161	-0.897	-0.44
	Harmonic mean	42.71	35.93	0.036	10.19	25.30	17.77
	Geometric mean	44.04	36.77	0.050	12.40	27.06	19.30

LL: Liquid limit, PL: Plastic limit; COLE: Coefficient of linear extensibility, SV: Volimetric shrinkage, FC: Field capacity, PWP: Permanent wilting point

The comparison of two locations by independend t test was given in Table 3. Soils of both sides were statistically different from each other in term of measured variables, except COLE. These differences were significant at P<0.001 level. This finding can be attributed to the fact that the soils of both sides are formed on different ophiolites. As detailed above, mineralogical composition of these two ophiolitic series were different. It is thought that this difference caused differences in the physical and mechanical properties of the soils. The most easily measurable property of fine-grained soils as the moisture content changes is their variation in consistency, which directly affects strength of soils. Commonly known as Atterberg limits, they have become an inherent part of almost all geotechnical investigations on soils (Kayabali et al., 2016). These limit parameters (LL & PL) and linear and volumetric sihrinkage (COLE & SV) are known to be depend on the soil's mineralogical composition (Sridharan, 2014; Medjnoun and Bahar, 2016). Rather the clayey type of soils are formed by chemical weathering which involves chemical reactions constituting hydration, carbonation and leaching (Zerdi et al., 2016). In both sides, the listed procedures have occurred at different levels. Due to these aspects the LL, PL COLE and SV in the Karacasu soils were generally higher than that in the Göksun-Elbistan soils.

Table 3. Comparison of two locations by independend t test in term of measured variables

Variables	t	Sig. (2-tailed)
LL	-4.623	0.000
PL	-4.977	0.000
COLE	-0.451	0.655
S_V	-4.465	0.000
FC	-4.549	0.000
PWP	-5.785	0.000

LL: Liquid limit, PL: Plastic limit; COLE: Coefficient of linear extensibility, SV: Volimetric shrinkage, FC: Field capacity, PWP: Permanent wilting point

Soil moisture constants (FC & PWP) are affected by inherent and dynamic soil properties. At the beginning of the inherent properties are the clay mineralogy and texture, at the beginning of the dynamic properties is the soil organic matter content. In the present study, both site soils were statistically different in terms of FC and PWP. These differences can attributed to the fact that measured variables are affected by inherent and dynamic soil properties, and those properties were different in both ophiolith area. Moisture percentages at FC and PWP are influenced by distribution of primary soil particles, soil mineraogy and soil organic matter content (Gülser and Candemir, 2015).

To explain relations between measured variables and soil organic matter and textural fractions, correlation matrices have been prepared and presented in Tables 4 and 5. In the soils of Göksun-Elbistan district, SOM-LL and SOM-PL relations were satatiscially significant (P< 0.01). All relations between sand content and measured variables were statistically significant at the different significance level. All relations between clay content and measured variables were statistically significant (P<0.01) except for Clay-PL. In addition, correlations of the measured variables with each other were found to be significant (Table 4).

In the soils of Karacasu district, the relationships between SOM and Atterberg limits were found significant as statisticially. All relations between sand content and measured variables were statistically significant (P<0.01). All relations between clay content and measured variables were also statistically significant at the different significance levels. In addition, correlations of the measured variables with each other gave high correlation coefficients, and these relations were found as statistically significant at the significance level of P<0.01 (Table 5). The results of this study are consistent with those of the studies mentioned above.

Table 4. Correlation matrix of data obtained from Göksun-Elbistan district

	Correlation coefficients and significance levels									
Variables	SOM	Sand	Clay	Silt	LL	PL	COLE	S_V	FC	PWP
OM	1	-0.387	0.201	0.532*	0.596**	0.680**	0.276	0.259	0.327	0.224
S	-0.387	1	-0.914**	-0.806**	-0.700**	-0.488*	-0.835**	-0.687**	-0.899**	-0.838**
C	0.201	-0.914**	1	0.496*	0.754**	0.448	0.825**	0.812**	0.885**	0.900**
Si	0.532*	-0.806**	0.496*	1	0.396	0.389	0.582*	0.286	0.633**	0.479*
PL	0.680**	-0.488*	0.448	0.389	0.786**	1	0.570*	0.497*	0.520*	0.495*
LL	0.596**	-0.700**	0.754**	0.396	1	0.786**	0.765**	0.805**	0.831**	0.832**
COLE	0.276	-0.835**	0.825**	0.582*	0.765**	0.570*	1	0.872**	0.885**	0.921**
S_V	0.259	-0.687**	0.812**	0.286	0.805**	0.497*	0.872**	1	0.823**	0.861**
TK	0.327	-0.899**	0.885**	0.633**	0.831**	0.520*	0.885**	0.823**	1	0.935**
DSN	0.224	-0.838**	0.900**	0.479*	0.832**	0.495*	0.921**	0.861**	0.935**	1

SOM: Organic matter content, S: Sand content, C: Clay content, Si: Silt content, LL: Liquid limit, PL: Plastic limit; COLE: Coefficient of linear extensibility, SV: Volimetric shrinkage, FC: Field capacity, PWP: Permanent wilting point

Table 5. Correlation matrix of data obtained from Karacasu district

	Correlation coefficients and significance levels									
Variables	SOM	Sand	Clay	Silt	LL	PL	COLE	S_V	FC	PWP
OM	1	-0.500*	0.372	0.225	0.544*	0.596**	0.493*	0.539*	0.298	0.474*
S	-0.500*	1	-0.809**	-0.348	-0.717**	-0.618**	-0.682**	-0.751**	-0.739**	-0.779**
C	0.372	-0.809**	1	-0.270	0.688**	0.554*	0.757**	0.794**	0.614**	0.730**
Si	0.225	-0.348	-0.270	1	0.077	0.128	-0.090	-0.037	0.231	0.111
PL	0.596**	-0.618**	0.554*	0.128	0.950**	1	0.628**	0.850**	0.826**	0.910**
LL	0.544*	-0.717**	0.688**	0.077	1	0.950**	0.719**	0.922**	0.900**	0.954**
COLE	0.493*	-0.682**	0.757**	-0.090	0.719**	0.628**	1	0.796**	0.621**	0.751**
S_V	0.539*	-0.751**	0.794**	-0.037	0.922**	0.850**	0.796**	1	0.799**	0.902**
TK	0.298	-0.739**	0.614**	0.231	0.900**	0.826**	0.621**	0.799**	1	0.947**
DSN	0.474*	-0.779**	0.730**	0.111	0.954**	0.910**	0.751**	0.902**	0.947**	1

SOM: Organic matter content, S: Sand content, C: Clay content, Si: Silt content, LL: Liquid limit, PL: Plastic limit; COLE: Coefficient of linear extensibility, SV: Volimetric shrinkage, FC: Field capacity, PWP: Permanent wilting point

Conclusion

In this study, it was concluded that the physical properties of the soils developed on the mantle section of the ophiolitic suite from the Karacasu region in Kahramanmaraş province and the crustal rocks that in the vicinity of Göksun-Elbistan in the north of the city were different. It was found that the LL, PL FC, PWP and LV values of the soils formed on the Karacasu ophiolites were higher than that of the soils formed on the Elbistan-Göksun ophiolites. It was determined that the two ophiolitic terrains were statistically different in terms of the measured variables except the COLE value. These differences were attributed to the fact that the ophiolites in the Karacasu area have been further altered than the ophiolites in the Göksun-Elbistan area. It was thought that this alteration difference was due to the different mineralogical composition of the two ophiolitic areas, in accordance with the changing mineralogical properties, soil characteristics of the two areas changed too.

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Microbial communities and their characteristics in a soil amended by nanozeolite and some plant residues: Short time *in-situ* incubation

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Abstract

Soil microbial communities and their related characteristics are an important agent for soil fertility, productivity, and sustainability. Also, they are useful indicators of soil quality and life index in agricultural systems. The objectives of this study were the effect of nanozeolite and plant residues on soil microbial communities and their characteristics and also, the assessment of incubation timing on soil microbial properties. Soil microorganisms are very important in the decomposition of plant residues. In this regard, the soil samples were treated by nanozeolite (0, 10 and 30% Weight), Alfalfa and wheat straw (0 and 5% Weight). The treated soil samples were incubated in lab condition for 90 days. The result of this study showed that Bacterial, Fungal, and Actinomycete populations increased by the addition of 30% of nanozeolite and 5% of plant residues, especially alfalfa straw. Also, the addition of nanozeolite and plant residues treatments improved MBC, BR, and SIR as microbial characteristics. These parameters increased after 30 days of starting incubation, then decreased until the 75th day and finally increased slightly on the 90th day. In fact, the addition of nanozeolite and plant residues into the soil had positive effects on improvement of carbon pools and increasing carbon sequestration in it. Applied nanozeolite and plant residues in soil, improved carbon pools and increased carbon sequestration in soil. Also the application of nanozeolite and plant residues especially alfalfa straw had positive effects on improvement of soil biological communities and characteristics.

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Introduction

Plant residues, particularly cereal straw, which are mostly often returned to the soil are known as a potential source of bioenergy in arable farming in many countries (Su et al., 2006; Lal, 2007). One of the most important advantages of leaving higher densities of crop residues in the field is the increasing inputs of organic materials that benefit to the soil biological and biochemical properties (Guo et al., 2015). Recycling these residues can be led to the increase of soil organic matter (SOM) content, soil fertility, and also agricultural production. The decomposition, nutrient mineralization, microbial biomass (Baumann et al., 2013) and microbial community structure (Balser and Firestone, 2005) of soil can be related to the chemical properties of plant residues. In this regards, residues with lower carbon to nitrogen ratio (C:N) and lower concentrations of resistant compounds (e.g. lignin, condensed tannins, and insoluble waxes) lead to the faster decomposition (Chander and Joergensen, 2002; Grandy et al., 2013), increase carbon (C) mineralization (Fang et al., 2007) and increase microbial biomass (Jedidi et al., 2004; Nair and Ngouajio,

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2012) in soil. In contrast, plant residues with higher C:N ratio and higher concentrations of resistant compounds have more slowly putrefaction and nutrient cycling for instance C and even nitrogen (N) (Lal, 2004; Cordovil et al., 2007). Moreover, such residues could be caused an increase in relative abundance of soil microbial groups (e.g. fungi, bacteria, and actinomycete) that are adapted to nutrient-poor environments (Parham et al., 2003; Lucas et al., 2007).

Microorganisms play an integral unique role in organic matter decomposition, nutrient cycling and other chemical transformations in soil (Sinegani et al., 2009). Microorganisms also immobilize the significant amounts of C and other nutrients within their cells. The total mass of living microorganisms (microbial biomass) therefore has a central role as a source, sink, and regulator of the transformations of energy and nutrients in the soil. In agricultural systems, soil fauna can be important in organic matter decomposition, nutrient cycling, and SOM dynamics. In this regard, bacteria and fungi are mostly responsible for 90–95% of the total heterotrophic metabolism occurring in most soils (Fang et al., 2007; Sinegani et al., 2009). The microbial community and its diversity have been significantly positively correlated with a wide range of environmental variables such as soil pH, C:N ratio, and so on. Margesin et al. (2009) reported that fungi are able to grow and be active at low temperatures that this is a reason to increasing of fungal to bacterial ratio. Moreover, Djukic et al. (2010) provided evidence that the microbial community structure depends on the condition of decomposition in soil. The alterations in SOM pools due to modifications in the quantity and quality of available substrates are affected by changes in microbial community structures and activities (Balser and Firestone, 2005).

Zeolites (a Greek word meaning boiling stones) are generally found in rocks near active or extinct volcanoes, which means that zeolite deposits exist in many parts of the world (Montalvo et al., 2012). For many years, zeolites have attracted attention due to their physical and chemical properties (Colella and Gualtieri, 2007). According to the results of Gerrard et al. (2004) and Yeritsyan et al. (2008), zeolites are porous materials characterized by their ability to 1) lose and gain water reversibly, 2) adsorb molecules of appropriate cross-sectional diameter (adsorption property or acting as molecule sieves), and 3) exchange their constituent cations without a major change in their structure (ion-exchange property). Zeolites are known due to having many different potential applications in agriculture (Ramesh et al., 2010). Zeolites were commonly used as soil conditioners (Bansiwal et al., 2006). The study of Koci (1997) illustrated that zeolites were not usually toxic for organisms, who studying the possible toxic effects of water extracts of some cation zeolite forms on some water organisms. Chuprova et al. (2004) concluded that zeolite fertilizers have the beneficial effect not only on mobile humus substances of chernozem but also on the biological productivity of maize. Aminiyan et al. (2015a) reported that nanozeolite and alfalfa straw led to the increase of carbon pools and improvement of aggregation stability in the soils which treated and incubated in lab condition.

To date, many studies have demonstrated that the implementation of organic resources either from plants or animal sources improves SOM pools, supports rapid nutrient cycling through microbial biomass, as well as improves nutrient retention from applied mineral fertilizers in soils that located in both tropical and temperate regions. Organic resources are arguably short-lived especially in the tropics due to accelerated decomposition rates. Therefore, several applications of these organic materials are required in every cropping season. Currently, the interactive effect of nanozeolite and organic sources of nutrients like plant residues have been limitedly studied (Aminiyan et al., 2015a,b).

In this research, we investigated the synergistic effect of nanozeolite and some plant residues (alfalfa and wheat straws) as soil amendments on biological soil properties. The choice of these plant residues was based on their nutrient supply capabilities and wide usage as soil amendments on Iranian smallholder farms (Sinegani et al., 2009). We hypothesized that combining nanozeolite and some plant residues would significantly improve soil biological properties in comparison to lonely applied nanozeolite or even plant residues. In addition, nanozeolite interaction with alfalfa straw would be comparable to when combined with wheat straw in relation to the impact on biological soil parameters.

Material and Methods

Site description

This study was conducted in Hamedan province, the western part of Iran. This area is located between longitudes 47° 42' and 48° 45' E and latitudes 33° 28' and 34° 29' N. The climate of the region is semi-arid with a mean annual precipitation of 300 mm and a mean annual temperature of 10 °C. Agriculture is an industry and principal land use in Hamadan. The soil of studied area was classified as Typic Haplocalcids (Aminiyan et al., 2015a).

Nanozeolite and its characteristics

The nanozeolite was prepared from Fadak Institute, Isfahan scientific and technology park, Iran (Kamali et al., 2009). The morphology and the particle size of the nanozeolite examined by CM12 Phillips transmission electron microscope (TEM). X-ray diffraction (XRD) measurement was carried out using a D8ADVANCE diffractometer (BRUKER) with the Cuk$_{\alpha}$ (λ=1.54 Å) source at 40 kV and 40 mA. The agglomerated nanoparticles of nanozeolite were de-agglomerated by a milling process to obtain the product with 80–200 nm particle size.

Sampling, treatment and analysis of soil

The methods used to soil sampling, treatment and analysis were reported in (Aminiyan et al., 2015a). The treated and moistened soils were incubated in the lab condition (20-25 °C) for 90 days. After 1, 5, 10, 20, 30, 45, 60, 75 and 90 days of incubation, a portion of each soil was taken for the study of abundance of bacterial, fungi, actinomycete, and microbial characteristics (i.e. basal respiration (BR), substrate-induced respiration (SIR) and microbial biomass carbon (MBC)). Untreated soils were also incubated as controls.

Soil biological factors

To counting soil microorganisms, the plate count method was employed to estimate the number of bacteria, fungi, and actinomycete. The fresh soil suspension was serially diluted with saline buffer to obtain an appropriate number of colonies on each plate. The media of nutrient agar (NA), potato dextrose agar (PDA) and rose Bengal starch casein nitrate agar (RBSCNA) were, respectively, employed for culturing bacteria, fungi and actinomycetes (Alef and Nannipieri, 1995). Each dilution was plated in triplicate and the population was expressed as the number of colonies forming units (log CFU. $g^{-1}{}_{soil}$). After preparing each specific media in plates 0.1 ml of soil suspension of each serial dilution was spread across the plates (spread plate method). The incubation time at 28 °C for bacteria, fungi and actinomycete were 3, 4 and 14 days respectively (Alef and Nannipieri, 1995).

MBC was determined using the chloroform fumigation-extraction method (Vance et al., 1987). Thirty grams (weighed dry equivalent) of moist soil was fumigated with ethanol-free chloroform for 24 hours. $CHCl_3$ was then removed and carbon was extracted from fumigated and non-fumigated soil samples with a 0.5 M K_2SO_4/soil ratio of 1:5 (v/w). After shaking for 30 min, suspensions were immediately centrifuged at 3000 rpm for 10 min. Then these soil suspensions were decanted and filtered. Thereafter, extractable carbon was determined in both of fumigated and non-fumigated soil. The microbial biomass carbon (MBC) was calculated according to the following equation (Vance et al., 1987):

$$MBC = \frac{EC}{KEC} \quad \text{(Eq. 1)}$$

Where EC is the difference between extractable carbon from fumigated and non-fumigated samples and KEC = 0.38 (Dai et al., 2004).

Soil respiration (an estimation of the mineralization rate of the organic matter in the soil) was measured using the Isermeyer method (Isermeyer, 1952) at days 1, 5, 10, 20, 30, 45, 60, 75 and 90 after incubation. The 50 grams of soil samples (weighted dry equivalent) were moistened with distilled water to 80% of their water-holding capacities and put into closed jars containing 25 mL of 0.5 M NaOH. Incubations were carried out at 25 °C for 7 days for basal respiration (BR) and then titration of NaOH by 0.25 M HCl was done (Alef and Nannipieri, 1995). For substrate-induced respiration (SIR), a combination of 0.5 g glucose, 0.07 g NH_4Cl, and 0.01 g K_2HPO_4 was added to the soil, which was moistened and mixed carefully, and then incubated for 3 days with NaOH followed by titration with HCl. Titrations were calculated as (mg CO_2. $g^{-1}{}_{soil}$ day^{-1}).

Statistical data analysis

The experiment was a completely randomized factorial design with three replicates. Experimental data (i.e. the abundance of bacterial, fungi, and actinomycete, and also BR, SIR, and MBC) was subjected to analysis of variance and means compared by Duncan's new multiple range test (α = 0.01) by SAS Ver.9.2.

Results and Discussion

Table 1 illustrates that sand, clay, and silt contents were 69, 12 and 19% in studied soil respectively. Therefore, the soil texture was loamy sand. The soil was not saline (EC, 1.1 dSm^{-1}); equivalent calcium carbonate and pH values were 1.79% and 7.2 respectively, with low cation exchange capacity (CEC) 4.80 ($cmol_+$. $kg^{-1}{}_{Soil}$). And also, total organic carbon in pre-treatment soil was 3.41 $g.kg^{-1}$.

Table 1. Some of the chemical and physical properties of applied soil.

EC, dS. m^{-1}	pH	CEC, $Cmol^{+}. kg^{-1}_{Soil}$	Total organic C, g. kg^{-1}	CCE*	Sand, %	Clay, %	Silt, %
1.1	7.2	4.80	3.41	1.79	69	12	19

* Carbonate Calcium Equivalent

Table 2 presents some properties of applied plant residues. Alfalfa and wheat straw had a neutral pH (6 and 7.97), high OC (511 and 532 $g.kg^{-1}$) values and C:N (23.30 and 90.75) and C:P (85.20 and 123.50) ratios respectively. Some properties of applied nanozeolite present in Table 3. The pH value of nanozeolite was neutral, and nanozeolite is not saline. CEC in nanozeolite was 400.39 ($cmol_{+}. kg^{-1}{}_{soil}$). Figures 1 (A) and (B) demonstrate transmission electron microscopy (TEM) image of synthesized nanozeolite and X-ray diffraction (XRD) pattern of nanozeolite respectively.

Table 2. Some properties of applied plant residues in this study

	pH	EC, dS. m^{-1}	Total Organic C, g. kg^{-1}	Total N, g. Kg^{-1}	Total P, g. kg^{-1}	C/N	C/P
Alfalfa straw	6.00	9.50	511.00	22.00	5.98	23.30	85.20
Wheat Straw	7.97	4.30	532.00	7.00	4.31	90.75	123.50

Table 3. Some properties of applied Nanozeolite

EC, dS. m^{-1}	pH	CEC, $Cmol^{+}. kg^{-1}_{Soil}$
0.98	7.17	400.39

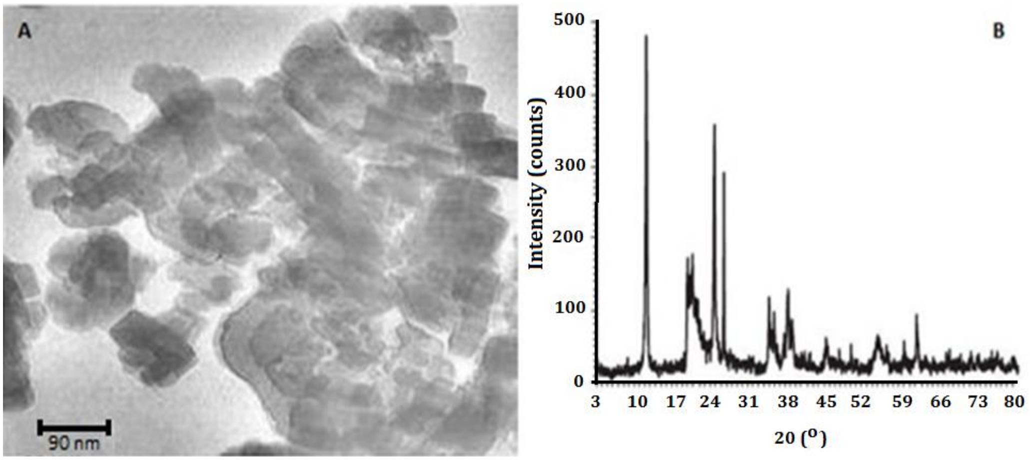

Figure 1. (A) TEM image and (B) XRD pattern of applied nanozeolite

According to the Table 4, it can be found that the addition of a greater percentage of nanozeolite, as well as wheat and alfalfa straws, particularly alfalfa straw, caused increasing microbial communities in all of the treatments. Bacterial colonies significantly increased ($p < 0.01$) with the addition of 30% nanozeolite and 5% alfalfa straw into the soil (N30A5 treatment). In other words, bacterial colonies increased (1.16 log $CFU.g^{-1}{}_{Soil}$) by the addition of 30% nanozeolite and 5% alfalfa straw than control. Also, a bacterial colony in N30A5 treatment was 0.76, 0.50 and 1.06 (log $CFU.g^{-1}{}_{soil}$) higher than N0W5, N10A5 and N30PR0 treatments respectively (Table 4).

Table 4. The abundance of Bacteria, Fungi, and Actinomycete (Log CFU. g^{-1}_{Soil}) colonies in all of the treatments

Treatment	**Bacteria, Log CFU. g^{-1}_{Soil}**	**Fungi, Log CFU. g^{-1}_{Soil}**	**Actinomycete, Log CFU. g^{-1}_{Soil}**
Control	8.79±0.130 *g	5.08±0.274 g	7.02±0.182 g
N0A5	9.19±0.138 e	5.84±0.281 e	7.58±0.206 e
N0W5	8.99±0.146 f	5.56±0.287 f	7.36±0.209 f
N10PR0	8.90±0.145 g	5.16±0.279 g	7.12±0.210 g
N10A5	9.45±0.136 c	6.48±0.275 c	8.04±0.205 c
N10W5	9.32±0.137 d	6.27±0.276 d	7.83±0.208 d
N30PR0	8.89±0.133 g	5.20±0.275 g	7.16±0.206 g
N30A5	9.95±0.127 a	6.91±0.273 a	8.46±0.207 a
N30W5	9.64±0.128 b	6.67±0.274 b	8.28±0.206 b

*. Mean ± Standard deviation. N0A5 (0% nanozeolite+5% alfalfa straw), N0W5 (0% nanozeolite+5% wheat straw), N10PR0 (10% nanozeolite+0% Plant Residue), N10A5 (10% nanozeolite+5% alfalfa straw), N10W5 (10% nanozeolite+5% wheat straw), N30PR0 (30% nanozeolite+0% Plant Residue), N30A5 (30% nanozeolite+5% alfalfa straw), N30W5 (30% nanozeolite+5% wheat straw).

Figure 2 reveals the change trend of the abundance of bacterial colonies during on the 90 days of incubation period. Accordingly, it shows that bacterial colonies increased with the passage of time from the 1st day of the incubation period (9.19 log CFU. g^{-1}_{soil}) to the 30th day (9.31 log CFU. g^{-1}_{soil}). Then it decreased until on the 75th day (8.91 log CFU. g^{-1}_{soil}) and finally it increased again until on the 90th day (8.96 log CFU. g^{-1}_{soil}). In this regard, (Yi et al., 2013) reported that the abundance of total bacterial colony was increased in soil following slurry incubation from the 1st day of the experiment (8.8×10^8 CFU. g^{-1}_{soil}) until the 5th day (9.5×10^8 CFU.g^{-1}_{soil}) and then it decreased until the 20th day (9×10^8 CFU. g^{-1}_{Soil}) and finally it increased until the 30th day (9.2×10^8 CFU. g^{-1}_{soil}) of the experiment period.

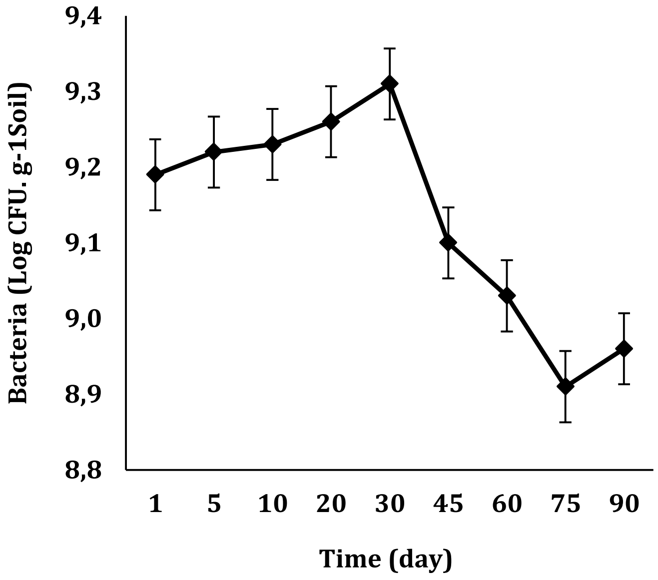

Figure 2. Abundance of bacteria (log CFU. g^{-1}_{soil}) with the passage of time

Abubaker et al. (2013) reported that the soil incubation with residue-A, residue-B, and cattle slurry for 120 days resulted in significant shifts in bacterial community structures compared with the control within each soil, especially in the sandy soil. Furthermore, they concluded that bacterial community structure in the cattle slurry treatment was significantly different from that in both of residue treatments in all soils.

Table 4 shows that the addition of nanozeolite, wheat, and alfalfa straws into the soil interestingly increased fungal colonies abundance, especially in (N30A5) treatments. In other words, the fungal community had the highest abundance in this treatment in comparison with the other treatments ($p < 0.01$). Hence, fungal colonies (1.83 log CFU. g^{-1}_{soil}) had more interestingly increased in (N30A5) treatment than control. And also as shown in Table 4, this treatment was 1.07, 0.43 and 1.71 (log CFU. g^{-1}_{soil}) higher than N0W5, N10A5, and N30PR0 treatments respectively. Figure 3 shows that fungal colonies abundance increased correspondingly during the first 30 days of the incubation period. In other words, fungal colonies increased from (5.73 log CFU. g^{-1}_{soil}) on the1st day up to (6.37 log CFU. g^{-1}_{Soil}) on the 30th day. Then fungal colonies decreased until the 75th day (5.59 log CFU.g^{-1}_{soil}) and finally they were increased until the 90th day (5.7 log CFU. g^{-1}_{soil}).

In another study, (Abubaker et al., 2013) found similar cultural bacterial and fungal species composition in low input and conventional agriculture. Marschner et al. (2003) reported that the addition of organic and inorganic amendments can be led to the significant changing in the biological and chemical properties of soil. Accordingly, they concluded that long-term addition of organic amendments at a low rate may increase bacterial biomass while having no effect on fungal biomass. They also reported the fundamental importance of OC for soil microorganisms. Different amendments affected the bacterial and eukaryotic community structure through their effect on OC and the C:N ratio of the soil.

Changes in microbial community composition are often observed after the addition of organic or inorganic amendments but organic matter with a high C:N ratio is only slowly degraded by microorganisms (Garcia-Pausas and Paterson, 2011). In a number of short-term studies, it has been shown that organic amendments increased microbial community and microbial biomass (Wang et al., 2013; Ninh et al., 2015). An increase in soil microbial abundance and enzyme activity was also observed after the addition of either NPK fertilizer or farmyard manure in a long-term study (Su et al., 2006; Lucas et al., 2007). However, Crecchio et al. (2001) reported no changes in bacterial community structure after the addition of municipal solid waste compost in a short-term study. A higher frequency of bacteria and their activity in soil against fungi is because the fungi are more important for macroaggregate formation because of their hyphae as compared with bacteria. So that, fungi predominantly proliferate in larger pores among macro- and micro-aggregates; whereas bacteria reside in smaller pores within microaggregates (Ventorino et al., 2012). In other words, they concluded that the larger size of pores may make fungi more vulnerable to predation, whilst small pores provide refuge for bacteria against predators.

Table 4 indicates that actinomycete colonies abundance increased with the addition of nanozeolite and also wheat and alfalfa straws into the soil, especially in Nanozeolite and alfalfa straw treatments. In other words, (N30A5) treatment caused a significant increase in the abundance of actinomycete colonies (*p <0.01*). So this treatment had more increased actinomycete colonies (1.44 log CFU. g^{-1}_{Soil}) in comparison with the control and also 0.88, .42 and 1.30 (log CFU. g^{-1}_{Soil}) higher than N0W5, N10A5 and N30PR0 treatments respectively (Table 4). As shown in Figure 4, the abundance of actinomycete colonies increased during the first 30 days of the incubation period. In other words, their colonies increased from (7.95 log CFU. g^{-1}_{Soil}) to (8.3 log CFU. g^{-1}_{Soil}) on the 1st day and the 30th day respectively. From the 30th day to on the 75th, they decreased (7.74 log CFU. g^{-1}_{Soil}) and finally they increased once again on the 90th day (7.76 log CFU. g^{-1}_{Soil}). The results of this study reveal that the abundance microbial colonies in the N30A5 treatment were significantly different from other treatments. A small, but significant, separation was also observed between N30A5 and N30W5.

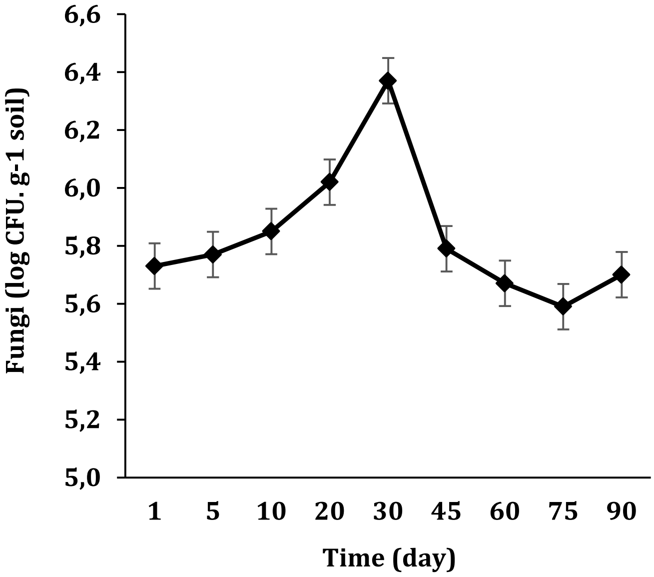

Figure 3. Abundance of Fungi (log CFU. g^{-1}_{Soil}) with the passage of time

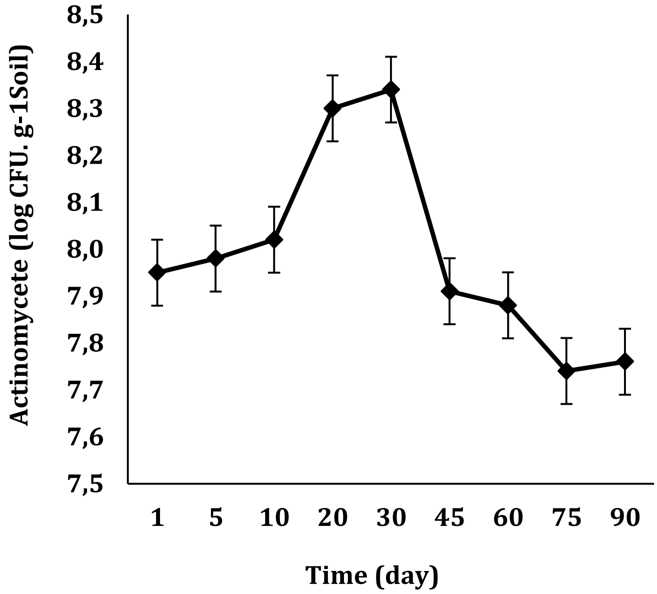

Figure 4. Abundance of Actinomycete (log CFU. g^{-1}_{Soil}) with the passage of time.

Andronikashvili et al. (2012) reported that under the influence of clinoptilolite-containing tuffs in red and podzolic soils, which are weakly populated by actinomyces, their quantity sharply increases. This contributes to the sterilization of soil from undesirable microflora since it is known that these microorganisms are antibiotics protecting soil against bacterial microflora (Andronikashvili et al., 2012). Mühlbachová and Šimon (2003) concluded that the microbial populations could respond to zeolite amendment in different ways. Zeolites have high ability to bind with humic acid by the action of the surface extra-framework cations. This ability markedly enhanced, if the zeolitic material enriched by divalent cations especially Ca^{2+} (Capasso et al., 2005). Therefore, the zeolite can be led to the improvement of soil structure through formation of micro- and macroaggregates (Aminiyan et al., 2015a). Likewise, Andronikashvili et al. (2012) concluded that in the presence of 5% zeolites in the soil, both qualitative and quantitative change of microflora is observed because mycolytic bacteria were dominated which led to lysis and/or devouring of mold fungi. Also, they found that the increasing of zeolite quantity (10-15%) to the soil, can be caused much more diverse in the microbial community. This is easily explained by the continuous inputs of organic material in the treatments with residue, which serve as C source for energy synthesis.

Soil management practices, such as the cover cropping and compost application can be enhanced the biological activity of soil such as bacterial, fungal and actinomycete diversity and populations (Nair and Ngouajio, 2012). Other studies have also shown high soil microbial diversity and populations following manure or compost application (Tu et al., 2006; Treonis et al., 2010). Manure and other organic and inorganic amendments can have numerous positive influences on soil microbial and biochemical properties including soil microbial biomass, activity, and enzymes (Parham et al., 2003; Cordovil et al., 2007; Vineela et al., 2008; Liu et al., 2010).

According to Table 5, whenever the application of higher percentage of nanozeolite and also plant residues especially alfalfa straw, the MBC, BR and SIR parameters increased in the whole treatments. MBC value was maximum in (N30A5) treatment; so that its MBC value (0.381 gr C. kg^{-1}_{soil}) was higher than control and it had a significant difference (*p <0.01*) with other treatments (Table 5). Figure 5 demonstrates that MBC increased from the 1st day (0.491 gr C. kg^{-1}_{soil}) until the 30th day (0.545 gr C. kg^{-1}_{soil}) of the incubation period then it decreased until the 75th day (0.453 gr C. kg^{-1}_{soil}) and finally, it increased until on the 90th day (0.461 gr C. kg^{-1}_{soil}). It could be due to the pre-incubation period that may have contributed to microbial growth, initiated by the favorable environmental conditions (25°C) and strengthened by soil watering and organic matter provision. During the early phase of the incubation, the soil microbial biomass preferentially incorporated labile C pools derived from the added residue over the native and more recalcitrant material. Jorge-Mardomingo et al. (2013) concluded that the trend of MBC changes was similar to the results of the present study. Previous studies have shown that MBC was increased during the initial days of the incubation period but it decreased in the later days of the experiment and then MBC increased at the end of the experiment with the addition of plant residue (Jedidi et al., 2004; Raiesi, 2004; Fereidooni et al., 2013).

Table 5. MBC, BR and SIR values in all of the treatments

Treatment	MBC, gr C. kg^{-1}_{Soil}	BR, mg CO_2. g^{-1}_{Soil}. Day^{-1}	SIR, mg CO_2. g^{-1}_{Soil}. Day^{-1}
Control	0.289±0.034 * **e**	0.22±0.017 e	0.74±0.20 g
N0A5	0.421±0.035 f	0.27±0.018 e	0.84±0.21 g
N0W5	0.389±0.033 g	0.24±0.016 e	0.80±0.19 g
N10PR0	0.482±0.035 e	0.65±0.020 d	1.85±0.21 f
N10A5	0.640±0.036 b	0.82±0.023 c	2.21±0.23 d
N10W5	0.590±0.040 c	0.78±0.021 cd	2.12±0.24 e
N30PR0	0.523±0.039 d	1.01±0.022 b	2.61±0.19 c
N30A5	0.670±0.038 a	1.18±0.019 a	2.96±0.20 a
N30W5	0.632±0.040 b	1.13±0.018 ab	2.86±0.22 b

*. Mean ± Standard deviation. The same letter is not significantly different at $p < 0.01$ using Duncan's LSD.
N0A5 (0% nanozeolite+5% alfalfa straw), N0W5 (0% nanozeolite+5% wheat straw), N10PR0 (10% nanozeolite+0% Plant Residue), N10A5 (10% nanozeolite+5% alfalfa straw), N10W5 (10% nanozeolite+5% wheat straw), N30PR0 (30% nanozeolite+0% Plant Residue), N30A5 (30% nanozeolite+5% alfalfa straw), N30W5 (30% nanozeolite+5% wheat straw).

Generally, the addition of residue as a new C source enhanced soil microbial activity, causing to a significantly greater accumulation of MBC at the beginning of the incubation. A lack of residue addition, in each treatment with lower contents of residue, decreased the MBC significantly compared to higher residue amended treatments. This is because recalcitrant C pools in the treatments which have lower contents of residue and also were not able to supply the same quantity of energy to the microbial community. For instance, microbial activity is stimulated and decomposition occurs more readily when residues with a lower lignin content and a low C:N ratio, such as alfalfa, are added to the soil. In fact, it was expected that residue type changes would strongly influence MBC because microbial biomass is a sensitive short-term indicator that can detect these changes.

Chander and Joergensen (2002) also found that soil microbial biomass increased after the addition of zeolite amendment. Microbial biomass and community are primarily affected by soil structure and substrate availability. Microbial processes take place at the scale of soil aggregate, which is essentially a porous structure that varies both spatially and temporally. This is because soil organic matter located within soil aggregates which are physically protected from biodegradation, aggregates enhance carbon sequestration and soil structural stability (Aminiyan et al., 2015a). Also, they found that zeolitic amendment firstly promotes aggregates formation and its associated C incorporation caused by direct and indirect binding agents. In general, microbial biomass increases with aggregate size (from micro- to macroaggregates) because of increasing OM amount. In contrast microaggregates, the macroaggregates occlude more manure-derived SOC due to the physical entrapment of particulate OM (Bichel et al., 2016).

BR and SIR values increased with the addition of a greater percentage of nanozeolite and plant residues, hence, these indicator values were maximum in (N30A5) treatment, as BR and SIR values were higher (0.96 mg CO_2. g^{-1}_{Soil} Day^{-1}) and (2.22 mg CO_2. g^{-1}_{Soil} Day^{-1}) in this treatment than the control respectively. In another word, this treatment had a significant difference ($p < 0.01$) with other treatment (Table 5). In the studied soil treatments, the differences of SIR contents between the whole of treatments may be related to differences in carbon quality of the added materials but were of a small magnitude. These results are in agreement with a previous pot experiment conducted by Chen et al. (2012), which showed that the application of cattle manure had significantly positive effects on soil biological properties. So that it let to increase soil carbon's pool, and microbial biomass, as well as caused changes in microbial community structure. As shown in Figure 6, the trend of changes in BR and SIR with over time was similar to that of MBC; BR increased from

(0.638 mg CO_2. g^{-1}_{Soil} Day^{-1}) on the 1st day to (1.08 mg CO_2. g^{-1}_{Soil} Day^{-1}) on the 30th day. Then it began to decrease up to the 75th day (0.438 mg CO_2. g^{-1}_{Soil} Day^{-1}) and at the end of the incubation period (90th day) it increased (0.458 mg CO_2. g^{-1}_{Soil} Day^{-1}) once again. The trend of SIR was upwards from the 1st day (0.74 mg CO_2. g^{-1}_{Soil} Day^{-1}) until the 30th day (2.27 mg CO_2. g^{-1}_{Soil} Day^{-1}) of the experiment. Then its value began to decrease until the 75th day (1.59 mg CO_2. g^{-1}_{Soil} Day^{-1}) and finally its value (1.62 mg CO_2. g^{-1}_{Soil} Day^{-1}) increased on the 90th day of the incubation period (Figure 6).

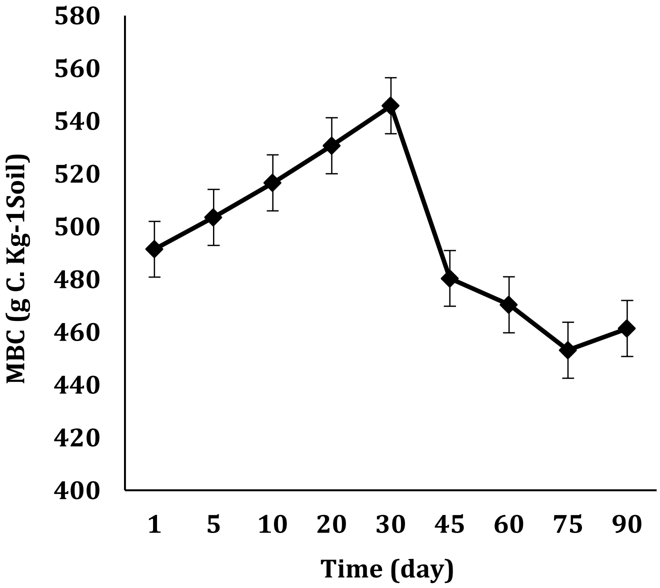

Figure 5. Microbial biomass carbon (MBC) (gr C. Kg^{-1}_{soil}) changes with the passage of time

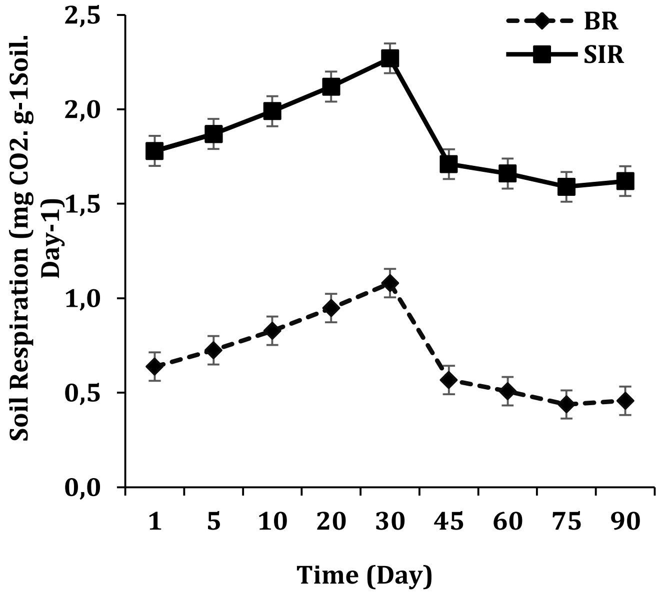

Figure 6. Basal respiration (BR) and Substrate-induced respiration (SIR) (mg CO_2. g^{-1}_{soil}. Day^{-1}) changes with the passage of time.

Jorge-Mardomingo et al. (2013) reported that BR had a similar trend to the results of the present study during the incubation period. The cause of enhancement of frequency and function of microorganisms in the first 30 days of incubation is increasing readily biodegradable materials in soil. And also, decreasing of them after 75 days of incubation is due to the reduction of the availability of simple biodegradable ingredients in it. And also, again the enhanced frequency and function of microorganisms in the final days of the incubation period is probably due to the adaptation of soil microorganisms to deficiency of simple biodegradable ingredients in soil (Chen et al., 2012; Grandy et al., 2013). Organic farming systems with compost applications had 34% higher microbial biomass than treatments which did not get any manure application (Fließbach et al., 2007). Also, they reported higher basal respiration in organically managed production systems compared to unfertilized control plots.

Abubaker et al. (2013) also suggested that both biogas residues and cattle slurry reduced bacterial substrate-induced respiration (SIR) in organic soil than in sandy and clay soil. However, Chen et al. (2012) demonstrated in a pot experiment that the addition of biogas residues can be stimulated and increased both basal respiration (BR) and substrate-induced respiration (SIR), during shorter incubations. The assessment of fifty years of crop residue management showed that residue management had a limited impact on heterotrophic respiration, metabolic diversity of soil bacteria and soil cold-water extracted carbon (Buysse et al., 2013). In fact, soil heterotrophic respiration increased in the initial days of the incubation period but in the continuation of the experiment it decreased and finally it increased at the end of the experiment, these results suggested that both short and long-term processes are likely to occur concurrently in response to residue management (Fereidooni et al., 2013). Govaerts et al. (2007) observed significant differences 15 years after the initiation of a long-term tillage and residue management to improve soil properties such as low tillage with the addition of residue into the soil. These results were in line with those of the present study.

Conclusion

Soil microbial communities and their related characteristics are an important agent for soil fertility, productivity, and sustainability. Also, they are useful indicators of soil quality and life index in agricultural systems. Soil microorganisms are very important in the decomposition of plant residues. The achieved results from this study showed that bacterial, fungal and Actinomycete populations increased by the addition of nanozeolite and plant residues especially alfalfa straw as the (N30A5) treatment were more effective than the other treatments. Also, the (N30A5) treatment was more effective in increasing and improving MBC, BR, and SIR than the other treatments. According to the trend of MBC, BR, and SIR changes, these characteristics increased in the initial days of the experiment until the 30th day but they declined in the continuation of the experiment period until on the 75th day, and then, the increased slightly on the 90th day once again. In fact, the application of nanozeolite and plant residues into the soil improved carbon pools and increased carbon sequestration in it. Also the application of nanozeolite and plant residues especially alfalfa straw had positive effects on improvement of soil biological communities and characteristics.

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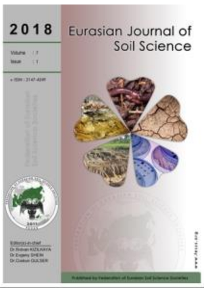

Multi-criteria approach with linear combination technique and analytical hierarchy process in land evaluation studies

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Abstract

Land evaluation analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of yields has contributed to the low production. The aim of this study was to determine the most suitable areas for agricultural uses. For that reasons, in order to determine land suitability classes of the study area, multi-criteria approach was used with linear combination technique and analytical hierarchy process by taking into consideration of some land and soil physico-chemical characteristic such as slope, texture, depth, derange, stoniness, erosion, pH, EC, $CaCO_3$ and organic matter. These data and land mapping unites were taken from digital detailed soil map scaled as 1:5.000. In addition, in order to was produce land suitability map GIS was program used for the study area. This study was carried out at Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages in Yenişehir district of Bursa province. Total study area is 7059 ha. 6890 ha of total study area has been used as irrigated agriculture, dry farming agriculture, pasture while, 169 ha has been used for non-agricultural activities such as settlement, road water body etc. Average annual temperature and precipitation of the study area are 16.1°C and 1039.5 mm, respectively. Finally after determination of land suitability distribution classes for the study area, it was found that 15.0% of the study area has highly (S1) and moderately (S2) while, 85% of the study area has marginally suitable and unsuitable coded as S3 and N. It was also determined some relation as compared results of linear combination technique with other hierarchy approaches such as Land Use Capability Classification and Suitability Class for Agricultural Use methods.

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Introduction

Land evaluation analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of yields has contributed to the low production. The term "Land suitability assessment" refers to assessment of land performance to derive maximum benefits with minimum degradation when used for a specific purpose. This assessment involves many biophysical factors that directly or indirectly control the ability of this part of land to host the land use under investigation. Performing land suitability evaluation and generating maps of land suitability for agricultural or non-agricultural uses will facilitate to reach sustainable agriculture (FAO, 1976; Vargahan et al., 2011; Rabia and Terribile, 2013).

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Studies of land evaluation are of great importance in guiding decision on land uses in terms of their potential and conserving natural resources for feature generations (Dengiz et. al., 2003). Moreover, the concept of sustainable land use involves producing quality products in an environmentally benign, socially acceptable and economically efficient way (Addeo et al., 2001), ensuring optimum utilization of the available natural resource for efficient agricultural production.

Land evaluation is the process of assessing the performance of land when used for a given purpose. Different types of soils present widely different properties, and therefore the response to each use differs. Land evaluation is based on the idea that this response is a function of these properties. In order to comply with these principles of sustainable agriculture, one has to grow the crops where they suit best and for which first and the foremost requirement is to carry out land evaluation and suitability analysis (Nisar Ahamed et al., 2000). Suitability is a function of land use requirements and land characteristics (Mustafa et al., 2011). Therefore, suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 1976).

Land evaluation methods can be divided into two categories which are parametric and hierarchical approaches. Parametric systems have one category and mathematical formulae are applied so that the final result is expressed in numerical terms. It is generally accepted that the parametric methods are, according to McRae and Burnham (1981) simple, objective, quantitative, reliable, easy to understand and apply, even by the non-specialist, and easy to modify and adapt to new uses. Three main kinds of manipulation can be recognized and these are additive, multiplicative and complex functions such as Storie (1938), Square root (Sys et al., 1991), Productivity index (Delgado and Lopez, 1998), and so on. Categorical systems group the classes into a series of levels of importance (order, class, subclass, type, etc.). In other words, hierarchic systems group land into categories with a different land use potential such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Land Capability Class (Klingebiel and Montgomery, 1966), Suitability Class for Agricultural Use (Şenol and Tekes, 1995) and FAO (1976) systems. In order to overcome the management and analysis of large volumes of spatial data for land evaluation of heterogonous natural land system, the Geographic Information System (GIS) and Multi-Criteria Assessment (MCA) approaches which can be used for solving complex geographical problems associated with AHP are useful because various soil and land characteristics can be evaluated and each weighted according to their relative importance on the optimal land use (Dengiz et. al., 2015).

In this study, AHP was applied in integrating MCA with GIS in order to generate map of land suitability classes for agricultural and non agricultural uses. The main objectives of the current study were to identify the most suitable areas for agricultural land based on physic-chemical properties of various soils in the Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages located in Yenişehir district of Bursa province in the Marmara Region of Turkey. In addition to that, after determination of land suitability distribution classes for the study area, it was also detected some relation as compared results of linear combination technique with other hierarchical approaches such as Land Capability Classification and Suitability Class for Agricultural Use.

Material and Methods

Field description

This study was performed at Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages in Yenişehir district of Bursa province in the Marmara Region of Turkey (Figure 1). Total study area is 7059 ha. 6890 ha of total study area has been used as irrigated agriculture, dry farming agriculture, pasture, bare land while, 169 ha has been used for non-agricultural activities such as settlement, road, water body etc. Average annual temperature and precipitation of the study area are 16.1^{o}C and 1039.5 mm, respectively. The majority of soils on the study area is Entisol and Inceptisol. Clay content can reach high amount but ranging from 25% to 51% in surface layers. Moreover, these soils include slightly basic to basic (pH 7.05-8.15), non-saline and low and poor organic matter content, which is slightly higher in the surface horizon. From the bedrock point of view, the study area is predominantly located on limestone, marl and alluvial deposit. Topography and slope show great variations and hilly and rolling physiographic units are particularly common in the study area. The research area lies at an elevation from sea level 220-692 m. Besides, slope groups derived from DEM are presented in Table 1 and Figure 2. It can be seen that 54.4 % of the study area has less than 12 % slope whereas, 45.6 % has more than 12 % slope varying from steep to very steep.

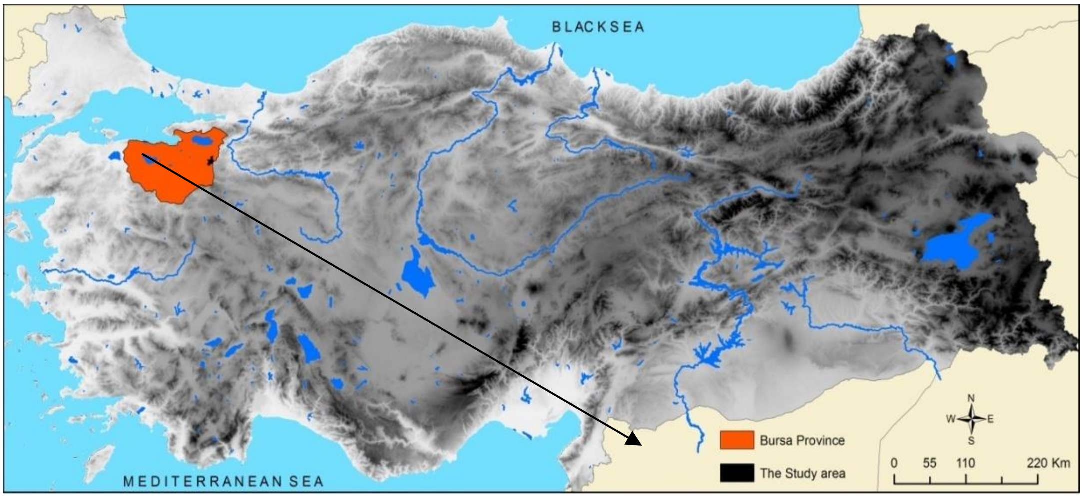

Figure 1. Location map of the study area

Table 1. Distribution of slope degree for the study area

Slope %	Description	Area (ha)	Ratio (%)
0-2	Very gentle	176.1	2.6
2-6	Gentle	1384.3	20.1
6-12	Moderate	2184.6	31.7
12-20	High	1604.7	23.3
20-30	Steep	564.4	8.2
30+	Very steep	975	13.7
Total		6890.0	100.0

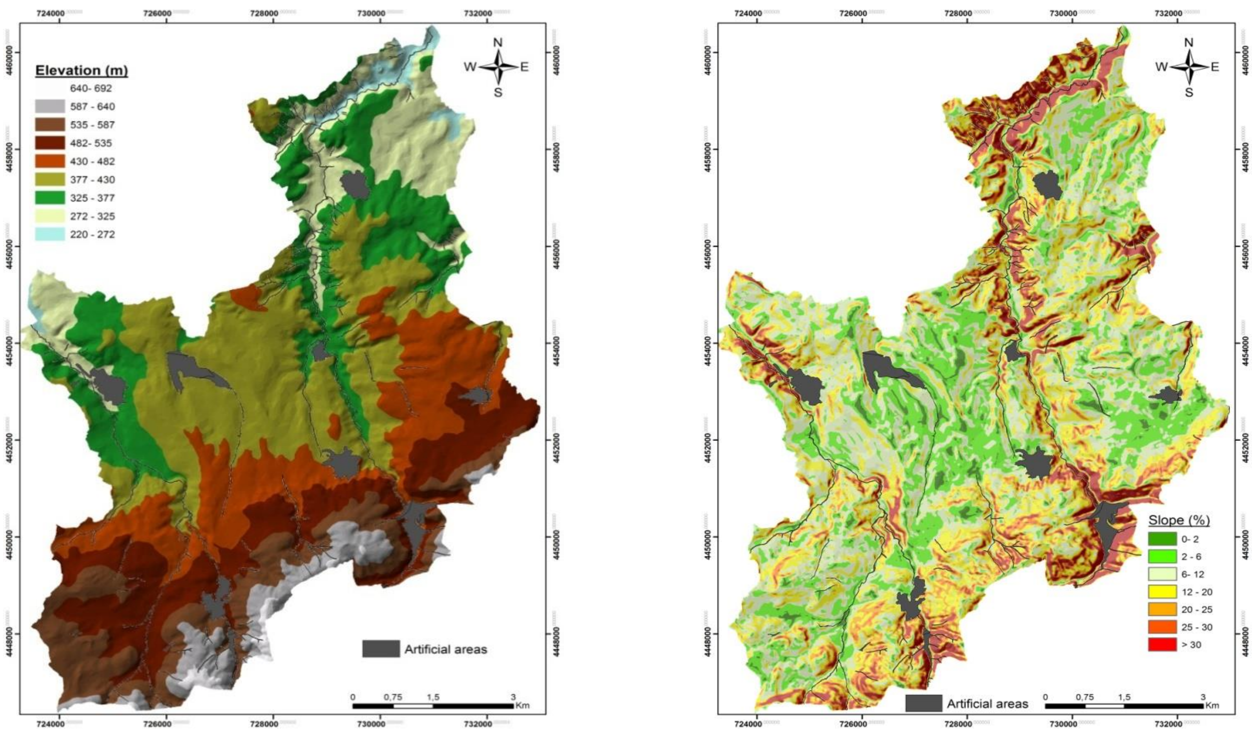

Figure 2. Elevation and slope maps of the study area

Multi criteria assessment approach

The objective of using MCA models is to find solutions to decision-making problems characterized by multiple alternatives, which can be evaluated by means of decision criteria.

Soil and land characteristics criteria taken from digital soil database can be separated into the two categories. First criteria are physical parameters such as texture, soil depth, slope, drainage, and erosion. Another category is chemical criteria which are pH, EC, organic matter, $CaCO_3$ content, and soil fertility (according to macro and micro plant nutrition elements content), their sub-criterion and weighting rates normally employed in land suitability evaluation for agricultural uses were used to compile information on the study area. To analyse MCA, weighted linear combination technique was applied using following formula;

$$\mathrm{LSI} = \sum_{i=1}^{n} (\mathrm{Wi.Xi})$$

Where; abbreviations are: LSI: suitability index, Wi: weighting of parameter i, Xi: Sub-criterion score of parameter i. The above formula is applied to each soil sample. In the overall result, the higher LSI value is the higher suitability of land-use for agricultural activities (Table 2).

Table 2. Land suitability index classes

Definition	Class	Index value
Highly suitable	S1	> 3.500
Moderately suitable	S2	3.000 - 3.500
Marginally suitable	S3	2.000 - 3.000
Unsuitable	N	0.000 - 2.000

In this study, weighting rate takes value between 0 and 4. The least favour value of sub-criteria is 0 and the most beneficial value of sub-criteria is 4 for agricultural land suitability. In other words, the limiting nature of each sub-criterion is taken into account by its effect in reducing productivity (Table 3).

In order to determine which criteria (and at what levels or weights) affect to land evaluation for agriculture; experts are consulted to provide judgments on important of criteria. Using Analytical Hierarchy Process technique these judgments on important of criteria are converted to criteria weights (Wi). Score for each criterion (Xi) on each sample point is then determined. The AHP is developed by Saaty (1980). The principles utilized in AHP to solve problems are to construct hierarchies. The hierarchy allows for the assessment of the contribution individual criterion at lower levels make to criterion at higher levels of the hierarchy.

Using Pair Wise Comparison Matrix, factor weights were calculated by comparing two factors together. The PWCM were applied using a scale with values from 9 to 1/9 or 0.111 introduced by (Saaty, 1980). The comparison can be made using a nine point scale or real data, if available (Saaty and Vargas, 2001). The nine point scale includes: [9, 8, 7, . . ., 1/7, 1/8, 1/9], where 9 means extreme preference, 7 means very strong preference, 5 means strong preference, and so on down to 1, which means no preference (Table 4). This pair-wise comparison allowed for an independent evaluation of the contribution of each factor, thereby simplifying the decision making process (Rezaei-Moghaddam and Karami, 2008).

The pair-wise comparisons of various criteria were organized into a square matrix. The diagonal elements of the matrix were 1. The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted with respect to the criteria or sub-criteria and rated with respect to the alternatives (Bhushan and Rai, 2004). The consistency of the matrix of order n was then evaluated. If this consistency index failed to reach a threshold level, then the answers to comparisons were re-examined. The consistency index, CI, was calculated as:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}$$

Where; CI is the consistency index (1), λmax is the largest or principal eigenvalue of the matrix, and n is the order of the matrix. This CI can be compared to that of a random matrix, RI (Table 5), such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, CR ≤ 0.1 should be maintained for the matrix to be consistent. Homogeneity of factors within each group, a smaller number of factors in the group, and better a understanding of the decision problem improve the consistency index (Saaty, 1993).

Table 3. Site Selection Criteria and their weighting factor rates for land suitability sites

Physical parameters									
Slope (%)		Texture		Drainage		Depth (cm)		Erosion	
Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate
Flat 0-2	4	Very fine (C->%45)	2	Good	4	0-20	1	1-Low	4
Gently 2-6	3	Moderately fine (C-<%45, CL, SiL, SCL	3	Moderate	3	20-50	2	2-Moderate	3
Moderate 6-12	2	Moderate (L, Si, SiL, fSL)	4	In Sufficient	2	50-90	3	3-High	2
High 12-20	1	Coarse (S, SL, LS)	0	Poor	1	90+	4	4-Severy	1
Very high 20+	0								

Chemical Parameters									
pH		EC (dS/m)		$CaCO_3$ (%)		Organic Matter (%)		Fertility	
Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate
>8.2-<6.5	1	0-2	4	0-5	2	>3	4	Very poor	1
5.5-6.5	2	2-4	4	5-10	4	2-3	3	Poor	2
6.5-7.5	4	4-8	1	10-20	3	1-2	2	Moderate	3
7.5-8.2	3	8-10	0	20-30	1	<1	1	Fertile	4
		10+	0	30+	0				

Table 4. The comparison scale in AHP

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 5. Values of Random index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Results and Discussion

In order to determine the suitable score for each land mapping unit (LMU), it is composed of two main steps. Firstly, AHP was used to assess and evaluate scores or eigenvector based on suitable criteria. Secondly, after determination of eigenvector for each criteria, weighted linear combination technique was used to determine LSI for each LMU. In first step, AHP requires evaluation of the pair-wise comparison matrices. The pair-wise comparisons of various criteria were organized into a square matrix that was given in Table 6 and normalized pair-wise comparison matrix was also calculated and given in the same table. A standardized eigenvector is extracted from each comparison matrix, allowing us to assign weights to criteria, sub-criteria. It was found the highest value (0.2614) for slope whereas, the lowest value (0.0208) was determined for calcium carbonate content. In order to apply mechanical cultivation in field without taking any measurements, slope degree of the area should not be more than about 10-12% (Sönmez, 1994; Dengiz and Sarioglu, 2013). For that reason, slope is the most important factor in selected criteria to fulfill mechanical agricultural activities. Moreover, slope degree is not only necessary for field traffic applications but also has important role in terms of soil erosion which occurs when slope exceeds a critical angels under absence of vegetation cover and determined second the highest eigenvector value. In addition to that process, for each level in the hierarchy it is necessary to know whether the pair-wise comparison has been consistent in order to accept the results of the weighting. The parameter that is used to check this is called the Consistency Ratio. For this study, consistency ratio was found almost less than 0.1. This indicates that the comparisons of criteria were perfectly consistent, and the relative weights were suitable for use in the suitability evaluation analysis. In second step, weighted linear combination formula was used to assemble a land suitability index for each LMU.

The distribution map of land suitability site for agricultural uses in the study area is illustrated in Figure 3 and classified as four levels according to Table 2. As seen from the land suitability map for agricultural activities, the number of hectares available to each suitability class is as follows: 15.0% of the study area has highly (S1) and moderately (S2) while, 85% of the study area has marginally suitable and unsuitable or non arable lands coded as S3 and N where soils have some main cultivation limitations factors such as high slope (slope degree value > 20%), high soil erosion, low soil depth, low plant nutrient elements, high sand and coarse fragment content, high calcium carbonate content and low drainage condition.

On the other hand, highly and moderately suitable areas (S1 and S2) are only small part of the study area have been mostly used under current crop growing. These S1 and S2 areas were characterized by: slope level of 0-2%, soil pH level between 7.1 to 7.5, soil drainage good and moderate drained, texture class clay loam, these values are in agreement with those considered in the literature such as FAO (1976, 1983, 1985). Unsuitable areas (N) were generally located at north and sought parts in the study areas and covers about 1019.1 ha.

Table 6. Pair wise comparison matrix and eigenvector of criteria in AHP

Pair Wise Comparison Matrix

	Slope	Texture	Depth	Drainage	Erosion	pH	EC	$CaCO_3$	OM	FR
Slope	1.000	3.000	3.000	5.000	3.000	3.000	5.000	9.000	5.000	7.000
Texture	0.333	1.000	0.333	3.000	0.333	3.000	5.000	5.000	3.000	7.000
Depth	0.333	3.000	1.000	3.000	0.500	5.000	5.000	5.000	7.000	7.000
Drainage	0.200	0.333	0.333	1.000	0.200	1.000	5.000	3.000	5.000	7.000
Erosion	0.333	3.000	2.000	5.000	1.000	3.000	3.000	5.000	5.000	7.000
pH	0.333	0.333	0.200	1.000	0.333	1.000	2.000	3.000	0.500	0.500
EC	0.200	0.200	0.200	0.200	0.333	0.500	1.000	2.000	2.000	3.000
$CaCO_3$	0.111	0.200	0.200	0.333	0.200	0.333	0.500	1.000	0.333	0.333
OM	0.200	0.333	0.142	0.200	0.200	2.000	0.500	3.000	1.000	1.000
FR	0.142	0.142	0.142	0.142	0.142	2.000	0.333	3.000	1.000	1.000
Total	3.185	11.541	7.550	18.875	6.241	20.833	27.333	39.000	29.833	40.833

Normalized Pair Wise Comparison Matrix

	Slope	Texture	Depth	Drainage	Erosion	pH	EC	CaCO3	OM	FR
Slope	0.314	0.260	0.397	0.265	0.481	0.144	0.183	0.231	0.168	0.171
Texture	0.105	0.087	0.044	0.159	0.053	0.144	0.183	0.128	0.101	0.171
Depth	0.105	0.260	0.132	0.159	0.080	0.240	0.183	0.128	0.235	0.171
Drainage	0.063	0.029	0.044	0.053	0.032	0.048	0.183	0.077	0.168	0.171
Erosion	0.105	0.260	0.265	0.265	0.160	0.144	0.110	0.128	0.168	0.171
pH	0.105	0.029	0.026	0.053	0.053	0.048	0.073	0.077	0.017	0.012
EC	0.063	0.017	0.026	0.011	0.053	0.024	0.037	0.051	0.067	0.073
CaCO3	0.035	0.017	0.026	0.018	0.032	0.016	0.018	0.026	0.011	0.008
OM	0.063	0.029	0.019	0.011	0.032	0.096	0.018	0.077	0.034	0.024
FR	0.045	0.012	0.019	0.008	0.023	0.096	0.012	0.077	0.034	0.024

Eigenvector

Criteria	Normalized Sum of Rows	Normalized Average Rows	Eigenvector
Slope	2.6136	2.6136/10	0.2614
Texture	1.1744	1.1744/10	0.1174
Depth	1.6926	1.6926/10	0.1693
Drainage	0.8673	0.8673/10	0.0867
Erosion	1.7753	1.7753/10	0.1775
pH	0.4812	0.4812/10	0.0481
EC	0.4229	0.4229/10	0.0423
$CaCO_3$	0.2076	0.2076/10	0.0208
OM	0.4020	0.4020/10	0.0402
FR	0.3492	0.3492/10	0.0349

FR: Fertility, OM: Organic Matter, EC: electrical conductivity , λ_{max} = 11.443, CI: 0.160, CR: 0.1

The results of this investigation were adequate in terms of the evaluation criteria set used here because, in a particular project, only a limited number of land qualities need be selected for use in evaluation (FAO, 1993). In this investigation, the evaluation criteria were selected taking into considering the crop requirements regarding local conditions. In this MCA, the factors were selected based on agronomic knowledge of local experts and reviews of existing literatures. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful precedent for future studies of agricultural cultivation.

It was also determined some relation as compared results of linear combination technique with other hierarchy approaches which are Suitability Class for Agricultural Use (SCAU) and Land Use Capability Classification (LUCC) in this research and their results were given in Table 7 and Figure 3. SCAU values were produced using ILSEN software program created by Şenol and Tekes (1995) based on FAO' principles (FAO, 1976) while, LUCC information was derived from soil database (Anonymous, 1970) prepared by the Rural Affairs General Directory of Agricultural Ministry. SCAU has five classes from best (C1) to non-agriculture

(C5) while, LUCC includes eight classes divided two categories. The first four classes showed as roman number are suitable for agricultural actives whereas, rest of four classes are not suitable for arable lands. In addition, each method class was matched to make interpretation among models. As it can be seen from Table 6, 21.5 % of the total area is coincident with best and relatively good class in SCAU. In the same model, 19.3% of the territory also shows C5 class described as non arable lands. As far LUCC, results of suitability classes for this method were found significantly different from other two methods except for I. class (0.8%) which shows almost parallel with highly suitable (0.5%-LSI) and with best suitable (0.6%-SCAU) values. On the other hand, when compared each methods amount of areas for all other classes in LUCC were determined much higher than others. 42.7 % of the total area was classified as I and II class for agricultural uses whereas, 34.5% area were described as non arable land.

Table 7. Distribution of LSI, SCAU and LCC classes

Land Suitability Index (LSI)			Suitability Class for Agricultural Use (SCAU)			Land Use Capability Class (LUCC)		
Class and description	ha	%	Class and description	ha	%	Class	ha	%
S1: Highly suitable	34.8	0.5	C1: Best	40.9	0.6	I	58.5	0.8
S2: Moderately suitable	997.2	14.5	C2: Relatively good	1440.4	20.9	II	2887	41.9
S3: Marginally suitable	4838.9	70.2	C3: Problematic	2482.2	36.0	III	416.9	6.1
			C4: Restricted	1598.2	23.2	IV	1150.1	16.7
N: Unsuitable	1019.1	14.8	C5: Non-agriculture	1328.3	19.3	VI	668	9.7
						VII	1709.5	24.8
Total	6890.0	100.0	Total	6890.0	100.0	Total	6890.0	100.0

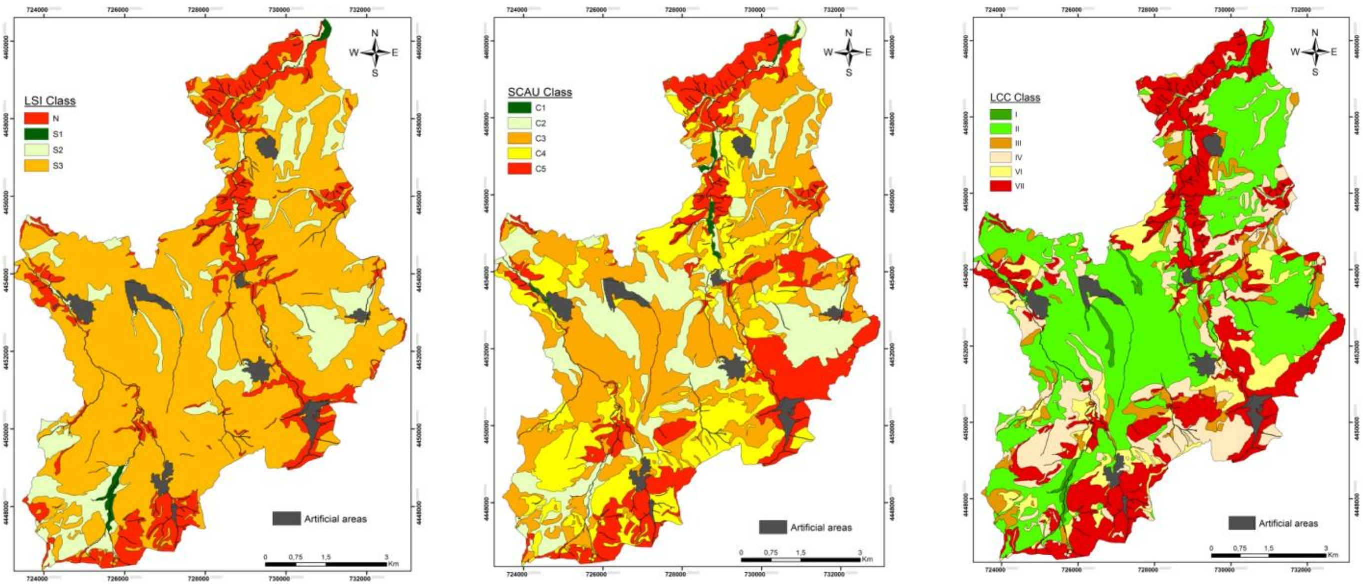

Figure 3. Distribution land suitability maps of three hierarchical (LSI, SCAU and LCC) methods

Conclusion

Land suitability analysis is a vital operation for assessing the value and proficiency of the land and provides great contribution in planning for future sustainable land resources. There are many land evaluation approaches which were given under two main categories that are parametric and hierarchic methods. Accurate assessment methods give better results and consequently facilitate establishment of improved management plans. In this study, multi-criteria approach was used with analytical hierarchy process associated with GIS technique by taking into consideration of some land and soil physico-chemical characteristic in order to generate map of land suitability classes for agricultural and for nonagricultural uses. In this method, the final suitability index value of the equation was based principally on the factor that has the maximum influence on land use suitability with regard to the other factors. As well, results have shown that the limiting factors for agricultural uses in the study area are slope, soil erosion and depth. Moreover, this approach was also compared with SCAU and LUCC methods. According to three methods' results, it was detected high correlation between LSI and SCAU, whereas values of land suitability classes of LUCC were higher especially for its second class (41.9%) includes many some factors that restrict land use in present condition. Although LUCC is of great importance in guiding on land uses in terms of their potential and conserving land resources, this result can be explained that LUCC data have been not upgraded and soil map unit contains one or more soil components (typically great soil groups) with soil properties that are defined by not enough precise definitions.

In present study, it can be strongly recommended that the first 2 suitability classes must be considered simultaneously for land allocation for cultivation areas, using GIS techniques and taking into consideration land-use information, including the results obtained from the MCA model. This study confirms the capability of GIS to integrate spatial and attribute data and to offer a quick and reliable method of land suitability assessment with high accuracy. On the other hand, while GIS has been a powerful tool to handle spatial data in land-use analysis, application of this tool alone could not overcome the issue of inconsistency in expert opinion when trying to judge and assign relative importance to each of many criteria considered in a suitability analysis. To address this issue, the Analytical Hierarchy Process, and Weighted Linear Combination methods are also used in combination with the GIS tool.

This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, the results of this study could be useful for other investigators who could use these results for diverse studies. For further study, we propose to select more number of factors like topography, climate, irrigation facilities and socio-economic factors which influence the sustainable use of the large scale land.

Consequently, the results obtained from this study indicate that the use of GIS and application of Multi-Criteria Assessment using AHP could provide a superior database and guide map for decision makers.

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Understanding phosphorus status and P translocation within wheat plant in a split-root system

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Abstract

Plants are not uniform in their nutritional requirements, most of them survive under adverse conditions of humidity, temperature, and nutrients. Because they are genetically adapted to their habitats and even some varieties of the same species show differences in absorption, translocation, accumulation and nutrient use. This study is aimed at examining the phosphorus (P) status in the different parts of wheat (*Triticum aestivum* L.) plant and its influence on plant growth and P translocation in a split-root soil culture. KH_2PO_4 was used as the source of phosphorus for the different level of P application. Two recently BARI developed wheat varieties namely BARI GOM 25 and BARI GOM 26 were used as testing plants. . Result showed the growth parameter increased with the increase of P application. Likewise, P uptake by wheat plant also increases with the elevated P application. However, no significant differences were observed between wheat varieties irrespective of growth and P uptake by wheat plant. Moreover, elevated P concentrations in the shoot of wheat plants probably provide more P for shoot unloading of P and for P assimilation in the controlled roots. This phenomenon results in increased P concentrations in the roots of wheat plants that mean translocation of P in the roots. These findings indicate that the added soluble P increases the absorption of nutrients from the soil solution. So, this study concluded that the application of elevated P in split-root system is efficient both for increasing shoot development and root growth and plays significant role in thePtranslocationwithin the wheat plants.

Keywords: Phosphorus uptake, P use efficiency, P translocation, xylem, phloem.

Introduction

Phosphorous (P) plays a key role in plant growth and is the major plant growth-limiting nutrient despite of its abundance in soils in both inorganic and organic forms (Gyaneshwar et al., 1999). It is absorbed by the plants, in the orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}) forms (Hinsinger, 2001). The concentrations of inorganic P in soil solution are, however, typically very low, due to inorganic P's propensity to bind strongly to soil surfaces or form insoluble complexes with cations (Talboys et al., 2014). This means that inorganic P is often a limiting factor in plant growth and development.

The split-root system is the division of the plant root into two media. This system has been used by researchers (Shani et al., 1993; Zhu and Ito, 2000; Shen et al., 2005; Shu et al., 2005), but not for improving plant nutrition. Using localized fertilization in row crops is a similar phenomenon as the split-root system, Tworkoski et al. (2003) report that the greatest number of roots grew at 43 to 46 cm from the root collar where localized, polypropylene, nonwoven fabric fertilizer was applied, resulting in rapid shoot growth as a

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response to daily fertilization. Ma and Rengel (2008) studied phosphorus distribution in split-root systems to examine the influence of plant phosphorus status and distribution in the root zone and phosphorus acquisition on the growth of root and shoot of wheat (*Triticum aestivum* L.). The results of their research suggest that root proliferation and greater phosphorus uptake in the phosphorus-enriched zone may meet the demand for phosphorus by phosphorus - deficient plants only for a limited period of time.

Our previous study showed that elevated P taken a significant part in the development of wheat plant in acidic soil (Shabnam and Iqbal, 2016a). Likewise, application of elevated P is efficient both for increasing shoot development and root proliferation and plays a significant role in the P dynamics within the wheat plant in split-root system in alkaline soil (Shabnam and Iqbal, 2016b). Further, a study found that translocated P does not alleviate aluminium toxicity within plant tissue (Iqbal, 2014). However, no study was undertaken acidic and alkaline soil combination within split-root system. Phosphorus is readily translocated within the plants, moving from older to younger tissues as the plant forms cells and develops roots, stems and leaves (Schachtman et al., 1998). Moreover, in inorganic P-deficient plants, the restricted supply of P to the shoots from the roots via the xylem is supplemented by increased mobilization of stored P in the older leaves and retranslocation to both the younger leaves and growing roots (Jeschke et al., 1997). Understanding the mechanisms controlling these traits is, therefore, of great importance in the pursuit of improved crop inorganic P uptake. Keeping in view of the above facts, the study aims at following objectives: to understand mechanisms involved in the utilization of inorganic phosphorus by wheat plant under various split-root systems to quantify how translocated phosphorus effects on wheat plant within split-root system under P efficient condition. It will be hypothesized that elevated phosphorus will be affected on root morphology and growth response to wheat plant.

Material and Methods

Soil and Plant

Two types of soils (acidic and alkaline) were used in this study. The soil type I (acidic) having pH 5.2 was collected from Thakurgaon district, acidic region of Bangladesh and the soil type II (alkaline) having pH 7.9 was collected from Ganges River Floodplain (Rajshahi District, Bangladesh) which soil types predominantly include calcareous grey floodplain soils. The basic properties of soil are out-lined in Table 1. From the soil texture analysis the acidic soil contains 59% clay content (sandy clay) where; the alkaline soil contains 72% sand (sandy loam). The sandy loam means alkaline soil (P: 14.3 mg kg^{-1}) has a higher P content in the soil than the clay loam means acidic soil (P: 10.4 mg kg^{-1}). BARI GOM 25 and BARI GOM 26 wheat (*Triticum aestivum* L.) varieties were used as testing plants.

Table 1. Properties of soils used in this experiment

Properties	Soil I, Acidic	Soil II, Alkaline
Soil pH	5.2	7.9
Total N, %	0.05	0.03
Available P,mg kg^{-1}	10.2	14.3
Exchangeable K, cmol kg^{-1}	0.2	0.21
Available S, mg kg^{-1}	19.5	5.6
Available Zn, mg kg^{-1}	0.59	11.55
Organic matter, %	0.85	0.55
Sand, %	55	92.2
Silt, %	25.9	3.8
Clay, %	19.1	4.0

Experimental Design

The split-root experiment was conducted with the treatments described in Table 2. The BARI GOM 25 and BARI GOM 26 were compared. The treatments were replicated three times. KH_2PO_4 chemical was used as P. To avoid the interactions between soil nutrients and added P, no basal nutrients were added. The plants were allowed to grow for 28 days and they had to depend on the reserved food of the seeds and the added P for their growth.

The soil was incubated at 30^0C for 7 daysand then KH_2PO_4 as per P doses was applied directly to the soil in each cup and mixed thoroughly before sowing. The total experiment was conducted in the Research laboratories, Department of Agronomy and Agricultural Extension, Rajshahi University, Rajshahi.

Table 2. Split-root system with different treatments

Treatment	Symbols	Treatment symbols		P level	
		Compartment 1	Compartment 2	Compartment 1	Compartment 2
		Alkaline Soil	Acidic Soil	Alkaline soil	Acidic Soil
A	0P/0P	0P	0P	0 mg P kg^{-1}	0 mg P kg^{-1}
B	10P/50P	10P	50P	10 mg P kg^{-1}	50 mg P kg^{-1}
C	50P/200P	50P	200P	50 mg P kg^{-1}	200 mg P kg^{-1}
D	100P/400P	100P	400P	100 mg P kg^{-1}	400 mg P kg^{-1}

Construction of split-root system

Pots having two compartments or chambers with a fixed partition-wall at the middle of the pot were used for the treatment. Each compartment was filled with 500g of experimental soil. The soil was compacted. The whole split root system with soil and plant continued for 28 days.

Crop management

Seed germination and seedling preparation

Seeds of uniform size were selected for germination. The seeds of BARI GOM 25 and BARI GOM 26 were germinated in moist sand in two separate trays in dark at 25°C for 70h. To produce young seedlings, the germinated seeds were allowed to grow for 5 days in those separate trays.

Cultivation of plant

To support the transplanted seedlings, five slots were made on each side of the partition-wall of the pot. Five days old healthy seedlings, were transplanted. Each seeding bearing four seminal roots, (6-7 cm long), after cutting one-uneven root was taken. A single-seedling was put into each slot keeping two seminal roots in each compartment. Then the roots were covered with the same treated soil and watered immediately after planting. 20 ml water was added to each compartment every day and watering was stopped 3 days before harvesting.

Harvesting

Pots having two compartments or chambers with a fixed partition-wall at the middle of the pot were used for the treatment. Each compartment was filled with 500g of experimental soil. The soil was compacted. The whole split root system with soil and plant continued for 28 days.

The experimental plants were harvested 27 days after transplanting. The shoots were cut 0.5cm above the base part of the stem uniformly. Then the roots were cut 0.5cm below the base part and separated carefully into two halves as previously marked. Soils from two root halves were removed carefully so that the roots could not be torned or left in the soil. Then the collected bulk soil was air dried and stored in a controlled room temperature (25°C) until analysis. Then the roots were washed with DI water to remove the adhered soil from roots. The washed roots were oven dried at 70°C for 3 days. Shoots were also oven dried at the same temp for the same time. After drying, the root and shoot samples were weighed and stored for analytical experiments.

Laboratory analysis

Measurements of soil physical and chemical properties

Soil textural analyses were conducted by using an abbreviated version of the International Pipette method. Clay content was determined by a pipette method after pretreatment with H_2O_2 to remove organic matter (Gee and Bauder, 1986). The pH of the soil was determined before incubation in deionised water using a soil-to-solution ratio of 1:2,5. Organic carbon of the soil samples was determined by wet oxidation method (Walkley and Black, 1934). Soil organic matter content was determined by multiplying the percent value of organic carbon with the conventional Van-Bemmelen's factor of 1.724 (Piper, 1950). The nitrogen content of the soil sample was determined by distilling soil with alkaline potassium permanganate solution (Subhaiah and Asija, 1956). The distillate was taken in 20 ml of 2% boric acid solution with methylred and bromocresol green indicator and titrated with 0.02 N sulphuric acid (H_2SO_4) (Podder et al., 2012). Soil available S (ppm) was determined by calcium phosphate extraction method with a spectrophotometer at 535 nm (Petersen, 1996). The soil available K was extracted with 1N NH_4OAC and determined by an atomic absorption spectrometer (Biswas et al., 2012). The available P of the soil was determined by spectrophotometer at a wavelength of 890 nm. The soil sample was extracted by Olsen method with 0.5 M $NaHCO_3$ as outlined by Huq and Alam (2005). Zn in the soil sample was measured by an atomic absorption spectrophotometer (AAS) after extracting with DTPA (Soltanpour and Workman, 1979).

Phosphorus determination in soil and plant tissue

The amounts of P in root, shoot and soil were determined. After digestion in a mixture of concentrated nitric and perchloric acids (4/1; v/v), the concentration of P in root and shoot materials were determined using the vanadomolybdate method (Zheng et al., 2005). Colorimetric method for the determination of phosphorous concentrations in digest solutions was used. This method is called the molydovanado-phosphate method (AOAC, 1975). Briefly, phosphorous was assayed using the molydovanado-phosphate method adding 3-ml digested solution, 2-ml reagent and 5-ml distilled water. The absorbance reading was used at 470 nm (Iqbal et al., 2010).

Statistical analysis

Shoot and root parameters were analysed by three-way ANOVA (Treatment × Variety × Compartment), total P uptake as well as distribution of P in different plant parts were determined by one-way ANOVA using Genstat 11th edition for Windows (Lawes Agricultural Trust, UK).

Results

Effect on plant height

Plant height is a genetic character of a variety but its potential can be achieved by adequate crop management. The data on the effect of different P levels on plant height is given in Figure 1. The results showed for the variety BARI GOM25 that the maximum plant height (30.83 mm) was recorded in treatment C (50P/200P mg kg^{-1}), while minimum (14.78 mm) was found in treatment D (100P/400P mg kg^{-1}). Again, the results showed for the variety Bari GOM26 that the maximum plant height (30.85 mm) was recorded in treatment C (50P/200P mg kg^{-1}), while minimum (16.77 mm) was found in treatment D (100P/400P mg kg^{-1}). Plant height was significantly ($P \leq 0.001$) affected among all the various P applications and variety of wheat plants. It also increased with the increasing level of P application, but at high level P resulted in minimum plant height. Hence, among low level of various P application, phosphate had the gradual increasing effect on plant height with increasing P applications, but at high level P resulted in minimum plant height.

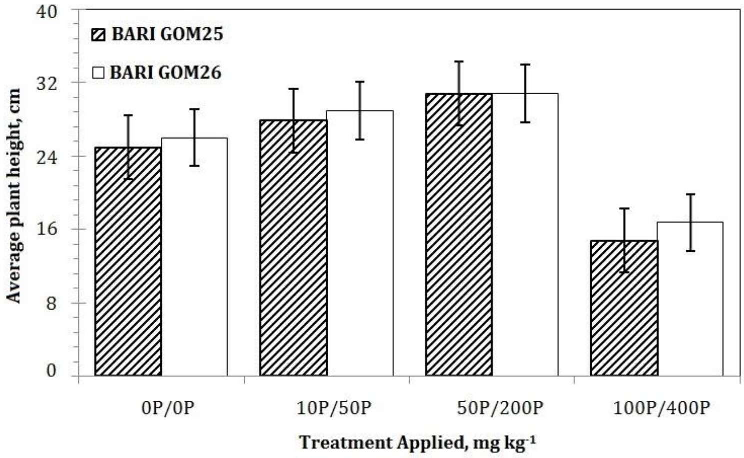

Figure 1. Effect of P application on average plant height of the wheat seedlings grown in various level of P for 28 days.

All the plant growth and P-uptake parameters were highly significant ($P \leq 0.001$) under P levels (Table 3). Similarly, significant differences among varieties were observed in relation with all the growth and P-uptake parameters.

Table 3. Significance levels for the main and interactive effect of P and varieties on seedlings growth

Source of variation	Plant height	Shoot dry weight	P concentration in shoot	Root dry weight	P uptake in root
Treatment (T)	***	***	***	***	***
Variety (V)	***	NS	***	NS	NS
Compartment (C)	-	-	-	NS	*
T×V	***	NS	***	NS	NS
T×C	-	-	-	NS	NS
C×V	-	-	-	NS	NS
T×V×C	-	-	-	*	NS

Where NS, ** and *** represent probability of > 0.05, ≤ 0.01 and ≤ 0.001, respectively,'-' (dash) indicates no data available.

Shoot dry weight

Like plant height, the shoot biomassshowed similar trend under different P applications. The results showed for the variety BARI GOM25 that the maximum shoot biomass (0.85 g pot^{-1}) was recorded in treatment C (50P/200P mg kg^{-1}), while minimum (0.25 g pot^{-1}) was found in treatment D (100P/400P mg kg^{-1}). Again, the results showed for the variety BARI GOM26 that the maximum shoot biomass (0.87 g pot^{-1}) was recorded in treatment C (50P/200P mg kg^{-1}), while it was minimum (0.26 g pot^{-1}) in treatment D (100P/400P mg kg^{-1}). The shoot biomass was significantly (P ≤0.001) affected among all the various P applicationson wheat plant. The shoot biomass did not significantly (P>0.05) differ between varieties of wheat plant. The shoot biomass also increased with the increased level of P application, but at high level P resulted in minimum shoot biomass (Figure 2).

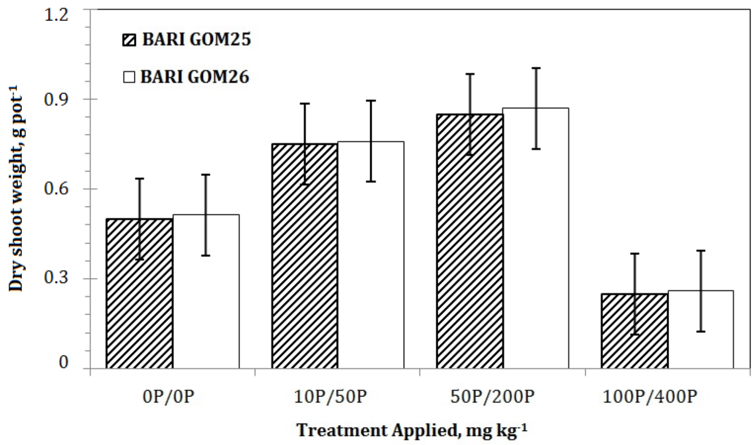

Figure 2. Effect of P application on dry shoot weight of the wheat seedlings grown in various level of P for 28 days.

Root dry weight

Total root biomass varied among the treatments. Total root biomass of BARI GOM26 inTreatment C on compartment II (200 mg kg^{-1} P in acidic soil) was the highest (0.57g pot^{-1}) and the lowest in Treatment D-II (400 mg kg^{-1} P in acidic soil) (0.17 g pot^{-1}), followed by gradual increase in the Treatment A-I (0 mg kg^{-1} P in alkaline soil) (0.26 g pot^{-1}), Treatment A-II (0 mg kg^{-1} P in acidic soil) (0.29 g pot^{-1}), Treatment B-I (10 mg kg^{-1} P in alkaline soil) (0.36 g pot^{-1}) , Treatment C-I (50 mg kg^{-1}P in alkaline soil) (0.41 g pot^{-1}), Treatment B-II (50 mg kg^{-1} P in acidic soil) (0.46 g pot^{-1}) and Treatment D-I (100 mg kg^{-1} P in alkaline soil) (0.51 g pot^{-1}) (Figure 3). Again, for BARI GOM 25 total root biomass was the highest in TreatmentC on compartment II (200 mg kg^{-1} P in acidic soil) (0.55 g pot^{-1}) and was the lowest in Treatment D-II (400 mg kg^{-1} P in acidic soil) (0.15 g pot^{-1}), followed by gradual increase in the Treatment A-I (0 mg kg^{-1}P in alkaline soil) (0.25 g pot^{-1}), Treatment A-II (0 mg kg^{-1} P in acidic soil) (0.28 g pot^{-1}), Treatment B-I (10 mg kg^{-1} P in alkaline soil) (0.35 g pot^{-1}), Treatment C-I (50 mg kg^{-1} P in alkaline soil) (0.40 g pot^{-1}), Treatment B-II (50 mg kg^{-1} P in acidic soil) (0.45 g pot^{-1}) and Treatment D-I (100 mg kg^{-1} P in alkaline soil) (0.50 g pot^{-1}). Similar to shoot dry weight, root biomass was significantly (P ≤0.001) affected among all the various P applications on wheat plant. But, the root biomass did not significantly (P>0.05) differ between varieties of wheat plant.

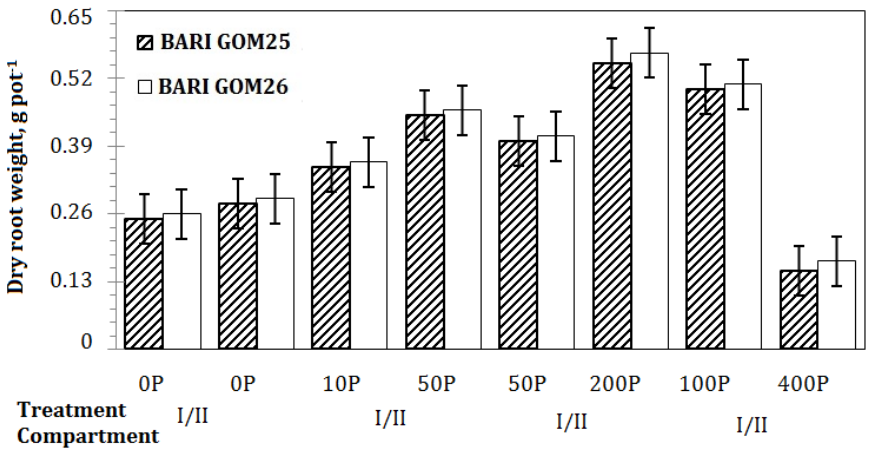

Figure 3. Effect of P application on dry root weight of the wheat seedlings was grown in various level of P for 28 days.

Shoot P concentration

In general, shoot P concentration was found in increasing trend under different P application on wheat plant. Shoot P concentration was significantly (P ≤0.001) affected among all the various P applicationson wheat plant. Total shoot P concentration in BARI GOM 26 was the highest and the lowestinTreatment C (50P/200P mg kg^{-1}) (2.74 g kg^{-1}) and Treatment A (0P/0P mg kg^{-1}) (0.41 g kg^{-1}) respectively, but intermediates in Treatments B(10P/50P mg kg^{-1}) (1.43 g kg^{-1}) and Treatment D (100P/400P mg kg^{-1}) (0.71 g kg^{-1}) (Figure 4). Again, for BARI GOM25 total shoot P concentration was the highest and the lowest in Treatment C(50P/200P mg kg^{-1}) (2.52 g kg^{-1}) and Treatment A (0P/0P mg kg^{-1}) (0.40 g kg^{-1}) respectively, but intermediates in Treatments B (10P/50P mg kg^{-1}) (1.30 g kg^{-1}) and Treatment D (100P/400P mg kg^{-1}) (0.63 g kg^{-1}). The shoot P concentration of BARI GOM25 and BARI GOM26 were dependent on the treatments. However, the two varieties had similar responses on shoot P concentration in the different treatments.

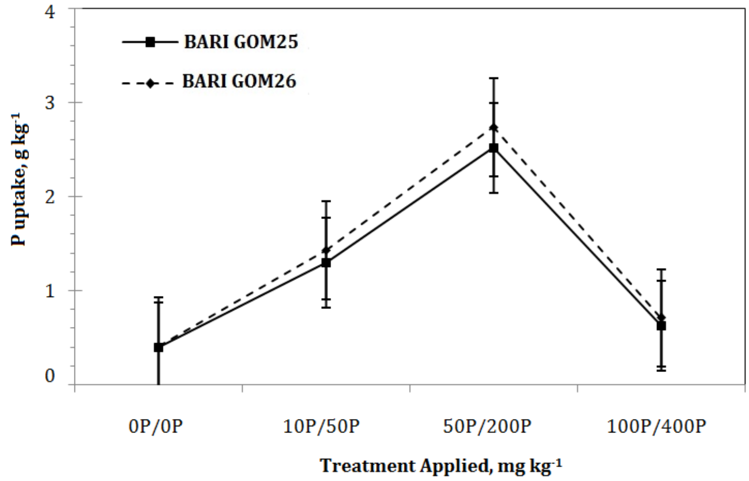

Figure 4. Effect of P application on P uptake of wheat shoot in various level of P for 28 days.

Root P concentration

In general, root P concentration was found in increasing trend under different P application on wheat plant. Root P concentration was significantly (P≤0.001) affected among all the various P applicationson wheat plant. Total root P concentration in BARI GOM 26 was the highest and the lowest in Treatment C in compartment II (200 mg kg^{-1} P in acidic soil) (2.77 g kg^{-1}) and Treatment D-II (400 mg kg^{-1} P in acidic soil) (0.19 g kg^{-1}) respectively, followed by gradual increase in Treatment A-I (0 mg kg^{-1} P in alkaline soil) (0.29 g kg^{-1}), Treatment A-II (0 mg kg^{-1}P in acidic soil) (0.31 g kg^{-1}), Treatment B-I (10 mg kg^{-1} P in alkaline soil) (0.53 g kg^{-1}) , Treatment B-II (50 mg kg^{-1} P in acidic soil) (0.68 g kg^{-1}), Treatments C-I (50 mg kg^{-1} P in alkaline soil) (1.63 g kg^{-1}) and Treatment D-I (100 mg kg^{-1} P in alkaline soil) (2.22 g kg^{-1}) (Figure 5).

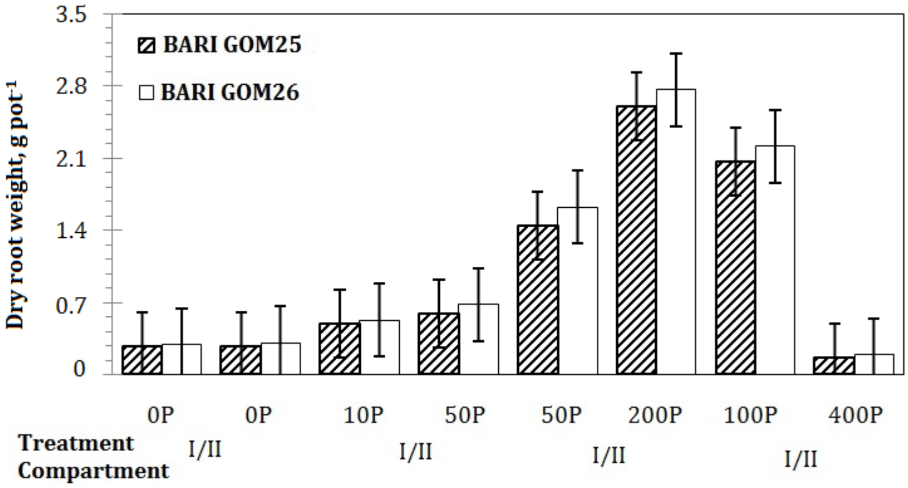

Figure 5. Effect of P application on P uptake of wheatroot in various level of P for 28 days.

Again, for BARI GOM 25 total root P concentrationwas the highest and the lowest in Treatment C in compartment II (200 mg kg^{-1} P in acidic soil) (2.61 g kg^{-1}) and Treatment D-II (0 mg kg^{-1} P in acidic soil) (0.17 g kg^{-1}) respectively, followed by gradual increase in Treatment A-I (0 mg kg^{-1} P in alkaline soil) (0.27 g kg^{-1}), Treatment A-II (0 mg kg^{-1} P in acidic soil) (0.28 g kg^{-1}), Treatment B-I (10 mg kg^{-1}P in alkaline soil) (0.49 g kg^{-1}) , Treatment B-II (59 mg kg^{-1} P in acidic soil) (0.68 g kg^{-1}), Treatments C-I (50 mg kg^{-1} P in alkaline soil) (1.45 g kg^{-1}) and Treatment D-I (100 mg kg^{-1} P in alkaline soil) (2.07 g kg^{-1}).The root P concentration of BARI GOM25 and BARI GOM26 were dependent on the treatments. However, the two varieties had similar responses on root P concentration in the different treatments.

Total P uptake and P distribution

In both varieties of BARI GOM25 and BARI GOM26 similar trend in total P uptake were found. The total P uptake by plant was significantly high in Treatment C (50P/200P mg kg^{-1}) from other treatments in both varieties. However, total P uptake was more thansix times greater in Treatment C (50P/200P mg kg^{-1}) than control Treatment A (0P/0P mg kg^{-1}). The total P uptake was greater in BARI GOM26 than that of BARI GOM 25 in all treatments. Total P uptake in BARI GOM 26 of Treatment C(50P/200P mg kg^{-1}) and Treatment A (0P/0P mg kg^{-1}) were the highest (7.14 g kg^{-1}) and the lowest (1.01 g kg^{-1}) respectively, but intermediates in Treatment B (10P/50P mg kg^{-1}) (2.64 g kg^{-1}) and Treatment D (100P/400P mg kg^{-1}) (3.12 g kg^{-1}) (Figure 6). Again, for BARI GOM25 total P uptake in Treatment C (50P/200P mg kg^{-1}) and Treatment A (0P/0P mg kg^{-1}) were the highest (6.58 g kg^{-1}) and the lowest (0.95g kg^{-1}) respectively, but intermediates in Treatments B (10P/50P mg kg^{-1}) (2.38 g kg^{-1}) and Treatment D (100P/400P mg kg^{-1}) (2.87 g kg^{-1}).

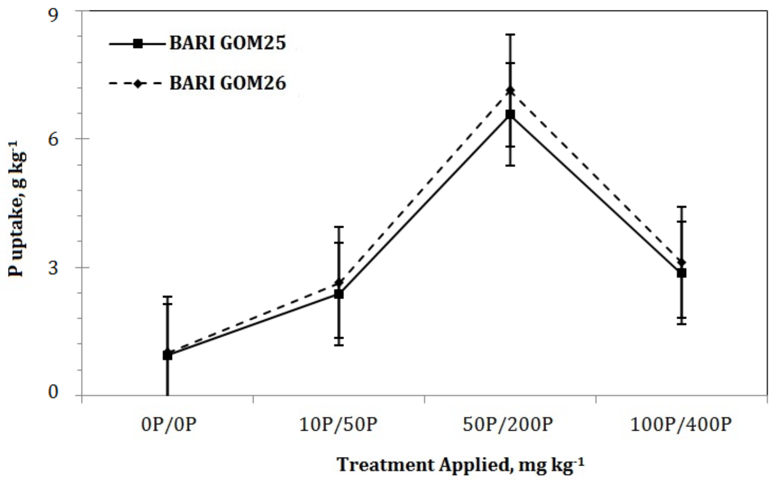

Figure 6. Effect of P application on P uptake of wheatplant in various level of P for 28 days.

Discussion

Growth response of wheat plant in split root system

Plants typically respond to P limitation by reducing total plant biomass, and diverting resources disproportionately towards root growth (Zhu and Lynch, 2004; Zhu et al., 2005). In many soil types, P is localized to the upper soil layers and immobilized with other molecules (Chu et al., 1966). It is predicted that under limiting phosphorous condition, plants that proliferate roots into these upper layers outperform varieties with deeper root systems (Zhu and Lynch, 2004; Zhu et al., 2005). Root proliferation and greater P uptake per unit of root in the nutrient-rich zones are often considered to be compensatory responses. So, thestudy was conducted to examine the influence of plant phosphorus (P) status and P distribution in the root zone on root P acquisition and root and shoot growth of wheat (*Triticum aestivum* L.) in a split-root soil culture. To investigate growth response of recently BARI released wheat varieties under elevated P applied condition, all growth measurements, including root biomass, plant height and shoot biomass measures were taken. The highly significant Treatment (T) interaction for plant growth ($P \leq 0.001$) in this study indicates that the plant growth responses of BARI GOM25 and BARI GOM26 seedlings were dependent on the level of added P. In all treatments, there were no significant differences between BARI GOM25 and BARI GOM26 seedlings for any growth measurement. Total plant biomass in BARI GOM 26 of Treatment C increased 74.5% (1.85 g pot^{-1}) in comparison with the controlled Treatment A (1.06 g pot^{-1}). Similarly in Treatment B increased 49.1% (1.55 g pot^{-1}) and in Treatment D decreased 11.3% (0.94 g pot^{-1}) in comparison with

Treatment A. Again, for BARI GOM 25 total plant biomass in Treatment C increased 74.7% (1.80 g pot^{-1}) in comparison with the controlled Treatment A (1.03 g pot^{-1}). Similarly in Treatment B increased 50.5% (1.55 g pot^{-1}) and in Treatment D decreased 12.6% (0.90 g pot^{-1}) in comparison withTreatment A. Similar trend was found in shoot biomass and root biomass of both wheat plant varietyin this study (Table 4). But internal biomass distribution in shoot and root wasfound no common trend among all treatments (Figure 7). The shoot biomass was found highest (48.5% of total plant biomass) in Treatment A of BARI GOM25 and in Treatment B, Treatment C and Treatment D were found in decreasing order 48.4%,47.2% and 27.8% respectively of total plant biomass. In this study of split root system both compartments were used different soil among all treatments. In compartment I of the split root system alkaline soil was used and in compartment II acidic soil was used. So, the trend in root biomass was found irregular order among all treatments (Figure 7).

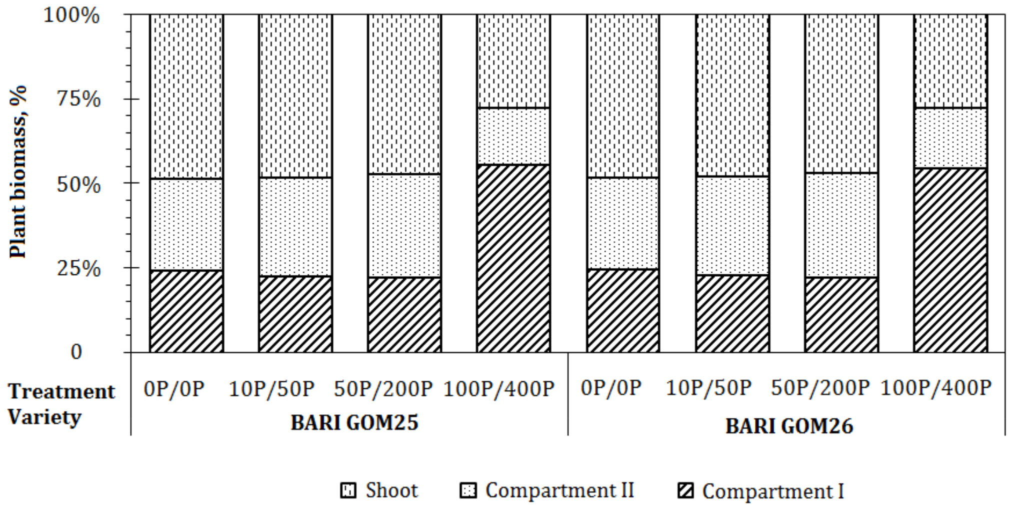

Figure 7. The distribution of plant biomass in different plant parts of the split-root system

In alkaline soil in compartment I of the split root system, the highest percentage of root biomass was found in Treatment D 55.6% of total plant biomass and in Treatment A, Treatment B and Treatment C the percentages were found in decreasing order 24.3%, 22.6% and 22.2% respectively of total plant biomass. In acidic soil in compartment II of the split root system, the highest percentage of root biomass was found in Treatment C 30.6% of total plant biomass and in Treatment B, Treatment A and Treatment D the percentages were found in decreasing order 29.0%, 27.2% and 16.7% respectively of total plant biomass. Similarly, in BARI GOM26 the highest percentage of shoot biomass was found in Treatment A 48.3% of total plant biomass and in Treatment B, Treatment C and Treatment D the percentages were found in decreasing order 48.1%, 47.0% and 27.7% of total plant biomass respectively. In alkaline soil in compartment I of the split root system, the highest percentage of root biomass was found in Treatment D 54.3% of total plant biomass and in Treatment A, Treatment B and Treatment C the percentages were found in decreasing order 24.5%, 22.8% and 22.2% respectively of total plant biomass. In acidic soil in compartment II of the split root system, the highest percentage of root biomass was found in Treatment C 30.8% of total plant biomass and in Treatment B, Treatment A and Treatment D the percentages were found in decreasing order 29.1%, 27.3% and 18.1% respectively of total plant biomass (Table 4). The inhibitory effect of increasing the P supply to whole root systems on the development of cluster roots of wheat plant (*Triticum aestivum*) is well documented (Ma et al., 2008; Pedas et al., 2011; Iqbal, 2014). In our split-root study, the percentage distribution differences in the total root and shoot dry weight among the three P treatments are due toelevated P supply which directly interferes with shoot root growth.

The root-shoot ratio is an important factor to understand growth responses of plants under elevated P applications. The root: shoot ratio of the wheat plant with and without treatments at the various level of P supply were analyzed (Table 5). Comparison of root: shoot ratio of different treatment showed an increase with increasing P application in both varieties of BARI released wheat plants. In the same line, Shane et al. (2003) reported that, the increaseof phosphate supply in root halves influenced the root/shoot ratio of wheat; because root growth increased more than shoot growth. Similar results were observed in wheat plant by Bingham et al. (2003) and Ma et al. (2011).

Table 4. Total Plant biomass, total shoot and root biomass in different plant parts of the split-root system and distribution of biomass in shoot and two separate compartments.

Plant parts /Variety	Total Plant Biomass (g pot^{-1})			
	Treatment A	Treatment B	Treatment C	Treatment D
BARI GOM 25	1.03	1.55	1.80	0.90
BARI GOM 26	1.06	1.58	1.85	0.94
Total Biomass (g pot^{-1}) in different plant parts of the split-root system				
BARI GOM 25				
Shoot	0.50	0.75	0.85	0.25
Compartment-I	0.25	0.35	0.40	0.50
Compartment-II	0.28	0.45	0.55	0.15
BARI GOM 26				
Shoot	0.51	0.76	0.87	0.26
Compartment-I	0.26	0.36	0.41	0.51
Compartment-II	0.29	0.46	0.57	0.17
The distribution of Biomass (%) in shoot and roots grown in two separate soil compartments (I and II)				
BARI GOM 25				
Shoot	48.50	48.40	47.20	27.80
Compartment-I	24.30	22.60	22.20	55.60
Compartment II	27.20	29.00	30.60	16.70
BARI GOM 26				
Shoot	48.30	48.10	47.00	27.70
Compartment I	24.50	22.80	22.20	54.30
Compartment II	27.30	29.10	30.80	18.10

Table 5. Root biomass, shoot biomass, and root/shoot ratio of two wheat varieties across different P applications

Variety	P rate (mg kg^{-1})	Treatment	Biomass Production (mg pot^{-1})		Root-shoot ratio
			Shoot	Root	
BARI GOM 25	0P/0P	A	0.50	0.53	1.06
	10P/50P	B	0.75	0.80	1.07
	50P/200P	C	0.85	0.95	1.12
	100P/400P	D	0.25	0.65	2.60
BARI GOM 26	0P/0P	A	0.51	0.55	1.07
	10P/50P	B	0.76	0.82	1.08
	50P/200P	C	0.87	0.98	1.13
	100P/400P	D	0.26	0.68	2.62

P distribution and translocation in wheat plant within split-root system

In general, plants grow better when partially soluble phosphate is applied in comparison with the soluble P source. Soil pH influences the charge of the P species in solution as well as the charge of the adsorbing particles in soils. The study was conducted in split-root system using both alkaline soil (compartment I) and acidic soil (compartment II) where P doses were applied directly to the soil. The shoot and root P fixation were found in increasing trend under different P application on wheat plant, except at highest level of P application in acidic soil. Shoot and root P fixation were significantly ($P \leq 0.001$) affected among all the various P applications on wheat plant. Again, similar trend in total P uptake were found in both varieties of BARI GOM25 and BARI GOM26. Total plant P fixation in BARI GOM 25 of Treatment C increased about7 times (6.58 g kg^{-1}) in comparison with the controlled Treatment A (0.95 g kg^{-1}). Similarly, in Treatment B and Treatment D total plant P fixation increased about 2.5 times (2.38 g kg^{-1}) and 3 times (2.87 g kg^{-1}) respectively in comparison with Treatment A. Again, for BARI GOM26, total plant biomass in Treatment C increased 7 times (7.14 g kg^{-1}) in comparison with the controlled Treatment A (1.01 g kg^{-1}). Similarly, in Treatment B and Treatment Dthe total plant P fixation increased about2.5 times (2.64 g kg^{-1}) and 3 times (3.12 g kg^{-1}) respectively in comparison with Treatment A. Similar trend was found in shoot P fixation and root P fixation of both wheat plant varieties in this study (Table 6); while internal P uptake by shoot and root was found irregular pattern among all treatments (Figure 8). The highest percentages of P uptake by shoot was found in Treatment B of BARI GOM 25, 54.6% of total plant P uptake while in Treatment A, Treatment C and Treatment Dit was found in deceasing order 42.1%, 38.3% and 22.0% respectively of total plant P uptake. Root P uptake was found in different pattern between compartmentswith increasing P supply (Table

6). In alkaline soil in compartment I of the split root system, the highest percentage of root P fixation was found in Treatment D 72.1% of total plant P uptake and in Treatment A, Treatment C and Treatment B the percentages were found in decreasing order 28.4%, 22.0% and 20.6% respectively of total plant P uptake.

Table 6. Total P uptake in different plant parts of the split-root system and distribution of P in shoot and root two separate compartments.

Plant parts /Variety	Total P uptake (g kg^{-1})			
	Treatment A	Treatment B	Treatment C	Treatment C
BARI GOM 25	0.95	2.38	6.58	2.87
Bari GOM 26	1.01	2.64	7.14	3.12
Total P uptake (g kg^{-1}) in different plant parts of the split-root system				
BARI GOM 25				
Shoot	0.40	1.30	2.52	0.63
Compartment-I	0.27	0.49	1.45	2.07
Compartment-II	0.28	0.59	2.61	0.17
BARI GOM 26				
Shoot	0.41	1.43	2.74	0.71
Compartment-I	0.29	0.53	1.63	2.22
Compartment-II	0.31	0.68	2.77	0.19
The distribution of P (%) in shoot and roots grown in two separate soil compartments (I and II)				
BARI GOM 25				
Shoot	42.10	54.60	38.30	22.00
Compartment-I	28.40	20.60	22.00	72.10
Compartment II	29.50	24.80	39.70	5.900
Bari GOM 26				
Shoot	40.60	54.20	38.40	22.80
Compartment I	28.70	20.10	22.80	71.20
Compartment II	30.70	25.80	38.80	6.100

In acidic soil in compartment II of the split root system, the highest percentage of root P fixation was found in Treatment C 39.7% of total plant P uptake and in Treatment A, Treatment B and Treatment D the percentages were found in decreasing order 29.5%, 24.8% and 5.9% respectively of total plant P uptake. Similarly, in BARI GOM 26 the highest percentage of P uptake by shoot was found in Treatment B (54.2% of total plant P uptake), while in Treatment A, Treatment C and Treatment D were found in decreasing order (40.6%, 38.4% and 22.8% respectively of total plant P uptake). In alkaline soil in compartment I of the split root system, the highest percentage of root P fixation was found in Treatment D 71.2% of total plant P uptake and in Treatment A, Treatment C and Treatment B the percentages were found in decreasing order 28.7%, 22.8% and 20.1% respectively of total plant P uptake. In acidic soil in compartment II of the split root system, the highest percentage of root P fixation was found in Treatment C 38.8% of total plant P uptake and in Treatment A, Treatment B and Treatment D the percentages were found in decreasing order 30.7%, 25.8% and 6.1% respectively of total plant P uptake (Figure 8). This percentage distribution differences in the total root and shoot P uptake between the three P treatments are due to elevated P supply which directly interferes with shoot root P status.

Mimura et al. (1996) and Jeschke et al. (1997) described a picture of patterns of inorganic P movement in whole plants. In P-sufficient plants most of the inorganic P absorbed by the roots is transported through the xylem to the younger leaves. Concentrations of inorganic P in the xylem range from 1 mm in inorganic P-starved plants to 7 mm in plants grown in solutions containing 125µm inorganic P (Mimura et al., 1996). There is also significant retained location of inorganic P in the phloem from older leaves to the growing shoots and from the shoots to the roots. In inorganic P-deficient plants the restricted supply of P to the shoots from the roots via the xylem is supplemented by increased mobilization of stored P in the older leaves and retranslocation to both the younger leaves and growing roots. This process involves both the depletion of inorganic P stores and the breakdown of organic P in the older leaves. A curious feature of P-starved plants is that approximately one-half of the inorganic P translocated from the shoots to the roots in the phloem and then transferred to the xylem and recycled back to the shoots (Jeschke et al., 1997).

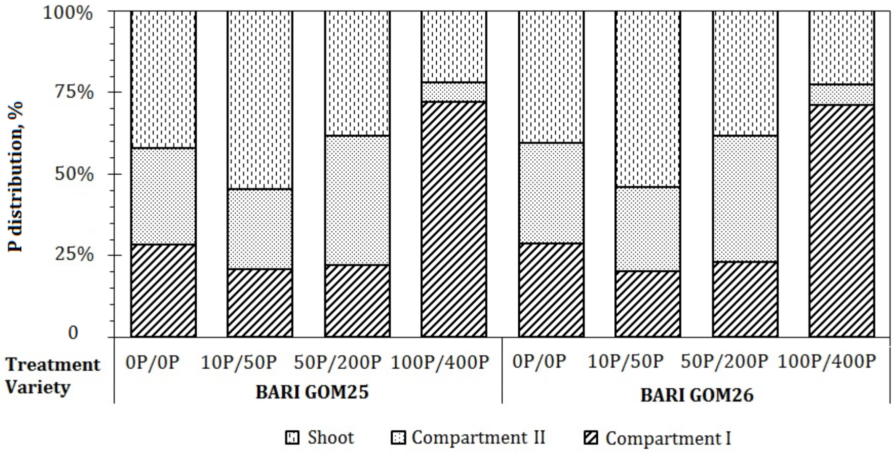

Figure 8. The P distribution in different plant parts of the split-root system

Increase of the external P supply to split root from 0 mg P kg^{-1} to 400 mg P kg^{-1} significantly increased the P concentration in those roots and shoots, but had no significant effect on the P concentration of the controlled roots. This lack of response of controlled roots has been demonstrated in other split-root studies with, e.g. barley (Drew and Saker, 1984), subterranean clover (Scott and Robson, 1991), tomato (Burleigh and Harrison, 1999) and Hakeaprostrata (Proteaceae) (Shane et al., 2003). In contrast with the results of split-root plants, the results of our wheat plant split-root study and those of others using foliar spray (e.g. Marschner et al., 1987) demonstrate that P retranslocated in the phloem sap can result in increased root P concentrations. In our studyof split root system, alkaline soil (pH 7.9) was used in compartment I and acidic soil (pH 5.2) was used in compartment II. P uptake rates are highest between pH 5.0 and 6.0 (Ullrich-Eberius et al., 1984; Furihata et al., 1992), which suggests that P is taken up at higher rate in acidic soil. So, it was expected that P fixation in compartment II was higher than that of compartment I. But, the difference in percentage between the P fixations of compartment-I roots and compartment II was much lower.It was due to plants that would be able to translocate P from the roots in compartment I to that compartment II. Studies with barley (Greenway and Gunn, 1966; Clarkson and Scattergood, 1982) indicated that P-stressed leaves absorb P more rapidly than control leaves do, and they export much larger amounts to the roots. Higher P concentrations in the shoot of our wheat plants probably provided more P for shoot unloading of P and for P assimilation in the controlled roots, resulting in increased P concentrations in the roots of wheat plants. In contrast, the split-root technique probably provides a more stable supply of P at a lower concentration.

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Local desalination treatment plant wastewater reuse and evaluation potential absorption of salts by the halophyte plants

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Abstract

The expansion of arid and semi-arid areas and consequently water scarcity are affected by climate change. This can influence on availability and quality of water while demands on food and water are increasing. As pressure on freshwater is increasing, utilization of saline water in a sustainable approach is inevitable. Therefore, bioremediation using salt tolerant plants that is consistent with sustainable development objectives might be an alternative and effective approach. In this study, saline wastewater from a local desalination treatment plant was utilized to irrigate four halophyte plants, including *Aloevera*, *Tamarix aphylla*, *Rosmarinus officinalis* and *Matricaria chamomilla.* A field experiment was designed and conducted in Zarrindasht, south of Iran in years 2012-2013 accordingly. Two irrigation treatments consisting of freshwater with salinity of 2.04 $dS.m^{-1}$ and desalination wastewater with salinity of 5.77dSm^{-1} were applied. The experiment was designed as a split plot in the form of randomized complete block design (RCB) with three replications. The results of variance analysis, ANOVA, on salt concentration in *Aloevera* showed that there was no significant difference between the effects of two irrigation water qualities except for Na. In *Rosmarinus officinalis,* only the ratio of K/Na showed a significant difference. None of the examined salt elements showed a significant difference in *Tamarix aphylla* irrigated with both water qualities. In *Matricaria chamomilla,* only Mg and K/Na ratio showed a significant difference (Duncan 5%). As a result, no significant difference was observed in salt absorption by the examined plants in treatments which were irrigated by desalination wastewater and freshwater. This could be a good result that encourages the use of similar wastewater to save freshwater in a sustainable system.

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Introduction

Water scarcity and salinity are the most serious challenges of sustainable agriculture in irrigated lands in arid and semi-arid areas, (Bernstein et al., 1993; Epstein, 1972). Soil salinity is a growing challenging issue, and about 70 percent of available water which is used for irrigation is adding millions of tons of salts to the fertile lands. Increasing human populations and food demands, will cause need more lands for agriculture (Kalantari

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and Hassanli, 2012; Tester and Davenport, 2003), consequently, the use of water resources with less quality including brackish water and recycled waste water for irrigation is vital. Also, the increase of evaporation as a result of global warming increases the risk of soil salinity especially in arid and semi-arid regions (Negahdari, 2012; Tester, and Davenport, 2003). Antcliff et al. (1983) stated that plant species which are able to limit the salt accumulation in the shoot are more resistant to salinity. According to Javadi et al. (2010) studies the extent of arid and semi-arid lands in Iran is enhancing and one of the associated challenges is salinity. They believe that one of the appropriate approaches to overcome this challenging issue can be the use of biological methods. Kalantari et al. (2015) emphasized that halophyte plants attracted more attention due to the salinity of soil and water resources. Larcher (1995) reported that as population growing, the greater emphasis needs to be put on more tolerant plants in the intensive conditions which resulted from the environmental degradation. The salt tolerant plants can be mostly found in salty and arid environments. Abedi et al. (2001) indicated that lack of adequate water generally is one of the important limited factors that lead to the restriction of maintenance and development of agricultural lands in arid and semi-arid areas. Therefore, wastewater can be used in order to overcome this congestion. The main requirement of efficient use of salty water is to consider the measures that may enhance sustainability of agricultural practices through soil and water conservation approach. The limited freshwater availability and the easy access to unconventional waters such as desalination wastewater and bioremediation as a sustainable approach, necessitate to carry out more research. Literature shows there is no much related research to the utilization of desalination plant wastewater and the absorption of salts ions by the halophytes.

The aim of this study were (i) indicating the impact of desalination waste water on the halophyte plants and (ii) reflecting the role of such plants on potential absorption of salt.

Material and Methods

This research was carried out in Zarrin Dasht Desalination Plant Station, located in south east of Iran; with area of 624 m^2, and longitude of 53º 58' 46" to 55º 01' 40" and latitude of 28º 00' 31" to 28º 36' 25" with elevation of 1021m above the sea level. The climate of Zarrin Dasht is hot and dry with average rainfall (2002-2012) of 179 mm, mostly occurs in January and February (www. frrw.ir). The average annual and average maximum temperature is 22 C° and 46.2 C°, respectively. The absolute minimum temperature in February is -3.2C° while the annual average evaporation is 2976 mm. Prior to soil and water data collection a field observation was carried out. The results of water and soil analyses prior to plantation are shown in Table 1 and 2.

Table 1. Chemical characteristics of irrigation water

Water	EC	pH	$HCO3^-$	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	SAR	Total hardness	TDS
	dS/m		meq/l							ppm	mg/l
Wastewater	5.77	7.96	10	3.04	38.8	6.13	29.1	16.99	4.05	1760	3692.8
Freshwater	2.04	7.58	7.2	2.9	1.3	2.7	6.1	9.15	4.36	440	1305.6

EC: electrical conductivity; SAR: sodium adsorption ratio; TDS: total dissolved solid

Table 2. Chemical and physical characteristics of the soil before plantation (Bioremediation)

Sampling depth	EC	pH	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K	OC	SAR	BD	FC	PWP
cm	dS/m		meq/l				mg/kg	%		g/cm^3	wt (%)	
0-25	9.08	7.58	50	15.25	24.8	19.4	152	0.15	4.3	1.43	40	25
25-50	6.3	7.71	43.9	12.96	23	15.4	182	0.13	3.6	1.21	40	25
50-75	7.63	7.99	50.8	14.47	25.5	18.8	154	0.13	4.2	1	40	25

OC: Organic Carbon; BD: Balk Density; FC: Field capacity; PWP: Permanent Wilting Pinot

The experimental design was a randomized split plot with two main treatments (desalination wastewater, freshwater) and four sub-main treatments (*Rosmarinus officinalis* L, *Matricaria chamomilla.* L, *Aloevera barbadensis*. Miller and *Tamarix aphylla*), each with three replications. This design consisted of 24 experimental plots. In each plot 90 plants were implanted and 30 plants were considered as the main line of monitoring and the rest were considered to eliminate the possible marginal effects. Monitoring of soil, water and plant was conducted in a 15-month period (October 2012 to December 2013). The statistical analysis was performed using the SAS statistical software package. For water monitoring (HosseiniFard and Aminiyan, 2015) ion analysis was performed using vanadate and molybdophosphoric acid method for potassium, nitrogen and phosphorus; bioassay method with EDTA for sodium, magnesium and calcium; turbid metric determination of sulfate; carbonate and bicarbonate ion concentration measured by titration method with sulfuric acid. In order to assess the amount of ions absorbed by the plants spectrophotometer for calcium and magnesium; flame photometry for sodium and potassium, vanadate and molybdate method and yellow color method for phosphorus were applied. Walky-block and flame photometry methods were used to calculate the amount of organic carbon and sodium and potassium, respectively. For calcium and magnesium, the bioassay method with EDTA was used (Van Reeuwijk, 2002). In addition, pH and salinity were measured using a digital pH meter and EC meter (Metrohm, 660). It worth to mention that the tests were repeated three times in order to increase the accuracy and reliability of the results. The applied irrigation water was based on the soil moisture at field capacity (FC) and the roots depth monitoring with a fixed interval time but the variable irrigation depths depending on the seasonal weather conditions and root depth. At each irrigation event, the soil moisture at root zone was measured by gravitational method, soil bulk density within the root zone was measured by a cylinder with given volume from the undisturbed soil. The volume of irrigation water at each event was estimated using Equations 1 to 4 and was controlled by a water meter and an automatic valve which was equipped to a timer.

$$\theta_w = (B - C)/(C - A) \times 100 \qquad \text{Equation 1}$$

$$d_n = (\theta_{fc} - \theta_w) A_s \times R \qquad \text{Equation 2}$$

$$d_g = \frac{d_n}{E_a} \qquad \text{Equation 3}$$

$$V = d_g \times A \qquad \text{Equation 4}$$

where d_n is the net water required to provide the soil water deficit to reach field capacity within the root zone (mm); θ_{fc} and θ_w are soil water contents at field capacity and at measuring time, respectively (%); A_s is the bulk density (g cm^{-3}); R is the root depth (mm); n is the number of days between the last irrigation and the current irrigation event; V is the volume of irrigation water (liters); and A is the area of each plot (m^2). d_g is gross irrigation depth (mm); E_a is the application efficiency. The measured irrigation water was applied through a drip irrigation system and noany fertilizers were used throughout the growing season.

Results and Discussion

Sodium (Na^+) accumulation in the irrigated plants

Analysis of variance (ANOVA) showed a significant difference between the effect of freshwater and wastewater on sodium accumulation in *Aloevera* at a rate of five percent (Figure 1). The plants irrigated with wastewater showed a significant increase of sodium concentration in plants' dry matter (7.66%) compared to those irrigated with freshwater (4.23%). This could be justified as a result of more sodium concentration in the wastewater (16.99 meq/l) comparing to the freshwater (9.15 meq/l). This finding is consistent with the results reported by Moghbeli et al. (2012). However, the results of variance analysis did not show a significant difference in sodium absorption by *Rosmarinus officinalis*, *Matricaria chamomilla* and *Tamarix aphylla* irrigated with freshwater and wastewater at significance level of 0.05 (Figure 1).

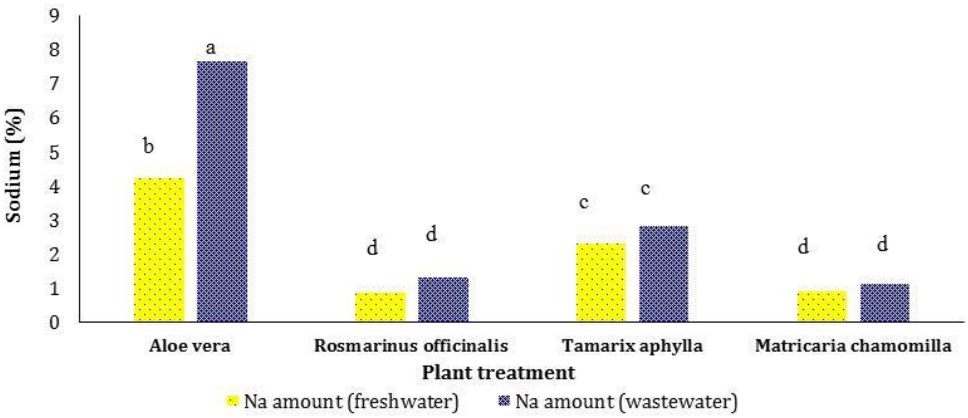

Figure 1. Comparison between the average sodium accumulations in plants irrigated with fresh water and wastewater

Potassium (K^+) accumulation in the irrigated plants

ANOVA analyses showed that there was no significant difference between potassium absorption in the examined plants irrigated with freshwater and wastewater at a rate of five percent, (Figure 2). This could be justified due to lack of significant differences of potassium in the both irrigation water qualities. Hassanli et al. (2009) showed that the absorption of potassium in the leaves and seeds of corn are not affected by water quality. It is worth to note that the amount of potassium in plants' dry matters for an appropriate growth has been reported more than 1% (Moghbeli et al., 2012). As shown in Figure 2 the amount of potassium in the examined plants irrigated with both types of irrigation water was in acceptable limits.

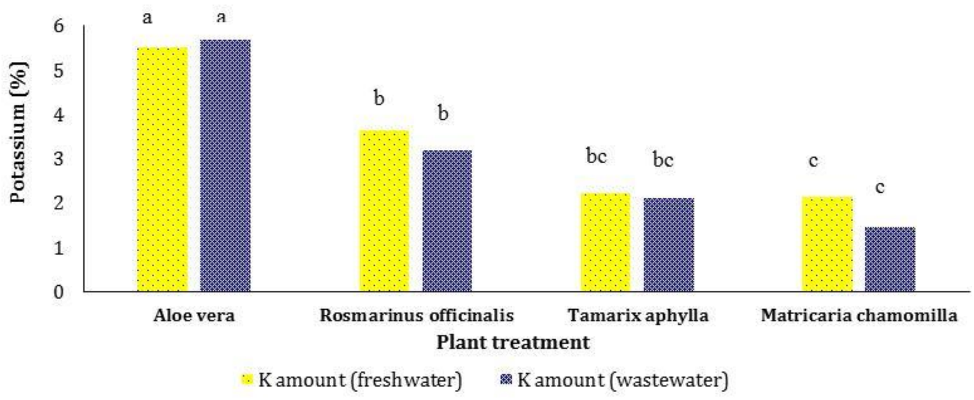

Figure 2. Comparison between the average potassium accumulations in the plants irrigated with freshwater and wastewater

Calcium (Ca^{2+}) accumulation in the irrigated plants

Calcium plays a crucial role in the protection of the structure and proper functioning of plant organs as well as strengthening of cell walls in regulating ion transportation and in selection and activities of cell wall enzymes (Ashraf, 2004; Aminiyan and Aminiyan, 2016). According to Patel et al. (2010), sodium chloride in Saline soils can have direct effect on the absorption of nutrients, for example on the reduction of calcium while calcium presence in the cell wall is necessary for salt tolerance in plants. In this study, ANOVA analysis indicated no significant difference for uptake of calcium in the all examined plants (Figure 3). Generally, irrigation with wastewater has not a significant effect on the accumulation of calcium in the plants due to lack of significant differences of Ca^{2+} between with the freshwater and wastewater. This result is consistent with the result of Hassanli et al. (2008). The concentration of this element in the plant for appropriate growth conditions is more than 1.5 percent in the dry matter of plant (Epstein, 1972). The amount of calcium absorbed in plants (Figure 3) indicates that the all plants are active in absorption of this element. It is shown that the amount of this element in all plants is much more than the desirable level.

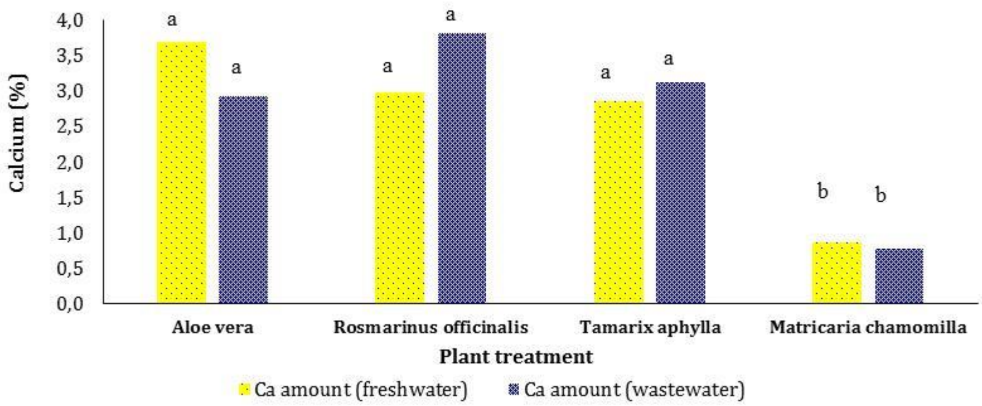

Figure 3. Comparison between the average calcium accumulations in all organs of the plants irrigated by two different water qualities

Magnesium accumulation (Mg^{2+}) in the treatment plants

ANOVA analysis showed that there was no significant difference in magnesium absorption by *Aloevera*, *Rosmarinus officinalis* and *Tamarix aphylla* plants irrigated with freshwater and wastewater at a rate of five percent (Figure 4). However, the results indicated that there was a significant difference in magnesium accumulation at a rate of five percent in *Matricaria chamomilla,* irrigated with two types of irrigation water. It was shown that absorption of magnesium in the dry matter of *Matricaria chamomilla* was significantly increased by 2.4% irrigated with freshwater compared to those plants irrigated with wastewater by 4.4%. As Mahler reported the desired amount of magnesium in the dry matter is 0.1 to 1% (Mahler, 2004). This indicates the role of *Matricaria chamomilla* in the absorption of magnesium. While there is no significant difference in the absorption of magnesium by Aloevera, *Rosmarinus officinalis*, *Tamarix aphylla* irrigated with freshwater and wastewater. But the absorption of magnesium by *Matricaria chamomilla* irrigated with freshwater is significantly more than that irrigated with wastewater.

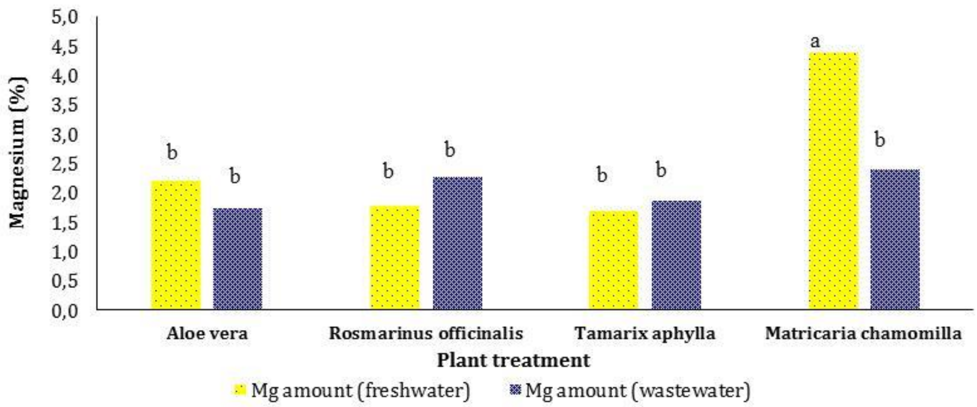

Figure 4. Comparison between the average magnesium accumulations in plants irrigated with freshwater and wastewater

Chlorine accumulation (Cl^-) in the treatment plants

The results of statistical comparison (Duncan 5%) of all examined plants showed that there is no significant difference in the absorption of the chlorine in the plants irrigated with two types of water as shown in Figure 5. One of the reasons could be the similarities of the chlorine concentration in both freshwater and wastewater (Table 1). As this experiment shows irrigation with wastewater has not a significant effect on chlorine absorption by the examined plants that is consistent with those of the Hassanli et al. (2009), Asano and Pettygrove (1987). The safe amount of chlorine in dry matter of a healthy plant recommended 70 to 100 ppm (0.007-0.01 %). As shown in Figure. 5 the chlorine concentration in the all examined plants are within the safe limits and only the concentration of this element in *Matricaria chamomilla* is beyond the border of the safe limit. Usually, in saline regions the main limiting anion is chlorine for crop growth, which is absorbed faster than the sodium. Damages caused by chlorine ion is more intense than sodium and its damage gets visible sooner. These ions are absorbed by the roots and accumulate in the leaves. Chlorine concentration varies in plant tissues and depends on the time when the plant is exposed to salt stress and also depends on the concentration of irrigation water (Negahdari, 2012). Comparative results in Figure 5 shows that *Matricaria chamomilla* can absorb more chlorine than the other examined plants.

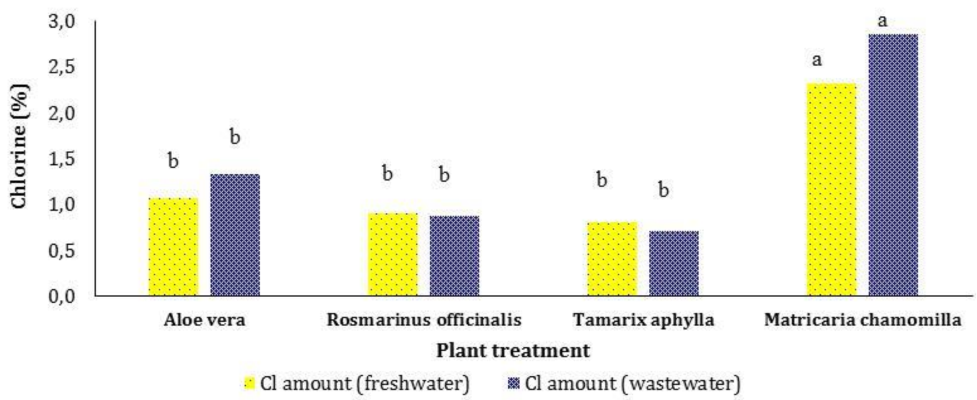

Figure 5. Comparison between the average chlorine accumulations in the examined plants irrigated with two different water qualities

The ratio of potassium to sodium in the irrigated plants

Based on the variance analysis there was a significant difference in the potassium to sodium ratio (K^+/Na^+) in the *Rosmarinus officinalis* and *Matricaria chamomilla* irrigated with freshwater and wastewater. The highest ratio was 4.28 in *Rosmarinus officinalis* irrigated with freshwater and the lowest ratio was 2.44 irrigated with wastewater. According to the variance analysis the ratio of potassium to sodium in the *Matricaria chamomilla* irrigated with freshwater was 2.3 and with wastewater was 1.2 with a significant difference (Figure 6). In contrast, the average ratio of potassium to sodium in *Aloevera* and *Tamarix aphylla* irrigated with freshwater and wastewater was 1.314 vs. 0.75 and 0.99 vs. 0.96, respectively without a significant difference. The high ratio of potassium to sodium in plants under salinity conditions could be an index to scale salinity (Ashraf, 2004). In fact, the ratio of potassium to sodium in the plant affected by saline conditions is one of the criteria for salinity resistance of the plant (Ashraf and Orooj, 2006).

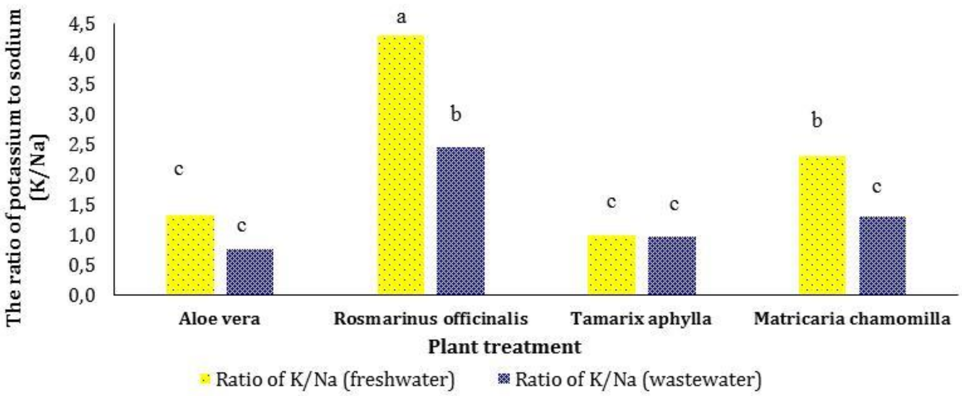

Figure 6. Comparison between the averages K/Na accumulations in plants irrigated with freshwater and wastewater

Organic carbon (OC %) in the plants

Based on Figure 7, the results indicated there is no significant difference in accumulation of OC in the examined plants with significance level of 0.05. The organic carbon percentage adsorbed by the plants irrigated with wastewater and freshwater was 0.41 and 0.43 for *Aloevera*, 0.48 and 0.50 for *Rosmarinus officinalis*, 0.47 and.0.49 for *Tamarix aphylla,* respectively.

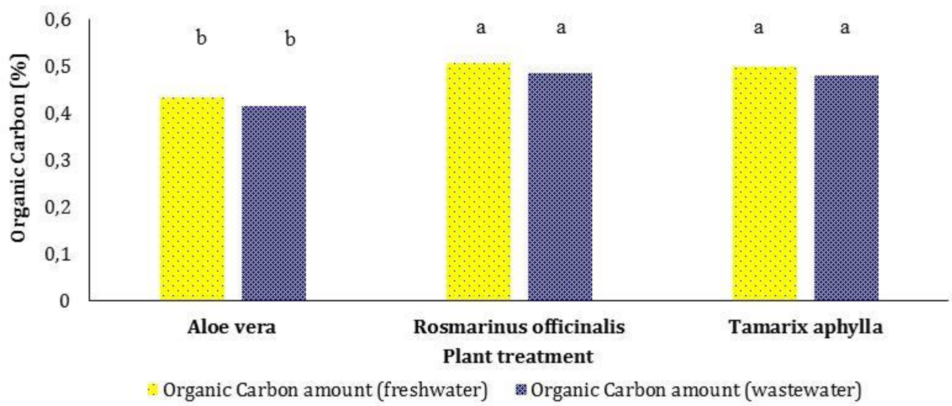

Figure 7. Comparison between the average organic carbon accumulations in plants irrigated with freshwater and wastewater

Essential oil and efficiency

Comparison results of average (Duncan 5%) for *Rosmarinus officinalis*'s essential oil samples indicated no significant difference between the effects of two water quality types. The average essential oil obtained from *Rosmarinus officinalis* irrigated with freshwater and wastewater was 0.75 and 0.67 grams per hundred grams of total dry matter, respectively. The amount of essential oil from *Matricaria chamomilla* irrigated with freshwater and wastewater was 0.40 and 0.43 grams, respectively. Similarly, the variance analysis results at significance level of 0.05 showed no significant difference between the effects of water quality on the essential oil obtained from *Matricaria chamomilla* (Figure 8 and 9). These results suggest that irrigation with desalination wastewater, which is saltier than the freshwater may not affect the quantity of essential oil production. Analysis of variance on *Rosmarinus officinalis* and *Matricaria chamomilla* as shown in Figure 9 indicated that there is no significant difference between the effects of quality of irrigation water on essential oil efficiency at significance level of 0.05. The results showed that essential oil efficiency in *Rosmarinus officinalis* and *Matricaria chamomilla* irrigated with freshwater and wastewater was 1.50 vs. 1.35 and 0.96 vs. 0.91 percent, respectively. It can be concluded that irrigation with desalination wastewater with salinity of 5.77 dS/m might be used for irrigation without inverse effect on essential oil efficiency. One of the challenges in relation to irrigation of medicinal plants with saline waters is possible change in the quality and quantity of their effective substances. Baghalian et al. (2008), and Bernstein et al. (1993), concluded that the effects of saline water on the quantity and quality of essential oil in *Matricaria chamomilla* and *Rosmarinus officinalis* had no significant differences.

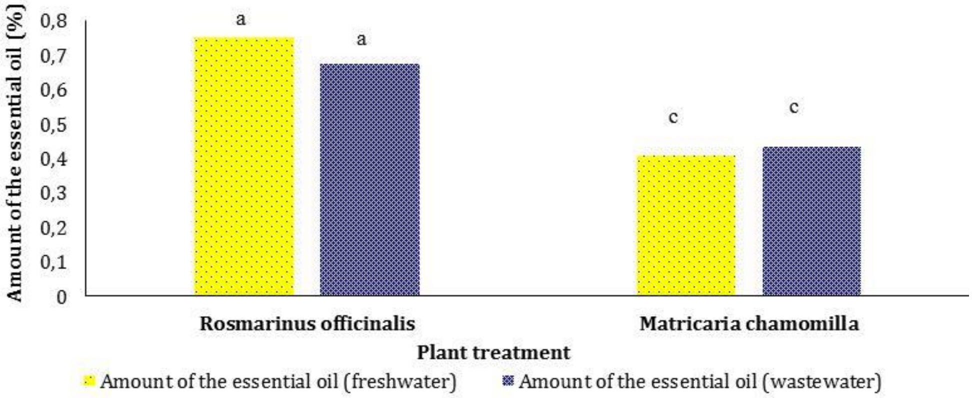

Figure 8. Comparison between the averages essential oil in hundred grams of dry matter in two plants irrigated with freshwater and desalination wastewater

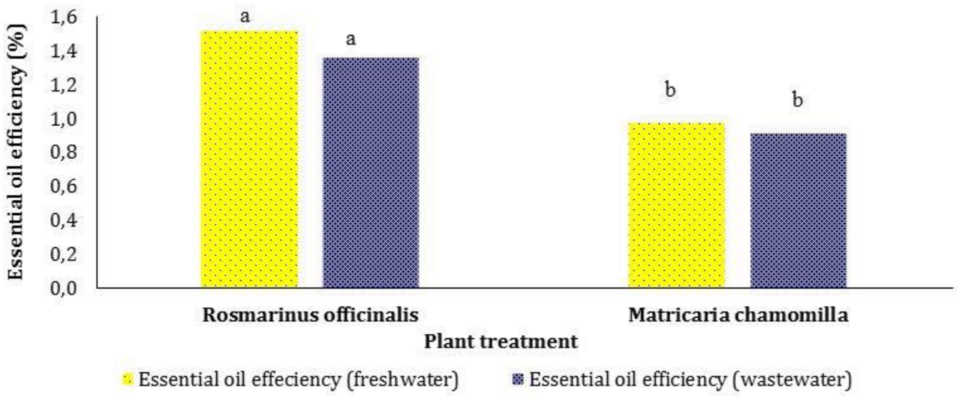

Figure 9**.** Comparison between the average essential oil efficiency influenced by irrigation with freshwater and desalination wastewater

Conclusion

Based on the achieved results, application of desalination wastewater in this study didn't show a significant difference compared to freshwater in terms of accumulation of potassium, calcium, chlorine, and organic carbon. Also the amount of essential oil and essential oil efficiency for *Tamarix aphylla*, *Aloevera*, *Rosmarinus officinalis* and *Matricaria chamomilla* irrigated with desalination wastewater and freshwater were not significantly different. However, ANOVA analyses showed that concentration of sodium and magnesium was significantly differences in *Aloevera* and *Matricaria chamomilla*, respectively (at significance level of 0.05). Also a significant difference in ratio of potassium to sodium *in Rosmarinus officinalis* and *Matricaria chamomilla* irrigated with wastewater and freshwater was observed. It might be concluded that due to the high proportion of potassium to sodium, the plants which are irrigated with freshwater would be more secure than the plants irrigated with wastewater. The complexity of the impact of desalination wastewater on the plants in this research indicates that it is necessary to extend and repeat this research to increase the validation of the findings. Since water in arid and semi-arid regions is a very scarce input it is essential to practice the sustainable use of desalination wastewater for irrigation.

Acknowledgements

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Effects of long-term tillage systems on aggregate-associated organic carbon in the eastern Mediterranean region of Turkey

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Abstract

The stability of aggregates plays a vital role in preserving and long term storing of soil organic carbon (SOC). In this study, the long-term (2006-2014) effects of six tillage systems on aggregate-associated SOC were investigated in a field experiment conducted under Mediterranean conditions. The tillage treatments were; conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow fallowed by no-tillage (RNT) for the second crop, and no tillage (NT). The most frequently encountered aggregates in all tillage systems were at 4.0-2.0 mm size and the least frequently found aggregates were 1.0-0.5 mm. The mean weight diameter (MWD) value increased in the NT compared to the conventional tillage practices at the rates of 137% and 204%, respectively at 0-15 cm soil depth. Aggregate-associated SOC contents in 0-15 cm depth were higher under conservation tillage systems. However, the highest SOC at 15-30 cm depth were greater mainly in conventional tillage systems as 9.4% for both CT1 and CT2. The results indicated that conservation tillage systems had greater aggregation and carbon storage at the soil surface.

Keywords: Aggregation, Mediterranean, soil organic carbon, soil tillage.

Introduction

Soil organic carbon (SOC) is an important indicator of soil quality because of its significant effects on soil physical, chemical and biological properties. SOC is closely linked with soil aggregate formation and stabilization (Balesdent et al., 2000) and is strongly affected by agricultural management practices such as soil tillage (Six et al., 2002).

Conventional tillage systems have a series of adverse effects on soil physical, chemical and biological properties in a semi-arid Mediterranean environment which induce the degradation of the soil ecosystems (Carter and Stewart, 1996). Excess tillage and removal of crop residues disrupt macro aggregate formation and stability via exposing physically protected organic carbon to microbial decomposition (Barto et al., 2010; Shu et al., 2015). However, use of conservation tillage systems improves soil structure and SOC, reduces soil erosion and enhances soil fertility and quality (Kabiri et al., 2015).

Many physical, chemical and biological processes taking place in soil such as seedling emergence and root growth, water and gas transfer, organic matter protection and dynamics depend on the intra and inter organization of the aggregates in the soil matrix (Blanco-Canqui et al., 2005). Mechanical forces can disrupt aggregates during tillage as the machinery fractures, crushes or compacts the soil structure (Blanco-Canqui

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and Lal, 2006). Macro aggregates are more sensitive to this effect of tillage than micro aggregates (Andruschkewitsch et al., 2014). Conservation tillage systems promote macro aggregation with time by reducing soil disturbance (Six et al., 2000). Macro aggregates, with enhanced development in no-tillage areas, have higher SOC and nutrient contents and macro porosity providing higher aeration and infiltration than micro aggregates (Dexter, 1988). For this reason, enhanced macro aggregates under conservation tillage systems are more durable than under conventional tillage systems (McVay, 2006).

Reduced tillage is becoming popular in the Çukurova region despite the long-standing history of the widely used conventional tillage systems throughout Turkey. However, research is limited concerning the effects of tillage systems on the SOC contents of the different sizes of aggregates in the soils of the country. In this respect, the objective of this study was to determine the long-term (8-year) effects of conventional, reduced and no tillage practices on the soil structural indicators. The indicators studied were the aggregate size distribution, SOC contents and mean weight diameters of the aggregates in wheat-corn and wheat-soybean rotations conducted on a heavy clay (mean 50% clay) soil in the eastern Mediterranean region of Turkey.

Material and Methods

Experimental site

A field experiment was conducted from 2006 to 2014 at the Experimental Farm (37°00′ 54″ N, 35°21′ 27″ E; 32 m above sea level) of the Çukurova University located in Adana, Turkey. The soils of the study were the clayey Arık soils, classified as fine, smectitic, active, mesic Typic Haploxererts (Soil Survey Staff, 1999) with a pH of 7.82, $CaCO_3$ of 244 g kg^{-1}, electrical conductivity of 0.15 dS m^{-1} and particle size distribution of 50% clay, 32% silt and 18% sand at the surface horizon (0-30 cm) (Celik et al., 2011).

The prevailing climate of the study area is Mediterranean with a long-term (30 years) mean annual temperature of 19.2 °C. The summers are hot and dry, and winters are wet and mild. The long-term mean annual precipitation is 639 mm, about 75% of which falls during the winter and spring (from November to May) and the long-term mean annual potential evapotranspration is 1557 mm.

Experimental design and tillage systems

The experiment was conducted in a randomized complete block design where similar experimental units were grouped into blocks or replicates. The treatments with three replications were conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow followed by no-tillage (RNT) for the second crop, and no tillage (NT). The tillage plots were 12 m wide and 40 m long (480 m^2). A buffer-zone of 4 m was reserved around each plot for tractor and, tillage equipment operations. The detailed information on treatments within each practice and sowing methods are shown in Table 1.

The rotations of winter wheat (*Triticum aestivum* L.)-corn (*Zea Mays* L.), winter wheat (*Triticum aestivum* L.) - soybean (*Glycine max.* L.) were applied in all treatments from 2006 to 2014. In each growing season, the first crop was winter wheat and the second crop was corn and soybean.

Two weeks prior to sowing, the total herbicide (500 g Glyphosate ha^{-1}) was used to control weeds in the NT and RNT treatments. Compound NP-fertilizers were applied in the seedbed at the rates of 172 kg N^{-1} ha and 55 kg P ha^{-1} for wheat, 250 kg N ha^{-1} and 60 kg P ha^{-1} for corn, and 120 kg N ha^{-1} and 40 kg P ha^{-1} for soybean. Winter wheat was sown in the first week of November from 2006 to 2013 at a seeding rate of 240 kg ha^{-1}, and harvested in the first week of June 2007 to 2014. The second crops (corn and soybean) were sown in the third week of June from 2007 to 2014, and harvested in the second week of October from 2007 to 2014. Corn and soybean seeding rates were 8.4 and 23.6 plants per m^2, respectively. Soybean and corn were nine times irrigated by sprinklers in 13 day intervals. The amount of water applied for each irrigation was identical for all treatments and no irrigation water was applied to the wheat.

Soil sampling and analysis

Soil samples (108) were collected at three sites of each individual plot (nine samples per tillage treatment) from 0-15 and 15-30 cm depths in October 2014. Field-moist samples were gently/ manually crumbled and sieved (<8 mm) to remove root material in the field and transferred to the laboratory. Soil samples were air-dried at room temperature (≈20°C) and dry sieved through 4, 2, 1 and 0.5 mm mesh for aggregate size distribution in the laboratory. Mean weight diameter (MWD) as a soil aggregation indicator was measured by using an instrument similar in principle to the Yoder wet sieving apparatus involving 4, 2, 1 and 0.5 mm meshes in samples initially sieved from an 8 mm mesh (Kemper and Rosenau, 1986). After sieving through an 8 mm sieve, 50 g soil sample was inserted on the first sieve (4 mm) and slowly moistened to avoid a sudden rupture of aggregates. Moistened soil was sieved in distilled water at 30 oscillations per minute. The soil above each sieve was dried after 10 minutes of oscillation, and then sands and aggregates were separated (Gee and Bauder, 1986).

Table 1. Tillage methods, depth of tillage, and equipment used in the study

Tillage Methods	Soil Tillage for Winter Wheat	Soil Tillage for Second Crop Corn and Soybean
Conventional tillage with residue incorporated (CT1)	• Stover chopping of second crop • Mouldboard plough (30-33 cm)* • Disc harrow (2 passes, 13-15 cm) • Float (2 passes) • Drill (4 cm)	• Stubble chopping of wheat • Heavy tandem disc harrow (18-20 cm) • Disc harrow (2 passes, 13-15 cm) • Float (2 passes) • Planter (8 cm)
Conventional tillage with residue burned (CT2)	• Stover burning of second crop • Moldboard plough (30-33 cm) • Disc harrow (2 passes, 13-15 cm) • Float (2 passes) • Drill (4 cm)	• Stubble burning of wheat • Chisel plow (35-38 cm) • Disc harrow (2 passes, 13-15 cm) • Float (2 passes) • Planter (8 cm)
Reduced tillage with heavy tandem disc harrow (RT1)	• Stover chopping of second crop • Heavy tandem disc harrow (2 passes, 18-20 cm) • Float (2 passes) • Drill (4 cm)	• Stubble chopping of wheat • Rotary tiller (13-15 cm) • Float (2 passes) • Planter (8 cm)
Reduced tillage with rotary tiller (RT2)	• Stover chopping of second crop • Rotary tiller (13-15 cm) • Float (2 passes) • Drill (4 cm)	• Stubble chopping of wheat • Rotary tiller (13-15 cm) • Float (2 passes) • Planter (8 cm)
Reduced tillage with heavy tandem disc harrow + no-tillage (RNT)	• Stover chopping of second crop • Heavy tandem disc harrow (18-20 cm) • Float (2 passes) • Drill (4 cm)	• Stubble chopping of wheat • Herbicide treatment • No-till planter (8 cm)
No-tillage (NT)	• Stover chopping of second crop • Herbicide treatment • No-till drill (4 cm)	• Stubble chopping of wheat • Herbicide treatment • No-till planter (8 cm)

*Figures in parentheses are the average working depths of the equipment

The mean weight diameter was calculated as follows:

$$MWD = \sum_{i=1}^{n} (X_i W_i)$$

Where, MWD is the mean weight diameter of water stable aggregates, X_i is the mean diameter of each size fraction (mm) and W_i is the percentage of the total sample mass in the corresponding size fraction after the mass of sands deducted. SOC in aggregates was measured by the wet combustion method (Schlichting and Blume, 1966).

Statistical analysis

To assess the effects of different tillage practices on the soil properties determined, the JMP statistical programme was used for one-way analysis of variance (ANOVA). The least-significant difference (LSD) method was used for mean comparisons among different treatments. Moreover, the correlation test was conducted in order to determine the relationships between soil properties.

Results and Discussion

Soil aggregate size distribution

Long term tillage practices had statistically significant effects on aggregate size distribution (Table 2). In all soil tillage practices, the amount of 4.0-2.0 mm aggregate fraction was determined to be highest and the >4.0, 2.0-1.0 and 1.0-0.5 mm aggregate fractions followed this in the 0-15 and 15-30 cm depths, respectively. For the 0-15 cm depth, the highest aggregate fraction of 4.0-2.0 mm was obtained in NT which was 24% higher than of the RT1. For the 15-30 cm depth, the 4.0-2.0 mm aggregate fraction was 14% higher in NT than in RT1. Similar to the NT system, Gelaw et al. (2015) reported that continuous addition of leaf litter and biomass cover in open pasture lands provide habitat for soil biota which enhance the soil aggregation.

Table 2. Effects of different tillage treatments on aggregate size distribution

Tillage treatments	Aggregate size distribution (%)			
	> 4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
		0-15 cm		
CT1	30.7 ± 5.1[c]	56.9 ± 4.6[b]	9.1 ± 1.4[b]	1.0 ± 0.5[a]
CT2	30.8 ± 2.1[c]	57.3 ± 2.0[ab]	11.8 ± 1.4[a]	1.0 ± 0.5[a]
RT1	41.6 ± 5.5[a]	49.1 ± 5.4[c]	7.0 ± 2.0[c]	1.1 ± 0.7[a]
RT2	35.3 ± 3.3[b]	55.3 ± 2.2[b]	7.8 ± 2.0[bc]	0.9 ± 0.3[a]
RNT	31.2 ± 3.8[bc]	57.0 ± 1.7[b]	8.1 ± 1.4[bc]	1.4 ± 0.8[a]
NT	30.6 ± 2.3[c]	60.8 ± 1.3[a]	8.0 ± 1.1[bc]	1.1 ± 0.3[a]
LSD_{till}	4.22**	3.55**	1.73**	ns
		15-30 cm		
CT1	38.4 ± 5.8[a]	56.3 ± 2.7[ab]	7.1 ± 1.5[c]	0.9 ± 0.1[c]
CT2	37.4 ± 3.1[a]	52.7 ± 3.7[cd]	8.4 ± 1.9[abc]	1.7 ± 0.7[ab]
RT1	38.6 ± 5.4[a]	51.0 ± 3.7[d]	9.9 ± 1.9[a]	1.5 ± 0.5[bc]
RT2	34.4 ± 3.3[a]	55.0 ± 1.5[bc]	8.0 ± 1.6[bc]	2.3 ± 0.9[a]
RNT	29.4 ± 3.4[b]	58.0 ± 1.8[ab]	8.3 ± 1.7[abc]	1.3 ± 0.4[bc]
NT	28.0 ± 2.3[b]	58.3 ± 3.4[a]	9.4 ± 1.1[ab]	1.3 ± 0.6[bc]
LSD_{till}	4.44**	3.19**	1.76*	0.67**

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different (P < 0.05). *: Difference is significant at P <0.05 level, **: Difference is significant at P <0.01 level, ns: Difference is not significant. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow fallowed by no tillage for the second crop, NT: No tillage

Generally, conventional tillage practices of this study increased the amount of smaller aggregate fractions by breaking larger macro aggregates in the 0-15 cm depth. Microaggregates are attached to form macroaggregates by a labile fraction of soil organic matter which is highly sensitive to the soil disturbance (Ashagrie et al., 2005). Breaking larger aggregates into smaller ones increases the surface area for microorganisms to oxidize the organic carbon stored in macroaggregates. Hou et al. (2013) reported that the amount of >0.25 mm aggregate fraction decreased with conventional tillage practices in the 0-20 and 20-40 cm depths. This decreasing of >0.25 mm aggregate fraction in soil with conventional tillage could be mainly due to the mechanical disruption of macro aggregates from frequent tillage operations and reduced aggregate stability (Hou et al., 2013). Conservational tillage practices (reduced and no-till) receives higher crop residue input than the conventional practices. Formation and stabilization of aggregates in soil mainly depend on the amount of biomass input and the rate of organic matter mineralization (Blanco-Canqui and Lal, 2004). Similarly, the increased amounts of 4.0-2.0 mm aggregates in the NT tillage practice was also reported by Zhang et al. (2012) and Du et al. (2013) in long term experiments. Moreover, Zhang et al. (2012) found that the >2.0 mm aggregate size in a clay loam soil was higher under no-tillage in comparison to conventional tillage.

Soil organic carbon accumulation in different aggregate sizes

Concentration of SOC associated to different aggregate sizes at both soil depths are presented in Table 3. Tillage practices had statistically significant effects on the SOC of different aggregate sizes in surface soils (P<0.01). Conservation tillage systems in general provided significantly higher SOC accumulation than conventional tillage practices in 0-15 cm soil depth for all aggregate sizes (Table 3). For conventional practices, this may be due to tillage causing the destruction of the aggregates conserving organic matter and in turn the increased temperature and aeration of the soil. Many studies reported that higher SOC contents in aggregates were found in conservation tillage systems in comparison to conventional tillage practices (Pinherio et al., 2004; Bhattacharyya et al., 2009; Zhang et al., 2012; Andruschkewitsch et al., 2014).

Table 3. Effects of different tillage treatments on SOC in different aggregate sizes

Tillage treatments	SOC (g kg^{-1}) in Aggregates			
	> 4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
		0-15 cm		
CT1	9.6 ± 0.7^{d}	9.5 ± 0.6^{c}	8.5 ± 0.4^{b}	9.6 ± 0.6^{d}
CT2	9.7 ± 0.4^{d}	9.7 ± 0.5^{c}	8.2 ± 0.6^{b}	9.6 ± 0.6^{d}
RT1	12.6 ± 0.5^{c}	12.2 ± 0.6^{b}	11.5 ± 0.7^{a}	12.6 ± 0.7^{c}
RT2	13.5 ± 0.8^{ab}	13.2 ± 1.0^{a}	11.7 ± 1.3^{a}	14.4 ± 1.6^{a}
RNT	12.8 ± 0.6^{bc}	12.7 ± 0.8^{ab}	11.3 ± 0.8^{a}	13.3 ± 0.7^{bc}
NT	13.7 ± 1.8^{a}	13.5 ± 1.8^{a}	11.8 ± 2.0^{a}	14.0 ± 1.5^{ab}
LSD_{till}	0.85**	0.92**	1.06**	0.97**
		15-30 cm		
CT1	9.4 ± 0.4^{a}	9.1± 0.5^{a}	8.1 ± 0.7^{a}	9.4 ± 0.5^{a}
CT2	9.4 ± 0.7^{a}	9.3 ± 0.8^{a}	8.1 ± 0.6^{a}	9.2 ± 0.4^{a}
RT1	8.7 ± 0.6^{b}	8.5 ± 0.7^{a}	7.9 ± 0.8^{a}	8.7 ± 0.7^{a}
RT2	8.9 ± 0.7^{ab}	8.6 ± 0.6^{a}	7.8 ± 0.5^{a}	8.7 ± 0.5^{a}
RNT	8.8 ± 0.5^{ab}	8.5 ± 0.7^{a}	7.9 ± 0.4^{a}	8.9 ± 0.6^{a}
NT	8.5 ± 1.0^{b}	8.4 ± 0.9^{a}	7.6 ± 0.9^{a}	8.7 ± 0.8^{a}
LSD_{till}	0.63*	ns	ns	ns

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different ($P < 0.05$). *: Difference is significant at $P < 0.05$ level, **: Difference is significant at $P < 0.01$ level, ns: Difference is not significant. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow fallowed by no tillage for the second crop, NT: No tillage

Concentration of SOC followed a different trend in 15-30 cm soil depth. The SOC only slightly significant ($P<0.05$) in >4.0 mm aggregates, lowest in NT treatment and non-significant for other aggregate sizes. With increasing depth, the SOC contents of the different sizes of aggregates in the soils under conventional tillage were determined to be lower than the SOC contents of the aggregates of the soils under conservation tillage. This can be attributed to the shallow or no-till practice of the conservation systems when compared to the conventional practices, where the crop residues are not mixed under the surface (15-30 cm). In contrast to conservational practices, burying crop residues to subsurface layer resulted in higher SOC of conventional practices at all aggregate sizes. The SOC contents of macroaggregates (> 4.0 mm) in all tillage practices at both soil depths were higher than 4.0-2.0 mm and 2.0-1.0 mm size aggregates, and very similar to 1.0-0.5 mm size aggregates. Gelaw et al. (2015) found the highest SOC content of surface soils associated with macroaggregates (20.0 g kg^{-1}), in open pastures, whereas the highest SOC content was reported in agroforesty land.

Mean weight diameter (MWD)

Conservation tillage practices provided significant statistical development on soil structure in comparison to conventional tillage ($P<0.01$). Also, no-tillage enhanced soil structure development more than the other conservation tillage practices.

In two soil depths, the highest MWD value was obtained in the no-till system whereas the lowest was obtained in the conventional tillage systems (Table 4). In the 0-15 cm soil depth, the highest MWD values were obtained under NT (0.76 mm). On the contrary, the lowest MWD values were obtained under the CT2 (0.26 mm) and CT1 (0.32 mm). Similarly, the lowest aggregation index was found under CT2 (0.32 mm) and CT1 (0.42 mm) at 15-30 cm soil depth. When numerically considered, the NT method in 0-15 cm depth provided higher development of soil structure compared to CT2 by 204 % and CT1 by 137%. The NT practice also had higher contribution to soil structure development compared to CT2 (by 66 %) and CT1 (by 29 %) in 15-30 cm soil depth.

The reason for the high MWD values in conservation tillage compared to conventional tillage is most likely due to the high organic carbon contents obtained in the former (Table 4). SOC is the major cementing factor in aggregate formation in soil and moreover, according to most researchers, is significantly correlated with aggregate stability. (Spaccini et al., 2004; Tejada and Gonzales, 2006).

Table 4. Effects of different tillage practices on the mean weight diameter

Tillage treatments	Mean weight diameter (mm)	
	0-15 cm	15-30 cm
CT1	0.32 ± 0.07[d]	0.42 ± 0.05[b]
CT2	0.26 ± 0.04[d]	0.32 ± 0.06[c]
RT1	0.48 ± 0.11[c]	0.48 ± 0.05[ab]
RT2	0.66 ± 0.14[b]	0.55 ± 0.13[a]
RNT	0.48 ± 0.07[c]	0.45 ± 0.06[b]
NT	0.76 ± 0.10[a]	0.53 ± 0.08[a]
LSD_{till}	0.088**	0.073**

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different (P < 0.05). **: Difference is significant at P <0.01 level. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow fallowed by no tillage for the second crop, NT: No tillage

Above explained results relation to effects of tillage systems on soil structure were significantly similar to results in other studies. Compared to conventional tillage, soil aggregates under conservation tillage systems were found more stable (Pagliai et al., 2004). Celik et al. (2012) found that MWD values under no-tillage and reduced tillage were higher than conventional tillage. Abdollahi and Munkholm (2014) reported that reduced tillage systems increased MWD values, penetration resistance and water-stable aggregates.

Correlation between MWD and SOC in different aggregate sizes

The correlation test between MWD and SOC contents in different aggregate sizes showed that SOC contents were statistically significant (P<0.01) correlations with MWD in the surface soils (0-15 cm) (Table 5). Moreover, the effect of the SOC contents of the >4.0 mm aggregates was higher on MWD pointing out to a higher contribution on the stability of the aggregates of these sizes compared to the others.

Table 5. Correlation between mean weight diameter and SOC in different aggregate sizes

0-15 cm		MWD	SOC in Different Sized Aggregate			
			>4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
MWD		1.000				
SOC in Different Sized Aggregate	>4.0 mm	0.684**	1.000			
	4.0-2.0 mm	0.669**	0.967**	1.000		
	2.0-1.0 mm	0.569**	0.873**	0.884**	1.000	
	1.0-0.5 mm	0.650**	0.940**	0.932**	0.883**	1.000
15-30 cm						
MWD		1.000				
SOC in Different Sized Aggregate	>4.0 mm	-0.251	1.000			
	4.0-2.0 mm	-0.275*	0.860**	1.000		
	2.0-1.0 mm	-0.253	0.650**	0.724**	1.000	
	1.0-0.5 mm	-0.187	0.784**	0.861**	0.717**	1.000

* Difference is significant at P <0.05 level, ** Difference is significant at P < 0.01 level

In spite of the strong relation between the aggregation index of the surface soils and the SOC contents of the different aggregate sizes, there was no important relation between MWD and SOC contents in different sized aggregates in the subsurface (15-30 cm) soils (Table 5). This showed that the cementing components other than organic carbon were responsible for the aggregation, though organic carbon might have been effective for the endurance of the aggregates in the subsurface layer. The major component effective in aggregation and the endurance of the aggregates is humus which is most durable to decomposition after mineralization. Garcia-Orenes et al. (2009) also indicated that the amount of biomass incorporated to soil had a strong impact on stability of aggregates and the associated SOC content. Thus, higher correlation of MWD and SOC in surface soils is mainly associated to the residue input in surface soil.

Conclusion

The results indicated that the tillage systems significantly influenced soil aggregation and organic carbon contents in the aggregates. At the two sampling depths, the amount of 4.0-2.0 mm aggregates was determined highest in all treatments. Consequently, no-tillage was found to be the best practice for the improvement of the soil structure via the increased mean weight diameter among all other tillage systems. Conservation tillage systems provided higher organic carbon accumulation than conventional tillage practices in 0-15 cm soil depth for all aggregate sizes. The intensity of soil tillage and the amount of crop residue added to the soil significantly impacted SOC in surface soils. However, the soils of the conventional tillage practices were found to contain higher soil organic carbon than the conservation tillage system soils in the 15-30 cm depth. The relationship between soil aggregation and soil organic carbon was also supported by the correlation test performed in the 0-15 cm soil depth. However, there was no relationship between soil aggregation and soil organic carbon in 15-30 cm soil depth. Finally, our results suggest that conservation tillage systems could be useful to carbon sequestration and reduce soil erosion together with the crop residues on the soil surface in a high clay content soil under Mediterranean climatic conditions.

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Surface charge is a function of organic carbon content and mineralogical compositions of soil

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Abstract

A study of the distribution of the electric charges in the surface horizons of two highly weathered soils Fluvaquent and Haplaquept of West Bengal, India was made by direct measurement of adsorption of ions in the presence of varying concentration of electrolyte. The objective of this study was to evaluate charge properties of two highly weathered soil of India. The results show that pH_0 varies with soil according to the variation in organic carbon and sesquioxide/allophone content. Organic carbon strongly affects the variation of negative charge with pH, but sesquioxide/allophone is responsible for positive charge variation. Results used the difference between the soil pH values measured in 1M KCl and in water for estimating the point zero charge of the soil and ΔpH values estimating the net surface charge character. Surface charges is a function of organic carbon, clay content, composition of clay and amount of Fe, Al and there oxides.

Keywords: Soil surface charge, organic matter, clay content, mineralogical composition.

Introduction

Solid particle surfaces in soils develop an electrical charge in two principal ways: either from isomorphic substitutions in soil minerals among ions of differing valence, or from the reactions of surface functional groups with ions in the soil solution. The electrical charge developed by these two mechanisms is expressed conventionally in moles of charge per kilogram ($mol_C\ kg^{-1}$). For different types of surface charge contribute to the net total particle charge in soils, denoted σ_p. Each of these components can be positive, zero, or negative, depending on soil chemical conditions.

Previous researchers (Espinosa et al., 1975; Gallez et al., 1976; Van Raij and Peech, 1972) have examined the surface charge characteristics of a number of soils of varying pedogenic age from different parts of the world.

In discussing surface charge characteristics it is important to classify the definitions of the terms used. The zero point charge is the pH at which the net total charge on the solid phase is zero, whether the charge arises from the pH-dependent charge associated with isomorphus substitution or from pH-dependent charge associated with hydroxylated oxide or organic matter surfaces. The isoelectric point is the pH at which the net charge on the hydroxylated surface is zero. The zero point of titration is the pH or range of pH values resulting from the reaction of the solid species with the indifferent electrolyte of varying concentrations in the absence of added acid or base (Parks, 1967). In a pure oxide system the ZPC, IEP and ZPT are coincident.

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A given soil may be dominated by either permanent charge or variable charge or their mixture, depending on the degree of its weathering and type of mineral constituents (Sparks, 2002; Chorover et al., 2004; Sposito, 2008). Soils in the humid tropics cover nearly 22% of the earth surface. These soils are dominated by mineral and amorphous colloids possessing amphoteric surfaces. Surface charge in this system depends on the activities of potential determining ions (H^+ and OH^-) and electrolyte concentration (Van Olphan, 1977).

This study aims to contribute towards an understanding of surface charge properties of two highly weathered soils of India by Ion adsorption methods.

Material and Methods

Sampling sites

Six soil samples were collected (0-15cm depth) from Sarisha and Lataguri of south 24 parganas and Jalpaiguri district of West Bengal, India for the study. The soils are mostly in tropical monsoonal climate with a mean annual rainfall of approximately 12000mm and approximate average temperature 27°C. The classifications of the soils in this study are given in Table 1. The soil samples were air-dried, crushed and then passed through a 2mm sieve for laboratory analysis.

Table 1. Sampling site, Soil order, Vegetation Type

No.	Location	Soil order	Vegetation type	Texture	Textural class
1	Sarisha soil West Bengal, India 22°35´N, 88 °44´E	Fluvaquent	Rice-rice-rice	34% silt 26% clay 40% sand	Silty clay loam
2	Lataguri soil West Bengal, India 26.32°N,89.45°E	Haplaquept	Tropical decudious forest	32% silt 38% clay 30% sand	Clay loamy

Physico-chemical analysis

Soil pH as measured in a 1:1 soil : solution in H_2O and 1M KCl (National Soil Survey Centre, 1996), Organic Carbon (OC) was measured by the Walkley-Black method (Nelson and Sommers,1996) and used to calculate the amount on Organic matter (OM) (OM= OCx1.724). Cation exchange capacity was determined by NH_4OAC at pH 7.0 and is defined by the some of the exchangeable cations that a soil can absorb (Chapman, 1965). Anion exchange capacity is determined by colorimetric methods (Clarke, 1950). Particle size distribution was analysed by the pipette method (Gee and Bauder, 1986). The ΔpH index was calculated from the difference between pH_{kcl} and pH_{water} (Mekaru and Uehara, 1972). Exchangeable Al (Bertsch and Bloom, 1996) and exchangeable Fe Sparks et al. (1996). The Fe and Al contents associate d with secondary minerals were determined in extracts obtained after boiling both 1g of soil for 30minutes in 20ml 9M H_2SO_4. The acid extract were analysed for Al and Fe and soil fused with alkali and total Fe and Al estimated by Atomic Absorption Spectrometry (AAS) (Sparks et al., 1996).

Surface charge analysis

Ion adsorption method

An estimate of the CEC (Cation exchange capacity) and AEC (anion exchange capacity) as a function of pH was determined by measuring the amount of K^+ and Cl^- retained by the soils at different pH using a modification of Schofields method (Schofield, 1949). Based upon the unknown mineralogy of these soils, it was assumed that the clays contained essentially no sites capable of specifically absorbing K^+; and therefore that KCl could be treated as an indifferent electrolyte. Triplicate 2g samples of soil were weighed in centrifuge tubes and washed with 0.1 M KCl to minimise soluble Al; after discarding the supernatants,20ml of the same solution were added and the pH adjusted with KOH or HCl to give a pH range between 2 and 8. The samples were equilibrated at room temperature (24+/-2°C) by shaking intermittently on a reciprocal shaker for 12 hr. Then the samples were centrifuged, the supernatants discarded, and 20ml 0.01 M KCl added; this 0.01M KCl wash was repeated two more times. After the final washing, the supernatant pH was measured as well as the Cl^-, K^+ and Al concentrations. Next, the adsorbed K^+ and Cl^- ions were displaced by washing the soil with 0.5 M NH_4NO_3. The amounts of K^+ and Cl^- displaced, after correction for the entrained KCl with in the soil volume, were used as estimates of the negative and positive charges, respectively. Chloride was measured using a specific ion electrode with a double junction reference electrode filled with $100gKg^{-1}$ KNO_3 solution in the outer chamber, and K^+ by flame photometer.

Statistical analysis

Each experiment was treated as a completely randomized design. Because the experiments were performed individually on each soil, comparisons of surface charge of the soils as a function of pH were accomplished by the use of correlation coefficient, were used to determine statistical significance of any differences in the surface charge measurements.

Results and Discussion

Important soil chemical and physical properties of the soils used in this study are given in Table 2, where it can be seen that Haplaquept are more acidic (4.65) than Fluvaquent (6.25). Fluvaquent are poor in organic carbon (1.25%) compare to Haplaquept (1.85%). Exchangble Fe, Al and total Fe, Al both are much higher in Haplaquept than Fluvaquent. Both soil had ΔpH less than zero, which indicates that they present negative net surface charge (Mekaru and Uehara, 1972). With increasing percent of organic matter and clay content point of zero charge reduces. In the present study a significant positive relationship observed between point zero charge and content of soil organic carbon and clay. The result can be ascribed to the positive correlation ($r = 0.2242$, $p<0.05$) between clay and soil organic carbon contents with surface charge. In both soil PZC value lower than pH water, so the net surface charge is negative.

Table 2. Chemical characteristics of soils

	Sarisha soil	Lataguri soil
pH_{water}	6.25	4.65
pH in 1N KCl	5.92	4.20
ΔpH *	-0.33	-0.45
Electrical Conductivity (EC), mSm^{-1}	0.08	0.23
Organic Carbon (OC), %	1.35	1.85
Organic Matter (OM), %	2.35	3.22
Exchangble Fe g kg^{-1}	0.26	0.58
Exchangble Al, g kg^{-1}	0.14	0.52
Total Fe, g kg^{-1}	28.6	52.80
Fe_2O_3, g kg^{-1}	40.85	75.42
Total Al, g kg^{-1}	21.90	58.60
Al_2O_3, g kg^{-1}	41.38	110.72

*$\Delta pH = pH_{KCl} - pH_{water}$

Clay content in the Haplaquept was significantly higher than the Fluvaquent, and this is reflected in the corresponding CEC values of these soils, with relatively higher CEC for Haplaquept than the Fluvaquent indicated the dominance of kaolinite mineral in the clay fraction of this soils.

The magnitudes of charges in the Haplaquept are higher than those of Fluvaquent because of dissociation of organic matter functional groups. Organic matter is an important source of CEC in these soils (Carvalho et al., 2009). Thus CEC and organic matter affected charges in these soils (Oorts et al., 2000).

Determination of surface charge by ion adsorption

The ion adsorption method allows the determination of positive and negative electric charge, as well as the net charge, as a function of pH. Figure 1-4 show the surface charge as a function of pH determined by the adsorption of K^+ and Cl^- at an ionic strength of 0.01M for the two soil samples.

Cation exchange capacity of Haplaquept is higher than Fluvaquent presumably an effect of organic matter content (Morais et al., 1976; Van Raij and Peech., 1972). This was observed that CEC of Haplaquept is higher in magnitude than Fluvaquent. Blocking of the exchange sites of organic matter by Al^{3+}/Fe^{3+} could explain this phenomenon. Iron and aluminium oxide are high in Haplaquept than Fluvaquent provide a positive surface charge in the soil.

As a certain pH CEC and AEC are same that is zero point net charge (ZPNC), that value is much higher in Haplaquept than Fluvaquent (Figure 1 and 2) due to the presence of higher organic carbon.

Haplaquept possess higher AEC than Fluvaquent. Organic matter and clay fraction play important role for AEC. These soils also differ in mineralogical composition. Organic groups displace water ligands at positive sites on the oxide surfaces (Mc Bride and Wesselink, 1988), reduce AEC in Fluvaquent.

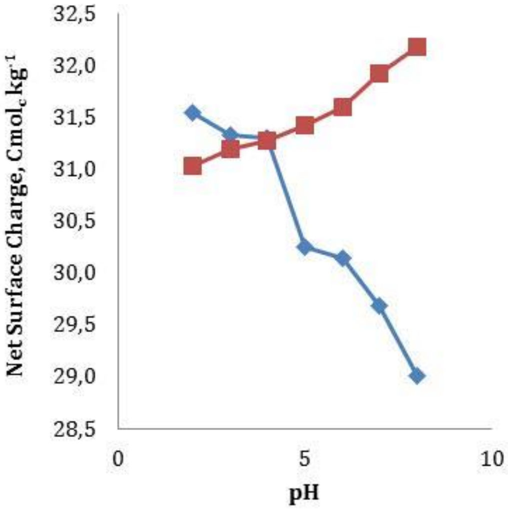

Figure 1. Estimation of net surface charge of Sarisha soil at different pH by ion adsorption Method

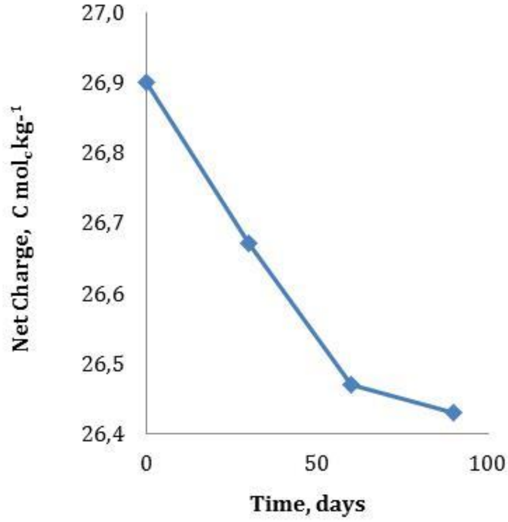

Figure 2. Net Charge vs Time curve in Sarisha soil

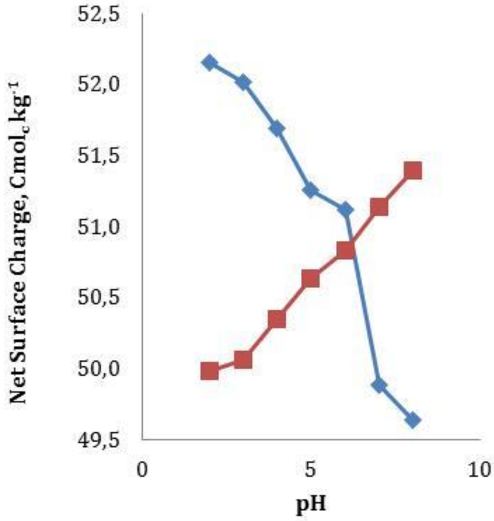

Figure 3. Estimation of net surface charge of Lataguri soil at different pH by ion adsorption method

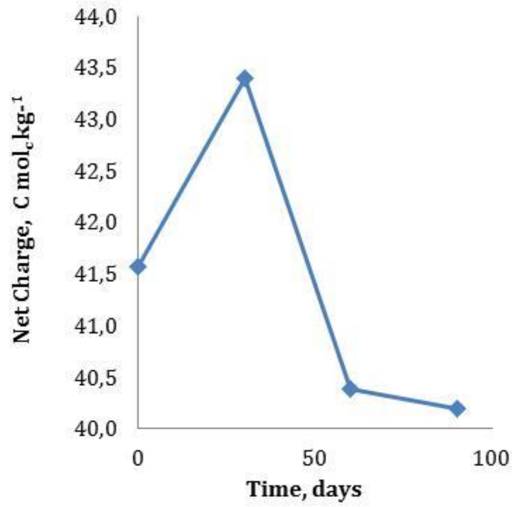

Figure 4. Net Charge vs Time curve in Lataguri soil

The net charge of the soil is estimated by subtracting the the CEC value at a given pH from the corresponding AEC value, these values are shown in Table 3 with calculated net charge values.

Table 3. PZC, CEC, AEC, Net charge and their relation with various chemical characters

	Sarisha soil	Lataguri soil
Point of Zero Charge (PZC) *	5.59	3.75
Anion Exchange Capacity (AEC), $Cmol_c\,kg^{-1}$	26.14	41.12
Cation Exchange Capacity (CEC) $Cmol_c\,kg^{-1}$	31.5	48.28
Net Charge ($Cmol_cKg^{-1}$)	5.36	7.16
Correlation between pH & Net Charge	-0.9672*	
Correlation between soil OC& PZC	-0.9997*	
Correlation between pH & PZC	0.9988nd	
Regression value(Clay & OC) (r*<0.05)	0.2242*	

* (PZC= $2pH_{KCl}-pH_{water}$)

Haplaquept possesses higher net charge value than Fluvaquent. This has been attributed to the negative charge arising from the greater organic matter content. These two soils are more different by net charge due to the presence of dissociated acidic organic functional group or greater unblocked exchange sites and amount of iron, aluminium oxide and content of clay.

Conclusion

The charge characteristics of the two highly weathered soils Haplaquept and Fluvaquent indicate that organic matter plays an important role on soil surface charge. Results clearly indicate that clay and organic matter fraction have important effects on the negative surface charge. Iron and aluminium oxide provide a positive surface charge in the soil. Point of zero charge varies with soil according to the variation of organic carbon and sesquioxide/allophone content. Charge characteristics of soil are a function of organic carbon content and mineralogical composition of soil.

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Prediction of infiltration from soil hydraulic properties

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Abstract

Field and laboratory infiltration measurements using infiltrometers have been the only methods of effectively determining the infiltration rates of soils. Infiltration is mainly controlled by soil hydraulic properties, especially the hydraulic conductivity. Due to the ease with which the saturated hydraulic conductivity can be determined, it is often preferred to the unsaturated hydraulic conductivity in hydrological studies. It is well known that, at saturation the steady state infiltrability controls the infiltration process. Thus, it is very clear that the saturated hydraulic conductivity K_s and steady state infiltrability K_o may be closely related in one way or the other, as suggested in some few studies, wherein functions have been developed to relate these two parameters. However, these functions are often site specific and do not always carry out accurately all the time. Determination of K_o can be tedious and time consuming, whereas K_s can be easily determined in the laboratory. The present study aimed to assess the predictability of a modified Philip's equation by substituting K_s for K_o. In this study, field infiltration measurements were conducted in two soil types under three different land use systems with a single ring infiltrometer. Field and laboratory hydraulic and hydrologic experiments were conducted on soils in a turf grass, an arable land and a pastureland in the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. Goodness-of-fit was used to compare the measured and predicted cumulative infiltration amounts from both K_o and K_s. The results showed that there was a robust relationship between the measured and predicted cumulative infiltration amount values from the Philip's and modified Philip's equations, respectively for all three fields. However, the use of K_s in place of K_o produced the best outcome in all the study areas. Thus, substituting K_s for K_o in the Philip's infiltration equation can better predict cumulative infiltration amount. The proposed modified Philip's infiltration equation and the key parameters (i.e., S_θ and K_s) provide new understanding into the realistic flow processes in soil. Furthermore, the K_s in the new equation is very close to the measured K_o.

Keywords: Cumulative infiltration amount, manometer, saturated hydraulic conductivity, sorptivity, steady state infiltrability.

Introduction

"*The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them*" – Sir Lawrence Bragg, the Nobel laureate in physics (Breverton, 2009; Su, 2010). Infiltration studies are necessary in hydrological advancements, such as irrigation design and planning, estimation of water requirements for crops, monitoring of groundwater recharge and prediction of runoff and erosion (Tuffour and Bonsu, 2015). Infiltration measurements in the field are often coupled with complicated apparatus for the hydrological characterization of soils, and also require larger computation times, especially, when steady state flow is required. Since field infiltration measurements are conducted on spot-to-spot basis on a field scale, a large number of determinations is required to assess the magnitude and structure of the variation

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within the field. These measurements have to be repeated at different times, especially in soils where structure varies over time because of natural or anthropogenic factors (Prieksat et al., 1994).

Using small volumes of water, easily transportable equipment and conducting short-duration experiments is desirable to obtain infiltration data at a great number of locations over a large area with the realistic use of resources in terms of time and costs. However, the use of predictive models has been shown to offer a very reliable alternative. In respect of this, infiltration models have gained wide spread usage across the globe in past and recent times (Tuffour et al., 2015). In view of this, several studies, (e.g., Mirzaee et al., 2013; Parhi, 2014; Tuffour and Bonsu, 2015) have highlighted the importance of infiltration modelling as an alternative to field infiltration measurements. As a result, several infiltration models have been developed. According to Tuffour and Bonsu (2015), the purpose of these numerous models is to identify an accurate method for simulating infiltration process for field water management. However, no single model can be expected to best meet all underlying hydrological requirements concurrently. Hence, the selection of a particular model may depend on several factors, such as type of application, desired level of physical-mathematical rigor, and user preference (Clausnitzer et al., 1998). This necessitates the in-depth knowledge of the fundamental assumptions on which a particular model is developed for better application. This has resulted in the widespread adoption of some models such as those of Green and Ampt (1911), Philip (1957a,b,c), Horton (1941) and Kostiakov (1932). Among these, the Philip's equation has been frequently adopted owing to its simplicity and ease of computing its fitting parameters (Mbagwu, 1993).

One key shortcoming identified with the Philip's infiltration equation is the restrictive boundary condition applied by the assumptions of uniform and constant concentration of soil moisture, instantaneous surface ponding of non-infiltrated surface water and saturation of soil at steady state. The assumption that rainfall will cause immediate surface ponding generally is unsubstantiated under field conditions. Even under conditions of relatively high rainfall intensity, the time to surface ponding can be appreciable. Further, the assumption of uniform soil-moisture concentration and soil hydraulic properties rarely is observed under actual field conditions. Under field conditions, the soil is seldom at full saturation even when infiltration approaches steady state, especially due to air entrapment. The objective of this study was to compare infiltration equations in terms of precision and accuracy of estimated parameter confidence intervals using the steady state infiltrability and laboratory column saturated hydraulic conductivity as constants in the Philip's equation.

Theory

When water is applied into a dry soil, initially, most of the water is absorbed by the capillary potential of the soil matrix. The capillary force dominates the initial water infiltration process, however, as infiltration proceeds, the gravitational force dominates. For cumulative infiltration, the general form of the Philip's equation is expressed as:

$$I = S_\theta t^{0.5} + K_o t \qquad \text{Eq.1}$$

where,

I = Cumulative infiltration [L]

S_θ = Sorptivity [L/T$^{1/2}$]

K_o = Steady state infiltrability

t = Time [T]

The first term of equation (1) is responsible for the uptake of water by capillary forces, and dominates infiltration at small time intervals. The coefficient S_θ in the first term, referred to as sorptivity, defined as the ability of the soil to absorb and desorb water by capillarity may also be described in terms of pore-liquid geometry (Philip, 1957b). This parameter is not a directly measurable soil attribute, but may be derived from actual soil properties (Hanks and Ashcroft, 1976). From equation (1), it is clear that as infiltration proceeds with time, the coefficient K_o in the second term, which describes the ability of the soil to transmit water under gravity dominates the infiltration process (Jaynes and Gifford, 1977). Thus, this parameter becomes active at steady flow or at field saturation after very long periods of infiltration measurements. It follows that K_o should be equal to K_s. By this, Philip (1969) reported that for very long time intervals, K_o approaches K_{fs}. According to Swartzendruber and Youngs (1974), this approximation does not introduce any significant error in the computation of cumulative infiltration as a function time. However, Whisler and Bouwer (1970), Smiles and Knight (1976), Skaggs and Khaleel (1982) reported that the assumption of $K_o = K_{fs}$ resulted in over prediction of cumulative infiltration over larger time intervals. Since the determination of K_o requires very long times, Elrick et al. (1995) stated that the use of this approach is highly difficult due to the insufficient information from the measurement of steady state flow in the evaluation of field saturated hydraulic conductivity K_{fs} [L/T] when using the single or double ring infiltrometer. However, since early time measurements of K_s can be achieved under laboratory conditions with reasonable accuracy (Bonsu and Laryea, 1989), this parameter can be adopted as a substitute for both K_o and K_{fs} in order to reduce the measurement times of K_o from long hours to very short minutes, relative to steady flow rate measurements. In this regard, an approximation of $K_{fs} = K_s = K_o$ is assumed at steady state in this study. Hence, equation (1) can be described as:

$$I = S_\theta t^{0.5} + K_s \qquad \text{Eq.2}$$

Material and Methods

Description of study areas

Field hydrological studies were carried out during the dry periods of early September, 2016 to January, 2017 in three different fields with variable soil physical and hydraulic properties. The sites chosen for the measurements were located in a turf grass in the Department of Horticulture (Figure 1a), an arable field in the Plantations section of the Department of Crop and Soil Sciences (Figure 1b) and a pastureland located at the Beef and Dairy Cattle Research Station of the Department of Animal Science (Figure 1c), KNUST. The sites were selected since the occurrence of spatial variability was anticipated because of expected worm activity and the presence of dead root channels. The soils are classified as Ofin series (Stagni-Dystric Gleysol), Kumasi series (Plinthi Ferric Acrisol or Typic Plinthustult) and Asuansi series (Plinthic Acrisol) in the turf grass, arable and pastureland, respectively (FAO-UNESCO, 1988; WRB, 2014). The turf grass site is a grown grassland area with love grass (*Eragrotis curvula*) as the dominant grass species produced for commercial purposes, and has been under different tillage operations. The selected arable land was grown with cowpea (*Vigna unguiculata*) in the previous major season, but was colonized by the regrowth of Guinea grass (*Panicum maximum*). The terrain is generally undulating with average slope of about 5%. The pastureland was a one year cattle-grazed paddock with *Paspalum vaginatum* as the dominant grass. The terrain is undulating with slopes ranging from 1 – 5%.

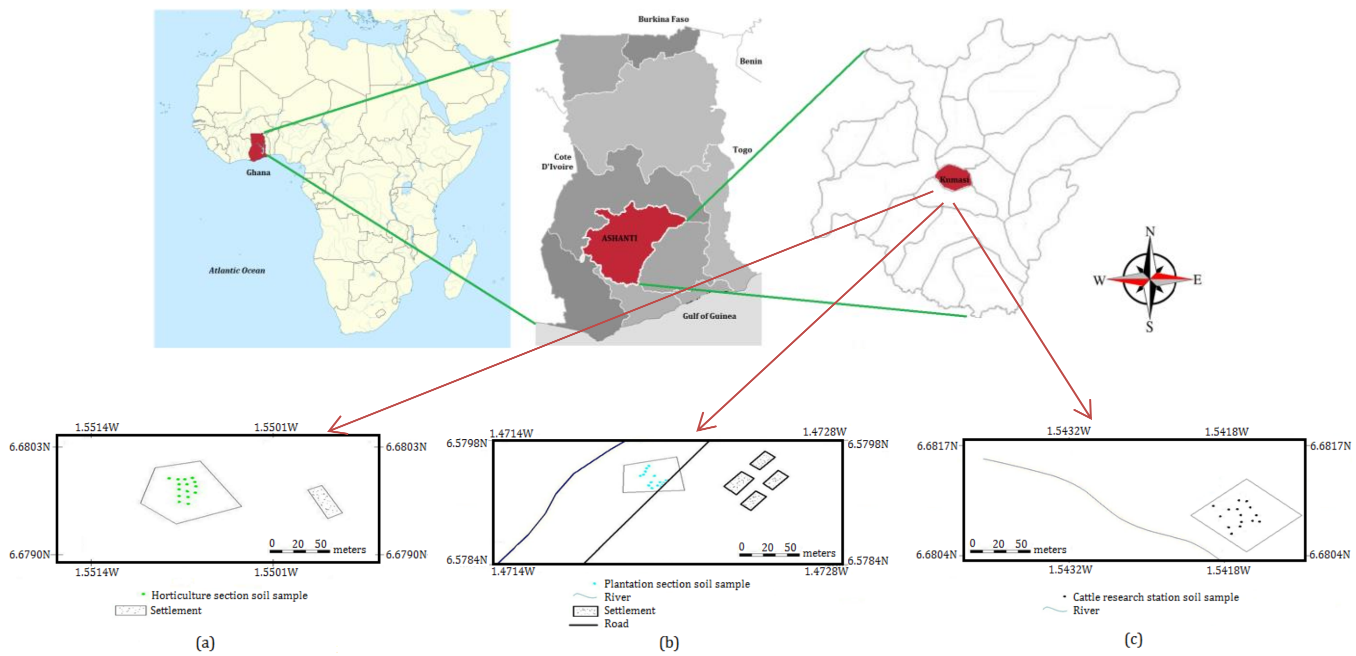

Figure 1. Map showing the outline of the experimental fields (a) turf grass experimental field (b) arable land experimental field (c) pastureland experimental field

Field infiltration measurements

Field infiltration studies were carried out in the selected study sites at fifteen (15) different spots enclosed within 30 cm diameter and 20 high single ring infiltrometers under both early time and saturated conditions. The experiments were designed to test predictions by investigating a range of saturated hydraulic conductivities, and initial and saturated soil water contents. The infiltrometer rings were pushed vertically into the soil to a depth of 10 cm to measure cumulative infiltration amounts and rates. The ponded infiltration experiments were conducted with an inclined plane manometer with angle of inclination β (herein 45°) (Plate 1). A plastic sheet was used to cover the surface of the soil as the water was being added, in order to prevent disturbance of the surface to cause slaking of aggregates and dispersion of clays. Water was gently added to give hydraulic head of 5 cm in the extended cylinder. The plastic sheet was removed and a flexible tubing, which had already been filled with water, was used to connect the surface of the water to a falling head device in the form of a piezometer made of burette connected to the inclined manometer, which allowed measurement of the cumulative volume of infiltration. The fall of the hydraulic head h_o at the soil surface was measured as a function of time t from the inclined water manometer. Early time measurements were conducted at regular time intervals of 10 seconds for two minutes after ponding when infiltration was very fast for the determination of sorptivity. The soil surface was then ponded with water until steady state was reached (approximately 45 minutes), after which the infiltration measurements were resumed at 2 minutes interval for ten minutes for the assessment of steady state flow. The depth of infiltration was computed from the relation:

$$Sin\beta = \frac{h_o}{h_t} \quad \text{Eq.3}$$

$$h_t = \frac{h_o}{Sin\beta} \quad \text{Eq.4}$$

where,

h_o = Inclined height [L]

h_t = Vertical height = Infiltrated volume of water [L]

β = Angle of inclination [°]

Cumulative infiltration amount (I) was calculated from the volume of infiltrated water as presented in the relation (Tuffour, 2015):

$$I = \frac{Q}{A} \quad \text{Eq.5}$$

where,

I = Cumulative volume of infiltrated water [L]

A = πr^2; Surface area of the ring infiltrometer [L^2]

r = $0.5d$; Radius of ring [L]

d = Ring diameter [L]

Sorptivities were estimated from the linear plots of cumulative infiltration amount against the square root of time for the first two minutes of infiltration measurements.

Plate 1. Set up of infiltration apparatus

Laboratory measurements

Saturated hydraulic conductivity was determined from laboratory column studies using the falling-head permeameter (Bonsu and Laryea, 1989). Moisture content was determined by gravimetric method. Particle size analysis was determined by the hydrometer method. The United States Department of Agriculture (USDA) Textural Classification Triangle was used to classify the soils based on the results obtained from the analysis.

Results and Discussion

The results on the soil physical and hydraulic properties of the three experimental fields are summarized in Table 1. Soils were predominantly sandy in texture in the three fields, with mean sand contents ranging from 83 – 89%. The average bulk densities ranged from 1.2 – 1.5 g/cm^3 with average porosities of 43 – 53%. The average initial moisture contents were 4, 24 and 26% at the pastureland, turf grass and arable fields, respectively. Generally, the CVs of the initial soil moisture content were high in all the three fields (34.82 – 61.28%), and this could be a key factor in the high variability observed in the soil hydraulic properties (Table 2). In addition, the results showed that the pastureland recorded the lowest bulk density among the three study areas. In view of the relatively dry soil in the pastureland (θ_v = 4.10%) and the high clay content (7.50%) compared to the other fields, this interesting observation was expected. Clay soils have the ability to crack when dry, which increased the creation of macropores in the pastureland, thereby reducing the bulk density and increasing the total porosity eventually. This observation was also true for the arable field which had a clay content of 7.20%. However, the highest moisture content of 26% recorded in the arable field could be attributable to the presence of the high vegetation cover in the field. The soil particle fractions did not significantly differ among the three fields, indicating that the soils had good scatter of texture and were intrinsically similar among the land use systems (Kelishadi et al., 2013).

Table 1: Soil physical and hydraulic properties of the experimental sites

Soil property	Experimental field		
	Turf grass	Arable	Pastureland
Sand (%)	89.00 (4.42)	86.00 (3.41)	83.00 (3.69)
Silt (%)	5.30 (65.93)	6.70 (32.82)	9.00 (19.82)
Clay (%)	5.30 (13.51)	7.20 (23.51)	7.50 (31.14)
Texture	Sandy loam	Loamy sand	Loamy sand
ρ_b (g cm^{-3})	1.50 (7.82)	1.40 (5.36)	1.20 (10.77)
f (%)	43.00 (10.20)	47.00 (6.13)	53.00 (11.38)
af (%)	24.00 (33.65)	33.00 (27.54)	50.00 (11.53)
θ_v (%)	20.00 (34.82)	26.00 (37.02)	4.10 (61.28)
K_s (cm min^{-1})	0.25 (81.87)	0.81 (42.81)	1.20 (49.59)
S_θ (cm min$^{-1/2}$)	0.75 (88.26)	2.60 (51.89)	3.40 (49.19)
K_o (cm min^{-1})	0.20 (88.07)	0.58 (42.88)	0.76 (51.08)
i (cm min^{-1})	0.16 (83.90)	0.57 (42.96)	0.73 (50.62)
I (cm)	9.60 (81.11)	34.00 (47.02)	44.00 (61.48)

ρ_b = Bulk density; f = Total porosity; af = Air-filled porosity; θ_v = Initial volumetric water content; K_s = saturated hydraulic conductivity, K_o = steady state infiltrability, S_θ = Sorptivity, I = Cumulative infiltration amount, i = Infiltration rate; () = Coefficient of variation (%)

From Table 1, the coefficients of variation of the soil hydraulic properties were greater than 36%, revealing very high spatial variability as described by Wilding (1985) and Tuffour et al. (2013; 2016). The greatest values of CV of the soil hydraulic properties were noted in the turf grass, with the highest being S_θ (88.26%) and the least I (81.11%). The high observed high CVs could be attributed to the heterogeneity of large-sized soil pores (Kelishadi et al., 2013). Consistent with the report by Kelishadi et al. (2013), the soil hydraulic properties were highly variable as evidenced by their CV values. An interesting trend observed was that the soil hydraulic properties (K_s, S_θ, K_o, i and I) decreased with increasing sand content. The corresponding CVs, however, increased with increasing sand content. This shows a low frequency of macropores in the soils at the turf grass site, which recorded the highest percentage of sand. The high values of the soil hydraulic properties recorded in the pastureland was as a result of the relatively high clay content, with increased macropores due to cracking. These cracks served as pathways through which water quickly entered the soil. Further, the low initial moisture content of the soil could have resulted in an increased affinity of the soil to water due to high matric forces as evidenced by the high S_θ value of 3.4 cm min$^{-1/2}$ in Table 2. In contrast, Tuffour et al. (2014) observed severe reductions in soil hydraulic parameters in pastureland, due to soil compaction resulting from structural damage and destruction of macropores due to grazing. Hence, the soils in the pastureland could be described as resilient, and are highly recommended for pastureland establishment (Tuffour et al., 2014). Additionally, the results showed that the averages of soil hydraulic properties were significantly affected by soil textural class and land use system.

In this study, the goodness-of-fit of the proposed modification of the Philip's equation and its ability to predict cumulative infiltration amount was evaluated using the root mean square error (RMSE) and the coefficient of determination (R^2). The R^2 values were high and ranged from 0.97 – 1.00. Similarly, the predictability of the Philip's equation was tested using the RMSE and R^2. The R^2 values were also high, ranging from 0.76 – 0.99. Values of the RMSE showed that the predicted cumulative infiltration amounts from both equations were closer to the measured ones. Thus, the predicted cumulative infiltration amount from K_s showed no disparity with that from K_o, even though the predictability was better with K_s than K_o (Table 2; Figures 2). The linear relationships between the measured and predicted cumulative infiltration amounts (Table 2) indicate the appropriateness of predicting infiltration form these simple soil hydraulic properties (i.e. sorptivity and laboratory-measured saturated hydraulic conductivity).

Table 2. Predictability of cumulative infiltration amount from steady state infiltrability and saturated hydraulic conductivity

Experimental field	Interactions	Prediction index			
		R^2	Slope	Intercept	RMSE
Turf grass	I_m vs I_{K_o}	0.97	0.58	0.34	0.0043
	I_m vs I_{K_s}	0.99	0.38	-0.059	0.0021
Arable	I_m vs I_{K_o}	0.76	0.60	3.80	0.053
	I_m vs I_{K_s}	1.0	0.39	-0.058	0.0012
	I_m vs I_{K_o}	0.99	0.39	0.39	0.005
Pastureland	I_m vs I_{K_s}	0.99	0.49	-0.57	0.003

R^2 = Coefficient of determination; I_m = Measured infiltration amount; I_{K_o} = Predicted infiltration amount from steady state infiltrability; I_{K_s} = Predicted infiltration amount from saturated hydraulic conductivity; RMSE = Root mean square error

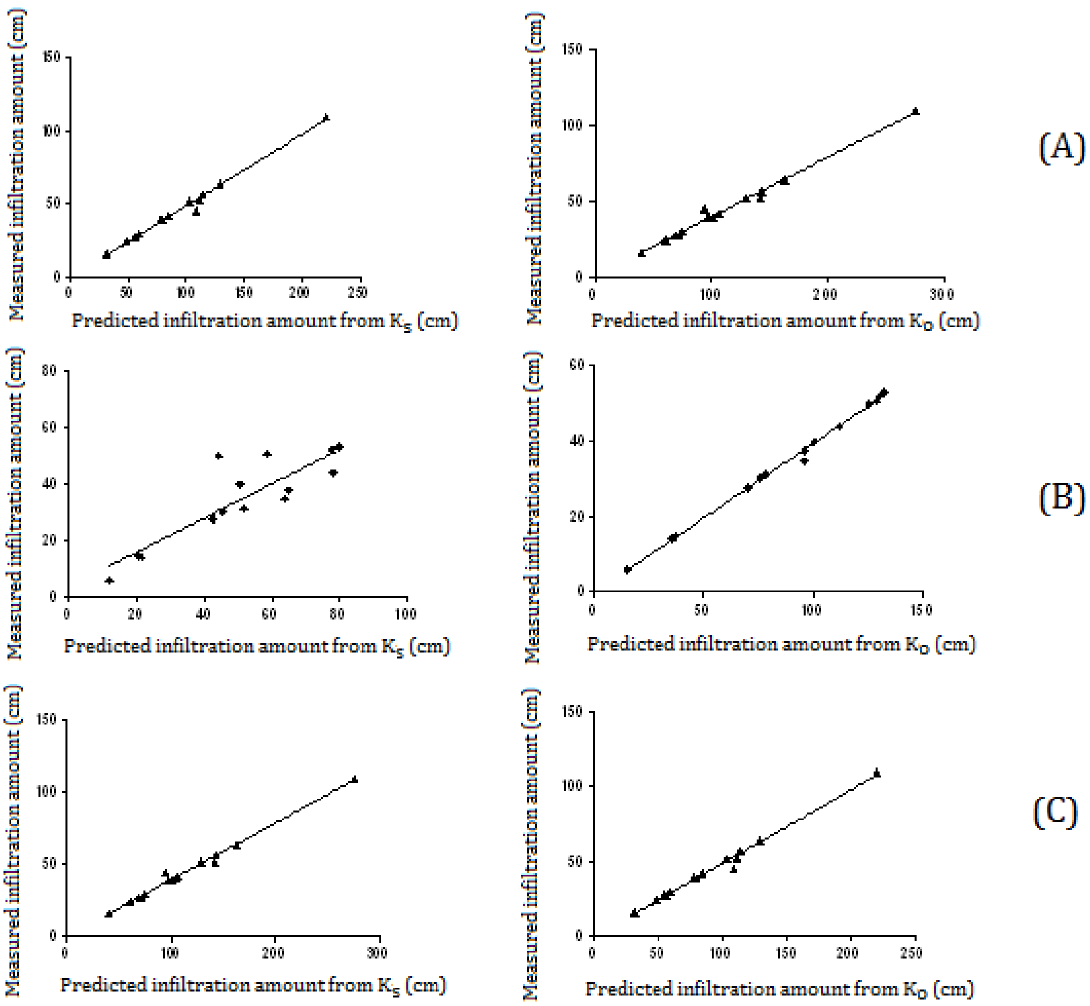

Figure 2. Goodness-of-fit of measured and predicted cumulative infiltration amount from K_o and K_s for soils (a) arable field (b) pastureland (c) turf grass

Overall, the lowest RMSE values were obtained with the modified equation. Thus, even though both forms of the equation gave very good predictions, the performance of the modified equation was found to be better in all the study sites. The differences in the RMSE values for the two equations at the different locations could be attributed to the variations in site conditions, such as soil particle size distribution (Haghighi et al., 2010) and soil structure due to their high influence on infiltration. Thus, the suitability of the two equations for the prediction of infiltration can be site-specific. This implies that in this study, the impact of spatial variation within relatively short distances and the occurrence of preferential flow through the macropores created by cracking of clay significantly affected the data and the model parameters. Hence, the predictability of infiltration models should be validated under different soil conditions (Haghighi et al., 2010). In this study, the low predictive ability of the Philip's equation for predicting the final infiltration amount could be due to the longer time taken to approach steady state infiltrability, owing to low initial soil moisture contents, especially in the pastureland and high soil porosities observed in all three fields.

Comparisons on correlation between K_s – and K_o – related parameters were carried out in the study using classical regression technique. Significant correlations were observed between K_o and K_s, as well as cumulative infiltration amounts predicted from these two parameters (Table 3; Figures 3). The results as shown in Table 3 is a clear evidence that the performance of equation (2) was better than that of equation (1). This confirms the reports by Philip (1957b), Youngs (1968) and Skaggs et al. (1969) that the approximation made in equation (1) is not physically consistent, and hence, predicts low infiltration values for long time periods. Curve fitting method has also been used to accurately relate the Philip's equation to measured infiltration data. For instance, Whisler and Bouwer (1970) obtained close agreement with experimental values when the parameters were determined by curve fitting, but the physical significance of the parameters was laid off. Similarly, Smiles and Knight (1976) suggested that the appropriateness of infiltration data to the 2-parameter Philip equation can be determined by plotting $It^{\frac{1}{2}}$ as a function of $t^{\frac{1}{2}}$.

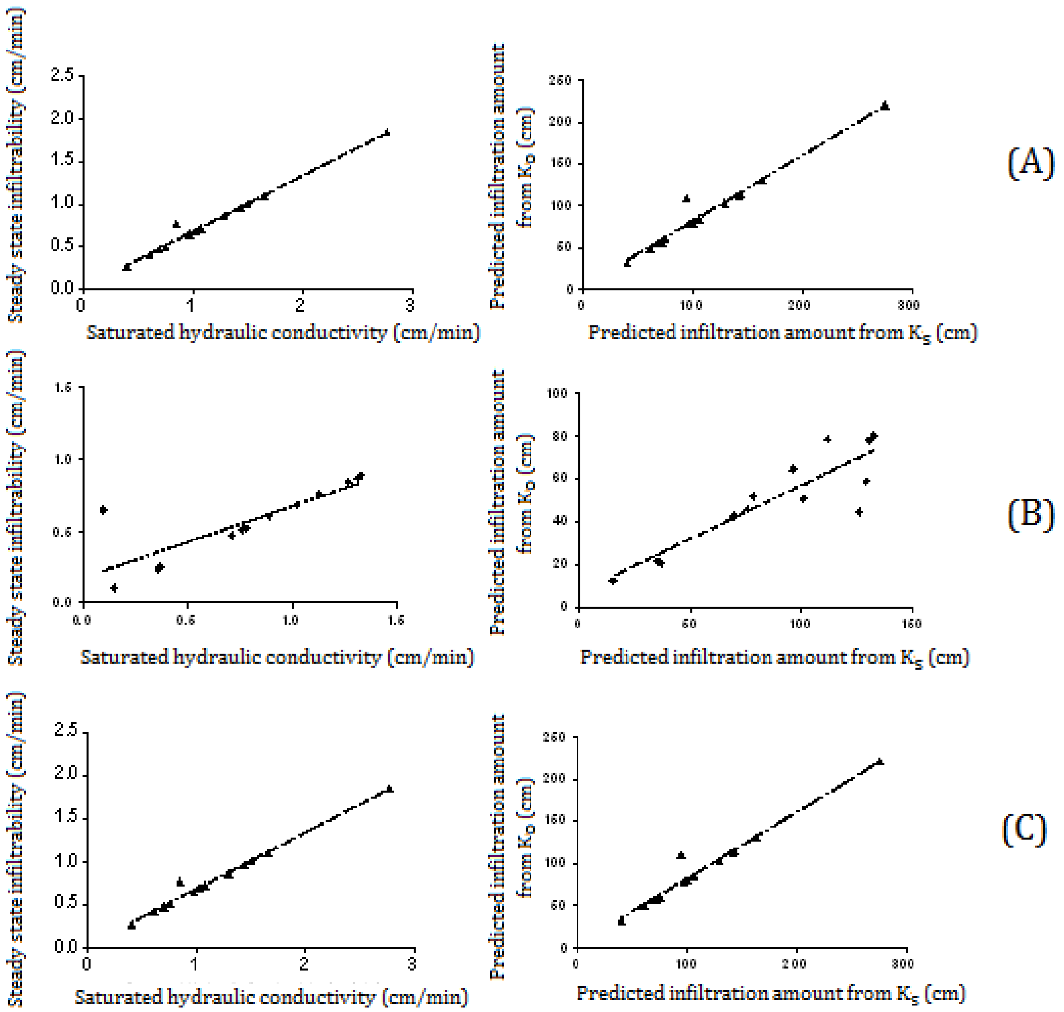

Figure 3. Goodness-of-fit of K_o and K_s and their predicted cumulative infiltration amounts for soils (a) arable field (b) pastureland (c) turf grass

Table 3. Summary of correlation analysis

Experimental field	Interaction	Correlation index		
		r	Confidence interval (95%)	
			Lower limit	Upper limit
Turf grass	I_{K_o} vs I_{K_s}	0.99	0.98	1.00
	K_o vs K_s	1.00	1.00	1.00
Arable	I_{K_o} vs I_{K_s}	0.88	0.67	0.96
	K_o vs K_s	0.85	0.59	0.95
Pastureland	I_{K_o} vs I_{K_s}	0.98	0.94	0.99
	K_o vs K_s	0.99	0.97	1.00

r = Correlation coefficient; K_o = Steady state infiltrability; K_s = Saturated hydraulic conductivity

Conclusion

This study evaluated the acceptability and applicability of substituting K_s for K_o in the Philip's equation. The Modified Philip's infiltration model was more suitable for predicting water infiltration into the soils than the Philip's equation. Consequently, the Modified Philip's model is recommended for use in coarse textured soils. This could be of immense importance in the design and planning of irrigation projects. For instance, once the values of the infiltration rate are constant, the basic infiltration rate has been reached and the established curve can be used to determine how long it will take to infiltrate a certain amount of water. This information is important for irrigation water management. The proposed new infiltration equation and the key parameters (i.e., S_θ and K_s) provide new understanding into the realistic flow processes in soil. The new equation not only fits the data very well; it also has considered K_s to imply that infiltration into soils at steady state occurs under full saturation of the topsoil. Furthermore, the K_s in the new equation is very close to the measured K_o.

Soil hydraulic properties were highly variable among the different soil types and land use systems. On the average, the soil hydraulic properties were significantly affected to a large extent by soil structure and management practices, but not by the soil textural class. Land use systems significantly affected the soil hydraulic parameters (hydraulic conductivity, steady-state infiltrability and sorptivity). Soil hydraulic conductivity was higher in the pastureland soils as compared to the other cultivated soils, which is related to the higher clay content and higher degree of cracking of the pastureland soil.

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Evaluation of land suitability for main irrigated crops in the North-Western Region of Libya

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Abstract

Land suitability analysis can help to achieve sustainable crop production with a proper use of the natural resources. The current study was carried out on the soils of north-western area of Libya to assess their morphological, physical and chemical properties and their suitability for growing irrigated crops. The studied area lies between latitudes 32° 30′ 00.9" and 32° 57′ 34.2'' N and between longitudes 11° 35′ 08.4" and 11° 45′ 09.2" E. Two suitability methods (Sys &Verhey and Storie methods) were used to assess the land suitability of this area. According to Sys and Verhye method, the soils of the studied area varied in the suitability for irrigation between highly suitable (S1) to marginally suitable (S3). However, according to modified Storie index method the soils productivity, ranged from excellent (grade 1) for agriculture to non-agricultural (grade 6). The modified Storie index method was more effective in assessing the land suitability of this area. The drip irrigation system was also more suitable than surface irrigation method for most of the soils of the studied area. The indeces of soil suitability rating and percentage for growing alfalfa, sorghum, barley, maize, millets, wheat and safflower were higher compared to those for growing soybean, sunflower and sesame. Onion and green pepper crops were moderately suitable to be grown in 42% of the soils of the studied area while the other vegetables were not suitable to be grown in most of the soils of the studied area. The evaluated fruit trees could be arranged according to the soil suitability rating and percentage in the order of date palm > olives > guava > citrus > banana. The results also revealed that the studied area has a good potential to produce the selected crops under irrigation provided that the water requirements for these crops are met. The main limiting factors for land suitability for growing crops are soil texture, soil depth, calcium carbonate, alkaline pH and soil salinity.

Keywords: Land evaluation, irrigation methods, suitability for crops.

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Introduction

Libya is one of the developing countries that are searching for alternatives in order to increase food production due to the rapid increase of population, particularly in the northern region (Elaalem, 2010). This region has significant natural resources, such as soil, water, natural vegetation and suitable climate as well as human resources. Approximately 70 percent of Libyan people live in this region (Ben Mahmoud et al., 2000). Libya is an arid country where water resources are divided into surface water and groundwater. The groundwater represents more than 97 percent of the water resources. The country aims to obtain self-sufficiency in agricultural products (Nwer, 2005). The assessment of land response to certain uses is necessary to reach the sustainable management of the land (Kamali et al., 2012). Land evaluation is a tool of land use planning for sustainable agriculture (Shahbazzi et al., 2009).

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The agricultural land suitability assessment is defined as the process of land performance assessment when the land is used for alternative kinds of agriculture (Prakash, 2003; Mu, 2006; He et al., 2011; Darwish and Abdel Kawy, 2014; Diallo et al., 2016; Ahmed, 2016). The principle purpose of the agricultural land suitability evaluation is to predict the potential land and its limitation for crop production (Pan and Pan, 2012; AbdelRahman et al., 2016). In Northern Libya, evaluating the land suitability for crops is vital for land use planning and agricultural development.

The main objective of this research is to assess the morphological, physical and chemical properties of the soils of selected areas of the north-western region of Libya and their suitability for growing the main crops (Field crops, vegetables and fruits trees) and their potentiality after correcting some limitation factors.

Material and Methods

Field description and soil sampling

The area under investigation is located in the North-Western area of Libya. It lies between latitudes of 32° 30′ 00.9" and 32° 57′ 34.2'' N and between longitudes of 11° 35′ 08.4" and 11° 45′ 09.2" E (Figure 1). Twelve soil profiles representing the area under study were selected on the basis of available geomorphologic information. These profiles were dug up to the bedrock or to the extremely hard layer and described for their morphological characteristics according to the standard procedures (Fanning and Fanning 1989; FAO, 2006; Soil Survey Staff, 2014). Soil samples were collected in clean bags from profile layers based on the morphological variations in the soil profiles. The samples were transferred to the laboratory air dried, crushed, sieved with a 2 mm-sieve and kept for different soil analysis. Soil color for both dry and moist samples was determined using Munsell color charts (Soil Survey Staff, 1975).

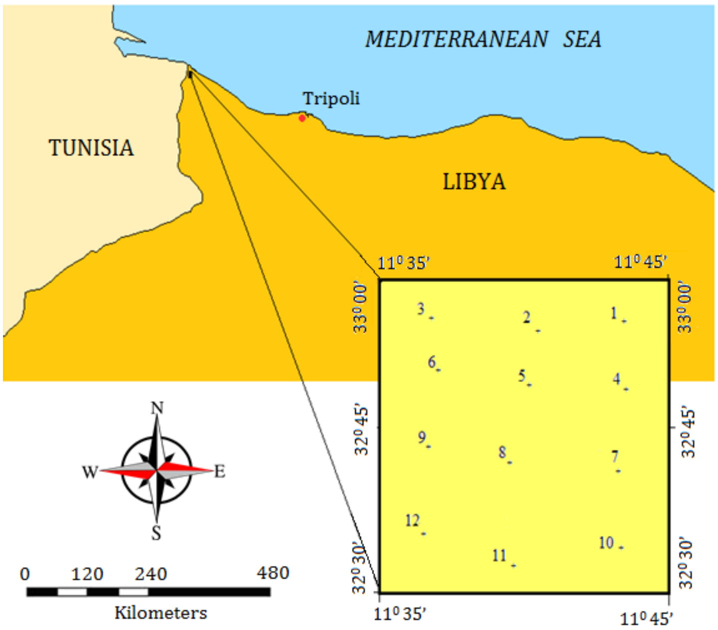


Figure 1. The location map of the study area

Climate of the Study Area

Northern Libya is situated in the Mediterranean climatic zone that is characterized by a hot and dry summer with cold and rainy winter. The most important climatic characteristics that are necessary for the suitability determination (temperature, rainfall, relative humidity, etc.) were collected from Zuara metrological station (last thirty years). The mean annual temperature was 19.4 °C, with a maximum temperature of 24.1 °C and a minimum temperature of 14.6 °C. The average annual rainfall was 188.0 mm/y and the relative humidity was 75 %, while the average annual evaporation was 1504 mm/year.

Laboratory analysis

Some physical and chemical properties of the soil samples were determined. Particle size distribution was performed on the studied soils samples according to Gavlak et al. (2005). Soil reaction (pH) of a 1:1 soil to water suspension was measured using a glass electrode. Calcium carbonate ($CaCO_3$) was determined using a calibrated Collie's calcimeter (Nelson, 1982). Soil salinity (ECe) in the saturated soil paste extract was determined using a conductivity meter (Rhoades, 1982). Determination of gypsum was done in a reference to a graph showing the relation between the concentration and electrical conductivity of gypsum solution (Nelson, 1982). The exchangeable sodium percentage (ESP) was calculated. Exchangeable sodium was estimated using ammonium acetate method while the cation exchangeable capacity (CEC) was determined using the sodium oxalates method (Bashour and Sayegh, 2007). The soil organic matter was estimated using Walkley-Black method (Bashour and Sayegh, 2007).

Soil classification

The prevailing climate of the studied area is extremely arid and the dominant soil moisture regime is aridic (torric) with a thermic soil temperature regime. The soils were classified up to the sub group according to Soil Taxonomy (Soil Survey Staff, 2014).

Land capability evaluation

Qualitative land suitability studies were conducted using both simple limitation methods and other information of climatic conditions. Two methods in determining the total ranking of each specific land unit were applied and their outcomes were compared with soil productivity. These methods included i) Simple limitations and ii) modified Storie index.

1. Simple limitations method (Sys and Verhey, 1978)

To evaluate the land suitability for irrigation, the parametric evaluation system of simple limitations (Sys and Verhye, 1978) was applied using soil characteristics. These characteristics deal with the environmental factors of drainage properties, soil physical and chemical properties. They are rated and used to calculate the capability index for irrigation (Ci) according to the formula:

$$Ci = (t \times W/100 \times S1/100 \times S2/100 \times S3/100 \times S4/100 \times n/100)$$

Where: t is the topographic rating, W is the wetness rating, S1 is the soil texture rating; S2 is the soil depth rating, S3 is the soil calcium carbonate status, S4 is the soil gypsum status and n is the soil salinity and alkalinity rating.

2. Modified Storie index (O'Geen, et al., 2008).

The Storie index (Storie, 1978) is a semi-quantitative rating method of soils that is used mainly for irrigated agriculture based on crop productivity data that are collected from major California soils in the 1920s and 1930s (O'Geen et al., 2008). The Storie index assesses the productivity of the soil using four characteristics factors of A, B, C and X; with a score ranging from 0 to 100 % that is determined for each factor. So, the original Storie index has been modified (O'Geen et al., 2008), and following the modified version was used in this study.

$$\text{Storie index rating} = [(A/100) \times (B/100) \times (C/100) \times (X/100)] \times 100$$

Where: Factor A is the degree of soil profile development, factor B is the surface texture, factor C is slope and factor X is other soil and land scape conditions including drainage, alkalinity, fertility, acidity, erosion, and microrelief subfactors.

Land suitability assessment

1. Land suitability for irrigation

The comparison among the different irrigation methods based on the parametric evaluation system was carried out according to the methods suggested by Sys et al. (1991). These parameters were slope, drainage properties, electrical conductivity, calcium carbonates status, soil texture and Soil depth. The Suitability index for irrigation (Ci) was developed using the following equation:

$$Ci = (A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100)$$

Where: A is the soil texture rating, B is the soil depth rating, C is $CaCO_3$ status, D is the electrical conductivity rating, E is the drainage rating and F is the slope rating.

2. Land suitability for field crops, vegetables and fruit trees

The quantitative analysis of the environmental conditions and soil characteristics were used to estimate the soil suitability for certain crops (SSCC). Ten field crops (wheat, barley, sesame, alfalfa, maize, sorghum, millets, safflower, soybean and sunflower), five vegetables crops (beans, tomato, potato, onion and green pepper) and five fruit trees (date palm, olive, guava, citrus and banana) were selected to assess their suitability to be grown in the studied area. The soil characteristics of the investigation profiles and the crop requirement parameters were matched to obtain the suitability classes according to Sys et al. (1993).

Results and Discussion

1. Morphological characteristics

The main morphological aspects of the studied soil profiles are shown in Table 1. The results reveal that the topography of the landscape is almost flat to gentle sloping. The soils have a depth which varies from deep to very deep and fairly well drained, having a sandy texture. Soil structure differs with depth. It has single grains in the top surface layers of all soil profiles and week to massive platy and subangular blocky structure in the subsoil layers. Wet consistence agrees well with soil texture and it is loose and very friable to friable while dry consistence is soft to extremely hard. The dominant soil color in the studied soil profiles is brown (7.5YR 5/4, dry to 7.5YR 4/4, moist) to strong brown (7.5YR 5/6, dry) to brown (7.5YR 4/4, moist). However, reddish yellow (7.5YR 6/6, dry) to strong brown (7.5YR5/6, moist) is also detected. In general, the soil color seems to be affected by calcium carbonate content and soil depth. The layer boundaries of all profiles are abrupt in distinctness and smooth in topography.

Table 1. Morphological description of the studied soil profiles.

Profile No	Depth (cm)	Soil Color			Texture (I)	Soil Structure (II)			Consistence (III)		Boundary (IV)
		Hue	Dry	Grade		Grade	Size	Type	Dry	Moist	
1	0 -25	7.5 YR	6/6	5/6	S	-	-	sl	so	loose	as
	25 - 70	7.5 YR	7/6	6/6	S	1	f	pl	slh	friable	as
	70 - 95	7.5 YR	8/3	7/3	S	2	m	pl	slh	friable	as
	95 - 160	7.5 YR	7/6	6/6	S	3	m	pl	h	friable	-
2	0 - 35	7.5 YR	5/6	4/4	S	-	-	sl	so	loose	as
	35 - 115	7.5 YR	5/6	4/4	LS	1	f	pl	slh	v-friable	as
	115 - 160	7.5 YR	6/4	5/6	SL	2	m	pl	h	friable	-
3	0 - 20	7.5YR	7/6	5/6	SL	-	-	sl	so	loose	as
	20 - 40	5YR	7/6	5/6	S	1	f	sbk	h	friable	as
	40 - 110	7.5YR	7/4	6/6	SL	2	m	sbk	vh	friable	-
4	0 - 25	7.5 YR	6/8	5/8	LS	-	-	sl	so	loose	as
	25 - 120	7.5 YR	6/6	5/6	S	-	-	sl	so	loose	as
	120 - 150	7.5 YR	6/6	5/6	S	1	f	pl	slh	friable	-
5	0 - 30	7.5 YR	6/8	5/8	LS	-	-	sl	so	loose	as
	30 - 50	7.5 YR	6/6	5/6	LS	2	m	pl	exh	friable	-
6	0 - 20	7.5 YR	5/4	4/4	S	-	-	sl	so	loose	as
	20 - 65	7.5 YR	5/4	4/4	S	1	f	sbk	slh	v-friable	as
	65 - 130	7.5 YR	5/4	4/4	S	2	m	sbk	vh	friable	-
7	0 -30	7.5 YR	5/4	4/4	S	-	-	sl	so	loose	as
	30 - 65	7.5 YR	5/4	4/4	SL	1	f	pl	slh	v-friable	as
	65 - 100	7.5 YR	5/6	4/4	LS	1	f	sbk	h	friable	as
	100 - 150	10 YR	5/4	3/3	LS	2	m	sbk	h	friable	-
8	0 - 20	7.5 YR	5/6	4/4	S	-	-	sl	so	loose	as
	20 - 60	7.5 YR	5/4	4/4	LS	1	f	pl	h	friable	as
	60 - 90	7.5 YR	5/8	4/4	LS	2	m	pl	h	friable	as
	90 - 150	7.5 YR	5/4	4/4	LS	3	co	sbk	vh	friable	-
9	0- 30	7.5YR	7/6	6/6	S	-	-	sl	so	loose	as
	30 - 50	5YR	6/6	5/6	S	-	-	sl	exh	loose	-
10	0 -15	7.5 YR	5/6	4/4	SL	-	-	sl	so	loos	as
	15 - 50	7.5 YR	6/4	5/6	SL	1	f	sbk	slh	v-friable	as
	50 - 150	7.5 YR	6/4	5/6	S	2	m	sbk	h	friable	-
11	0 - 40	7.5 YR	5/4	4/4	LS	-	-	sl	so	loos	as
	40 - 90	7.5 YR	5/4	4/4	SL	1	f	sbk	slh	v-friable	as
	90 - 120	7.5 YR	5/4	4/4	SL	2	m	sbk	h	friable	-
12	0 - 35	7.5 YR	5/6	4/4	SL	-	-	sl	so	loos	as
	35 - 70	7.5 YR	5/6	4/4	SL	1	f	pl	vh	friable	-

Abbreviations:

Texture (1) : S = Sand, LS= Loamy Sand and SL= Sandy Loam.

Soil structure (II) : 1= weak, 2= moderate, 3=strong, f=fine m=medium, co= coarse, sl=structureless, pl=platy, sbk= subangular blocky.

Consistence (III) : so = soft, slh = slightly hard, h= hard, vh= very hard, and exh = extremely hard.

Boundary (IV) : as = abrupt smooth

2. Soil properties

Selected soil physical and chemical properties of the study area are shown in Tables 2 and 3. Soil texture throughout the entire depth of these soil profiles is coarse and varies between sand to sandy loam. Most of soil samples are dominated by free calcium carbonate (<100 g/kg) with a few exceptions (subsurface layers of profiles 3, 7 and 11) that are slightly or moderately calcareous (>100 g/kg) (FAO, 2006). The results also reveal that the gypsum content is very low and ranges between 0.1 and 49 g/kg, with a few exceptions of the subsurface layers of profile 5 and 6 that have a medium level of gypsum of 74.5 and 73.1 g/kg, respectively, (FAO, 1988).

Table 2. Soil texture, calcium carbonate ($CaCO_3$) and gypsum contents as well as calcification of the investigated soil profiles

Profile No.	Depth, cm	Soil Texture, Grade	$CaCO_3$, g/kg	Gypsum, g/kg	Classification
1	0 -25	Sand	34	0.1	Typic Torripsamments
	25 - 70	Sand	49	0.4	
	70 - 95	Sand	94	0.5	
	95 - 160	Sand	20	0.4	
2	0 -35	Sand	10	0.6	Typic Torripsamments
	35 - 115	Loamy Sand	22	0.6	
	115 - 160	Sandy Loam	80	0.3	
3	0 – 20	Sandy Loam	56	0.9	Typic Haplocalcids
	20 – 40	Sand	86	1.9	
	40 - 110	Sandy Loam	329	32	
4	0 – 25	Loamy sand	41	0.8	Typic Torripsamments
	25 - 120	Sand	26	6.9	
	120 – 150	Sand	40	0.5	
5	0 – 30	Loamy sand	86	0.6	Lithic Petrogypsids
	30 – 50	Loamy sand	23.6	74.5	
6	0 -20	Sand	30	0.3	Typic Haplogypsids
	20 – 65	Sand	77	0.9	
	65 130	Sand	35	73.1	
7	0 – 30	Sand	26	0.7	Typic Natrargids
	30 – 65	Sandy Loam	44	6.6	
	65 – 100	Loamy sand	72	43.7	
	100 – 150	Loamy Sand	158	41.2	
8	0 – 20	Sand	26	1.0	Typic Haplosalids
	20 – 60	Loamy Sand	85	36.2	
	60 – 90	Loamy Sand	96	43.6	
	90 - 150	Loamy Sand	70	43.4	
9	0 - 30	Sand	57	0.4	Lithic Torripsamments
	30 - 50	Sand	49	0.5	
10	0 – 15	Sandy Loam	42	0.6	Typic Torriorthents
	15 – 50	Sandy Loam	15	0.5	
	50 – 150	Sand	27	0.5	
11	0 – 40	Loamy Sand	59	0.5	Typic Haplocalcids
	40 – 90	Sandy Loam	82	1.0	
	90 - 120	Sandy Loam	23	49	
12	0- 35	Sandy Loam	69	0.4	Typic Torriorthents
	35- 70	Sandy Loam	42	48.2	

Soil reaction (pH) varies considerably between 7.4 and 8.6, indicating a slight to moderate alkaline soil reaction (FAO, 2006). Most values of soil salinity (EC_e) indicate non-saline or slightly saline soils (FAO, 1988) except those of profiles 4, 7 and 8 that are moderate to highly saline (11.9 to 35.6 dSm^{-1}). Also, the worst soil salinity values were belonged to profile 8 (30.7-35.6 dSm^{-1}). Moreover, the soils generally have low organic matter content (less than 10 g/kg) due to the prevailing arid climate and barren nature of the soils. In addition, the coarse-textured soils of the study area has a low cation exchangeable capacity (CEC < 7 cmol (+)/ kg).

Table 3. Some chemical properties of the studied soil profiles

Profile No.	Depth, cm	pH (1:1)	EC_e, dSm^{-1}	OM, g/kg	CEC, cmol (+)/Kg	ESP , %	SAR
1	0 -25	7.4	0.3	2.4	3.6	3.1	0.3
	25 - 70	7.8	1.9	0.5	3.8	1.1	0.6
	70 - 95	7.7	2.7	1.4	4.6	1.3	2.0
	95 - 160	7.6	3.2	1.9	2.0	5.0	2.1
2	0 -35	8.1	0.3	3.8	3.1	6.8	0.6
	35 - 115	7.6	0.3	3.6	2.9	7.5	0.4
	115 - 160	8.2	1.9	2.1	3.0	5.7	8.2
3	0 – 20	8.3	0.3	1.9	4.4	4.6	0.4
	20 – 40	8.3	0.3	6.6	3.9	5.6	0.4
	40 - 110	8.3	0.3	2.4	4.4	4.4	0.4
4	0 – 25	7.8	11.9	2.4	2.8	2.5	11.8
	25 - 120	8.8	12.2	2.5	3.9	7.7	8.5
	120 – 150	8.4	19.5	1.7	5.1	6.1	18.1
5	0 – 30	7.7	7.2	5.3	5.9	5.8	10.9
	30 – 50	7.5	6.1	3.5	3.7	4.7	8.2
6	0 -20	8.0	0.8	6.0	3.1	4.4	0.5
	20 – 65	8.0	0.6	2.8	2.8	5.1	1.2
	65 130	7.9	0.8	1.5	2.7	4.6	0.8
7	0 – 30	8.5	0.6	6.4	3.6	1.9	1.3
	30 – 65	8.3	13.6	5.7	4.2	39.6	13.2
	65 – 100	8.4	15.2	5.2	6.3	20.9	11.8
	100 – 150	7.8	7.0	2.8	2.9	10.5	9.3
8	0 – 20	8.6	33.7	4.3	2.7	5.1	31.5
	20 – 60	8.2	35.4	5.4	3.6	9.0	24.1
	60 – 90	7.9	30.7	8.3	4.4	5.8	27.6
	90 - 150	7.4	35.6	6.6	4.3	5.6	25.9
9	0 - 30	8.1	0.6	6.0	2.6	2.0	0.4
	30 -50	7.4	0.4	4.8	2.7	2.1	0.5
10	0 – 15	8.1	0.3	6.9	3.4	5.7	0.4
	15 – 50	7.8	0.7	6.9	3.4	7.3	2.0
	50 – 150	8.3	0.3	4.5	2.8	8.2	0.8
11	0 – 40	7.7	0.4	4.8	3.8	11.0	0.3
	40 – 90	7.5	0.8	6.2	6.5	3.3	1.6
	90 - 120	7.5	0.5	3.4	4.9	2.7	1.0
12	0- 35	7.6	3.1	3.3	4.1	5.1	0.2
	35- 70	7.7	2.3	2.3	4.8	5.0	0.3

Abbreviations:
EC_e: Electrical conductivity, OM: Organic matter, CEC: Cation exchangeable capacity, ESP: Exchangeable sodium percentage
SAR: Sodium adsorption ratio

The exchangeable sodium percentage (ESP) of these soils ranges from 1.1 to 11.0 % for most of the samples except two subsurface layers of profile 7 which has ESP of 20.9 and 39.6 %. The sodium adsorption ratio (SAR) values of these soils are less than 13, except the four layers of profile 8 (24.1- 31.5) and the third layer of profile 4 (18.1) and the second layer of profile 7 (13.2). The high SAR values seemed to be associated with the ECe values due to the domination of sodium in the soil solutions of these samples (profiles 4, 7 and 8). Therefore, most soil profiles that show low ESP and SAR values indicate a low sodicity hazard (FAO, 2006).

3. Soil Classification

The prevailing climate of the studied area is extremely arid and the dominant soil moisture regime is aridic (torric) with a thermic soil temperature regime. These soils are classified according to Soil Survey Staff (2014) as Typic Torripsamments, Typic Torriorthents, Lithic Torripsamments, Typic Haplosalids, Typic Natrargids, Typic Haplocalcids, Typic Haplogypsids and Lithic Petrogypsids (Table 2 and Figure 2).

4. Land Capability Assessment

a. Sys and Verheye (1978) method

The limiting factors as well as the land capability classes and subclasses of the studied area are present in Tables 4 and 5 and are illustrated in Figure 3.

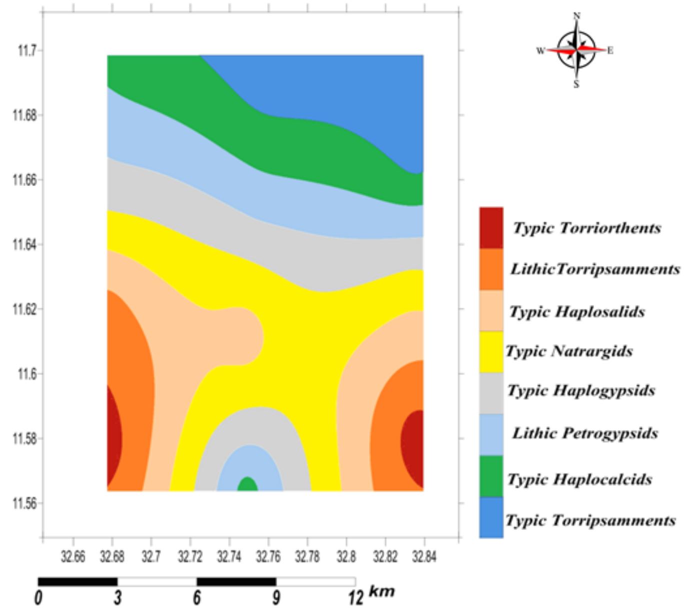
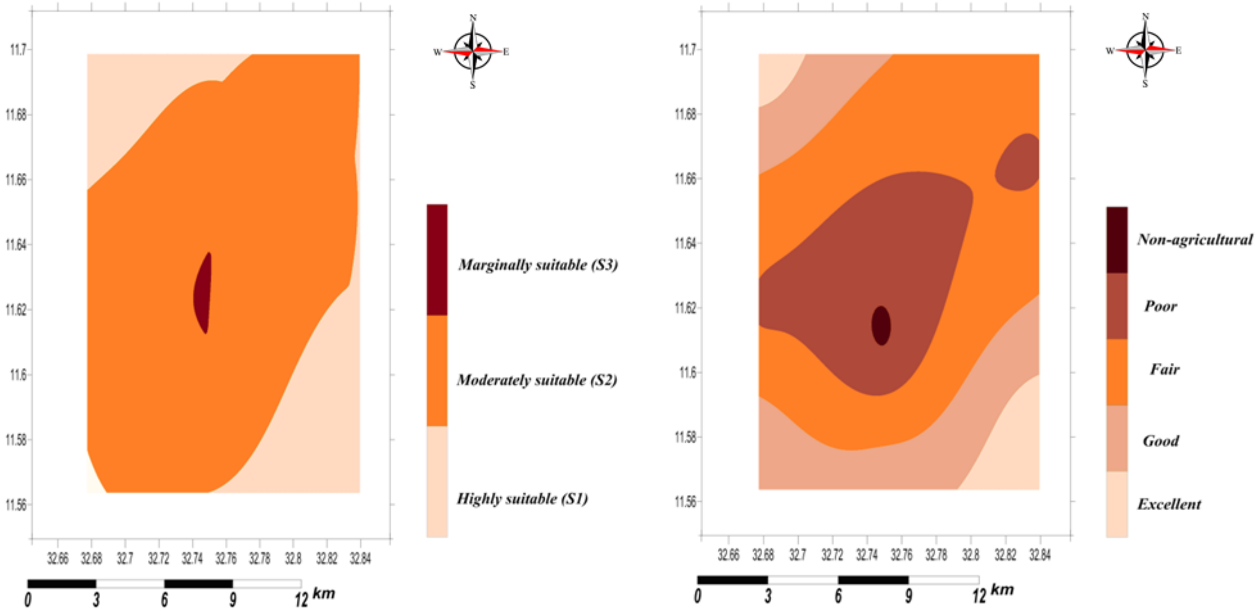


Figure 2. The soil classification map (subgroup level) of the study area



Sys and Verhey (1978) method | Modified Storie index (2008) method

Figure 3. Land capability map of the study area

It is clear that none of the studied land profiles was observed to be unsuitable (N) in this area. Accordingly, the studied area could be classified into the following three capability classes:

Class S1:

This class includes the soils which are highly suitable with capability index (Ci) that is higher than 75 % (79%). The soils of this class occupy 17 % of the total studied area. The soils of this class are slightly affected by some limitations such as texture and calcium carbonate content (profiles 3 and 10).

Class S2:

This class comprises the soils that are moderately suitable with capability index (Ci) that are varies between 50 and 75% (52 to 71%). Five subclasses were recorded in this class. These subclasses contain the moderately suitable soils which employ an area of 58% of the total studied area. The soils of this class are slightly to moderately affected by some limitations and could be distinguished into the following subclasses:

S2 s1: The soils of this subclass are affected by the coarse texture that ranges from sand to sandy loam (profiles 1, 2 and 11)

S2 s1, n: These soils are moderately suitable and are represented by the soil profile 4 which has a coarse texture and salinity and alkalinity limitations.

S2 s1, s4: These soils are moderately suitable and are delineated by the soil profile 6 that show a coarse texture and gypsum limitations.

S2 s2, s4: The soils of this subclass are moderately suitable and are represented by the soil profile 12 that has soil depth and gypsum limitations.

S2 s1, s4, n: The soils of this subclass are moderately suitable and are described by the soil profile 7 which has a coarse texture with gypsum, salinity and alkalinity limitations.

Class S3:

This class includes the soils which are marginally suitable and have moderate limitations with capability index (Ci) that varies between 25 and 50% (33 to 39 %). The soils of this class occupy 25% of the studied area. They are affected by moderately and slightly sever limitations and are distinguished into the following subclasses:

S3 s1, s2: The soils of this subclass marginally suitable and are represented by the soil profiles 5 and 9 which are of coarse texture and soil depth limitations.

S3 s1, s4, n**:** These soils are marginally suitable and are described by soil profile 8 that shows a coarse texture with gypsum, salinity and alkalinity limitations.

Table 4. Land evaluation of the studied soil profiles according to Sys and Verhey (1978)

Profile No.	Limiting factors							(Ci)	Order	Class	Sub- class (Sx)
	Slope (t)	Drainage (D)	Texture (S1)	Depth, cm (S2)	$CaCO_3$, % (S3)	Gypsum, % (S4)	Salinity &Alkalinity (n)				
1	100	100	70	100	95	100	100	67	S	S2	S2s1
2	100	100	75	100	95	100	100	71	S	S2	S2s1
3	100	100	91	100	92	94	100	79	S	S1	S1, s3
4	100	100	75	100	95	100	90	64	S	S2	S2s1, n
5	100	90	80	55	95	95	98	35	S	S3	S3s1, s2
6	100	100	70	100	95	93	100	62	S	S2	S2s1, s4
7	100	100	79	100	95	93	93	65	S	S2	S2s1, s4, n
8	100	100	77	100	95	88	60	39	S	S3	S3s1, s4,n
9	100	90	70	55	95	100	100	33	S	S3	S3s1, s2
10	100	100	83	100	95	100	100	79	S	S1	S1s1
11	100	90	84	100	95	98	100	70	S	S2	S2s1
12	100	90	90	75	95	90	100	52	S	S2	S2s2, s4

Table 5. Land capability classes and subclasses of the studied area according to Sys and Verhey (1978)

Suitability index (Ci)	Suitability class	Suitability subclass (Sx)	Profile No.	Area (%)
>75	S1	S1, s3 S1s1	3 10	17
50 -75	S2	S2 s1 S2 s1, n S2 s1, s4 S2 s2, s4 S2 s1, s4, n	1, 2, 11 4 6 12 7	58
25 - 50	S3	S3 s1, s2 S3s1, s4,n	5, 9 8	25

Where:
Sx = S1, S2, ...etc.
Sx = Soil limitations (s1= soil texture,s2= soil depth, s3= calcium carbonate, s4= gypsum and n = Salinity and / or alkalinity limitation)

b. Modified Storie index (2008) method

According to the Storie index modified by O'Geen et al. (2008), the studied area has capability classes excellent, good, fair, poor and non-agricultural due to different limiting factors (Tables 6 and 7, Figure 3).

Table 6. Land capability and modified Storie index rating of the studied area according to O,Geen et al. (2008)

Profile No.	Slope	Gravel	Depth (cm)	Texture	pH	SAR	EC_e (dSm^{-1})	Erosion	Drainage	Index	Capability
1	98	100	98	60	100	100	100	100	100	58	Fair
2	98	100	98	60	100	100	100	100	100	58	Fair
3	98	100	93	95	100	100	100	100	100	87	Excellent
4	98	100	97	80	100	75	56	100	100	32	Poor
5	98	100	53	80	100	77	75	100	90	24	Poor
6	98	100	95	60	100	100	100	100	100	56	Fair
7	98	100	97	60	100	100	100	100	100	57	Fair
8	98	100	97	60	94	56	19	100	100	6	Non-agricultural
9	98	100	53	60	100	100	100	100	90	28	Poor
10	98	100	97	95	100	100	100	100	100	90	Excellent
11	98	100	95	80	100	100	100	100	90	67	Good
12	98	100	68	95	100	100	99	100	100	63	Good

Abbreviations: SAR: Sodium adsorption ratio, EC_e: Electrical conductivity

Table 7. Land capability classes and soil limitations of the studied area according to O,Geen et al. (2008)

Capability index (Ci %)	Capability class (Soil grade)	Soil limitation	Profile No.	Area (%)
80 - 100	Excellent	---	3, 10	17
60 - 79	Good	texture depth	11 12	17
40 - 59	Fair	texture	1, 2, 6, 7	33
20 - 39	Poor	texture, SAR, EC_e texture, depth, drainage texture, depth, SAR, EC_e, drainage	4 9 5	25
20 >	Non-agricultural	texture, SAR, EC_e, pH	8	8

Some of these limiting factors are not correctable, such as soil depth and soil texture, while salinity and SAR factors can be correctable. Accordingly, the studied area could be classified into the following five classes:

Excellent (grade 1): These soils are deep and medium textured, with having no, or insignificant limitations to the given type of use. They are represented by soil profiles 3 and 10 and occupy an area of 17% of the total studied area.

Good (grade 2): These soils are also deep and medium textured and are suitable for most crops. Yields are generally good to excellent. They are delineated by soil profiles 11and 12 and have an area 17% of the total area.

Fair (grade 3): These soils are deep and coarse-textured and generally of fair quality, with a less wide range of suitability than both grades 1 and 2. They may give good results with certain specialized crops. They are described by soil profiles 1, 2, 6 and 7 and employ an area 33% of the total studied area.

Poor (grade 4): These soils are deep and coarse textured, that are moderately affected by the alkalinity and have poor nutrient levels. They are represented by soil profiles 4, 5 and 9 and occupy an area of 25% of the total studied area.

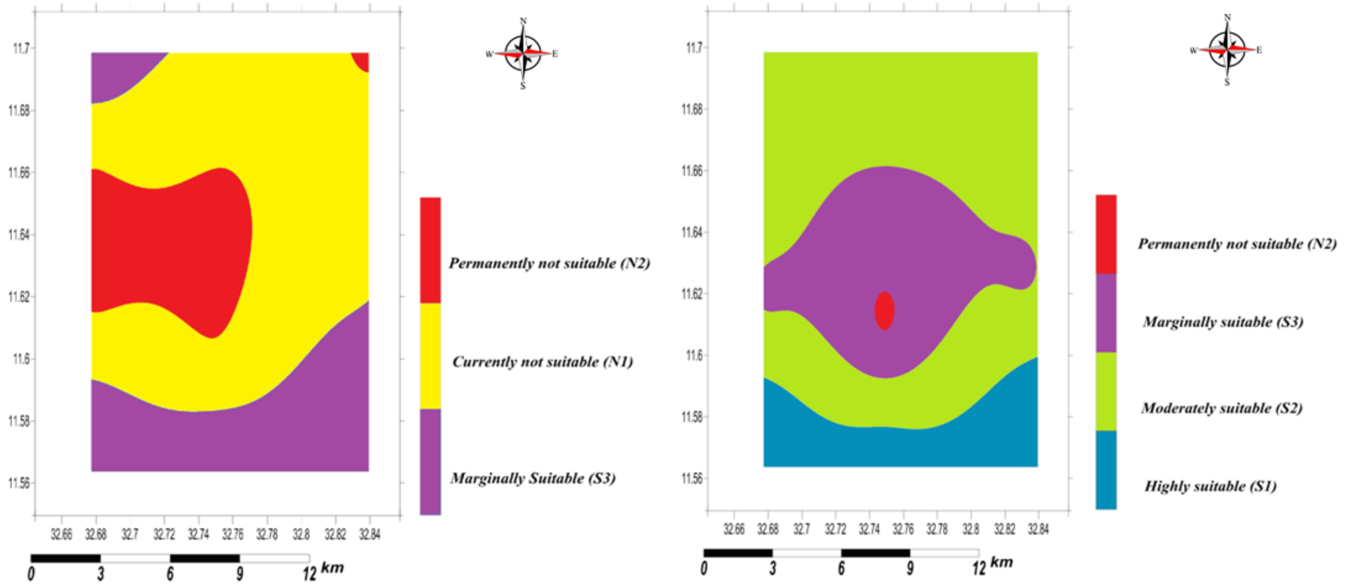
Non-agricultural (grade 6): These soils are deep to very shallow and coarse textured. They have moderate to strong limitations that are affected by the alkalinity and show poor to very poor nutrient levels. They are described by soil profile 8 and have an area of 8% of the total area.

The two methods do not vary in assessing the land suitability of this studied area. However, modified Storie index method is more accurate and realistic. In case of modified Storie method, numbers of land classes are much higher than in the other method. Generally, the main limitations in the studied soils profiles 6 and 7 were the soil texture of the surface layer and soil depth as well as salinity, alkalinity, gypsum, drainage and fertility levels. Drainage, soil salinity and alkalinity problems could be corrected. However, soil depth and texture cannot be changed. From the agriculture point of view, the soils of the studied area are considered promising ones (Elaalem, 2010). Evaluating their capability is an essential stage for future practical use. By improving the soil properties such as salinity and alkalinity and applying modern irrigation systems, the soils can attain a potential capability (high) and be high suitable to moderately suitable for the agricultural use. One of the best ways to improve light soils (sandy soils) is through additions of organic materials. Good sources of organic matter include manures, leaf mold, sawdust, and straw. Many farmers enrich the soils with natural fertilizers, such as animal manure, green manure, and compost. Continuous agriculture use of these soils will upgrade their suitability in the future.

5. Land Suitability Assessment

a. Land suitability for different irrigation systems

Several parameters of the field data are used to compare the land suitability for different irrigation systems. The results of soil evaluation for surface (gravity) and drip (localized) irrigation systems are present in Table 8 and illustrated in Figure 4. They show that the drip irrigation system is more suitable for the studied area than the surface irrigation one. Hence, changing the irrigation method to be pressurized (drip) irrigation in the study area is proposed. With using the surface irrigation, there is not any area that is classified as highly suitable (S1) or moderately suitable (S2). Only, 33% of the study area are slightly suitable (S3) using the surface irrigation and located in profiles 3, 10, 11 and 12. Most of the soils of this study are classified that are currently not suitable (N1, 25 %) and permanently not suitable (N2, 42 %) using the surface irrigation. The limiting factors in this study are mainly the soil salinity and soil texture that is mostly sand. In some cases, the soil depth and the calcium carbonate content also handicap the land use for surface irrigation.



Surface irrigation method Drip irrigation method

Figure 4. Land suitability classes for surface and drip irrigation

Table 8. Suitability index distribution of the surface (Gravity) and drip (localized) irrigation according to Sys et al.(1991)

Suitability index	Suitability class	Surface irrigation		Drip irrigation	
		Profile No.	Area (%)	Profile No.	Area (%)
>80	S1	---	---	10, 11, 12	25
60-80	S2	---	---	1, 2, 3, 4, 6	42
45-60	S3	3, 10. 11, 12	33	5, 7, 9	25
30-45	N1	2, 4, 7	25	---	---
<30	N2	1, 5, 6. 8, 9	42	8	8
---	Total	---	100	---	100

Using the drip (localized) irrigation, the soils of the study area are classified as highly suitable (S1, 25%), moderately suitable (S2, 42%) and marginally suitable (S3, 25 %).Only, a few proportion of the studied soils is almost not suitable (N2, 8%) and mainly located in the area represented by profile 8. Therefore, it would be more beneficial to irrigate these soils using drip or localized irrigation method. However, the area represented by profile 8 is unsuitable for both irrigation methods. It should not be used for crop production. Moreover, due to the insufficient surface water and ground water resources as well as the arid climate of the study area, only the drip and sprinkle irrigation methods are highly recommended for the sustainable use of this natural resource. The drip irrigation system is more suitable and recommended than the surface irrigation one in most of the areas in the Mediterranean and arid regions (Briza et al., 2001; Mbodj et al., 2004; Dengiz, 2006; Albaji et al., 2009; Nasab et al., 2010; Mehdi et al., 2012; Sayed, 2013). The drip irrigation can obviously be a way to improve the practice on light-textured soils. The main land use limitation factors for the drip irrigation method in this study are the salinity and the soil texture.

b. Land suitability for field crops, vegetables and fruit trees

The land suitability assessment for annual field crops, vegetables and fruit trees was shown in Tables 9, 10.

Table 9. Suitability rating of the studied soil profiles for growing some crops, vegetables and fruit trees according to Sys et al. (1993).

Crops		Profile No.											
		1	2	3	4	5	6	7	8	9	10	11	12
Field crops	Alfalfa	S2	S2	S3	N	S3	S3	N	N	S3	S2	S1	S2
	Sorghum	S2	S2	S2	S3	S3	S2	N	N	S2	S2	S2	S3
	Maize	S2	S2	S3	S2	S3	S3	N	N	S3	S2	S2	S2
	Millets	S3	S2	S3	N	S3	S3	N	N	N	S3	S2	S1
	Wheat	S3	S2	S3	N	N	S3	N	N	N	S2	S2	S2
	Barley	S3	S3	S3	N	S3	S3	N	N	N	S2	S2	S2
	Safflower	S3	S2	S3	N	S3	N	N	N	N	S3	S2	S2
	Sunflower	S3	S2	S3	N	N	N	N	N	N	S3	S2	S3
	Sesame	S3	S2	S3	N	N	N	N	N	N	S3	S2	S2
	Soybean	S3	S2	N	N	N	N	N	N	N	S3	S2	S3
Vegetables	Onion	S2	S2	N	N	S3	N	N	N	S3	S2	S2	S2
	Green pepper	S2	S2	N	N	N	S3	N	N	N	S2	S2	S2
	Potato	S3	S2	N	N	N	S3	N	N	N	S3	S2	S2
	Tomato	S3	S2	N	N	N	N	N	N	N	S3	S2	S3
	Beans	S3	S3	N	N	N	N	N	N	N	S3	S2	N
Fruits	Date palm	S2	S2	S2	S2	N	S2	S3	N	N	S2	S1	S2
	Olives	S2	S1	S2	S2	N	S2	N	N	N	S2	S1	S3
	Guava	S3	S2	S3	N	N	S3	N	N	N	S2	S2	S2
	Citrus	S2	S2	N	N	N	N	N	N	N	S2	S2	N
	Banana	N	N	N	N	N	N	N	N	N	N	S3	N

Abbreviations: S1 = Highly suitable (Ci >65), S2 = Moderately suitable (Ci 35-64), S3 = Marginally suitable (Ci 20-34), N = Not suitable (Ci<20)

Soil suitability evaluation for growing field crops

The area understudy has a good potential to produce selected crops under irrigation provided that the water requirements for each crop are met. The results indicate that only 9 and 8% of this area are highly suitable (S1) for alfalfa and millets, respectively. The soils that are moderately suitable (S2) for alfalfa, sorghum, maize, millets, wheat, barley, safflower, sunflower, sesame and soybean production represent 33, 58, 50, 17, 33, 25, 25, 17, 25 and 17% of the total studied area, respectively. However, 33, 25, 33, 42, 25, 33, 33, 33, 25 and 25% of the studied area are marginally suitable for alfalfa, sorghum, maize, millets, wheat, barley, safflower, sunflower, sesame and soybean respectively. In addition, 42, 42, 42, 50, 50 and 58% of the study area are currently not suitable (N1) for wheat, barley, safflower, sunflower, sesame and soybean production, respectively. Hence, the area under consideration has a good potential to produce alfalfa, millets, sorghum and maize followed by wheat, barley and safflower and then, sunflower, sesame and soybean under irrigation, provided that the water requirements of these crops are met.

Table 10. Soil suitability rating and percentage for growing some field crops, vegetables and fruit trees according to Sys et al. (1993)

Field crops (%)										
Rating suitability	Alfalfa	Sorghum	Maize	Millets	Wheat	Barley	Safflower	Sunflower	Sesame	Soybean
S1	9	--	--	8	--	--	--	--	--	--
S2	33	58	50	17	33	25	25	17	25	17
S3	33	25	33	42	25	33	33	33	25	25
N	25	17	17	33	42	42	42	50	50	58

	Vegetable crops (%)					Fruits trees (%)				
Rating suitability	Onion	Green pepper	Potato	Tomato	Beans	Date palm	Olives	Guava	Citrus	Banana
S1	--	--	--	--	--	9	17	--	--	--
S2	42	42	25	17	8	58	42	33	33	--
S3	17	8	25	25	25	8	8	25	--	8
N	41	50	50	58	67	25	33	42	67	92

Abbreviations: S1 = Highly suitable (Ci >65), S2 = Moderately suitable (Ci 35-64), S3 = Marginally suitable (Ci 20-34), N = Not suitable (Ci<20)

Soil suitability evaluation for growing vegetables

The results reveal that the study area is moderately suitable and marginally suitable for growing onion (42 and 17%, respectively), green pepper (42 and 8%, respectively) and potato (25 and 25%, respectively) production. However, most of the investigated area is not suitable for tomato (58%) and beans (67%) production. Therefore, the area under consideration shows a good potential to produce onion, green pepper and potato but it is not suitable for other vegetable crops. The high soil pH, ESP and salinity are the major limitation factors of this area for vegetable production which can be improved using specific management.

Soil suitability evaluation for growing fruit trees

Only 9 and 17% of the study area are highly suitable (S1) for growing date palm and olive, respectively. In addition, 58, 42, 33 and 33% of this area are moderately suitable (S2) for date palm, olive, guava and citrus production. However, most of the soils are not suitable (N) for banana (92%) and citrus (67%). High soil pH, salinity and ESP are the major limitations which may deter the farmers from cultivating these soils.

Generally, the area understudy has a good potential to produce the selected crops under irrigation provided that the water requirements of these crops are met. Some crops are considered unsuitable (N1 and N2) for growing due to moderate to severe soil limitations of fertility, salinity, alkalinity, soil depth and coarse texture. The coarse texture, ESP, calcium carbonate content, salinity and alkaline pH of most soil profiles are the main limiting factors for growing crops, especially vegetable crops and some fruit trees. Proper fertilization can improve the soil suitability for various crops under consideration. Correcting some soil limiting factors such as pH, salinity and alkalinity through the application of fertilizers and amendments which can reduce soil alkalinity and increase soil fertility is recommended. Also, additions of manures and crop residues to the soils can increase the soil organic matter and nutrient levels.

Conclusion

The study aims to evaluate the soil suitability of the north-western area of Libya and identify the factors that hinder the cultivation process. Qualitative evaluation for the actual soil parameters was employed to realize a precise and objective interpretation for this area and its suitability for a wide range of crops. The most effective soil parameters that influence the suitability classification of the studied area are texture, calcium carbonate content, ESP, alkaline pH and salinity. According to the Sys and Verhey (1978) method, about 17% of the studied area are highly suitable, 58% are moderately suitable and only 25 % are marginally suitable for agriculture. In addition, according to the modified Storie index method, 17%, of the investigated area are excellent, 17% of this area is good, 33% of this area is fair and 25% of this area is poor for agricultural use, and 8% of the studied area is non-agricultural. Moreover, this method is found to be more effective in assessing land capability. Concerning the irrigation systems, using the drip irrigation system in the area understudy is more suitable than the surface irrigation. It is clear that the drip irrigation in arid and semi-arid regions is mostly appropriate, because of water shortage. From the agricultural point of view, the soils of the studied area are considered promising ones. The potential capability of some soils of this area can be improved with cultural management. Meanwhile, the soils of this area are moderately suitable to marginally suitable for growing field crops and some fruit trees. On the other hand, the soil maps for agricultural suitability designed in this research can be helpful in carrying out the management processes.

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Does hazelnut husk compost (HHC) effect on soil water holding capacity (WHC)? An environmental approach

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Abstract

In this study, we applied hazelnut husk waste that was composted by using microbial biotechnological techniques into soil in the field conditions. The hazelnut husk compost (HHC) was applied in two hazelnut orchards having different textures such as sandy loam (SL) and clay loam (CL) soils and used different application rates (0, 1.25, 2.5, 5.0, 7.5 and 10 t da^{-1}). Soil sampling was done four times in a year (spring, summer, fall and winter). We investigated the effects of HHC on soil water holding capacity related to available water content of soil at both field capacity (FC) and permanent wilting point (PWP) with weight basis. Soil moisture coefficients were determined by using pressure plate and indicated as percentage weights at FC (-33 kPa) and PWP (-1500 kPa). Our results showed that HHC doses, sampling periods and soil textures effected soil water holding capacity at both FC and PWP. In addition, FC and PWP were found the highest at 10 t da^{-1} application dose. Findings of this study, the huge importance of HHC that related to protect soil water without harmful to the environment emphasized.

Keywords: Field capacity, permanent wilting point, hazelnut husk, environment, soil.

Introduction

During the recent, the general concern about the environment and its preservation is increasing. If valuable organic wastes are not well managed, they can create environmental problems. Hazelnut husk is consist of green piece of hazelnut. There are a lot of hazelnut husk in orchards as a waste. Composting is one of the environmental friendly options to reuse this product. Currently, composting is accepted as a sustainable strategy to maintain agricultural ecosystems in an environmentally safe manner (Jiang et al., 2015; Wang et al., 2015). This method is considered to reduce carbon emissions and improve land use. It is an effective process that converts different organic solid waste materials into stable organic products applied in agriculture under optimized control conditions, thereby recycling waste materials (Rynk, 1992; Gülser et al., 2015).

The compost of hazelnut husk waste should use as an organic material in soils after hazelnut harvesting. Applied hazelnut husk compost (HHC) into soils increases soil fertility. Because of hazelnut husk compost includes high in organic matter content, available plant nutrients improve soil physical, chemical and biological properties, and they may increase crop yield. Soil organic carbon can strongly influence aggregation processes, and in turn is influenced by the types of plant residues or organic amendments used and by their decomposition rate and products (Bronick and Lal, 2005; Hati et al., 2007). Hazelnut husk waste is picked up in the hazelnut orchards to prevent its harmful effect for environment and it is used in soils improving of soil quality parameters such as organic matter content, field capacity and permanent wilting point etc. Organic materials and wastes can used to as a compost

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material. Hazelnut husk which is organic waste is produced about 500000 tonnes per year in Turkey. The Black Sea Region is an important area for hazelnut production (Kızılkaya et al., 2015a,b).

Soil water holding capacity is an important soil physical property that is used to evaluate soil quality. Plant available water capacity is the difference in water content between field capacity (33kPa) and permanent wilting point (-1500 kPa), it is important so much for crop production because of plant uptake this water in the soils via their roots. Crops use available water more effectively. Additionally hazelnut husk compost waste has high in water holding capacity (Gupta et al., 1977; Klute anf Jacop, 1950; Kızılkaya et al., 2015a,b).

Importance of water increases day after day in the world. Water is an important vital matter for all living, plants and people. All livings need to water to alive. To provide continuity of water in soils is possible by its preservation. In soils to conserve water soil physical, chemical and biological properties must be improved by organic materials, wastes and other soil regulator. Hazelnut husk compost effects on soil quality related to physical properties such as water holding capacity, hydraulic conductivity, field capacity and permanent wilting point. Plants use water effectively between water content at field capacity (-33 kPa) and permanent wilting point (-1500 kPa) in soil (Klute anf Jacop, 1950; Gupta et al., 1977). Soil organic carbon content was positively correlated with available water content (Evrendilek at al., 2004; Kızılkaya et al., 2015a,b). Application of organic wastes to soil increase soil organic matter content, soil available macronutrients, water holding capacity, porosity, infiltration capacity, hydraulic conductivity, water stable aggregation, and decrease bulk density and surface crusting (Khaleel et al., 1981; Haynes and Naidu, 1998; Matsi et al., 2003; Gülser et al., 2015).

Our aim is to investigate the effect of hazelnut husk compost (HHC) on soil water holding capacity (WHC) at both field capacity (FC) and permanent wilting point (PWP) related to available soil water content for plant with an environmental approach.

Material and Methods

Hazelnut husk (C/N ratio 55.71; pH 5.81; $EC_{25°C}$ 1.93 dSm^{-1}; 0.97% N) was collected from the hazelnut orchard, was inoculated with carbon and the microorganisms used as an energy source was composted by windrow method and was used as a material in experiments using a windrow machine in the Research Facility of Soil Science and Plant Nutrition Department in Ondokuz Mayis University, Samsun, Turkey. HHC properties are as follows: pH is 6.76, $EC_{25°C}$ is 3.56 dS m^{-1}, organic matter (OM) content is 94.75%, total N content is 2.48%, and C/N ratio is 22.16 (Kızılkaya et al., 2015a,b).

Field experiments were based on with randomized complete block design were conducted in two different hazelnut orchard with different textures (sandy loam; sand 76.14%, silt 9.62%, clay 14.24%, pH 6.23, $EC_{25°C}$ 0.04 dSm^{-1}, Soil organic matter (SOM) 1.41% and clay loam; sand% 33.55, silt% 27.86, clay% 38.53, pH 6.69, $EC_{25°C}$ 1.43 dS m^{-1}, SOM 2.58%) located in Ordu district at the Black Sea Region of Turkey in November 2012. HHC was incorporated into the top 20 cm of the soil around the plant canopy without mixing any other material using a hoe in six application doses with three replication. Total experiment consisted of 36 parcels in order to increase the content of soil organic matter by 0, 0.5% (1.25 ton da^{-1}), 1% (2.5 ton da^{-1}), 2% (5 ton da^{-1}), 3% (7.5 ton da^{-1}) and 4% (10 ton da^{-1}). Soil samplings were done at the end of the March, June, September and December 2013) to determine water content with weight basis at soil field capacity and permanent wilting point. In statistical analysis, MINITAB Statistic 17.0 program was used (Kızılkaya et al., 2015a,b).

Results and Discussion

Applying of hazelnut husk compost (HHC) into soils increased soil moisture content (weight basis) at both field capacity (FC) and permanent wilting point (PWP). We found that applying of HHC with increasing doses increased water content at both FC and PWP in hazelnut orchards. The highest water content at field capacity obtained 10 ton da^{-1} application dose (%44.05) and the lowest water content at field capacity obtained in control. Effect of HHC application on FC was found statistically very important ($p<0.001$) effect. Also soil moisture coefficient was affected by texture at FC (Table 1, Figure 1). Organic waste and manure application increased water content at field capacity (Angın and Yağanoğlu, 2009).

Our results showed that soils with clay loam in texture (%44.9) have higher water content at FC than sandy loam soils (%34.5). The highest water content at FC was found in winter condition and the lowest water content at FC was found in summer condition (Figure 1). Soil x HHC application x sampling time interaction is not statistically important at FC (Figure 2). Field capacity was influenced by the application of different organic materials and compost application (Sohail-Ur-Raza et al., 2015).

Table 1. ANOVA for FC values (n=144)

Source	DF	Seq SS	Adj SS	F value	P value
Soils (a)	1	3894,8	3894,8	323,20	0,000
HHC Doses (b)	5	1618,3	323,67	26,86	0,000
Sampling Time (c)	3	148,9	49,62	4,12	0,009
(a) x (b)	5	333,7	66,75	5,54	0,000
(a) x (c)	3	286,0	95,35	7,91	0,000
(b) x (c)	15	391,8	26,12	2,17	0,013
(a) x (b) x (c)	15	200,1	13,34	1,11	0,361
Error	96	1156,9	12,05		
Total	143	8030,6			

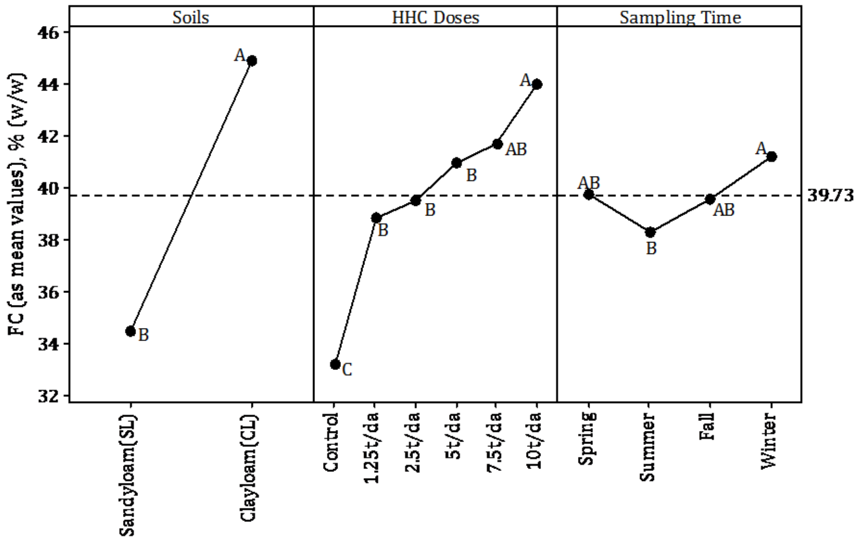

Figure 1. Main effects of soil texture, HHC doses and sampling time on the FC (means that do not share a letter are significantly different at p<0,01).

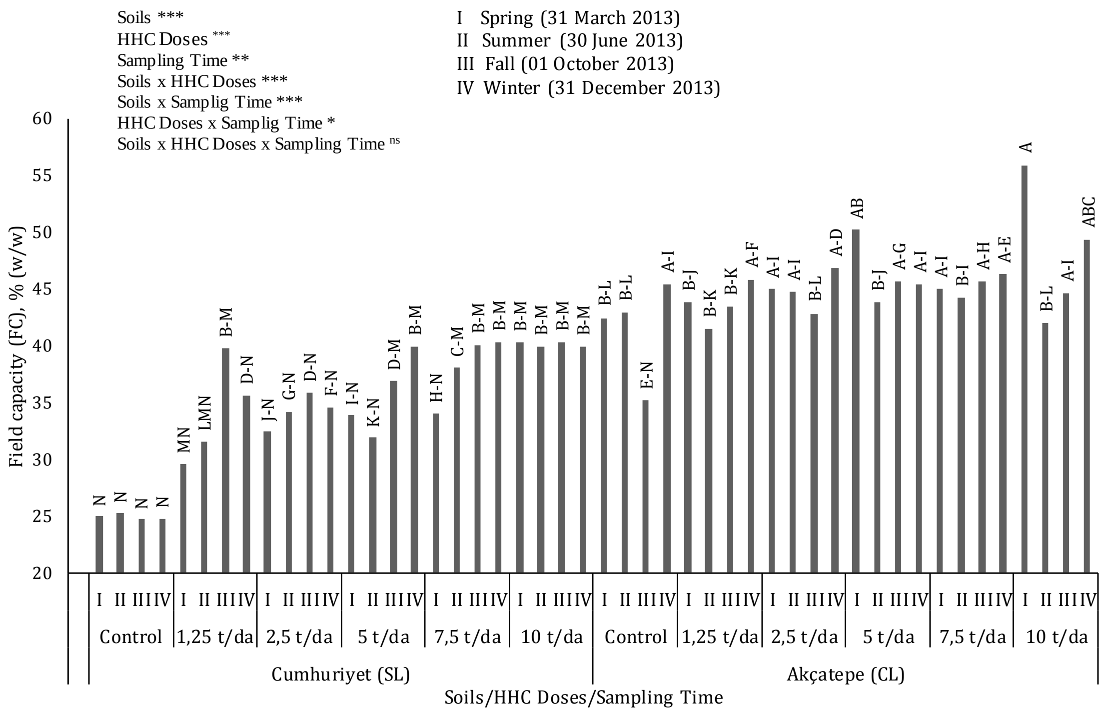

Figure 2. Effects of soil texture, HHC application and sampling time on FC (ns: non significant; *: p<0,05; **: p<0,01; ***: p<0,001; means that do not share a letter are significantly different at p<0,05).

Increases in the mean FC values according to soil textures and HHC doses were presented in Figure 3. Increasing of FC values (as mean value) depending of its texture were different. Increases of the FC were lower in clay loam (CL) soil than sandy loam soil (SL) in soil textures. Increases of FC for coarse-textured soils are larger than fine-textured soils (Gupta et al., 1977; Unger and Stewart, 1974). The results showed that effect of application dose of HHC, soil textures and sampling time on PWP were found statistically important (p<0,001) effect (Table 2, Figure 4).

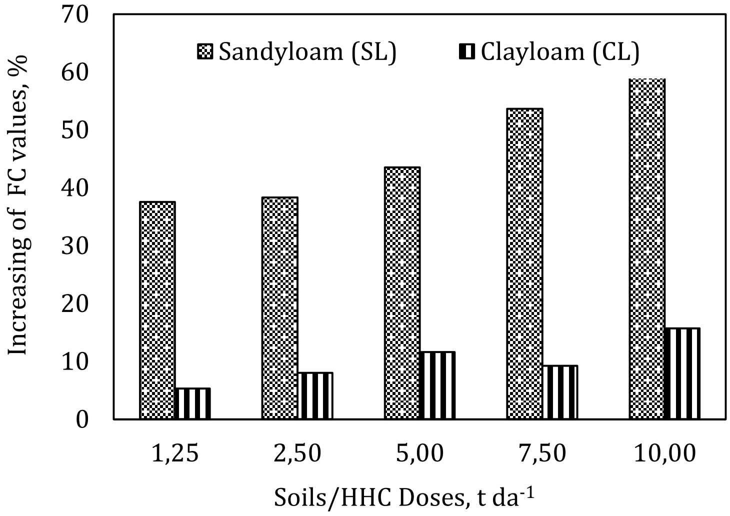

Figure 3. The comparison of FC values as a function of soils and HHC doses.

Table 2. ANOVA for PWP values (n=144)

Source	DF	Seq SS	Adj MS	F value	P value
Soils (a)	1	7314,5	7314,53	2117,51	0,000
HHC Doses (b)	5	1448,3	289,65	83,85	0,000
Sampling Time (c)	3	566,3	188,78	54,65	0,000
(a) x (b)	5	417,6	83,51	24,18	0,000
(a) x (c)	3	118,4	39,46	11,42	0,000
(b) x (c)	15	224,5	14,97	4,33	0,000
(a) x (b) x (c)	15	333,7	22,24	6,44	0,000
Error	96	331,6	3,45		
Total	143				

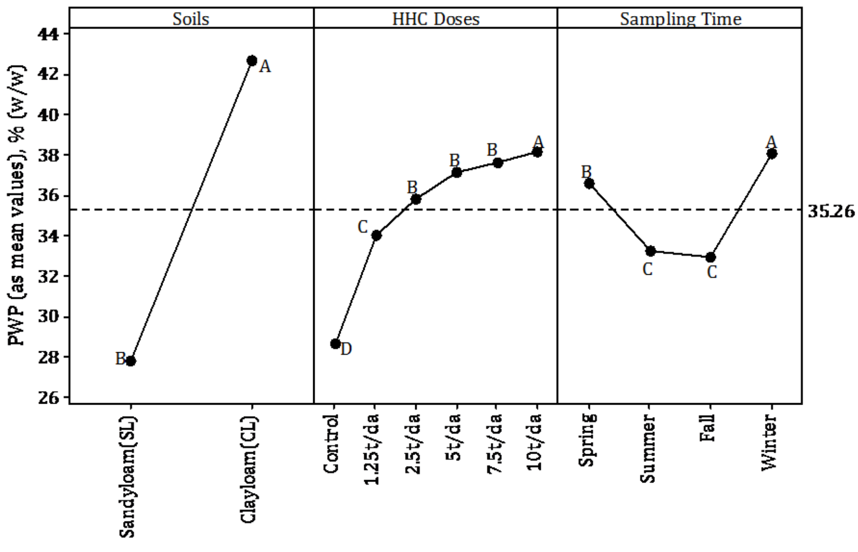

Figure 4. Main effects plot of soil texture, HHC doses and sampling time on the PWP (means that do not share a letter are significantly different at p<0,001).

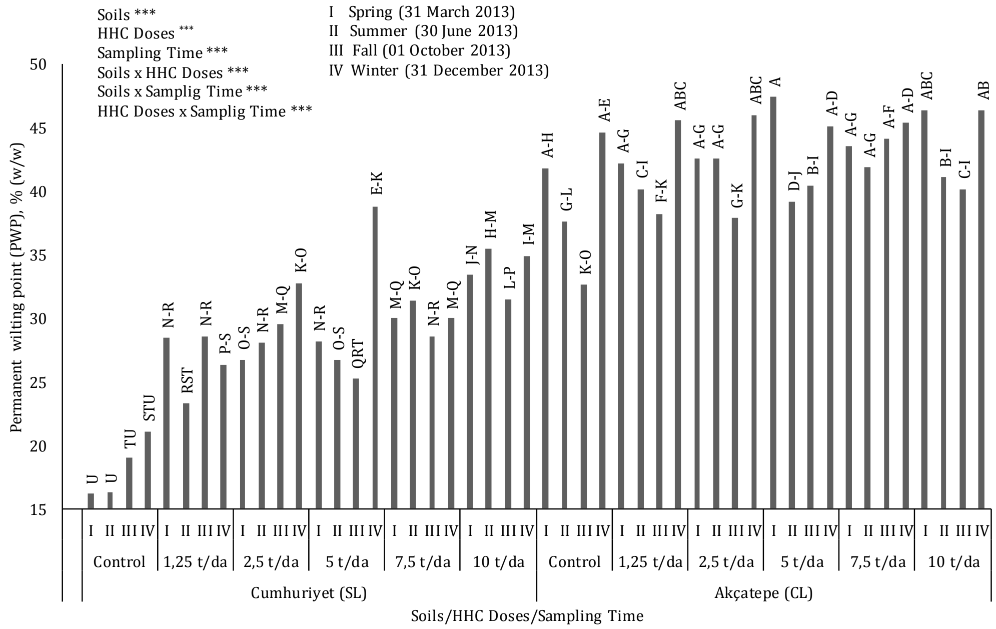

Figure 5: Effects of soil texture, HHC application and sampling time on PWP (*: p<0,05; **: p<0,01; ***: p<0,001; means that do not share a letter are significantly different at p<0,05).

Increases in the mean PWP values according to soil textures and HHC doses were presented in Figure 6. Increasing of PWP values (as mean value) depending of its texture were different. Increases of the PWP were lower in clay loam (CL) soil than sandy loam soil (SL) in soil textures. The available data on changes in water holding capacity at both FC and PWP as a result of organic waste application were reported by numerous study. For example, increases of PWP for coarse-textured soils are larger than fine-textured soils (Gupta et al., 1977; Unger and Stewart, 1974).

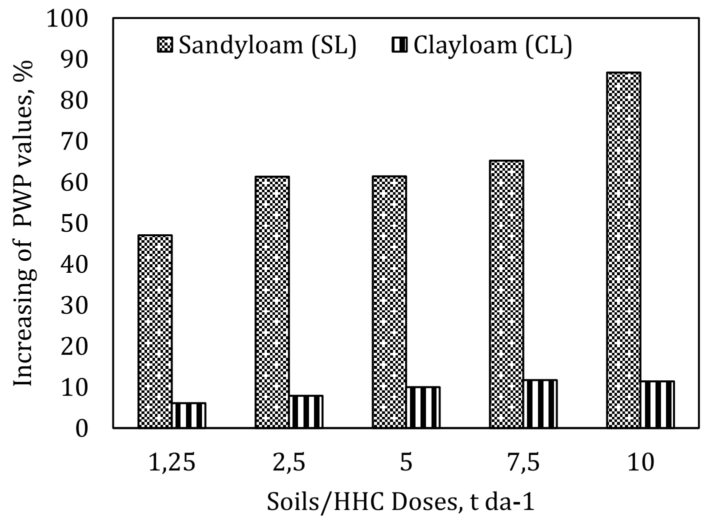

Figure 6. The comparison of PWP values as a function of soils and HHC doses.

Conclusion

Application of HHC in soil as an organic waste increased the soil organic matter content, water holding capacity (WHC) on a weight basis at both filed capacity (FC) and permanent wilting point (PWP), with an increase in HHC application doses during the studied incubation time. WHC (weight basis) at both FC and PWP increases with HHC addition rates varying of soil texture and soil sampling time. For coarse-textured soil, HHC application has greater effect than fine textured soil on FC and PWP. As a waste, hazelnut husk picked up hazelnut orchards. Hazelnut husk is a waste for environment and it has high in organic matter content so it should use as a carbon and nitrogen source for soil biota and crops. Hazelnut husk compost applied to soils both for a valuable nitrogen source for soils and plants and its harmful effect is obstructed on the environment. Additionally HHC increased soil moisture content due to higher infiltration and water holding capacity so runoff and soil erosion is decreased. Soil moisture content effects all microorganism and living in soils. If moisture content increase in the soils, all living organism must use it so it will be healthier for environment conditions. More clean environment more healthy life comes from soil.

These findings seem to confirm that the HHC applications are friendly for environment. This fact suggests that the use of HHC supports soil water retention relating of soil water save.

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