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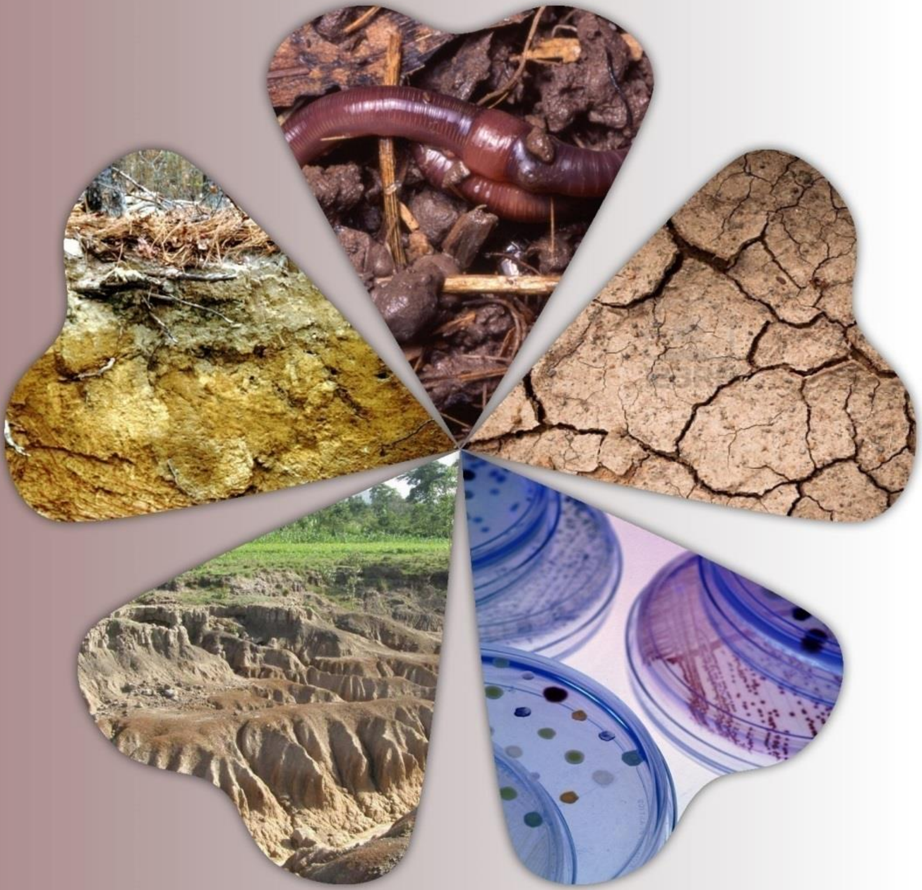

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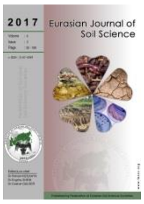

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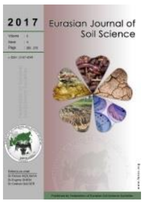

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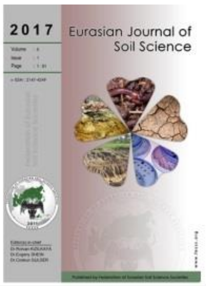

Evaluation of soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

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Abstract

Soil fertility evaluation of an area or region is most basic decision making tool for the sustainable soil nutrient management. In order to evaluate the soil fertility status of the Regional Agricultural Research Station (RARS), Tarahara, Susari, Nepal. Using soil sampling auger 81 soil samples (0-20 cm) were collected based on the variability of land. The collected samples were analyzed for their texture, structure, colour, pH, OM, N, P_2O_5, K_2O, Ca, Mg, S, B, Fe, Zn, Cu and Mn status. The Arc-GIS 10.1 software was used for the preparation of soil fertility maps. The soil structure was granular to sub-angular blocky and varied between brown- dark grayish brown and dark gray in colour. The sand, silt and clay content were 30.32±1.4%, 48.92±0.89% and 20.76±0.92%, respectively and categorized as loam, clay loam, sandy loam, silt loam and silty clay loam in texture. The soil was moderately acidic in pH (5.98±0.08). The available sulphur (2.15±0.21 ppm), available boron (0.08±0.01 ppm) and available zinc (0.35±0.03 ppm) status were very low, whereas extractable magnesium (44.33±6.03 ppm) showed low status. Similarly, organic matter (2.80±0.07%), total nitrogen (0.09±0.004 %), extractable calcium (1827.90±45.80 ppm) and available copper (1.15±0.04 ppm) were medium in content. The available phosphorus (39.77±5.27 ppm), extractable potassium (134.12±4.91 ppm), and available manganese (18.15±1.15 ppm) exhibits high status, while available iron (244.7±19.70 ppm) was very high. The fertilizer recommendation can be done based on determined soil fertility status to economize crop production. Furthermore, research farm should develop future research strategy accordance with the prepared soil data base.

Keywords: Macronutrients, micronutrients, research strategy, soil fertility maps, soil variation.

Article Info

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Introduction

Soil is a complex system comprised of minerals, soil organic matter (SOM), water, and air (Vishal et al., 2009; Flores-Magdaleno et al., 2011). Soil quality includes mutually interactive attributes of physical, chemical and biological properties, which affect many processes in the soil that make it suitable for agricultural practices and other purpose (Rakesh et al., 2012). The texture, structure, colour etc. are important soil physical parameters. Similarly, soil reaction (pH), organic matter, macro and micronutrients etc. are also important soil chemical parameters. These properties play important role for the soil fertility and determined after soil testing (Brady and Weil, 2004). The evaluation of soil fertility includes the measurement of available plant essential nutrients and estimation of capacity of soil to maintain a continuous supply of plant nutrients for a crop.

Soil properties vary spatially and temporally from a field to a larger region scale, and are influenced by both intrinsic (soil formation factors, such as soil parent materials) and extrinsic factors (soil management

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practices, fertilization and crop rotation) (Cambardella and Karlen, 1999). Describing the spatial variability of soil fertility across a field has been difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced. GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data (Burrough and McDonnell, 1998).

Nepal Agricultural Research Council (NARC) was established to strengthen agriculture sector in the country through agriculture research. Regional Agricultural Research Station (RARS), Tarahara, Sunsari, Nepal is an important wing among the research stations of NARC, in order to generate appropriate crop production technologies for the eastern Nepal. Studies related to the soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal are scarce. Therefore, it is important to investigate the soil fertility status and may provide valuable information relating to crop research. Keeping these facts, the present study was conducted with the objective to estimate the soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal.

Material and Methods

Study area

The study was carried out at Regional Agricultural Research Station, Tarahara, Sunsari, Nepal (Figure 1). The research farm is situated at a latitude 26^{0}42'17.4''N and longitude 87^{0}16'43.9"E as well altitude 125 m above sea level.

Figure 1. Location map of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Soil sample collection

Surface soil samples (0-20 cm depth) were collected from Regional Agricultural Research Station, Tarahara, Sunsari, Nepal during 2016. A total of 81 soil samples were collected from the research farm (Figure 2). The exact locations of the samples were recorded using a handheld GPS receiver. The random method based on the variability of the land was used for the collection of soil samples.

Laboratory analysis

The collected soil samples were analyzed at laboratory of Soil Science Division, Khumaltar. The different soil parameters tested as well as methods adopted to analyze is shown on the Table 1.

Table 1. Parameters and methods adopted for the laboratory analysis at Soil Science Division, Khumaltar

S.N.	Parameters	Units	Methods
1	Soil texture		Hydrometer (Bouyoucos, 1962)
2.	Soil colour		Munsell-colour chart
3.	Soil structure		Field-feel
4.	Soil pH		Potentiometric 1:2 (Jackson, 1973)
5.	Soil organic matter	%	Walkely and Black (Walkley and Black, 1934)
6.	Total N	%	Kjeldahl (Bremner and Mulvaney, 1982)
7.	Available P_2O_5	ppm	Olsen (Olsen et al., 1954)
8.	Extractable K_2O	ppm	Ammonium acetate (Jackson, 1973)
9.	Extractable Ca	ppm	EDTA Titration (El Mahi et al.,1987)
10.	Extractable Mg	ppm	EDTA Titration (El Mahi et al.,1987)
11.	Available S	ppm	Turbidimetric (Verma, 1977)
12.	Available B	ppm	Hot water (Berger and Truog, 1939)
13.	Available Fe	ppm	DTPA (Lindsay and Norvell, 1978)
14.	Available Zn	ppm	DTPA (Lindsay and Norvell, 1978)
15.	Available Mn	ppm	DTPA (Lindsay and Norvell, 1978)
16.	Available Cu	ppm	DTPA (Lindsay and Norvell, 1978)

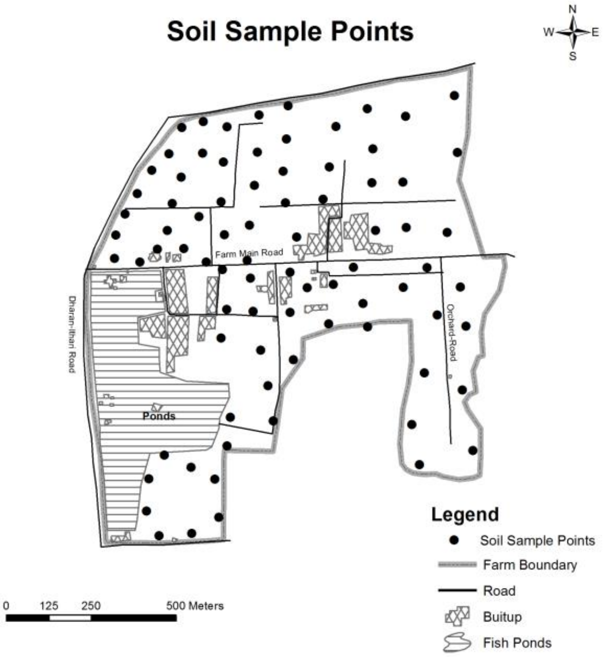

Figure 2. Distribution of soil sample points during soil sampling

Statistical analysis

Descriptive statistics (mean, median, range, standard deviation, standard error, coefficient of variation) of soil parameters were computed using the Minitab 15 package. Rating (very low, low, medium, high and very high) of determined values were based on Soil Science Division, Khumaltar. The coefficient of variation was ranked according to the guidelines of (Aweto, 1982) where, CV < 25% = low variation, CV >25 ≤ 50% = moderate variation, CV >50% = high variation. Arc Map 10.1 with spatial analyst function of Arc GIS software was used to prepare soil fertility maps while interpolation method employed was ordinary kriging.

Similarly, the nutrient index was also determined by the formula given by Ramamoorthy and Bajaj (1969).

$$\text{Nutrient index (N.I.)} = (N_L \times 1 + N_M \times 2 + N_H \times 3) / N_T$$

Where, N_L, N_M and N_H are number of samples falling in low, medium and high classes of nutrient status, respectively and N_T is total number of samples analyzed for a given area. Similarly, interpretation was done as value given by Ramamoorthy shown on the Table 2.

Table 2. Rating Chart of Nutrient index

S.N.	Nutrient Index	Value
1.	Low	<1.67
2.	Medium	1.67-2.33
3.	High	>2.33

Results and Discussion

The soil fertility status of the study area was assessed with respect to texture, colour, structure, pH, organic matter, primary nutrients, secondary nutrients and micronutrients such as B, Fe, Zn, Cu, and Mn and the results obtained are presented and discussed in the following headings.

Soil texture

Texture is one of the most important physical property of soils as it affects water retention, nutrient availability, pore space, slope stability aeration and erosion susceptibility (Brady and Weil, 2004). The % of sand were ranged from 6.6 to 67.0 % with a mean of 40.32 % and that of % silt were 24.8 to 62.2 % with a mean of 48.92%, while the range of % clay were 6.2 to 36.2 % with a mean of 20.76% (Table 3). Five textural classes such as loam, clay loam, sandy loam, silt loam and silty clay loam were observed in the 34%, 10%, 4%, 32% and 20%, respectively of the studied samples (Table 3, Figure 3 and 4). The coefficients of variation between the soil samples were 41.58%, 16.32% and 39.82% for sand, silt and clay contents, respectively. The occurrence of different types of land (low land, medium low land, upland etc.) might be the cause of different types of texture in the farm. Khadka et al. (2017) also found different classes of texture within the single research farm of similar size at National Rice Research Program, Hardinath, Dhanusha, Nepal.

Table 3. Particle size distribution of soils of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Descriptive Statistics	Particle size distribution		
	Sand, %	Silt, %	Clay, %
Mean	30.32	48.92	20.76
Standard Error	1.40	0.89	0.92
Standard Deviation	12.61	7.99	8.27
Min.	6.60	24.80	6.20
Max.	67.00	62.20	36.20
CV%	41.58	16.32	39.82

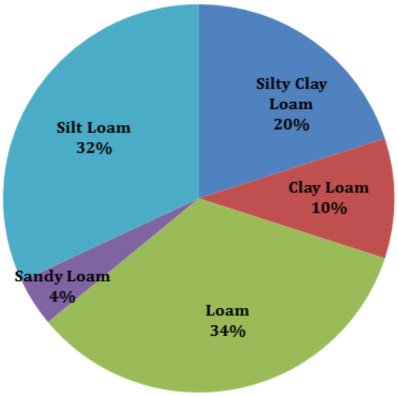

Figure 3. Distribution of Soil texture in the studied Samples

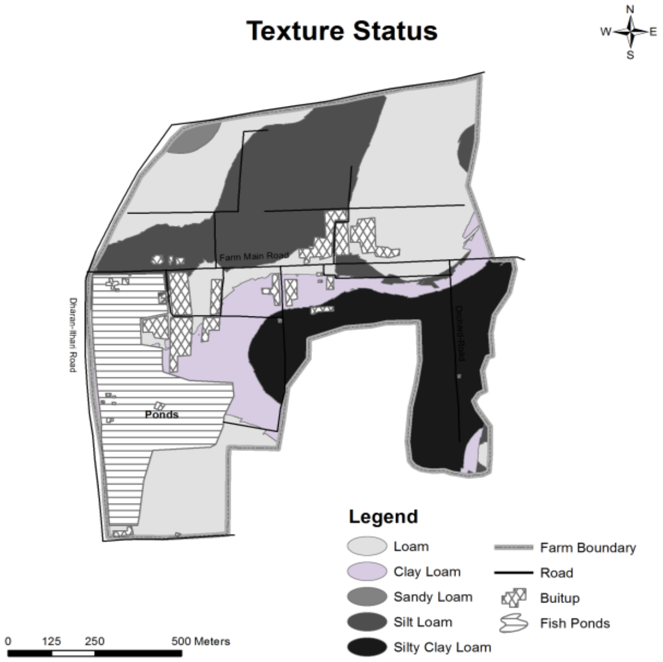

Figure 4. Soil texture status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Soil colour

Soil colour is an indirect measure of other important characteristics such as water drainage, aeration, and organic matter content of soils (Foth, 1990). Three kinds of colour namely; 10YR 4/2 (dark grayish brown), 10YR 4/1 (dark gray) and 10YR 5/3 (brown) were observed but 10YR 4/2 (dark grayish brown) was dominant.

Soil structure

The arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. It controls the amount of water and air present in soil (Brady and Weil, 2004). Majority of the area contains sub-angular blocky structure, except granular at orchard site. The granular structure in orchard site might be due to less disturbance of soil.

Soil reaction (pH)

Soil pH is an important chemical parameter as it helps in ensuring availability of plant essential nutrients (Deshmukh, 2012). The pH of soil was varied from 4.49 to 7.58 with a mean value of 5.98 (Table 4). This indicates moderately acidic soil reaction (pH). The pH of soil samples was found to be 41.98% of sample showed moderately acidic, 20.99% samples were slightly acidic, 11.11% samples were very acidic, while 16.05% samples were nearly neutral and only 9.88% samples were slightly alkaline in nature. The soils are acidic might be as a result of the leaching of basic Cation or due to incessant uptake by crops grown on the field (Brady and Weil, 2004). The soil acidity implied that nutrients are likely to be available or unavailable for crop uptake. Therefore, agriculture lime should be incorporate to increase soil pH of the very acidic and moderately acidic sites as shown on the Figure 5 and 6. The soil pH showed low variability (12%) in the studied soil samples. The adoption of heterogeneous management practice and occurrence of different types of land in the farm might be the reason for different classes of soil reaction (pH). Khadka et al. (2017) also found different classes of pH within the single research farm of comparable size of National Rice Research Program, Hardinath, Dhanusha, Nepal.

Table 4. Soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Descriptive Statistics	Soil Fertility Parameters				
	pH	OM, %	N, %	P_2O_5, ppm	K_2O, ppm
Mean	5.98	2.80	0.09	39.77	134.12
Standard Error	0.08	0.07	0.004	5.27	4.91
Standard Deviation	0.69	0.66	0.04	47.41	44.19
Min.	4.49	0.78	0.01	1.16	58.2
Max.	7.58	4.42	0.22	229.58	344.4
CV%	12	24	42	119	33

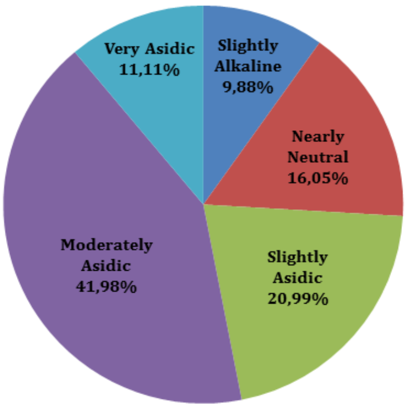

Figure 5. Distribution of soil reaction (pH) of the studies samples

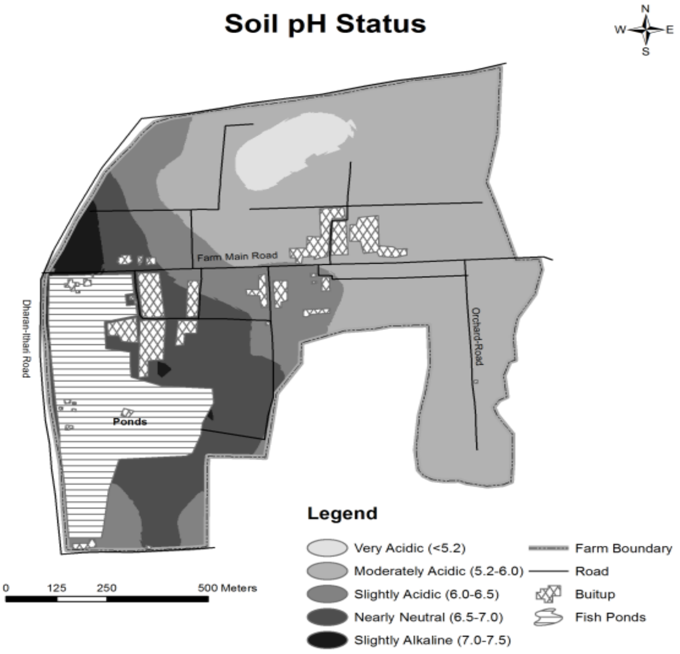

Figure 6. Soil pH status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Soil organic matter

Organic matter has a vital role in agricultural soil. It supplies plant nutrient, improve the soil structure, water infiltration and retention, feeds soil micro-flora and fauna, and the retention and cycling of applied fertilizer (Johnston, 1986). The organic matter content was ranged from 0.78 to 4.42% with a mean value of 2.80% (Table 4). This indicates medium status of the organic matter. Distribution of soil samples with respect to organic matter content indicates that about 6 % samples had low organic matter, while 49 % were medium and other 44 % samples had higher organic matter (Figure 7, Table 5). Organic matter showed low variability (24%) among the soil samples. This farm is more sustainably running than the majority of the terai regions farms of NARC. Because the organic matter content is satisfactory than most of the others (Khadka et al., 2016b; Khadka et al., 2016d; Khadka et al., 2017). The farm should run more consistently as adopted present practice for organic matter improvement in the future.

Total nitrogen

Nitrogen is one of the most important plant nutrients and the most frequently deficient of all nutrients (Havlin et al., 2010). The total nitrogen content was ranged from 0.01 to 0.22% with a mean value of 0.09%

(Table 4). This showed medium status of total nitrogen. The study indicates that about 38% of the sample exhibited low and 58 % under medium and other 4 % in high range of nitrogen content (Figure 8, Table 5). Moderate variability (42%) in total nitrogen was observed among the sampled soils. The satisfactory conditions in the organic matter might be the reason for medium status in total nitrogen. Those areas which have low status should be applied with full dose (100%) of the recommended nitrogen dose, whereas 75% of the recommended dose in medium status area might be sufficient (Joshy and Deo, 1976).

Table **5.** Nutrient indices and percentage distribution of studied soil parameters of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

S.N.	Parameters	% distribution of samples					NI	Remarks
		VL	L	M	H	VH		
1.	OM		6	49	44		2.38	H
2.	N		38	58	4		1.65	L
3.	P_2O_5	4.94	20.99	29.63	24.69	19.75	2.22	M
4.	K_2O	-	-	46.91	51.85	1.23	2.53	H
5.	Ca	-	-	67	33	-	2.33	M
6.	Mg	-	69	28	2	-	1.33	L
7.	S	75.3	23.5	1.2	-	-	1.01	L
8.	B	100	-	-	-	-	1.00	L
9.	Fe	-	-	-	-	100	3.00	H
10.	Zn	74.07	23.46	2.47	-	-	1.01	L
11.	Cu	-	22.22	38.27	39.51	-	2.21	M
12.	Mn	2.47	11.11	17.28	60.49	8.24	2.59	H

*VL=Very Low; L= Low; M= Medium; H= High; VH= Very High; NI= Nutrient Index

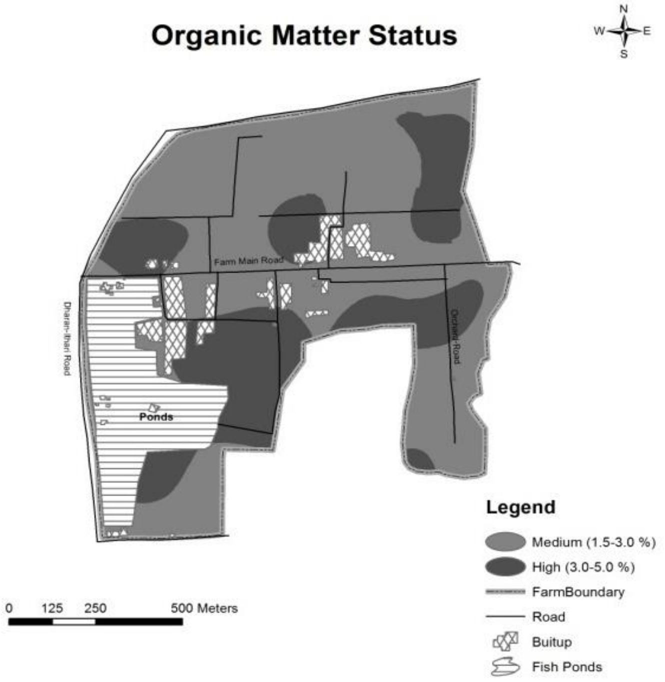

Figure 7. Organic matter status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

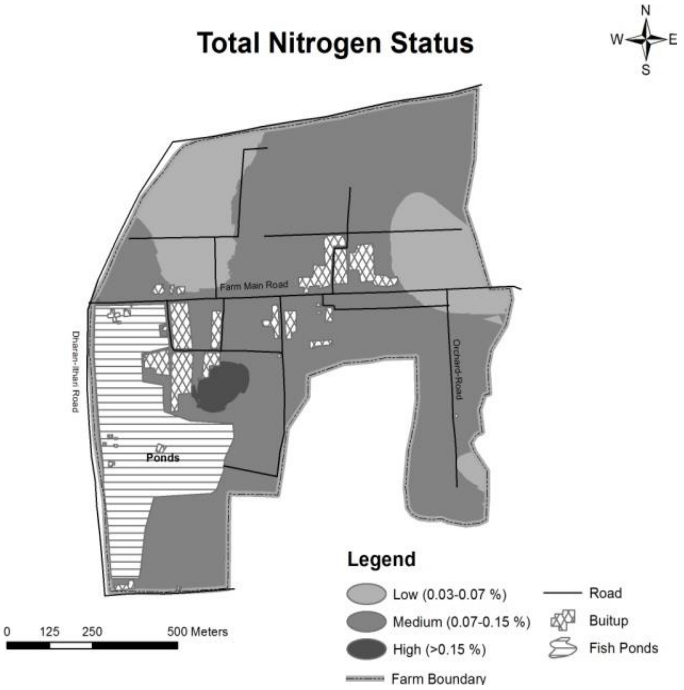

Figure 8. Total nitrogen status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Available phosphorus

Phosphorus plays an important role in energy transformations and metabolic processes in plants (Rai et al., 2012). The available phosphorus was ranged from 1.16 to 229.58 ppm with the mean value of 39.77 ppm (Table 4). This revealed high status of available phosphorus. The study indicates that about 4.94 % of the samples exhibited very low and 20.99% were low, while 29.63% samples were medium and 24.69 % under high and 19.75 % in very high range of Phosphorus content (Figure 9, Table 5). Available phosphorus showed high variability (119%) among the tested soil samples. The different classes of available phosphorus that the farm possesses might be due to adoption of heterogeneous management practices as well as occurrence of different classes of pH. The area having low, medium and high status, 100%, 60%

and 40%, respectively of recommended phosphorus dose should be applied in the farm (Joshy and Deo, 1976).

Extractable potassium

Potassium is not an integral part of any major plant component but it plays a key role in a vast array of physiological process vital to plant growth from protein synthesis to maintenance of plant water balance (Sumithra et al., 2013). The extractable potassium content was varied from 58.2 to 344.4 ppm with a mean value of 134.12 ppm (Table 4). This suggests high status of extractable potassium. The data reveals that 51.85 % soil samples tested were in high level of extractable potassium, while 46.91% samples were medium and other 1.23 % samples were very high in status (Figure 10, Table 5). Moderate variability (33%) in extractable potassium was determined among the soil samples. The satisfactory conditions of extractable potassium in the farm might be due to the optimum application of potash as well as less loss of potassium ion from the soil. Because majority of the study area soil texture of the study area was fine.. The fertilizer recommended practice is similar with phosphorus already mentioned in the phosphorus section for medium and high status.

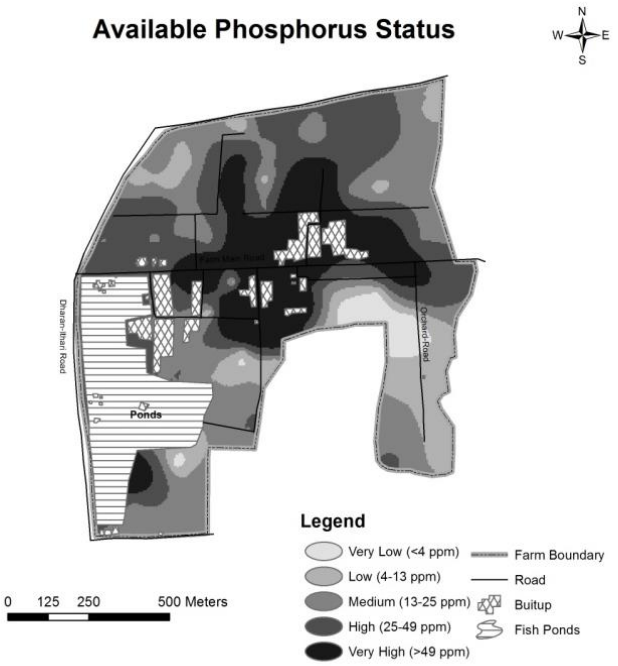

Figure 9. Available phosphorus status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

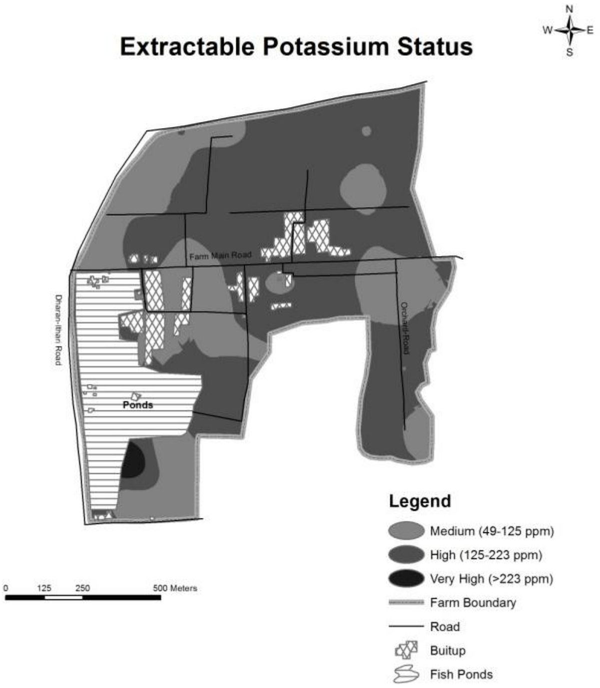

Figure 10. Extractable potassium status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Extractable calcium

Calcium is a key regulator of plant responses to endogenous stimuli and stress signals of both biotic and abiotic nature (Lecourieux, 2006).The extractable calcium content was ranged from 1034 to 2728 ppm with a mean value of 1827.9 ppm (Table 6). This showed medium status of extractable calcium. As per the percentage category, majority samples (67%) were medium and only 33% samples were high in status (Figure 11, Table 5). Low variability (23%) in extractable calcium was observed among the soil samples.

Table 6. Soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Descriptive Statistics	Soil Fertility Parameters			
	Ca, ppm	Mg, ppm	S, ppm	B, ppm
Mean	1827.90	44.33	2.17	0.08
Standard Error	45.80	6.03	0.21	0.01
Standard Deviation	411.80	54.27	1.93	0.07
Min.	1034	1.5	0.09	0.01
Max.	2728	330.0	8.70	0.35
CV%	23	122	89	87

Extractable magnesium

Magnesium ions (Mg^{2+}) are the second most abundant Cation in living plant cells, and they are involved in various functions, including photosynthesis, enzyme catalysis, and nucleic acid synthesis (Tanoi and Kobayashi, 2015). The extractable magnesium content was varied from 1.5 to 330.0 ppm with a mean value of 44.33 ppm (Table 6). This indicates low status of extractable magnesium. As per the percentage category; majority samples (69%) were low, while 28% samples were medium and only 2% samples were high in status (Figure 12, Table 5). The variation (122%) in the extractable magnesium of the observed samples is high. The maintenance of slightly acidic to slightly alkaline soil pH is suitable option for increasing availability of magnesium in the soil (Havlin et al., 2010).

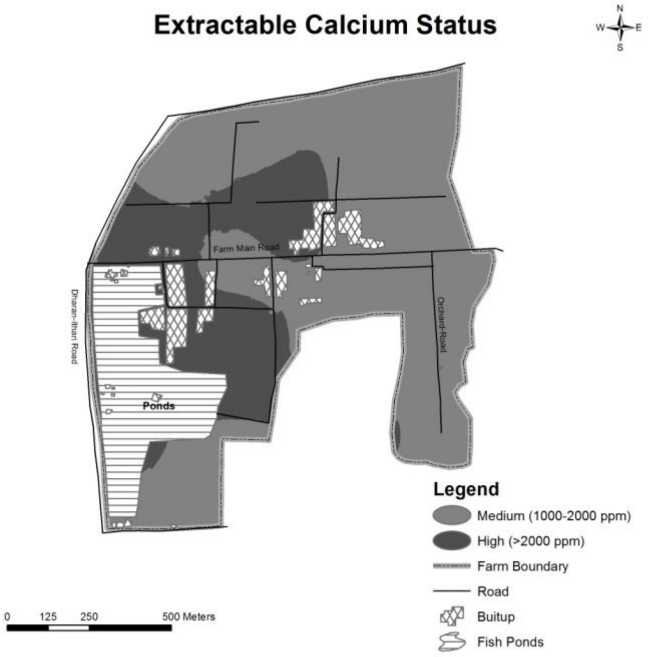

Figure 11. Extractable calcium status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

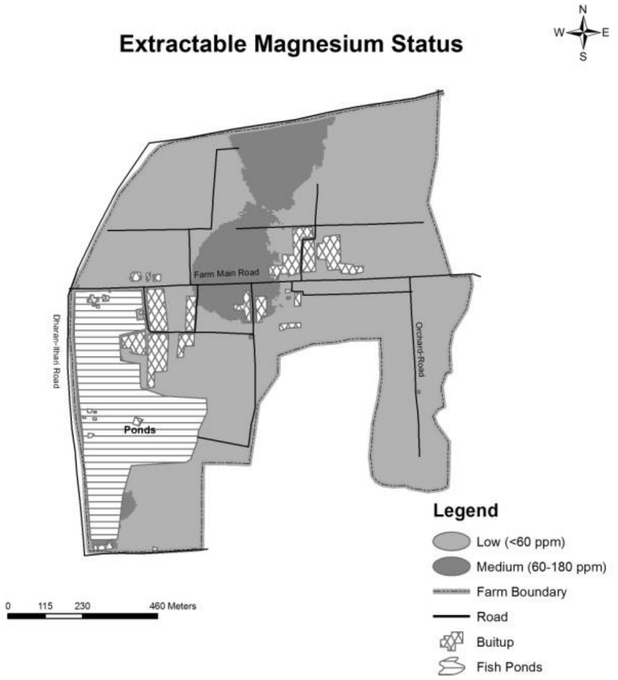

Figure 12. Extractable magnesium status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Available sulphur

Sulphur is an essential nutrient for plant growth due to its presence in proteins, glutathione, phytochelatins, thioredoxins, chloroplast membrane lipids, and certain coenzymes and vitamins (Takahashi et al. 2011). The available sulphur was ranged from 0.05 to 8.70 ppm with a mean value of 2.17 ppm (Table 6). This showed very low status of available sulphur. With regard of percent category, majority samples (75.3%) were very low, while 23.5% samples were low and 1.2% samples were medium in status (Figure 13, Table 5). Available sulphur showed high variability (89%) in the soil samples. Low sulphur is a major limiting factor for crop production in the terai region of Nepal (Khadka et al., 2016a, Khadka et al., 2016c, Khadka et al., 2016d; Khadka et al., 2017).The sulphur is a component of organic matter released after their mineralization (Havlin et al., 2010). The organic matter is satisfactory but available sulphur is low, which might be due to the occurrence of high nitrogen among all in the organic matter. Application of sulphur containing fertilizer regularly is sustainable option for reducing deficiency stress for plants.

Available boron

Boron is one of two nonmetal micronutrients required by plants for their cell wall structural integrity (Havlin et al., 2010). The available boron content was ranged from 0.01 to 0.35 ppm with a mean value of 0.08 ppm (Table 6). This indicates very low status of available boron. As per the percentage category, all the samples (100%) were very low in available boron (Figure 14, Table 5). High variability (87%) in available boron was observed among the soil samples. Boron content is also inadequate in the nearby sites of the study area (Khadka et al., 2016d; Khadka et al., 2017). Regular soil application of 2-3 kg/ha Boron is suitable option for reducing boron deficiency stress for the plants.

Available iron

Iron is an essential nutrient for plants. It accepts and donates electrons, and it plays important roles in the electron transport chains associated with photosynthesis and respiration (Das, 2000). The available iron content was varied from 38.4 to 793.0 ppm with a mean value of 244.7 ppm (Table 7). This indicates very high status of available iron. As per the percentage category, all the samples (100%) possessed very high content of available iron (Figure 15, Table 5). Available iron showed high variability (72%) among the soil samples. The iron content is high in the most of the terai region of Nepal (Khadka et al., 2015; Khadka et al., 2016a; Khadka et al., 2016b; Khadka et al., 2017). The very high availability of iron might be due to high possibility of primary and secondary iron minerals like hematite, olivine, siderite, goethite, magnetite etc (Das, 2000). High iron availability reduces the uptake of elements K, P, Mn and Zn, thereby increasing the deficiency symptoms of these nutrients (Fageria et al., 2008). Therefore, proper management of these nutrients is one option for reducing deficiency stress of these nutrients due to iron toxicity. Similarly, selection and cultivation of iron toxicity tolerant genotype is another suitable option for its toxicity management.

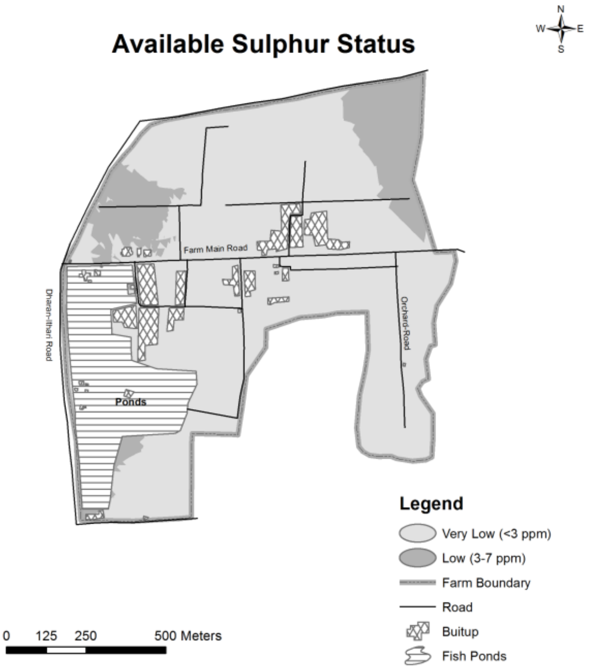

Figure 13. Available sulphur status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

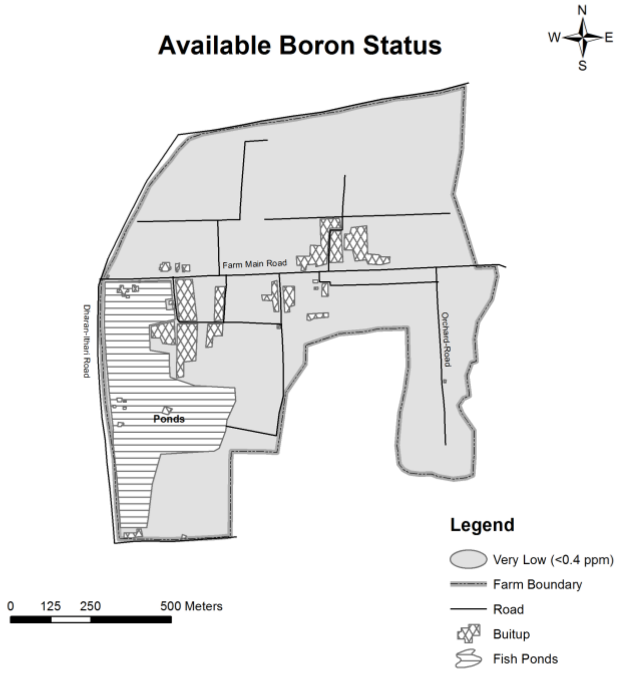

Figure 14. Available boron status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Table 7. Soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Descriptive Statistics	Soil Fertility Parameters			
	Fe, ppm	Zn, ppm	Cu, ppm	Mn, ppm
Mean	244.70	0.35	1.15	18.15
Standard Error	19.70	0.03	0.04	1.15
Standard Deviation	177.40	0.30	0.37	10.35
Min.	38.40	0.004	0.30	0.20
Max.	793.0	1.52	1.94	51.28
CV%	72	86	32	57

Available zinc

Zinc plays very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Havlin et al., 2010). The available zinc content was ranged from 0.004 to 1.52 ppm with a mean value of 0.35 ppm (Table 7). This showed very low status of available zinc. As per the percentage category; majority of samples (74.07%) were very low, while 23.46% samples were low and only 2.47% samples showed medium in status (Figure 16; Table 5). The available zinc showed high variability (86%) among the soil samples. Zinc content is inadequate in the nearby sites of the study area (Khadka et al., 2016d; Khadka et al., 2017). Regular soil application of 6-8 kg/ha Zinc is suitable option for reducing zinc deficiency stress for the plants.

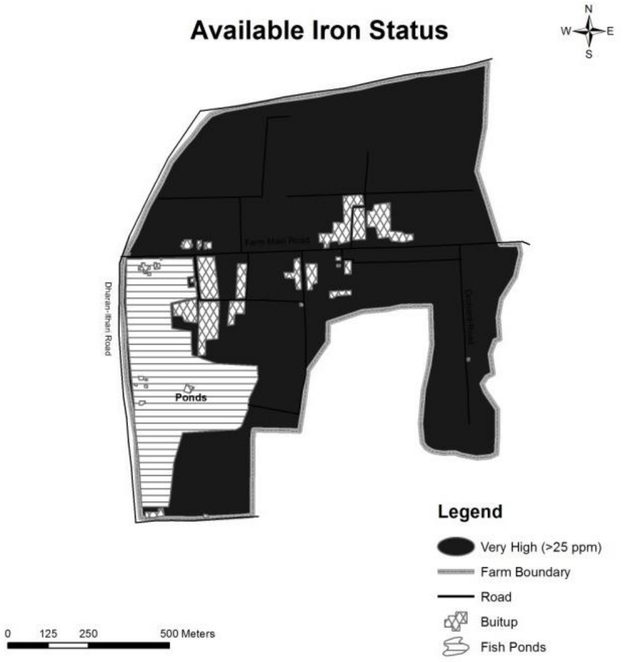

Figure 15. Available iron status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

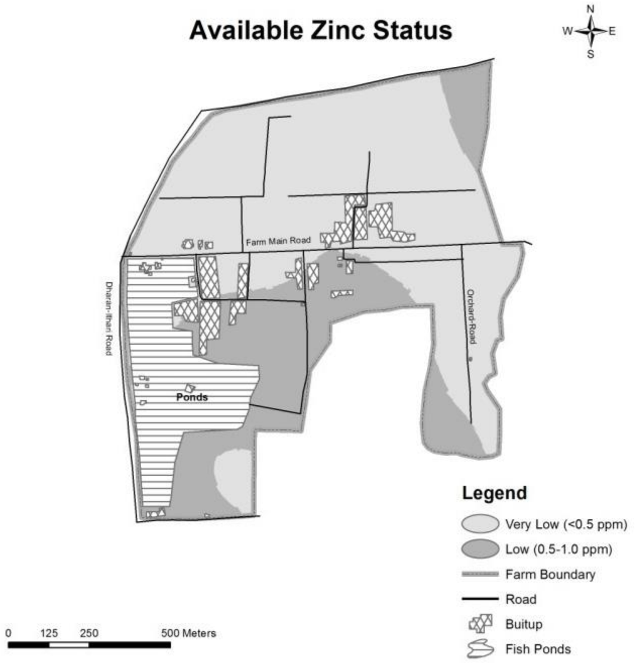

Figure 16. Available zinc status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Available copper

Copper is one of the oldest known metals and is the 25th most abundant element in the Earth's crust. The available copper of the soil depicted from 0.30 to 1.94 ppm with a mean of 1.15 ppm (Table 7). This showed medium status of available copper. As per the percent category, 22.22%, 38.27% and 39.51% samples were low, medium and high in status, respectively (Figure 17, Table 5). Moderate variability (32%) in available copper was recorded among the soil samples.

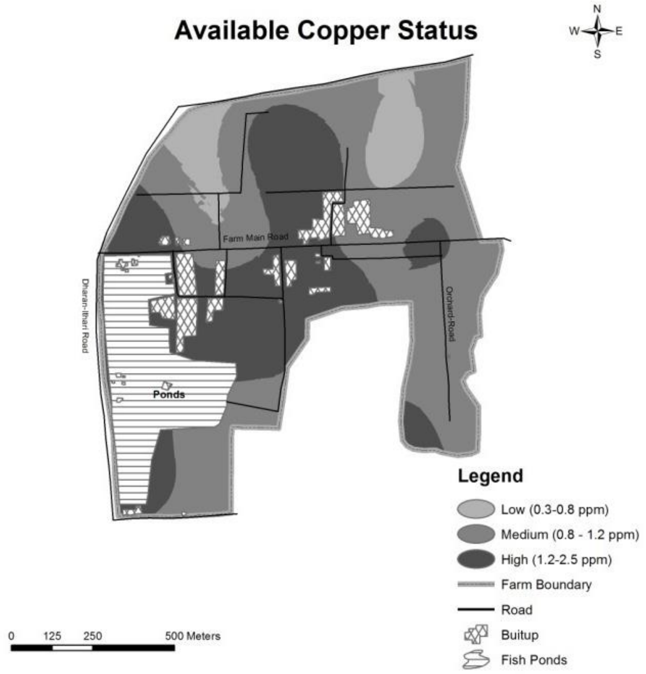

Figure 17. Available copper status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

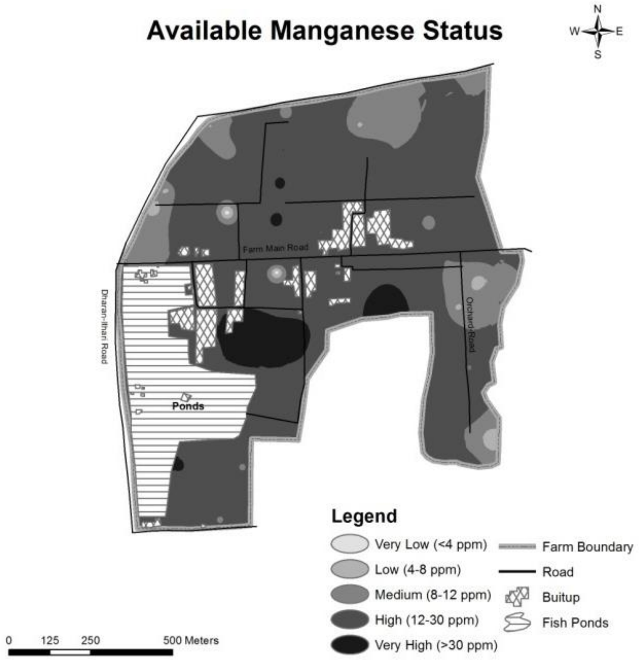

Figure 18. Available manganese status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal

Available manganese

Manganese is the tenth-most abundant element on the surface of the earth. It is involved in many biochemical functions, primarily acting as an activator of enzymes such as dehydrogenases, transferases, hydroxylases, and decarboxylases involved in respiration, amino acid and lignin synthesis, and hormone concentrations (Burnell, 1988). The available manganese of the soils ranged from 0.20-51.28 ppm with a mean of 18.15 ppm (Table 7). This exhibits high status of available manganese. As per the percentage category, majority of samples (60.49%) were high, while other 17.28%, 11.11% , 8.24% and 2.47% samples exhibited medium, low, very high and very low in status, respectively (Figure 18, Table 5). The available manganese showed moderate variability (52%) among the studied soil samples.

Conclusion

The prepared soil data base is very useful for fertilizer recommendations for different crops to economize their production. The crops may suffer from the deficiency and toxicity stress of the particular determined such nutrients. The proper nutrient management should be adopted especially for these nutrients during cultivation. Similarly, soil fertility variation is very high in the majority of nutrients due to various intrinsic and extrinsic factors. Keeping one season fallow before starting any experiment is advisable for reducing error in the experimentation due to soil fertility variation. Furthermore, the research farm should develop future research strategy like identification of iron toxicity, boron and zinc deficiency stress tolerant genotypes, soil acidity amelioration mechanism etc. based on the prepared soil data base.

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The authors would like to acknowledge Nepal Agricultural Research Council (NARC) for funding this research. We are very much thankful to Regional Agricultural Research Station, Tarahara, Sunsari, Nepal for their cooperation. Similarly, support of the Soil Science Division, Khumaltar, Lalitpur, Nepal for providing laboratory facilities to analyze the soil samples as well as other technical support is highly acclaimed.

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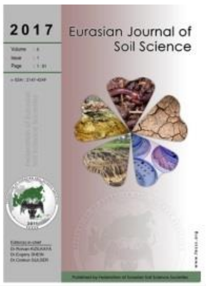

Clay activity index as an indicator of soil erodibility

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Abstract

Activity index (AI) value characterizes the relationship between the plasticity index and clay content. In this study, AI value was investigated to determine whether it might be used as an indicator of soil structural stability or not. The AI values of 75 soil samples gave the significant negative correlations with their dispersion ratio (DR), soil erodibility factors (K) and erosion ratios (ER). Also, the AI values of the soils including clay and sandy clay loam textural class showed significant positive correlation with soil structural stability index (SSI). It seems that the AI value may be used as an indicator of soil structural stability.

Keywords: AI value, erosion ratio, soil erodibility, structure stability index.

Introduction

As the world population rate increases, cultivation of agricultural lands becomes increasingly necessary to feed this high population. Therefore, soil management and cultivation practices should be improved to sustain soil fertility and to prevent high erosion vulnerability. Almost 80% of Turkish soils are affected by erosion requiring radical precautions, especially on cultivated land. Hence it is of primary importance to know the major factors, which influence erosion at various degrees (Özdemir and Aşkın, 1999; 2003). It is known that soil properties limit the land use and management or establish the severity of the limitation. An abundance of nutrients in soil does not always indicate high crop production. Soil structure one of the most important soil physical properties is known as an indicator of the productivity of a given soil and also controls the severity of soil erosion.

Soil structure can be improved or destroyed readily through our choice and timing of soil management practices (Hillel, 1982). Soil structure influences some soil erodibility indices such as, dispersion ratio (DR), erosion ratio (ER), erodibility factor (K) and soil structural stability index (SSI). These indices have been developed to determine soil erosion susceptibility and used to assess sustainable soil use and management (Bryan, 1968; Karagül, 1999; Morgan, 2005).

Atterberg limits and clay content have been combined into a single parameter called the Activity Ratio developed by Skempton (1953). Activity Raito, sometimes called the Activity Index (AI), is defined as the ratio of the plastic index to the percentage of clay sized minerals. Gülser et al. (2009) studied the relationships between soil workability and soil mechanical properties such as; activity index, Atterberg limits, soil consistency in the field of Karadeniz Agricultural Research Institute, Samsun-Turkey. It may be used for a rapid and quantitative method to assessing soil structure. The objective of this study was to determine whether clay activity index might be used as an indicator of soil structural stability or not.

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Material and Methods

In this study, 75 soil samples used were taken from 0 to 20 cm depth around Samsun province of Turkey. Some soil physical and chemical properties were determined as follows; particle size distribution by the hydrometer method (Demiralay, 1993); lime content by Scheibler calsimeter (Soil Survey Staff, 1993); soil reaction (pH) in 1:2.5 (w:v) soil-water suspension by pH meter (Black, 1965); organic matter content by Walkley-Black method (Kacar, 1994). Field capacity (FC) was measured at 33 kPa on a ceramic plate (Klute, 1986). Activity index (AI), dispersion ratio (DR), erosion ratio (ER), soil erodibility factor (K), and structural stability index (SSI) values were estimated by the following equations:

$$AI = \frac{LL - PL}{Clay, \%}$$

Where, LL is a percent moisture in liquid limits, PL is a percent moisture in plastic limits (Baumgartl, 2002).

$$DR\ (\%) = (a/b) * 100$$

Where, a is the percentage of silt plus clay in suspension, b is the percentage of silt plus clay dispersed with chemical agent (Bryan, 1968).

$$ER\ (\%) = (a/b) * (A/c) * 100$$

Where, a is the percentage of silt plus clay in suspension, b is the percentage of silt plus clay dispersed with chemical agent, A is the field capacity, c is the percentage of clay dispersed with chemical agent (Akalan, 1967).

$$K = [(2.1 * 10^{-4}\ (M)^{1.14}\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3))\ 1.292] / 100$$

Where, M is the particle size parameter (% silt + % very fine sand)*(100 - % clay), a is the percentage of organic matter, b is the soil structure code and c is the profile permeability class (Wischmeier and Smith, 1978).

$$SSI\ (\%) = \sum b - \sum a$$

Where, b is the percentage silt plus clay dispersed with chemical agent, a is the percentage of silt plus clay in suspension (Leo, 1963).

Descriptive statistics of AI Value and soil erodibility indices was calculated by using SPSS. The correlations between AI value and the other indices, DR, ER, K and SSI were also estimated (Steel and Torrie, 1982).

Results and Discussion

Some physical and chemical properties of soil samples

Some physical and chemical properties of the soil samples used in this study are given in Table 1. According to soil particle size distribution, 75 soil samples were classified into five different textural classes with 25 in clay (C), 27 in clay loam (CL), 12 in sandy clay loam (SCL), 7 in loam (L) and 4 in sandy loam (SL). Cation exchange capacity (CEC, cmol/kg), lime ($CaCO_3$) and organic matter contents of the soil samples varied from minimum 16.00 cmol/kg, 0.31% and 1.02% to maximum 57.82 cmol/kg, 44.87% and 3.25% with the means of 34.38 cmol/kg, 5.98%, and 1.84% respectively. Soil reaction (pH) of the samples was generally alkaline and changed from strongly alkaline (8.7) to slightly acid (5.7) (Soil Survey Staff, 1993).

Table 1. Mean and standard deviation (SD) values of physical and chemical properties of soil samples (n=75)

Soil textural class	Sand, %		Silt, %		Clay %		pH (1:2.5)		$CaCO_3$, %		Org. Mat., %		CEC, cmol/kg	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
C	26.13	5.9	27.34	4.7	46.52	5.1	7.38	0.5	8.02	10.1	2.31	0.4	41.47	6.4
CL	36.96	6.1	28.15	5.3	34.88	3.5	7.75	0.3	5.92	4.3	1.78	0.4	34.10	3.9
SCL	53.09	2.8	21.42	4.9	25.49	4.4	7.36	0.8	3.58	3.6	1.63	0.6	32.03	4.2
L	38.76	5.1	36.93	4.8	24.30	3.2	7.80	0.6	4.28	4.3	1.34	0.3	24.68	6.1
SL	62.02	2.5	22.00	1.1	15.98	1.6	7.63	0.5	3.93	3.9	1.35	0.1	17.60	1.1
n=75	37.34	11.8	27.39	6.3	35.27	10.3	7.57	0.5	5.98	6.7	1.84	0.5	34.38	8.2

AI value and soil erodibility indices of the soil samples

Descriptive statistical results for activity index (AI) value and soil erodibility indices; dispersion ratio (DR), erosion ratio (ER), erodibility factor (K) and structural stability index (SSI) in different textural classes are given in Table 2. The AI value describes the relationship among plasticity index and clay content in soil. Regardless of textural classes, the AI values of all soil samples varied from 0.16 to 0.78 with a mean of 0.44 and 37.36 % coefficient of variance (CV). Coefficient of variance values of AI depend on textural classes were between 4.63% found in SCL and 14.46% found in C.

Table 2. Descriptive statistics of AI value, soil erodibility indices such as, dispersion ratio (DR), erosion ratio (ER), erodibility factor (K) and structural stability index (SSI) of the soils

Factor	Soil Texture	Min.	Max.	Mean	SD	CV	Skewness
AI	C	0.49	0.78	0.62	0.09	14.46	0.39
	CL	0.33	0.48	0.41	0.04	11.87	0.11
	SCL	0.30	0.32	0.30	0.01	4.63	0.38
	L	0.21	0.27	0.24	0.02	7.63	0.35
	SL	0.16	0.21	0.18	0.02	12.21	-0.12
	n =75	0.16	0.78	0.44	0.16	37.36	0.49
DR (%)	C	11.85	31.00	20.50	5.58	27.25	0.04
	CL	20.00	47.25	27.84	6.42	23.05	0.36
	SCL	23.02	39.88	30.82	3.33	17.78	0.64
	L	27.00	54.05	35.60	8.57	24.07	1.39
	SL	31.00	41.00	37.17	4.09	10.99	-1.51
	n =75	11.85	54.05	27.90	8.26	29.69	0.46
ER (%)	C	7.12	22.00	15.72	4.34	27.59	-0.32
	CL	23.00	31.02	27.27	2.58	9.44	-0.16
	SCL	34.00	44.14	34.45	1.94	5.18	-0.04
	L	41.00	5.00	45.53	3.02	6.63	-0.15
	SL	51.00	81.00	63.66	11.25	17.68	1.41
	n=75	7.12	81.00	28.73	13.19	45.94	0.38
K	C	0.11	32	0.19	0.04	20.50	0.49
	CL	0.21	0.38	0.26	0.04	14.00	0.15
	SCL	0.33	0.42	0.37	0.02	4.74	-0.20
	L	0.42	0.44	0.43	0.01	1.60	0.31
	SL	0.46	0.50	0.48	0.02	3.25	0.01
	n=75	0.11	0.50	0.28	0.09	34.28	-0.40
SSI (%)	C	42.00	72.96	57.22	6.82	11.75	0.53
	CL	31.44	57.00	44.20	6.76	15.45	-0.19
	SCL	26.82	42.00	36.80	4.41	11.97	-1.44
	L	27.33	41.45	34.82	4.21	12.10	4.34
	SL	30.00	36.00	34.00	1.36	2.60	-2.00
	n=75	26.82	72.96	46.05	10.71	23.27	0.384

Positive values of the skewness or third central moment suggest tailing to the right, while negative values of the skewness suggest tailing to the left on the horizontal axis of a plot. A symmetrical distribution always has zero for the value of skewness (Isaaks and Sarivastava, 1989). Therefore, the AI values in CL and SL texture classes showed almost a symmetrical distribution due to their skewness values becoming close to zero. While the lowest mean AI value was 0.18 found in SL textural class, the highest mean AI was 0.62 found in C textural class. Also, the highest skewness, (0.39) and standard deviation (0.09) for AI values were obtained in the C textural class. Atterberg limits and clay content can be combined into a single parameter called activity (Skempton, 1953). Activity value is used as an index for identifying the swelling potential of clay soils. Skempton (1953) suggested three classes of clays according to activity: i) inactive, AI less than 0.75, ii) normal, AI between 0.75 and 1.25 and iii) active, AI greater than 1.25. According to this assessment, the soils sampled from around Samsun province of Turkey were mostly considered inactive. Gülser et al. (2009) reported that activity index values of soils in Karadeniz Agricultural Research Institute Field, Samsun Turkey varied between 0.44 and 0.65 with a mean of 0.53 which was less than 0.75, and they concluded that soils in the field have inactive clays with only little swelling-shrinking activity.

Dispersion ratio was used to evaluate soils erodibility by the amount of silt plus clay in a dispersed state (Bryan, 1969). Dispersion ratios for all soil samples varied between 11.85% and 54.05% with a mean of 27.90% and 29.69% CV. While the texture class changed from fine to coarse, mean dispersion ratio increased 20.50 % in C to 37.17 % in SL. Erosion ratio is the form of dispersion ratio that is combined with the ratio of “colloidal content/field capacity” (Bryan, 1968). Erosion ratio for all soil samples changed from 7.12 to

81.00% with a mean of 28.73%. While the texture class changed from fine to coarse, mean erosion ratio increased from 15.72% in C to 63.66 % in SL. Erodibility, the vulnerability or susceptibility of the soil erosion, is a function of both the physical characteristics and the management of soil (Hudson, 1995). Erodibility factors (K) for all soil samples varied from 0.11 in C to 0.50 in SL with a mean of 0.28. Structural stability index (SSI) by the sum of the difference between mechanical and aggregate analyses of silt plus clay fractions was introduced as a rapid technique for estimating structural stability of soils by Leo (1963). SSI for 75 soil samples varied from 26.82% to 72.96% % with a mean of 46.05 %. While the texture of soil samples changed from fine to coarse, the mean SSI values decreased 57.22% in C to 34.00% in SL.

Relationships between AI value and soil erodibility indices

The relationships between the AI value and the soil erodibility indices of soil samples in different textural classes are given in Table 3. It was found that AI values of soil samples in all textural classes had negative relationships with DR, ER, K and positive relationships with SSI. When 75 soil samples were evaluated together, the AI value gave the statistically significant negative correlations with dispersion ratio (-0.721**), erosion ratio (-0.910**), erodibility factor (-0.939**) and a positive correlation with structural stability index value (0.692**) in Figure 1. If the texture classes are considered individually, the AI values in C textural class gave the significant correlations with the most erodibility indices such as, DR, ER, K and SSI. Except SL textural class, AI value showed the significant negative relations with almost all ER and K values in the other texture classes too. Also, AI values only showed significant positive correlations with SSI of soil samples in C (0.524**) and in SCL (0.642**) textural classes.

Table 3. Relationships between AI Value and Erodibility Indices

Soil Textural Class	DR, %	ER, %	K	SSI, %
C	-0.545**	-0.838**	-0. 920**	0.524**
CL	-0.597**	-0.979**	-0.986**	0.217
SCL	-0.380	-0.963**	-0.931**	0.642*
L	-0.774*	-0.984**	-0.904**	0.474
SL	-0.880	-0.851	-0.778	0.540
n=75	-0.721**	-.910**	-0.939**	0.692**

*significant at the 0.05 level, ** significant at the 0.01 level.

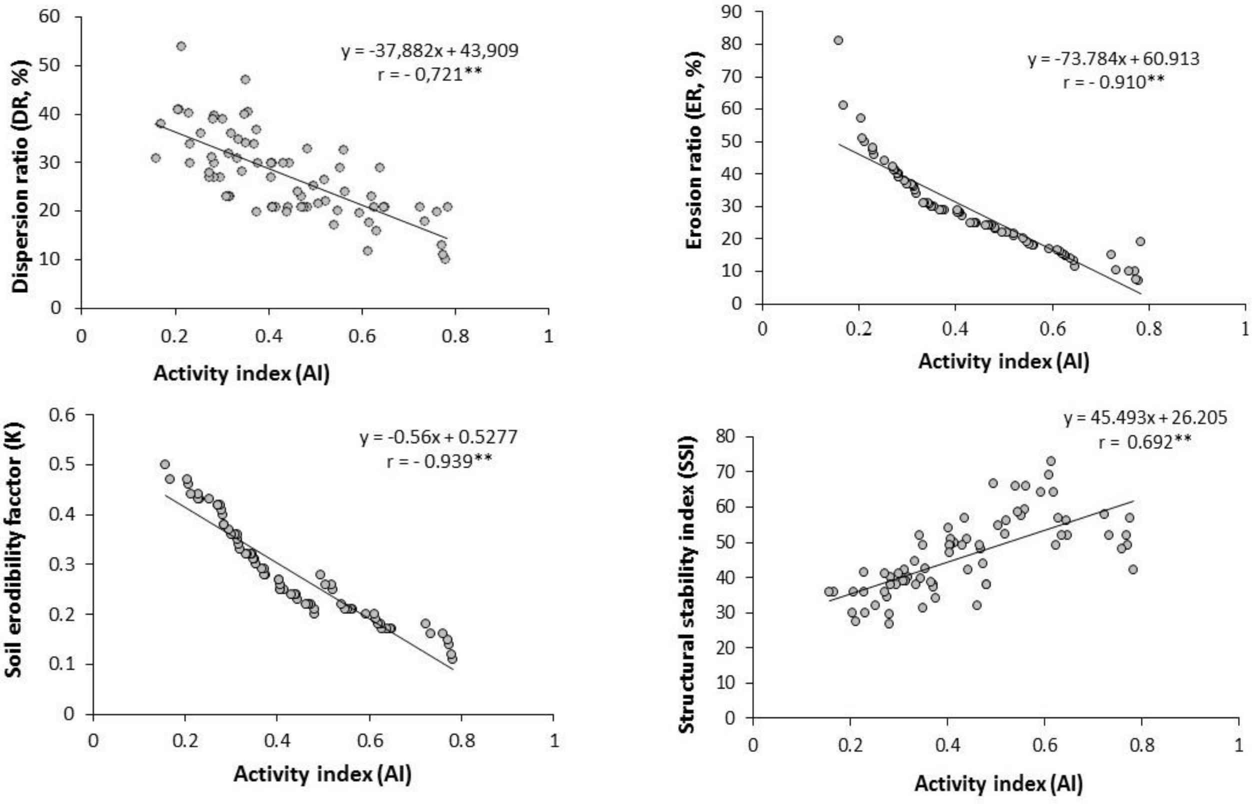

Figure 1. The relationship between AI value and soil erodibility parameters indexes within 75 soil samples

Conclusion

AI values in this study usually had higher correlation with erosion ratio and erodibility factor than the other erodibility indices. It may be explained that there are some similar parameters used in the estimations of highly correlated these indices. For example, field capacity and organic matter content used in estimation of erosion ratio and erodibility factor were only different parameters from the other parameters used in calculation of dispersion ratio and structure stability index. Because, silt plus clay content were only parameters used in estimation of DR and SSI. Plasticity index value and clay content other than particle size distribution were also used in estimation of AI value. Therefore, it seems reasonable that AI value would give high correlations with ER and K due to including similar parameters in their estimations.

As a result, due to significant relationships between AI value and the other erodibility indices, the AI value may be used as an indicator of soil structural stability especially in soils having fine textural class. Besides particle size distribution, using plasticity index value in estimation of AI value gives more details about soil structure than DR and SSI. It will be useful that further studies in field and laboratory conditions should be made along this line to increase validity of this study.

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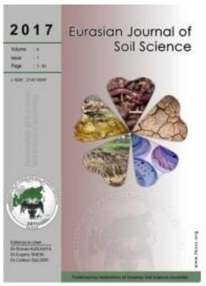

Phosphorus release dynamics under phosphate rock and ammonium sulphate in soil amendment

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Abstract

This study was undertaken to assess the release pattern of available phosphorus in a Togo phosphate rock and ammonium sulphate soil amendment. Treatments were prepared through the combinations of soil, phosphate rock (PR) and ammonium sulphate (AS) fertilizer. The treatments were; Control, 12.5g PR, 25g PR, 12.5g PR+1g AS, 12.5g PR+2g AS, 25.0g PR+1g AS and 25.0g PR+2g AS kg^{-1} soil. Standard laboratory methods were used to assess pH, available phosphorus (P) and total phosphorus (P). Generally, the pH of treatments decreased to the lowest levels between the 4th and 6th weeks after amendment. The AS fertilizer treatments had significantly ($p \leq 0.05$) lower pH values than those without. Amendments with the 2gAS kg^{-1} soil had significantly ($p \leq 0.05$) lower mean pH values than those with the 1gAS kg^{-1} soil. The AS fertilizer treatments also had significantly ($p \leq 0.05$) higher levels of the available P than those without. The higher the amount of the AS in the amendment, the higher the level of the available P concentration. Increase in the level of AS in the amendment also increased the mean value of the available P released. The peaks of available P released were observed between the 6th and the 8th weeks, after the lowest pH values had been attained. Decreased soil pH relatively increased the amount of phosphorus released ($y = -12.47x + 111.4$; $R^2=0.53$). Addition of PR in the treatments increased the total P levels. In conclusion, combined application of AS and PR has the potential to increase soil P availability, which is beneficial to crop farmers.

Keywords: Phosphate rock, ammonium sulphate, soil amendment, pH, available phosphorus, total phosphorus.

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Introduction

Soils in the sub-humid and humid tropics including sub-Saharan Africa are inherently poor. The inherent low fertility could be attributed to inappropriate land use, poor management and lack of nutrient inputs. These have led to decline in crop production, soil erosion, salinization and loss of vegetation (Bationo, 2009). Improvement of soil fertility and plant nutrition to sustain adequate yield of crops is therefore imperative. The continent has the lowest rate of fertilizer consumption in the world, with an average consumption estimated at 8.3 kg ha^{-1} (Morris et al., 2007). Farmers lack sufficient money or access to credit to purchase fertilizers, resulting to low fertilizer input and a gradual decrease of soil fertility (Buresh and Smithson, 1997).

The use of alternative sources of nutrient inputs to reduce the cost of synthetic fertilizer application would go a long way in reducing the cost of crop production. One such way of reducing the use of synthetic

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fertilizer is through the use of phosphate rock (PR), which has been considered as cheaper than synthetic phosphate fertilizers for supplying available phosphorus to plants (Lorion, 2004). The problem with PR is, however, its low solubility, particularly in non-acidic soils (Caravaca et al., 2004). Phosphate rock must therefore be treated to convert phosphate to available forms for plant use in soils.

Dissolution of PR to release available phosphorus has been done by some previous studies. Combined application of PR with phosphate-solubilizing microorganisms, which has the ability to bring insoluble soil phosphates in the PR into soluble forms by secreting organic acids have been employed in this sense (Delvasto et al., 2006; Prasanna et al., 2011).The use of organic manure or composting of agricultural wastes with phosphate rock is known to increase the solubility of phosphate rock (Van den Berghe, 1996; Zapata and Roy, 2004; Agyarko et al., 2016). The main principle behind composting of phosphate rock with organic manure or farm wastes is the production of organic and mineral acids as a result of their decomposition. Phosphate dissolution rates can be greatly accelerated in the soil in the presence of these organic acids (Kumari and Phogat, 2008). According to Kumari and Phogat (2008), various scientists have also tried acidulation of phosphate rock with different acids (usually with sulphuric or phosphoric acid), singly or in combination, in different ratios to enhance the dissolution of phosphate rock.

Ammonium sulphate [$(NH_4)_2SO_4$] is widely used as a source of nitrogen (N) for crop production by farmers in the sub-Saharan region of Africa. The fertilizer has an acidifying effect on soils due to the nitrification process in warm soils, where microbes will rapidly begin to convert ammonium to nitrate in the process of nitrification [$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$]. During this microbial reaction, H^+ is released, which ultimately decreases soil pH after repeated use (IPNI, 2016).

Such characteristics of ammonium sulphate fertilizer would be beneficial to farmers when combined with phosphate rock in fertilizer regimes to supply plants with phosphorus. The current study therefore, was to assess the release pattern of available phosphorus in a phosphate rock and ammonium sulphate soil amendment.

Material and Methods

The study was carried out at the College of Agriculture Education, University of Education, Winneba, Ghana (07° 04'N, 01° 24'W), from the latter part of April to the first week of August, 2015. The experiment was conducted in plastic pots (diameter - 10cm; 5kg soil capacity) with the treatments buried in the soil up to the tip of the pots under field conditions. Treatments were prepared through the combinations of soil (sampled from the top 0 – 15cm top layer of the College's experimental field and sieved through a 2mm sieve), ground Togo phosphate rock (PR) and ammonium sulphate (AS) fertilizer (Table 1). Treatments were replicated three (3) times. Some properties of the soil and the PR are presented in Tables 2 and 3. Samples were assessed at 0, 2, 4, 6, 8, 10, 12 and 14 weeks after placement of treatments on the field to determine pH, available and total phosphorus (P).

Table 1. Experimental treatments

Treatment kg^{-1} soil
Control (Soil only)
12.5gPR
25.0gPR
12.5gPR+1gAS
12.5gPR+2gAS
25.0gPR +1gAS
25.0gPR+2gAS

The total P of treatment samples was determined by the colorimetric method (Anderson and Ingram, 1989) and available P was determined by the Bray 1 method (Bray and Kurtz No. 1 Method) (IITA, 1985) (Bray and Kurtz, 1945) The pH (H_2O) of samples was also measured (Rowell, 1994). All data were subjected to analysis of variance (ANOVA) and the means were compared with the Least Significant Difference Test ($p \leq 0.05$) using the GenStat (11th Edition) statistical software package.

Results

Figure 1 shows the changes of soil pH in phosphate rock (PR) and ammonium sulphate (AS) fertilizer amended soil with weeks of application. Soil pH in all the treatments decreased to their lowest levels between the 4th and the 6th weeks after amendment. Throughout the 14 weeks following the soil amendment, the AS fertilizer treatments showed lower soil pH curves than those without AS fertilizer additions. The soils amended with 2g AS kg^{-1} had slightly lower pH curves than those with the 1g AS kg^{-1} soil. The treatments without AS fertilizer application showed an almost unchanging soil pH values throughout the 14 weeks of amendment.

Table 2. Chemical and physical properties of the soil

Property of Soil	Value and degree	
<u>Chemical</u>		
pH (1:1)	6.33	
OC (%)	1.18	
N(%)	0.12	
Ca (	4.63	
Mg (Cmol$_{(+)}$kg^{-1} soil)	1.60	
K (Cmol$_{(+)}$kg^{-1} soil)	0.16	
Na (Cmol$_{(+)}$kg^{-1} soil)	0.09	
OM (%)	2.04	
Avail. P (mg kg^{-1})	28.14	
Exch. A(Al+H)	0.10	
TEB (Cmol$_{(+)}$kg^{-1} soil)	6.48	
BS (%)	98.47	
<u>Physical</u>		
Sand(%)	78.28	
Silt (%)	2.21	*Sandy loam*
Clay (%)	19.51	

Source: Agyarko et al. (2016)

Table 3.Chemical properties of the phosphate rock

Property	Ca (%)	Mg (%)	K (%)	P (%)	N (%)
Value	46.82	0.03	0.02	11.04	0.04

Source: Agyarko et al. (2016)

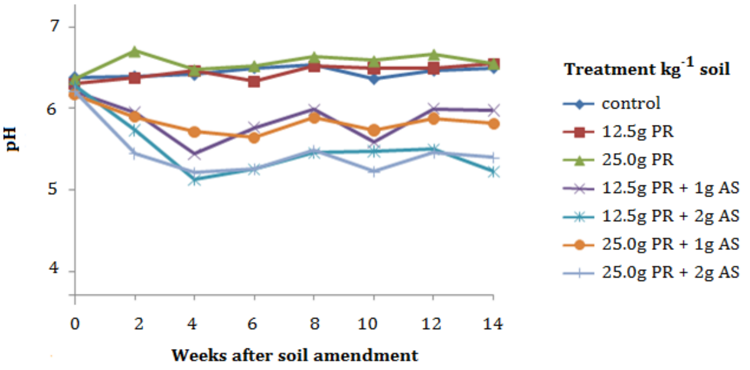


Figure 1. Changes in pH of treatments with time (PR=Phosphate rock; AS=Ammonium sulphate)

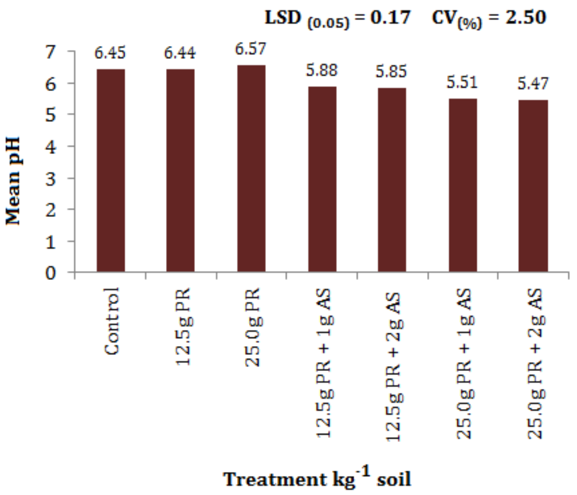


Figure 2. Mean pH of treatments after 14 weeks (PR=Phosphate rock; AS =Ammonium sulphate)

The mean soil pH values measured after the 14 weeks of soil amendment varied significantly ($p \leq 0.05$) among the different treatments (Figure 2). The AS fertilizer amended soils had significantly ($p \leq 0.05$) lower mean soil pH values than those without AS fertilizer application. Amendments with the 2g AS kg^{-1} soil had significantly ($p \leq 0.05$) lower mean soil pH values (5.64 and 5.65) than those with the 1g AS kg^{-1} soil (5.97 and 6.04). The mean soil pH values in the treatments with the only 12.5g or 25g PR were significant ($p \leq 0.05$) the same as the control treatment. Changes in available P concentrations in PR and AS fertilizer treated soil with weeks of application are presented in Figure 3. Treatments with the PR had curves that were conspicuously higher than the control treatment that received no P addition. Treatments with the addition of the AS had higher levels of the available P than those without. The higher the amount of the AS in the soil, the higher the level of the available P curve. In all the treatments, the peak amounts of available P released were observed between the 6th and the 8th weeks after amendment, generally after the lowest soil pH had been recorded between the 4th and the 6th weeks of amendment.

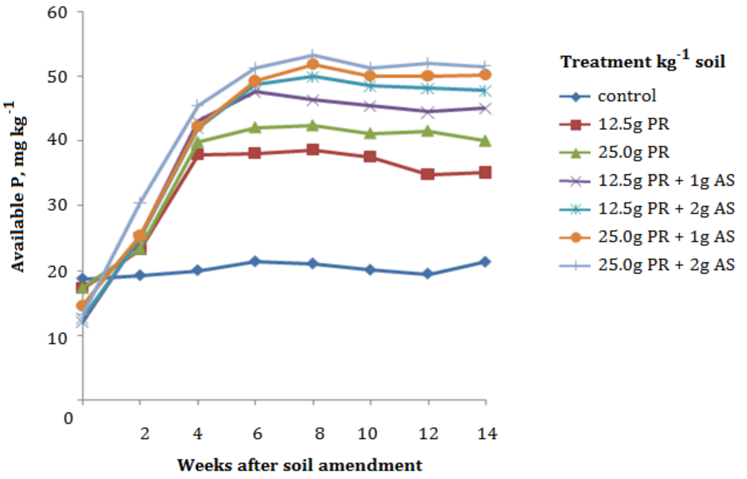


Figure 3. Changes in available P of treatments with time (PR=Phosphate rock; AS =Ammonium sulphate)

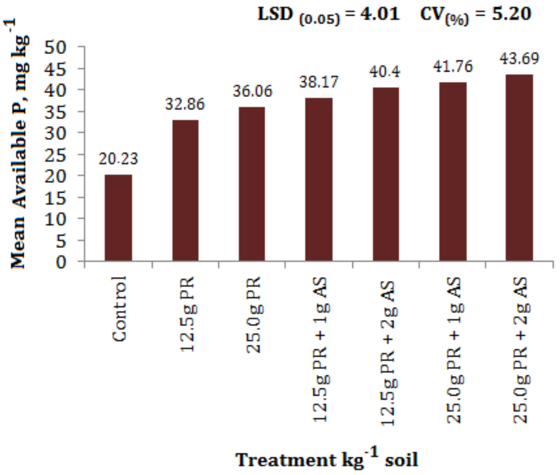
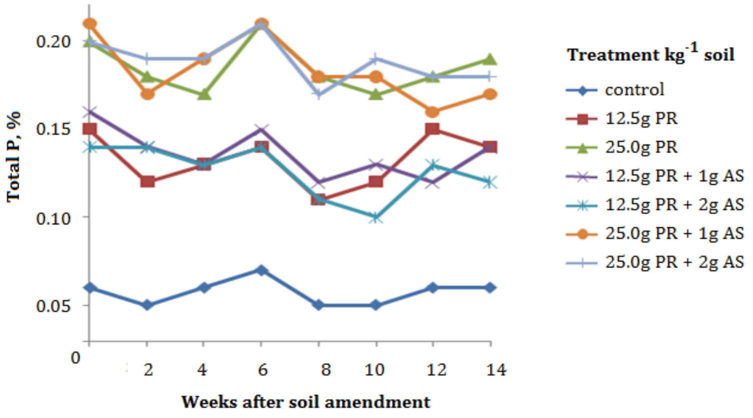


Figure 4. Mean available P of treatments after 14 weeks (PR=Phosphate rock; AS=Ammonium sulphate)

The mean available P concentrations in the different treatments at the end of the 14th weeks of amendment are shown in Figure 4. The combined addition of the AS and PR resulted in significantly ($p \leq 0.05$) higher mean available P concentrations than when the PR was applied solely. Mean available P concentrations increased with increased amounts of AS applied, which resulted in a decrease in soil reaction. Thus, soil pH significantly correlated negatively with the amount of available P released ($y = -12.47x + 111.4$; $R^2=0.53$). The combined additions of 1g AS and the 2g AS with 12.5g PR increased the mean available P concentration by 17.80% and 22.95%, respectively, while the addition of the same amounts of AS to the 25g PR increased the mean available P concentrations by 15.81% and 21.16%, respectively.

Although, PR application increased the total soil P concentrations (Figure 5), the total P curves remained almost constant throughout the study period. All the PR treatments had higher total P curves than the control that received no P source. All the soils amended with 25g PR kg^{-1} soil had statistically similar mean total P concentrations (18 and 19%), which were significantly ($p \leq 0.05$) higher than those found in the soils amended with12.5g PR kg^{-1} soil (13 and 14%), which were also not significantly different (Figure 6).



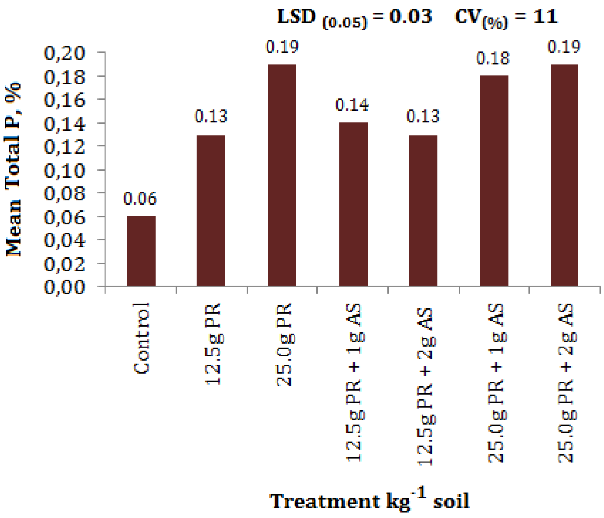


Figure 5. Changes in total P of treatments with time (PR = Phosphate rock; AS = Ammonium sulphate)

Figure 6. Mean total P of treatments after 14 weeks (PR=Phosphate rock; AS=Ammonium sulphate)

Discussion

In agreement with previous studies, soil pH in the different treatments decreased with the addition of the AS, in that ammoniacal or NH_4^+ containing inorganic fertilizers induce soil acidification through the production of hydrogen(H^+) ions during the nitrification of NH_4^+ to NO_3^- (Eq. 1 and Eq. 2) (Bolan and Hedley, 2003; IPNI, 2016):

$$(NH_4)_2\,SO_4 \leftrightarrow 2NH^+{}_4 + SO_4{}^{2-} \qquad [Eq.\ 1]$$

$$NH^+{}_4 + 2O_2 \leftrightarrow NO^-{}_3 + 2H^+ + H_2O \qquad [Eq.\ 2]$$

The release of H^+ during the nitrification process possibly explains why the higher dose of 2gAS kg^{-1} soil induced lower soil pH values than in the1gAS kg^{-1} soil treatments. In other studies, Fageria et al. (2010) and Ferrari et al. (2015) also found the soil pH to decrease with increasing doses of AS fertilizer rates. Ammonium sulphate is an acidic reaction fertilizer and it is stated that it will increase the microflora and S-oxidizing bacteria in the soil as a sulphur containing fertilizer, thus accelerating the pH decrease (Lluch and Olivares, 1979; Müftüoğlu and Sarımehmet, 1993).

According to the Penn State Agronomy Guide (2017), the change of NH_4^+ to NO_3^- in soils becomes complete within a period of 1 month (approximately 4weeks) after the application of NH_4^+ compounds. This is indicative that maximum soil hydrogen (H^+) ions concentrations are recorded when the nitrification reactions (Equations 1 and 2) are completed, leading to a decline in soil reaction. This mechanism is likely to be the underlying reasons for the decrease in soil pH observed in this study between the 4th and the 6th weeks after amendment.

The combined addition of AS and PR enhanced the release of available P, which increased with the amount of the AS in the amendment and the concomitant decrease in soil reaction. Dissolution of PR has been previously achieved through the use of both organic and inorganic materials in soil amendments to reduce soil reaction. For instance, Rodriguez et al. (2006); Kumari and Phogat (2008); Prasanna et al. (2011); Hellal et al. (2012) and Agyarko et al. (2016) have used organic materials in this regard, while Rajan et al. (1994); Chien (1979); Friesen et al. (1987); Ghosal and Chakraborty (2012); Ullah et al. (2012); Osman (2015) and Kumar et al. (2015) used inorganic substances including $(NH_4)_2SO_4$ and urea along with PR, as in the current study to increase PR dissolution.

The study showed that, the highest available P concentrations were observed between the 6th and the 8th weeks of amendment, after the lowest pH had been attained between the 4th and the 6th weeks of amendment. This trend is line with the observation made by Apthorp et al. (1987) who indicated that, increased dissolution of phosphate rock did not occur until acidity, generated by nitrification or sulphur oxidation of the fertilizer materials, had significantly lowered soil reaction.

The place of hydrogen (H^+) ion in the dissolution of PR [$Ca_5(PO_4)_3(F, OH)$] is presented in the following chemical processes (Equations 3 to 6) (Dorozhkin, 2012):

$$Ca_5(PO_4)_3(F, OH) + H_2O + H^+ \leftrightarrow Ca_5(PO_4)_3(H_2O)^+ + HF, H_2O \qquad [Eq.\ 3]$$

$$2Ca_5(PO_4)_3(H_2O)^+ \leftrightarrow 3Ca_3(PO_4)_2 + Ca^{2+} + 2H_2O \qquad [Eq.\ 4]$$

$$Ca_3(PO_4)_2 + 2H^+ \leftrightarrow Ca^{2+} + 2CaHPO_4 \qquad [Eq.\ 5]$$

$$CaHPO_4 + H^+ \leftrightarrow Ca^{2+} + H_2PO_4^- \qquad [Eq.\ 6]$$

Generally, inorganic fertilizers and other soil amendments increase the total soil nutrients levels. Therefore, the trend of increased total P concentration in the PR amended soil in the current study is not unexpected.

Conclusion

The combined application of ammonium sulphate (AS) fertilizer and phosphate rock (PR) in soil decreased the soil pH, with the lowest values occurring around the 4th and 6th weeks after amendment. The acidity produced enhanced the release of available P from PR. The highest available P values occurred after the lowest pH values had been achieved, between the 6th and 8th weeks after amendment. The higher the amount of the AS in the amendment the lower the pH and the higher the amount of the available P produced. Combinations of AS and RP in soil amendments would be beneficial to crop farmers.

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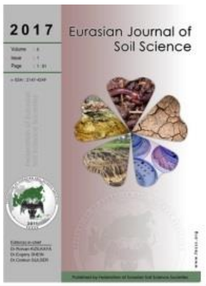

Synergistic use of nitrogen and zinc to bio-fortify zinc in wheat grains

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Abstract

Our daily diet is largely contributed by cereals, which have low genetic abilities to amass higher concentrations of micronutrients in their grains. Hence, wide spread deficiencies iron, zinc and other essential nutrients have prevailed. Present study focuses the bio-fortification of Zn in wheat grains, taking advantage of nutrient-nutrient synergy between Zn and N. Three wheat genotypes (NIA-Amber, BWQ-4 and SD-998) were tested in a field experiment following randomized complete block factorial design with three replicates. Urea fertilizer was applied at the rates of 120 (recommended), 150 and 180 kg N ha^{-1} in combination with three levels of Zn (0, 5 & 10 kg ha^{-1}). Outcomes of the experiment revealed that NIA-Amber had the highest grain yield of 6.03 tons/ha against 150 kg N ha^{-1} and 10 kg Zn ha^{-1}. Maximum Zn contents of 447.86, 429.56 and 395.56 g ha^{-1} were observed in BWQ-4, SD-998 and NIA-Amber at 180 kg N ha^{-1} in combination with 10 kg Zn ha^{-1}. Maximum enhancement in protein contents was observed in BWQ-4 (743 kg ha^{-1}) at 180 kg N ha^{-1}and combined with 5 kg Zn ha^{-1}. For NIA-Amber, 180 kg N ha^{-1} in combination of 10 kg Zn ha^{-1} proved the most suitable in terms of Zn concentration and other quality attributes. Nitrogen @ 180 kg N ha^{-1} with 5 kg Zn ha^{-1} depicted appreciable zinc and protein contents in grains of BWQ-4 and SD-998.

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Introduction

Bio-fortification is the production of crops with increased concentration of essentials minerals and protein to be provided to consumers through agricultural research and food trades (Allen, 2000). Such crops can serve as sustainable solution to the prevailing malnutrition among half of the world population (Riezzo et al., 2005).

Industrial fortification by supplementation and food processing; contrasts with bio-fortification (Vincent and Menefee, 2007; Mayer et al., 2008). Bio-fortification depends upon plant physiological efficiency of crops to accumulate higher concentration of desired mineral/nutrient (UNO, 2004; FAO, 2013). Breeding fortified crops, by using genetic variations and genetic modification can be a fruitful approach (Welch and Graham, 2004; Vijayaraghavan, 2002; Stein, 2006; Stein et al., 2007). Yet, fortification through nutritional management is of greater adaptability at farm level and less laborious (Bouis and Welch, 2010).

Cereals fulfill almost 61% of the total daily protein needs in human diet. Nitrogen has prime role in protein synthesis and crop yield especially in the country, where cereals are growing in almost 100% N deficient soils (Warraich et al., 2002). Crops respond to applied N due to its vital role in metabolism and growth (Abedi et al., 2010; Marino et al., 2011). Particularly, nitrogen in plants has role in proteins assimilation, protoplasm formation, nutrient regulation (Rodrigues et al., 2000), enzymatic functions and cell division (Oscarson, 2000; Warraich et al., 2002).

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Zinc is an important plant nutrient needed in small concentration. Its acute deficiency can lead up to 40% reduction in crop yield (Salvagotti and Miralles, 2007; Kutman et al., 2010; Kutman et al., 2011). Chlorophyll and auxin synthesis necessitate adequate Zn contents in plant tissues (Nadim et al., 2012; Jiang et al., 2013). Zinc also performs as cofactor to various enzymes hence, controls their activities. Wheat in comparison with other field crops has relatively better tolerance to Zn deficiency (Chauhan et al., 2014). However, its continuous cultivation in Zn deficient soils has resulted in wide spread Zn deficiency in grains; hampering crop production and causing low Zn supply to human (Chauhan et al., 2014).

Nitrogen and Zinc supplementations in wheat have prominent role in sustaining wheat production. The synergy between both can be used to augment Zn concentration in the edible portion and improving quality (Kutman et al., 2010; Shi et al., 2010; Cakmak, 2010; Cakmak et al., 2010a,b). Zinc uptake from soil to roots, mobilization in plant body and accumulation to sink is supported by nitrogenous proteins. (Wang et al., 2011). N is involved in the production of natural chelating agents (Kutman et al., 2010) like nicotianamine (NA) (Takahashi et al., 2003) and deoxymugeinic acid (DMA), involved in translocation of metals from flag leaves to grain (Barunawati et al., 2013). Therefore, the present study was executed to assess to N-Zn interaction to improve plant growth, nutrient contents, quality and Zn concentration in wheat grains.

Material and Methods

An field experiment was conducted at Nuclear Institute of Agriculture (NIA), Tando Jam, Sindh-Pakistan from 25th November, 2015 to 18th April, 2016. The experimental site was 29 m above sea level at latitude of $20^0$24'49.4" north and longitude of $68^0$31'03.7" east. The climate of the area is arid with an average high and low temperatures of 41^0C and 11^0C, respectively and annual precipitation less than 10.8mm (NAMC, 2016). Eighty one experimental units each of 4m × 4 m were allotted to three wheat genotypes (NIA-Amber, BWQ-4 and SD-998). Nine treatment combinations of three N levels (120, 150 and 180 kg ha^{-1}) and three levels of Zn (0, 5 and 10 kg ha^{-1}) were applied to each genotype with three replications. Phosphorus in the form of di-ammonium phosphate (90 kg P_2O_5 ha^{-1}) and potassium in the form of sulfate of potash (60 kg K_2O ha^{-1}) were applied at the time of sowing. Urea as nitrogen source was applied in three equal splits viz., at the time of sowing, tillering and panicle initiation. Zinc sulfate was applied along with second split of nitrogen to maintain three levels of zinc in the respective treatments. Experiment was irrigated with canal water at critical growth stages. Manual and chemical eradication of weeds and other cultural practices were performed as and when required. At harvest, yield attributes were recorded. From each replication, grain and straw samples were randomly collected and dried in oven at 70 ^{0}C for three days. A uniform portion of dried plant samples (straw and grain) was digested in di-acid (HNO_3 and $HClO_4$) mixture for the determination of phosphorus and Zn (Chapman and Pratt, 1961). Vanadomolybdate yellow color method was used for the determination of phosphorus (Ryan, 2000). Zn concentrations were determined as described by Rashid (1986) by using atomic absorpotion spectrophotomerty (Analytical jena AAS-NOVA-400, Germany) in digested samples. Grain N was determined through Kjeldal method (Jones, 1991). Subsequently, protein contents were calculated by multiplying grain N with 6.25 (FAO, 2003). Statistical analysis were performed using Statistix 8.1 at 5% probability level.

Results

Data recorded for the yield attributes (Table 2) of wheat depicted that higher doses of N appreciably increased grain yield in comparison to 120 kg/ha N (recommended dose). The grain yield increased by 29, 24 & 32 % over 120 kg N ha^{-1} when NIA-Amber, BWQ-4 and SD-998 were supplemented with 150 kg N ha^{-1}. On application of 180 kg N ha^{-1} recorded grain yields of NIA-Amber, BWQ-4 and SD-998 were 2, 1 & 4.6 % higher than that of recommended N level. Similarly, straw yields were also enhanced up to 16, 1 & 24 % by increasing N dose for 120 kg ha^{-1} to 150 kg ha^{-1}. Highest straw yields were recorded when N was supplemented @ 180 kg ha^{-1}. Crop yield was affected positively by the application of Zn in combination with all levels of N input. Maximum grain yield of 6.03 t/ha was recorded in NIA-Amber with 5 kg Zn + 150 kg N ha^{-1} which was statistically similar to grain yield (6.01 t/ha) of genotype SD-998 achieved by the application of 10 kg Zn +180 kg N ha^{-1}. However, grain yield remained almost stagnant with the increase of input rates from higher to highest. Straw yield was also improved by the interactive use of N and Zn 10.45 t/ha was recorded as highest among all genotypes shown by SD-998 at 10 kg Zn + 180 kg N ha^{-1}.

Increasing the N dose in wheat from 120 to 180 kg N ha^{-1} escalated N contents (Table 3) in grain from 53.64 to 88.64 kg N ha^{-1} in NIA-Amber, from 78.45 to 104.77 kg N ha^{-1} in BWQ-4 and from 64.68 to 102.32 kg N ha^{-1} in SD-998. Upon application of Zn doses (5 and 10 kg ha^{-1}) further increase in N contents was recorded.

Grain contents of 135. 64 kg N ha^{-1} by BWQ-4 in response to interactive use of 10 kg Zn+180 kg N ha^{-1} was highest among all the genotypes in comparison to all Zn + N combinations. Increase in phosphorus uptake (Table 3) was recorded with increasing the N in all the genotypes however with the application of Zn, P uptake tended to decrease slightly. In NIA-Amber, BWQ-4 and SD-998 P uptake decreased from 13.78 to 11.58 kg P ha^{-1}, from 13.53 to 9.88 kg P ha^{-1}and from 15.99 to 15.10 kg P ha^{-1} with increasing Zn from 5 to 10 kg ha^{-1} in combination with 120 kg N ha^{-1}. While average P uptake of the genotype was reduced from 22.44 to 18.74 kg P ha^{-1} when Zn was applied with 150 kg N ha^{-1}. Similar, results were recorded in case of 180 kg N ha^{-1} applied to wheat along with 5 and 10 kg Zn ha^{-1} and mean reduction of 1.8 kg P ha^{-1} was observed. Zn contents (Table 4) in edible portion of wheat were enhanced by the interactive use of N and Zn. Significant increments from 55.78 g Zn ha^{-1} to 171.79 g Zn ha^{-1}, 135.59 to 320.65 g Zn ha^{-1}and 173.33 to 424.33 g Zn ha^{-1} were recorded by supplementing Zn in combination with 120, 150 and 180 kg N ha^{-1}, respectively. Highest uptake was recorded in SD-998 when supplied with 10 kg Zn + 180 kg N ha^{-1}.

Momentous and steady increase in wheat grain protein (Table 4) contents were recorded with increasing levels of N and maximum were recorded with 180 kg N ha^{-1}. Increasing protein contents are the direct indication to improved quality of produce. Zn application also influenced protein contents significantly as 10 kg Zn + 180 kg N ha^{-1} showed maximum protein contents (847.75 kg ha^{-1}) in grains of BWQ-4 followed by SD-998 (740.22 kg ha^{-1}) and NIA-Amber (613.25 kg ha^{-1}).

Discussion

Increased input levels of N imparted higher photosynthetic activity (Rodrigues et al., 2000), cell division (Warraich et al., 2002), increased number of leaf, vigorous vegetative growth (Protic et al., 2007) and better assimilation and metabolic rates (Oscarson, 2000) which resulted in better crop productivity in wheat (Goswami, 2007). Similar responses of various levels of N application have been reported by Yadav et al. (2012) and Singh et al. (2013). Increase in grain and straw yield (Table 1) is due to role of Zn in stimulation and catalysis of various metabolic processes. As co-factor of enzymes Zn is involved in growth and development of plants eventually leading to higher yields of wheat (Imran et al., 2015). However, lower rate of Zn was more favorable than higher rate in terms of grain yield. Grain yield was improved with increasing rates of N at each level of Zn. Combination of 5 kg Zn and 150 kg N ha^{-1} has more pronounced effect because these levels might have maintained optimal balance between the nutrients as artificially modified soil fertility through the addition of fertilizer in proportion to the crop needs can promote growth and increase or sustain yield. This is comparable with the results recorded by Sahay et al. (2009) and Protic et al. (2007) while studying the effect of N and Zn on wheat in deficient soils. Significant positive correlations (r = 0.896) between mean nitrogen contents of grains and mean grain yields of tested genotypes illustrate the role of nutrients contents in better crop yield (Figure 1). The correlation (r = 0.755) between grain zinc contents and grain yield (Figure 2) supports the role of zinc in yield enhancement.

Table 1. Physico-chemical characteristics of the soil

Characteristics	Value
Textural class	Silty clay loam
Organic matter	0.73 %
Electrical conductivity	1.20 dS m^{-1}
pH	7.56
Kjeldhal nitrogen	0.035%
Extractable Phosphorus	6.8 µg g^{-1}
Extractable potassium	145 µg g^{-1}
Extractable Zinc	0.36 µg g^{-1}

Improved nutrient contents can be attributed to enhanced nutrient demands of plants due to escalated grain and straw yield (Brown et al., 2005). Application of N improved Zn uptake majorly due to the improved enzymes activities and more efficient metabolic processes. (Imran et al., 2015).

Phosphorus uptake (Table 3) was improved by the higher doses of N explains the role of N in enhanced P uptake as ammonium ions temporarily lowers the pH in the micro-sites of the plant roots which facilitates more P uptake in plants (Chaudhary et al., 1997; Singh et al., 2007) . This increased uptake of P in grains can also be physiological prompted rather than root system ramification. On the contrary, P uptake declined with the application of Zn might be due to antagonism between the two nutrients (Singh et al., 2010).

Table 2. Effect of synergistic use of nitrogen and zinc on grain and straw yields of wheat genotypes

Treatment	NIA-Amber	BWQ-4	SD-998	Mean	NIA-Amber	BWQ-4	SD-998	Mean
	Grain yield (ton/ha)				Straw yield (ton/ha)			
120 kg N/ha	4.48 b	4.39 b	4.25 b	4.37 B	4.54 ij	5.20 g-j	5.69 f-j	5.14 B
120 kg N/ha + 5 kg Zn/ha	4.54 b	4.50 b	4.60 b	4.55 B	4.61 ij	5.81 e-j	7.48 b-h	5.97 B
120 kg N/ha + 10 kg Zn/ha	4.75 b	4.64 b	4.67 b	4.69 B	4.39 j	6.33 d-j	7.83 b-g	6.18 B
150 kg N/ha	5.78 a	5.44 a	5.65 a	5.62 A	5.31 g-j	5.29 g-h	7.11 b-i	5.90 B
150 kg N/ha + 5 kg Zn/ha	5.80 a	5.83 a	5.96 a	5.86 A	5.15 h-j	6.46 d-j	7.48 b-h	6.36 B
150 kg N/ha + 10 kg Zn/ha	6.03 a	5.91 a	5.96 a	5.97 A	5.55 f-j	6.59 c-j	8.31 a-e	6.82 B
180 kg N/ha	5.87 a	5.49 a	5.91 a	5.76 A	7.88 a-f	7.95 a-f	9.15 a-c	8.33 A
180 kg N/ha + 5 kg Zn/ha	5.92 a	5.75 a	5.98 a	5.88 A	8.04 a-f	8.63 a-c	9.43 ab	8.70 A
180 kg N/ha + 10 kg Zn/ha	5.99 a	5.82 a	6.01 a	5.94 A	8.39 a-e	9.39 ab	10.45 a	9.41 A
Mean	5.46 A	5.31 B	5.44 A	5.4	5.98 C	6.85 B	8.1 A	6.97

Means sharing similar letters are statistically similar to each other at $p < 0.05$

Table 3. Effect of synergistic use of nitrogen and zinc on grain nitrogen and phosphorus contents of wheat genotypes

Treatment	NIA-Amber	BWQ-4	SD-998	Mean	NIA-Amber	BWQ-4	SD-998	Mean
	Nitrogen contents in grains (kg/ha)				Phosphorus contents in grains (kg/ha)			
120 kg N/ha	53.64 k	78.45 f-j	64.69 i-k	65.59 F	13.79 d-b	13.53 d-h	15.99 b-f	14.44 C
120 kg N/ha + 5 kg Zn/ha	59.60 jk	91.52 e-h	73.97 h-k	75.03 F	12.04 f-h	12.79 e-h	15.65 c-g	13.49 C
120 kg N/ha + 10 kg Zn/ha	76.47 g-k	95.87 b-h	82.59 e-h	84.98 E	11.58 f-h	9.88 gh	15.10 c-g	12.18 C
150 kg N/ha	81.78 e-j	100.56 b-f	90.89 d-h	91.08 DE	22.32 a-c	21.9 a-c	23.09 a	22.44 A
150 kg N/ha + 5 kg Zn/ha	83.92 e-i	103.55 b-e	93.61 b-h	93.69 C-E	20.70 a-c	19.49 a-e	22.08 a-c	20.76 AB
150 kg N/ha + 10 kg Zn/ha	92.63 e-h	117.05 a-d	95.01 b-e	101.56 BC	18.85 a-e	16.88 a-f	20.51 a-d	18.75 B
180 kg N/ha	88.64 e-h	104.77 b-e	102.32 b-e	98.58 B-D	23.21 a	22.73 ab	23.06 a	23.00 A
180 kg N/ha + 5 kg Zn/ha	90.24 e-h	118.97 ab	104.69 b-e	104.64 B	22.01 a-c	21.48 a-c	22.92 a	22.14 A
180 kg N/ha + 10 kg Zn/ha	98.12 b-g	135.64 a	118.43 a-c	117.40 A	21.82 a-c	20.33 a-d	21.44 a-c	21.20 AB
Mean	80.56 C	105.16 A	91.8 B	92.51	18.48 B	17.67 B	19.98 A	18.71

Means sharing similar letters are statistically similar to each other at $p < 0.05$

Table 4. Effect of synergistic use of nitrogen and zinc on grain zinc and protein contents of wheat genotypes

Treatment	NIA-Amber	BWQ-4	SD-998	Mean	NIA-Amber	BWQ-4	SD-998	Mean
	Zinc contents in grain (g/ha)				Protein contents in grain (kg/ha)			
120 kg N/ha	56.68 m	58.52 m	52.13 m	55.78 E	335.25 k	490.34 f-j	404.29 i-k	409.96 F
120 kg N/ha + 5 kg Zn/ha	84.86 l	145.99 jk	179.67 hi	136.84 D	372.48 jk	572.02 e-h	462.33 h-k	468.94 F
120 kg N/ha + 10 kg Zn/ha	135.56 jk	181.42 g-i	198.38 f-h	171.79 D	477.95 g-k	599.19 b-h	516.21 e-j	531.12 E
150 kg N/ha	123.30 k	128.59 jk	154.87 ij	135.59 D	511.14 e-j	628.62 b-f	568.07 e-h	569.28 DE
150 kg N/ha + 5 kg Zn/ha	188.53 f-h	268.49 de	289.99 d	249.01 C	524.47 e-i	647.16 b-e	585.07 d-h	585.57 C-E
150 kg N/ha + 10 kg Zn/ha	209.55 fg	375.02 c	377.38 c	320.65 B	578.91 e-h	731.54 a-d	593.83 c-h	634.76 BC
180 kg N/ha	154.23 ij	147.96 jk	217.79 ab	173.33 D	554.00 e-h	654.83 b-e	639.51 b-e	616.11 B-D
180 kg N/ha + 5 kg Zn/ha	255.51 e	424.77 ab	418.91 a	366.40 B	564.02 e-h	743.58 ab	654.31 b-e	653.97 B
180 kg N/ha + 10 kg Zn/ha	395.56 bc	447.87 a	429.57 a	424.33 A	613.25 b-g	847.75 a	740.22 a-c	733.74 A
Mean	178.2 B	242.07 A	257.63 A	225.96	503.5 C	657.23 A	573.76 B	578.16

Means sharing similar letters are statistically similar to each other at $p < 0.05$

Increased Zn uptake in wheat grains can be attributed to the role of N dependent proteins in Zn uptake and translocation in plant (Cakmak et al., 2010b). This phenomenon can excellently be understood by taking in account of pre-anthesis accumulation of Zn in vegetative parts of wheat and role of N in extending Zn supply to grains during anthesis and grain filling (Kutman et al., 2012; Barunawati et al., 2013; Sperotto et al., 2013). Very strong correlation was found (r = 0.904) between the mean N contents in grains and mean Zn contents in grains (Figure 3), explains the positive influence of nitrogen on zinc uptake in crop.

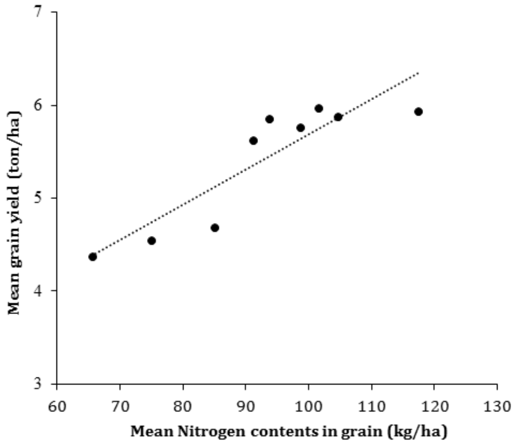

Figure 1. Correlation (r=0.896) between mean nitrogen contents in grains to mean grain yield of wheat genotypes

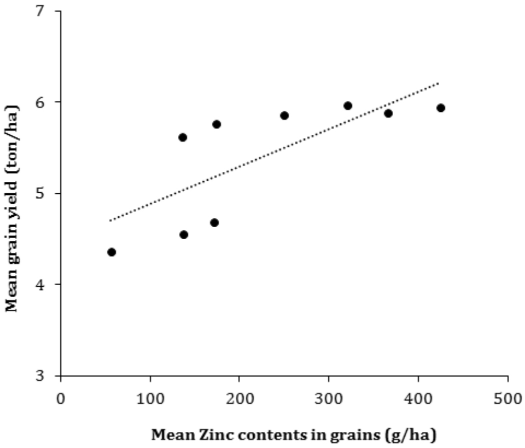

Figure 2. Correlation (r = 0.755) between mean grain zinc contents to grain yield of tested wheat genotypes

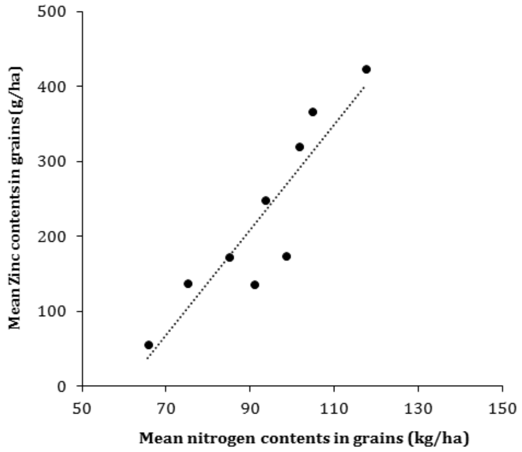

Figure 3. Correlation (r = 0.904) between grain nitrogen contents to grain zinc contents of tested wheat genotyptes

Plant accumulated larger concentration of N with the increasing N input levels hence depicted more grain protein contents. N plays pivotal role in amino acids and protein synthesis (Brown et al., 2005; Abedi et al., 2011). Therefore, its higher doses can be attributed to increased protein contents. Levels of Zn also played important role in stimulating protein contents in grains (Nadim et al., 2012; Jiang et al., 2013) Zn is indispensable nutrient for N metabolism due to its catalytic influence on numerous enzyme systems, biochemical activities responsible for nitrate reduction and protein synthesis (Khare and Dixit, 2011).

Conclusion

On the basis of experimental results it is concluded that N and Zn fertilization is crucial not only for the yield maximization in wheat but also to improve quality of produce. 150 kg N ha^{-1} in combination with 5 kg Zn ha^{-1} can be recommended as optimal dose to achieve better growth, productivity and quality of wheat.

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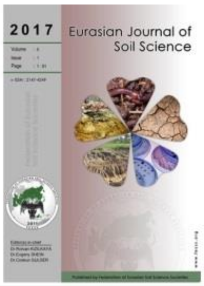

Evaluating inverse distance weighting and kriging methods in estimation of some physical and chemical properties of soil in Qazvin Plain

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Abstract

Today, the presence of accurate information about variability of soil properties been considered more than ever to apply this information in economic modeling, environmental predictions, accurate farming and natural resources management. The present research was conducted in some lands of Qazvin plain to study variability of some chemical and physical properties of soil by sampling 62 observational points in depth of 20 cm above soil surface. Initial statistical study of data indicated that the studied properties follow normal distribution in the region. Spatial variations of the studied properties showed that spherical model was the best fitted model to semivariogramin other properties than silt percent and bulk densityand total porosity. The highest radius for the studied properties was 21100 m related to bulk density, total porosity and electric conductivity and pH. Spatial dependence class was observed medium to strong in all physcial and chemcial properties. To validate intrapolation methods, three indices of evaluation, R^2, MBE, MAE which indicate accuracy of each of the intrapolation methods were used and results showed that the studied properties had spatial structure, their impact range had good variability and kriging estimator better can show variability of the studied properties in the region in comparison to IDW method. At the end, considering the best interpolation method, spatial variability map of each of the properties was prepared in ArcGIS software**.**

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Introduction

Information about variability of the soil properties is very important in ecological modeling, environmental predictions, accurate farming and natural resources management (Lin et al., 2004). Spatial variability of soil input data can be highly effective on results of deductive, experimental and theoretical soil models (Wilding et al., 1994). Geostatistics is one of the very useful methods in estimation of spatial distribution of data. Spatial variability of soil properties or non-uniformity resulting from spatial differences in the observed soil properties includes two structural or non-structural components (Pang et al., 2011; Mohammadi, 2006). These variations result from both inherent process (soil constituent factors) and managerial process (such as fertilizer consumption, crop rotation and type of cultivation) in any spatial and temporal scale (Castrignanò et al., 2000). Estimation accuracy of each variable depends on two factors: 1- Selection of desirable interpolation method for obtaining soil properties in the non-sampled points, 2- suitable

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application of the interpolation methods considering nature and properties of data. The most common interpolation methods in agricultural researches are inverse distance weighing and kriging methods (Kravchenko and Bullock, 1999). Many researchers have compared IDW and kriging. In some cases, the performance of kriging was generally better than IDW (Kravchenko and Bullock, 1999; Kravchenko, 2003). Robinson and Metternicht (2005) used three inverse distance weighing and kriging and spline methods for estimation of electric conductivity and organic carbon. Gallichand et al. (1992) and Heisel et al. (1992) studied and evaluated different interpolation methods to prepare surface soil clays and found that weighted moving average (WMA), kriging and co-kriging methods are similar to each other. Reza et al. (2010) Evaluated and comprised of some soil chemical parameters by ordinary kriging and inverse distance weighting methods and they reported spatial variability for different soil parameters (except available nitrogen) may be better understood by ordinary kriging than by IDW method. Moustafa and Yomota (1998) measured soil salinity and prepared contour-maps for drainage projects with geostatistical methods such as kriging. Result of their studies showed that kriging method showed more accurate estimation than other methods. Laslett et al. (1987) conducted researches on study and evaluation of some Interpolation methods for estimation of surface soil pH. They used inverse distance weighing and kriging methods and used data obtained from Digital Elevation Model and climate for estimation of pH and finally recognized the kriging method as the most suitable method. Shakoori Katigari et al. (2011) reported the best semivariogram model for the fitted model on bulk densityas spherical model and range of influence of bulk density as 500m.

Mohammadzamani et al. (2007) in a research in wheat farm managed by the local farmers in Sorkhan kalateh located in 25 km of Guilan Province reported the fitted models to bulk density, sand , silt , clay , pH, ESP, lime as spherical and reported electrical conductivity, soil saturation moisture and cation exchange capacity as Gaussian model. Importance of the spatial variations in soil properties is evident. Rosemary et al. (2017) using geostatistical spatial variability of some soil properties (EC, pH, OC, CEC and textures) in different applications examined in Sri Lanka. The researchers reported that the spatial dependence of different soil properties and spatial dependence class for EC and pH stronger won.

Although factors of variations are different in various points, understanding sources of variations helps us do better management and considering that no studies have been conducted on spatial variability of soil properties in this region, the present research was conducted to study spatial variations of some physical and chemical properties of soil in Qazvin plain and two inverse distance weighing and kriging methods were used for zoning of points and two mentioned methods were evaluated for estimation of these properties.

Material and Methods

Study area and experimental design

This research was conducted in Abyek City located in east of Qazvin province. Range of variations in elevation of the region varied from 1150 to 1450 m above open sea level (Figure 1). Range of variations of slope also varied from 1 to 15%. The region with approximate area of 16630 hectares is located in latitude of 36´1´´ to 36´9´´ and longitude of 50´21´´ to 50´14´´. It has mean annual precipitation of 257 mm and average annual temperature of 14 °C and the coldest month of the year is January and the hottest month of the year is July. For this purpose, geographical position of the sampling points was recorded with global positioning device at the beginning of sampling. Then, the soil samples were extracted from 62 observational points which are located in an irregular network with mean distance of 800 m from each other. After transferring the samples to the laboratory, they were dried under air. For the next tests, it was passed through 2-mm sieve. Schematic Position of the sampling points was presented in the studied region (Figure 2).

Physical and chemical properties measurements

Percent of sand, silt and clay particles was calculated with hydrometric method (Bouyoucos, 1962), bulk density of soil was calculated with sampling cylinder (Klute and Dirksen, 1986), and total porosity of soil samples was calculated with apparent and real specific mass of soil as a follow (Eq. 1):

$$F = 1 - \left(\frac{\rho b}{\rho s}\right) \qquad (1)$$

Where ρb is bulk density (g.cm^{-3}) and ρs is soil real specific mass (g.cm^{-3}) and F is total porosity of soil (%). The pH in saturated extract was measured with pH meter (Thomas, 1996), electrical conductivity was measured with electric conductivity meter in saturated extract (Richards, 1954), Percent of calcium carbonate was measured with neutralization method with normal Hydrochloric acid 1 Normal and titration with sodium hydroxide (Nelson, 1982).

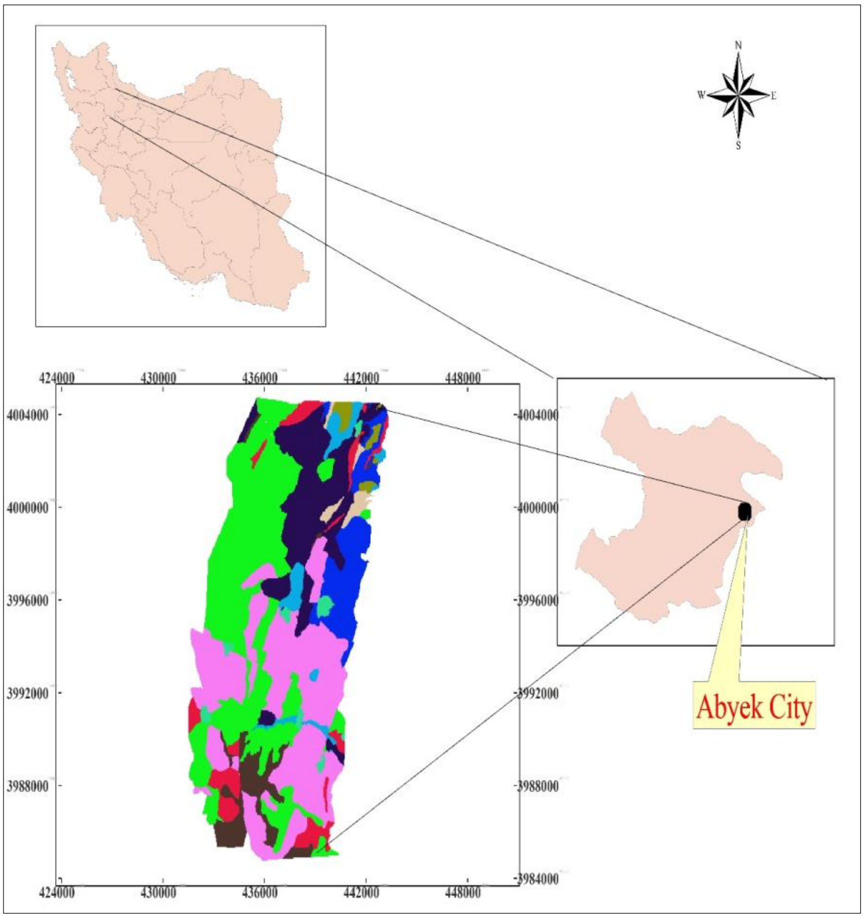


Figure 1. Location of the studied area

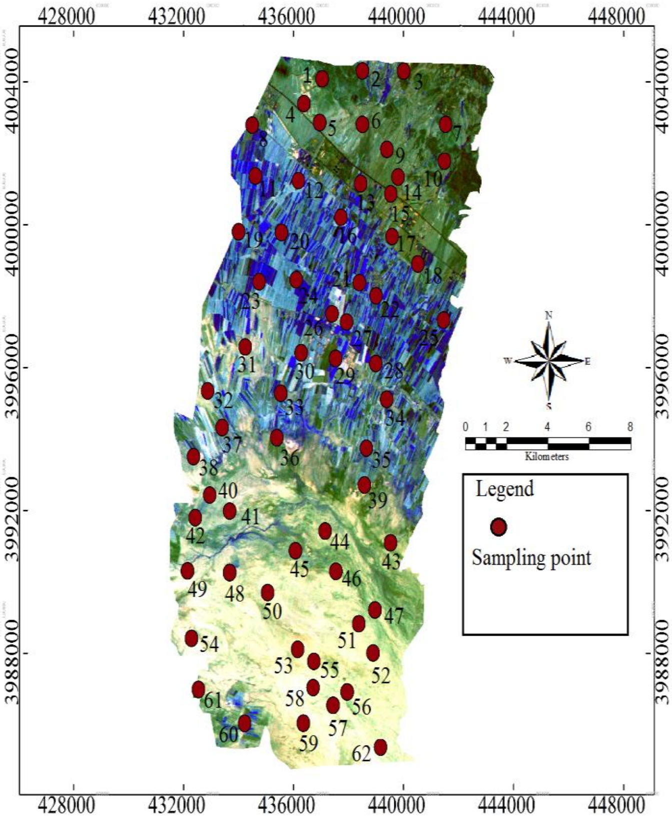


Figure 2. Schematic description of the sampling design of the study area

Geostatistical Analysis

Geostatistical Analysis was performed with the measured specifications in 62 points of the studied region. To study frequency distribution and determine descriptive statistics of each variable, maximum and minimum statistics, mean, standard deviation, skewness and Kurtosis were determined. To study normality of data in confidence level of 95%, Kolmogorov–Smirnov test was used and to study normality of data, logarithmic transform method was used. To study spatial variations of the studied properties, experimental semivariogram was calculated for all variables and spatial structure of the data was studied in the studied zone. Variogram is a mathematical model and a vector quantity which shows spatial relationship between values of the measured variable in terms of squared value difference of two points and considering their distance and direction. Considering that it is not possible to calculate the whole studied population, semivariogram is estimated in a specified separation distance with the follow (Eq. 2):

$$\acute{\gamma}(h) = \frac{1}{2N(h)}\{\sum_{i=1}^{N(h)}[Z(xi) - Z(xi + h)]^2\} \ = \ 1, \ldots \ \mathrm{n} \tag{2}$$

Where γ (*h*) is semivariogram value in distance of h, Z (x_i+ *h*) is the measured value of variable in spatial position, (x_i+ *h*) ، $Z(x_i)$ is the measured value of variable in position (x_i) and $N(h)$ is the number of paired comparisons in distance of (h) in the studied zone. In structural analysis process, the standard models have been obtained considering values of (R^2) and Residual sum of squares (RSS). The model which had the maximum R^2 and minimum RSS was selected as the best semivariogram model. Then, the experimental semivariogram related to each one of the properties was calculated and different theoretical models including spherical and exponential models were fitted to them. Definition of the fitted models is as following equations (Eq. 3 and 4) (Mohammadi, 2006):

$$\text{Spherical model: } \gamma(h) = C_{\circ} + C[1.5\frac{h}{a} - 0.5(\frac{h}{a})^3 \text{for h} \leq \text{a} \tag{3}$$

$$\gamma(h) = C_{\circ} + C \ \ for\ h \ > a \ \ or \ \gamma(o) = 0 \, for \ h = 0$$

$$\text{Exponentional model: } \mathrm{\gamma(h) = C_{\circ} + C \ \left(1 - e^{-4/a}\right)} \tag{4}$$

Where semivariogram include variables such as C_0, nugget effect (the minimum value of semivariogram) which has been calculated and shows discontinuity of semivariogram curve adjacent to the origin coordinates reflecting variance of sampling errors and spatial variance in shorter distances from the sampling distance (Li and Heap, 2008). C_1 is Variogram threshold, total nugget effect (C_o) and structured part of semivariogram (C) which is equivalent to total variance of the studied variable and relatively constant value with random variations is called threshold), a is radius of influence or range (the distance in which semivariogram is fixed and reaches sill), h is separation distance. To determine different classes of spatial dependence of the studied variables, ratio of structured effect to total variance was used. if ratio of structured effect (C) to sill ($C+C_0$) is less than 25%, between 25 and 75% and more than 75%, that specification will be in range of weak, medium and strong spatial dependence (Cambardella et al., 1994). To evaluate the estimator methods, several evaluation indices can be used concurrently. In this research, statistical indices of coefficient of determination (R^2), mean bias error (MBE), mean absolute error (MAE) were used (Mishra et al., 2010). MBE indicates deviation of the method and MAE indicates accuracy of each method. Positive values of MBE indicate overestimation of the model and its negative values indicate its underestimation. The manner of calculating statistics of (mean bias error (MBE) and mean absolute error (MAE)) is as follows equations (Eq. 5 and 6) (Wakernagel, 2003):

$$\mathrm{MBE} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{Z} * (\mathrm{xi}) - \mathrm{Z(xi)})}{\mathrm{n}} \tag{5}$$

$$\mathrm{MAE} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}}|\mathrm{Z}{*}(\mathrm{xi}) - \mathrm{Z(xi)})|}{\mathrm{n}} \tag{6}$$

where Z* (x_i) is the estimated value in point X, Z (x_i) is the observed value in point X_i and n is the number of points. In the next stage, the desired variables were estimated with kriging interpolation methods and inverse distance weighing method. Kriging is a weighted moving average and is defined as follows: (Eq. 7) (Pang et al., 2011):

$$Z^*(x_\circ) = \sum_{i=r}^{n} \lambda_i Z(x_i) \qquad i = 1 \dots n \tag{7}$$

$$\sum_{i=r}^{n} \lambda_i = 1$$

And inverse distance weighing method is defined as following (Equation 8)

$$\lambda_i = \frac{D_i^{-\alpha}}{= \sum_{i=1}^{n} D_i^{-\alpha}} \tag{8}$$

Where D_i is the i - th observed point distance to the estimated point, (α) is the inverse distance weighing power and (n) is the number of neighborhood points. The contour maps were drawn for each one of the physical and chemical properties measured in the studied region with results of suitable estimation method. All geostatistical operations were performed with GS$^+$ 5.1 software and properties zoning in Arc GIS9.3 software.

Results and Discussion

Statistical analysis

Statistical description of physical and chemical properties of the measured soil has been summarized in 62 points of the studied region (Table 1). Results of Kolmogorov–Smirnov test also showed that the properties have relatively normal distribution and results of skewness coefficient in Table 1 confirm the said results. Study of the physical and chemical properties of soil showed that mean percent of all three particles have relatively equal means and generally, the soil tissue of the region is clay, sandy – clay – loam and sandy loam considering mean size distribution of the soil particles. Mean of the lime in the studied region was regarded as the lime soils based on the criterion provided by Pansu and Gautheyrou (2006) who states that the soils of which calcium carbonate is above or equal to 6. As Soil and Water Research Institute (1989) reported that the soils which have electrical conductivity of lower than 4 dS/m are in unrestricted range. Considering that insignificant area of the southern part of the region has electrical conductivity of above 4dS and with high restriction, other soils of the region will lack salinity restriction, also electrical conductivity has the highest CV, more than 35% (Table 1) this result shows that there was high variation between Electronical conductivity range in northern and southern part of study area. Based on classification by Pansu and Gautheyrou (2006), the studied soil is classified as a part of soils with low bulk density**.** Variability class of the variations coefficient has been obtained based on criterion presented Wilding (1985) such that if variations coefficient is below 15%, it will be in low variability class, if variations coefficient is between 15% and 35%, it will be in medium variability class and if variations coefficient is above 35%, it will be in high variability class. Considering the obtained results, bulk density, porosity and pH were included in low variability class and silt percent was included in medium class and sand, clay, electrical conductivity and lime were included in high variability class. Results also showed that the maximum and minimum variance related to percent of sand and Total porosity respectively.

Table 1. Descriptive statistics for soil Physical and chemicals properties. Descriptive statistics

Soil variable	Min.	Max.	Range	Mean	Std. D	Variance	%CV	Skewness	Kurtosis
Sand	13.26	58.97	45.71	36.10	12.13	147.13	33	0.15	-0.59
Silt	24.20	34.20	10.00	29.30	2.10	4.41	7	-0.73	1.39
Clay	17.33	58.57	41.24	34.09	11.02	121.44	32	0.56	-0.17
BD	1.30	1.52	0.22	1.42	0.13	0.01	9	0.87	-0.18
F	0.44	0.51	0.07	0.48	0.05	0.00	10	-0.85	-0.18
pH	7.62	8.56	0.94	8.08	0.30	0.09	3	0.11	-0.51
EC (dS.m-1)	0.47	21.29	20.82	2.45	2.88	8.29	117	0.85	0.88
CCE (g.kg-1)	4.11	19.73	15.62	10.27	3.81	14.51	37	0.40	-0.82

BD, dry bulk density; F, Total porosity of soil; EC, soil saturated paste electrical conductivity; CCE, calcium carbonate equivalent. *Min., minimum value; Max., maximum value; CV, coefficient of variation.

Spatial correlation analysis

Results of fitting standard models to experimental variograms showed that all of these variables had spatial structure and the spherical and exponential model has had the best fitting with variations of the studied properties (Table 2). Considering results of this research, other properties than silt percent and total porosity (for which the best fitted model to semivariogram was exponential were spherical). Mohammadzamani et al. (2007) reported spherical model as the best fitted model to bulk density, sand and clay. The best fitted model for pH was aspherical (Yang et al., 2011). Variogram study of the studied properties in the studied region showed that their variability in the region was independent of the special geographical direction.

Table 2. Coefficients of the best fitted model to semivariogram of some physical and chemical properties of soil measured in 62 points of the studied region

Soil variable*	Model	Nugget**	Sill	Range	c/(c0+c)***	Spatial class	R^2	RSS
Sand	Spherical	74	231.8	15580	0.68	M	0.97	8.31E+01
Sılt	Exponential	36.1	72.4	10740	0.501	M	0.97	1.5
Clay	Spherical	0.47	1.6	20070	0.81	S	0.92	1.00E-02
BD	Exponential	8.06E-03	1.62	21100	0.503	M	0.88	3.03E-07
F	Exponential	2.00E-03	0.004	21100	0.501	M	0.78	5.10E-05
EC	Spherical	1.90E-01	0.4	21100	0.7	M	0.913	5.50E-04
pH	Spherical	0.23	0.52	21100	0.68	M	0.74	2.30E-03
CCE	Spherical	0.16	1.4	19770	0.88	S	0.93	0.01

CCE, pH, EC, F, BD, clay, silt, sand* are percent of sand, silt, clay, bulk density (gr. cm^{-3}), total porosity percent, electrical conductivity (dS m^{-1}), pH, equivalent calcium carbonate (percent).

^{**if} if ratio of structured effect (C)to sill ($C+C_0$) is less than 25%, between 25 and 75% and more than 75%, that specification will be included in weak, medium and strong spatial dependence Cambardella et al. (1994).

RSS is Residual sums of squares and R^2 is coefficient of determination (R^2).

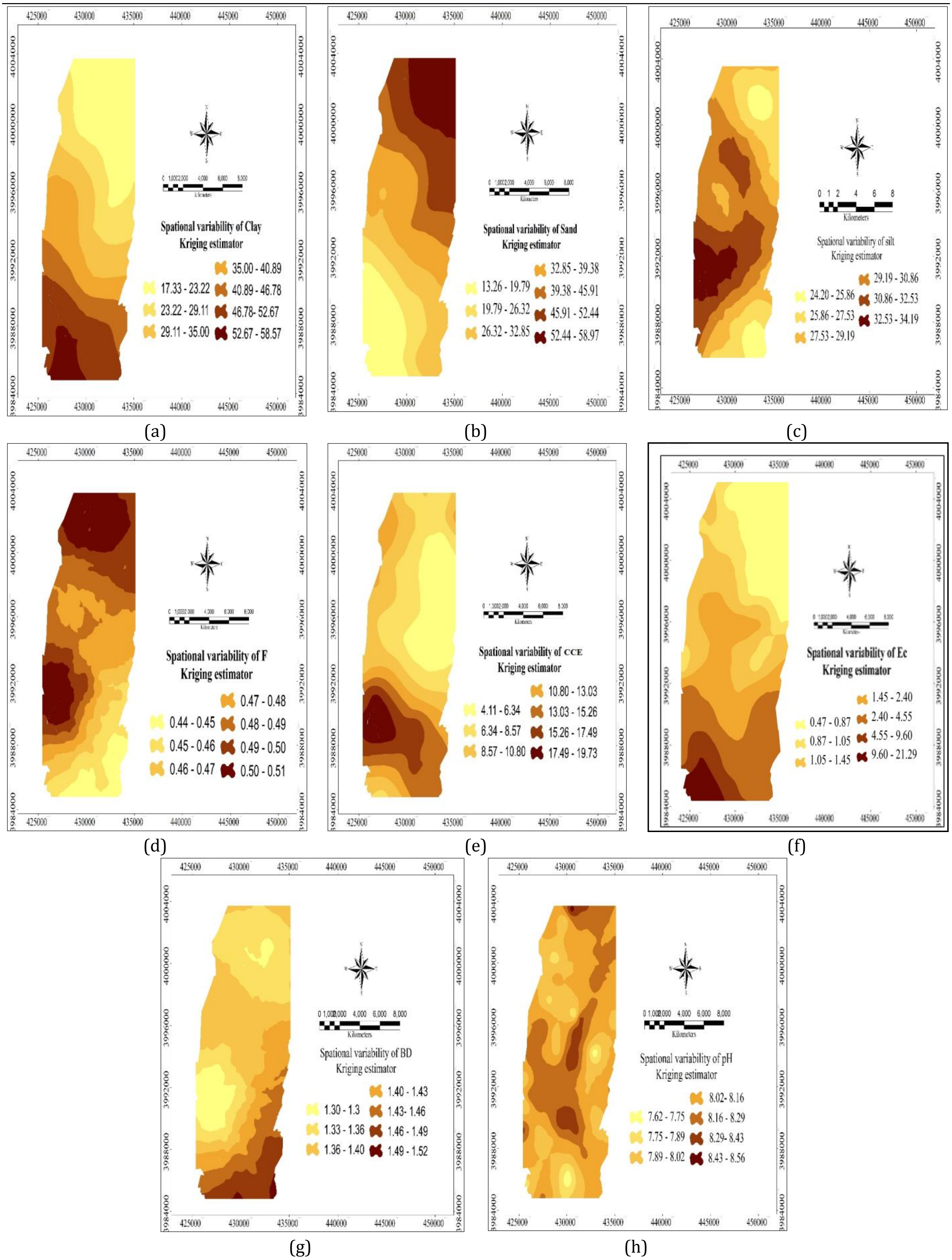
**Nugget (%)(nugget variance/total variance)*100

S, strong spatial dependence (Nugget 75%); M, moderate spatial dependence (25% Nugget 75%). RSS is residual sum of squares.

Results show that the minimum nugget effect of the chemical and physical properties of the region relates to bulk density and total porosity of soil and this result shows that relative variance and sampling size are suitable for clarifying spatial structures and the highest nugget effect relates to sand percent indicating strong random variance in short intervals resulting from error, measurement and short range variations and the studied property in shorter distance from the shortest sampling distance. The smallest sill of the studied properties relates to total porosity and the highest hill relates to percent of sand indicating random or unstructured variations or total variance of all samples which have been applied in calculation of semivariogram. Oji et al. (2012) in their studies, reported that the maximum sill related to percent of sand (159.3%).

The maximum effective range among the studied properties is 21100 m related to bulk density, total porosity and electrical conductivity and pH indicating extensive influence of the mentioned variables on their adjacent points. With increasing effective range, sampling distances have increased and the numbers of necessary samples for sampling and necessary costs for sampling are reduced. The minimum radius of influence is 10740 m related to silt percent. Oji et al. (2012) reported that clay percent as the maximum radius of influence (2296 m). Results showed that the highest ratio of structured effect to semivariogram related to lime (0.88) indicating that 88% had spatial structure and only 12% was random and the minimum related to silt percent, bulk density and total porosity of soil (0.5) indicating that about 50% of total variations relating to the desired properties of the soil had spatial structure and about 50% of these variations was random and lacked spatial structure. Spatial dependence class was medium in all properties except lime and percent of clay (strong class) and other properties had medium spatial dependence. Strong spatial structure of the studied properties means that the use of geostatistical methods can be useful in analysis of the variability models of the studied variables. Strong spatial dependence of the soil properties can depend on inherent properties of soil (formation of soil) while medium spatial dependence is majorly attributed to external factors (soil management methods). Cambardella et al. (1994) concluded that there is a medium dependence for bulk density. López-Granados et al. (2002) also reported the strong dependence for silt in two depths of 0 to 10 and 25 to 35 cm.

As shown in the Table 3, the maximum coefficient of determination and the minimum MBE and MAE relate to total porosity of soil. Results show that kriging method shows better estimation of the studied properties than the inverse distance weighing method and the intended maps were zoned in the region with kriging estimator (Figure 3).



(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 3. (a) Spatial variability of %Clay. (b) Spatial variability of %Sand. (c) Spatial variability of %Silt. (d) Spatial variability of Total porosity (%F). (e) Spatial variability of CCE. (f) Electronical conductivity (EC)dS/m. (g) Spatial variability of Bulk density (BD). (h) Soil function (pH).

Table3. Suitable method for estimation of physical properties of soil and the calculated criteria for evaluation and accuracy of the performed estimations in the studied region

Indices of evaluation estimator				
MAE	MBE	R^2**		
0.1300	-0.0003	0.64	Kriging	Sand
0.1330	0.0025	0.62	IDW	
0.0890	-0.0025	0.3	Kriging	Sılt
0.0903	-0.005	0.28	IDW	
0.1214	0.011	0.58	Kriging	Clay
0.1223	0.0142	0.59	IDW	
0.0019	-0.0002	0.50	Kriging	BD
0.0018	0.0001	0.49	IDW	
0.0006	-3.16 E-06	0.40	Kriging	F
0.0006	-1.81 E-05	0.30	IDW	
0.1100	-0.0007	0.34	Kriging	pH
0.0110	0.002	0.30	IDW	
0.0100	-0.0007	0.38	Kriging	EC
0.0100	0.0024	0.34	IDW	
0.0521	0.006	0.47	Kriging	CCE
0.0530	0.0067	0.46	IDW	

**R^2, MBE, and MAE are coefficient of determination, mean bias error, and mean absolute error, respectively.

The maximum and minimum quantity of sand are found in northeast and southwest of the region and the highest quantity of silt is found from west to center of the region and the lowest quantity is found in southwest and southeast.

It is assumed that soils with higher clay rate have been formed in physiographic units with low slope (alluvial piedmont plain and lowlands) and there has been enough chance of depositing the carried particles due to erosive processes. Physiographical unit of the alluvial piedmont plain has been due to accumulation of fine deposits with higher clay quantity to which water of upstream lands cause them to be transferred. The highest bulk density is found in southeast and we also find minimum total porosity in southeast. Considering high clay quantity in south of the region, bulk density of soil is low in this part. considering increase of electrical conductivity in southeast of the region, we find the highest pH in this part and also soil texture of the region has become finer in this part and the main reason for such results is formation of soils in this region in physiographical unit of the lowlands and one of the major properties of soils in these regions is observation of the mentioned characteristics. The minimum electrical conductivity and pH are observed in northeast of the region. Soils of these regions are alternatively affected by flood flows of the region due to location in hills with high slope (10-16%). For this reason, there has been shorter time for accumulation of salts due to soil erosion. Equivalent calcium carbonate map in the studied zone indicates calcification of the soils in the studied region. The highest quantity of the equivalent calcium is found in west to south and the minimum quantity is found in east of the region. This can be related to role of geogenetic factor of parent material considering that soils with parent material of calcareous marl were found in these regions. The properties interpolation results showed that the kriging estimator better can show variability of the studied properties in the region in comparison to IDW method (Smith and Halvorson, 2011). Also in another study, similar results were achieved by Zare-Mehrjardi et al. (2010) who reported that the kriging method for estimating spatial distribution of soil properties better than the inverse distance weighting method. Thereby, kriging method for all properties has the highest value for R^2 and has lowest value for MAE and MBE. At the end, considering the best interpolation method, spatial variability map of each of the properties was prepared in ArcGIS 9.3 software**.**

Conclusion

The present research showed that Geographical Information System and Geostatistical System had high ability to spatial distribution and zoning of some physical and chemical properties of soil. Results of fitting standard models to experimental variograms showed that all of these variables had spatial structure and the spherical and exponential model had the best fitting to variations of the studied properties. The highest coefficient of determination and the minimum MBE and MAE related to total soil porosity. Considering the applied error indices, ordinary kriging has acted as a suitable estimator in zoning of the studied properties in the studied region. Spatial structure and range of influence of variables were highly affected by non-inherent variability and managerial factors. Accuracy of the resulting maps relating to soil properties showed suitable agreement with observational results. Therefore, Variogram and its related properties can be applied as an efficient tool for design of sampling networks and identification of managerial zones in accurate farming. For this reason, soil can be managed better for saving agricultural inputs and environmental protection with geostatistical technique and kriging technique and zoning of farms and creation of isolated zones. It is necessary to note that results of this research can be used in the studied region and cannot be generalized to other regions and spatial scattering of soil variables should be studied for each region.

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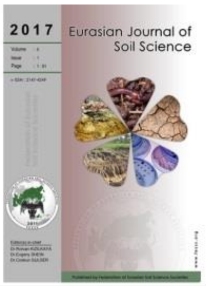

Determination of engineering properties of soil on railway track routes (An example of Turkey between the cities of Sivas and Erzincan)

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Abstract

Subsurface structure and engineering properties of the Sivas and Erzincan railway route were investigated by using velocities of seismic wave, electrical resistivity, standard penetration test (SPT) data and laboratory results, which were collected from survey sites referred to in this study. For this reason, 62 seismic refraction and vertical electrical resistivity (VES) measurements at 59 points were done along the survey route. Moreover, 11 mechanical boreholes with SPT were drilled. Laboratory tests were applied on soil samples taken from boreholes for geotechnical features. Longitudinal, shear wave velocities and elastic parameters were determined by seismic refraction method, and underground resistivity distribution was calculated by VES and geotechnical data and SPT results were evulated for the subsurface integrity. Engineering properties of a 6.8 km stretch of planned railway alignment in southeastern Sivas were calculated in this study. According to these results, unsuitable segments of the high-speed alignment which have low groundwater level and low bearing capasities which depend on dynamic properties were examined.

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Introduction

One of the most efficient transportation network is high speed railway which is depend on technical, economical and environmental issues. When a railway line has to be built between two points, there are several possible routes. First of all, experts have to determine a suitable alignment. Areas of high bearing capacity and hard soils are regarded as geological properties suitable for railway tracks. Factors which influence planning of railway track routes are geological structure, topography, landslides regions, bearing capasity of soil and groundwater level. Track route investigations can be done by using geophysical, geological and geotechnical methods.

Geophysical methods have been used for many years by engineers in soils and foundation applications (Telford et al., 1990; Sharma, 1997). Geophysics has proved quite relevant in highway site investigations since recently (Moore 1952; Nelson and Haigh 1990; Lippincott et al., 2000). Seismic not only provides means for probing the properties of soils, sediments and rock outcrops but are also used to calculate dynamic properties of soils including the soil's compression and shear wave velocities. These properties are key parameters in predicting the response of soils and soil-structure systems to dynamic loading. Geophysical methods like electrical resistivity have been used in mapping subsurface geologic sequence and

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concealed geological structures (Olorunfemi et al., 2004; Adiat et al., 2009). The main aim of resistivity surveys is to delineate vertical and horizontal underground structures with electrical contrasts.

Geotechnical properties of soils have been identified by laboratory tests and in situ measurements (Bowless, 1988; Kulhawy and Mayne, 1990; Das, 2009). Investigations of bearing capacity of soil was started with Prandtl's work which includes plastic equilibrium theory (Prandtl, 1921). After this work, several fundamental research papers were written about this topic (Terzaghi, 1943; Terzaghi and Peck, 1948; Meyerhof, 1956, 1965). Equation of bearing capacity which was offered by Meyerhof is safety zone and Bowless was improved a new bearing capasity formulae which Meyerhof's equation need to increase about percent of fifty depend on SPT (N) values (Bowless, 1996). Schulze indicated that using the seismic wave velocity technique is more realistic than using boreholes data which have soil samples and geotechnical methods which include laboratory results (Schulze, 1943). Imai and Yoshimura (1976), Tahtam (1982), Wilkens et al. (1984), Phillips et al. (1989), Keçeli (1990), Jongmans (1992), Sully and Campanella (1995), Pyrak-Nolte et al. (1996), Uyanık (1999), Kurtuluş (2000), Turker (2004), Tezcan et al. (2006), Ulugergerli and Uyanık (2007), Uyanık and Turker (2007), Uyanık and Ulugergerli (2008) and Tezcan et al. (2009) worked about bearing capacity of soil formulae according to longitudinal wave velocity (V_p), shear wave velocity (V_s) and features of foundation.

The study includes the most important part of railway network which is between the cities of Sivas and Erzincan in Turkey. A 6.8 km stretch of railway track was investigated for engineering properties of soil. Before railway track route construction, geophysical and geological, boreholes and laboratory tests surveys were done. In terms of suitability, railway track is analysed by using data which are gained from geological and geotechnical surveys and dynamic results which are calculated in-situ.

Material and Methods

Geology of survey site

The study area is away from 15 km the city centre of Sivas which is located within Sivas Basin characterised which includes different kinds of formations (Figure 1a). This basin is spreaded in northeastern and southwestern direction in the middle of Sivas city. Its length and width are about 250 km and 50 km, respectively. The railway track sits on formations of Quaternary allivium and pliocene conglomera, sandstone and siltstone. Sivas Basin's stratigraphy includes Pazarcık Volcanites (Paleocene), Gülandere Formation (Eocene), Selimiye Formation (Oliocene), Kemah Formation (Alt Miocene), Hafik Formation (Lower - Middle Miosene), İncesu Formation (Upper Miocene - Lower Pliocene), Bayat Volcanites (Upper Pliocene), Travertines and Allivium (Quaterner) (Ayaz and Atalay, 2006) (Figure 1b).

Gülandere and Kemah Formations, Selimiye and Hafik Formations are settled down shallow seabed, transition zones, sabkha, inta-continental zones and transient lakes. İncesu Formation is also deposited in rivers and lacustrine lakes zones. Pazarcık volcanites which contain basalt, andesite and tuff are located southwest of the basin, between Yıldızeli and Akmağdeni, outcropped around Refahiye. Angular uncomformity can be seen on fundamental rocks.

Methods

The velocity of sound travelling through the sub-surface varies with material composition and compaction. Seismic energy transmitted from a source at the surface will undergo refraction at boundaries between different media and eventually return to the surface. Seismic refraction surveying makes use of this phenomenon to determine ground structure by observing the time taken for energy to travel through the subsurface. The SeisImager software is generally used in near surface surveys of the seismic refraction method (Sheehan et al., 2005). The seismic refraction time-term inversion method found in this programme is a quick data analysis approach which will accurately provide information such as depth to bedrock as long as the seismic velocity of site increases with depth.

A commercially available 12-channel seismic system was used to record seismic arrivals in this study. The system consisted of 12 vertical 14 Hz geophones and 12 horizontal 4.5 Hz geophones connected to a Geometrics seismograph, which in turn was linked to a laptop computer. After recording of seismic data, first step is to pick the first arrival times for this method. The first arrival picking was done with the aid of the SeisImager Pickwin 4.2 software in our study. After this section, you have to draw the time-distance graphs which to assign 2 or 3 layers for using time-inversion method. The SeisImager Plotrefa 2.9 software was used to estimate depth of layers and velocities by time-term inversion method.

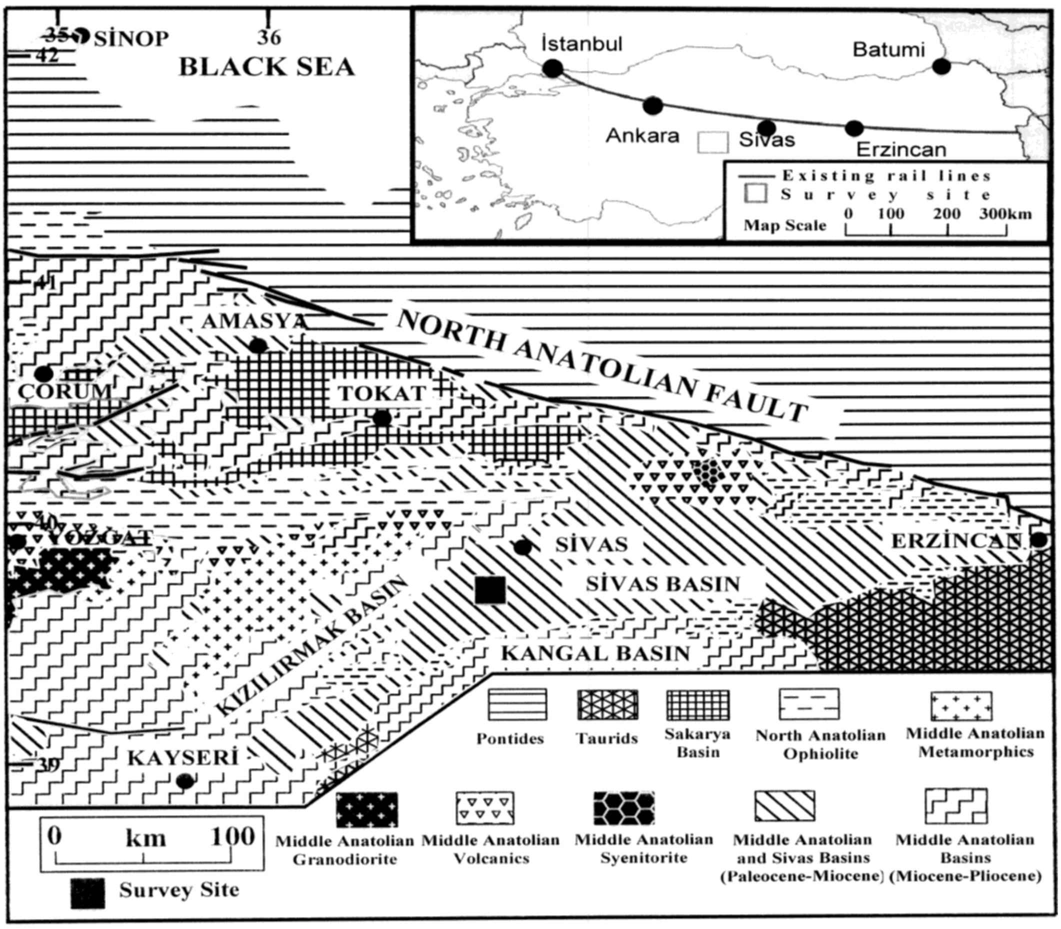

Figure 1a. Location and general geology map of survey site

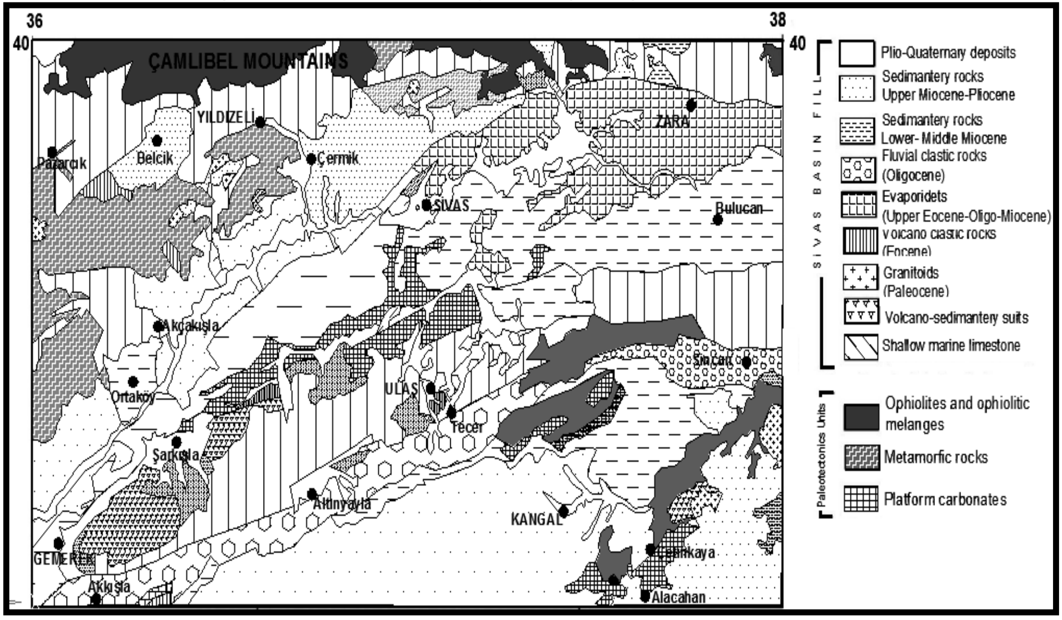

Figure 1b. Local geology map of survey site (Sivas Basin)

After estimating depth of layers and velocities, you can calculate elastic parameters for determining engineering properties. The mechanical properties associated with dynamic loading are shear wave velocity, Shear Modules, Young Modules, Bulk Modules and Poisson Ratio. Elastic parameters were calculated from shear wave and compressional wave velocities measured using seismic refraction method. Poisson ratio is a fundamental parameter is difficult to measure and it is usually estimated in engineering calculations. A suggested range of values changes 0.00-0.5. Young modules is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. Bulk modulus is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume. We used the formulas of elastic parameters mentioned below (Table 1).

Table 1. Formulas for dynamic-elastic parameters

Parameters	Formulas	Units
Density	$\rho = 0.31 V_p^{0.25}$	gr / cm^3
Shear Modulus	$G = \frac{1}{100} \rho V_s^2$	kg / cm^2
Poisson Ratio	$\nu = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}$	-
Young Modulus	$E = G \frac{3V_p^2 - 4V_s^2}{V_p^2 - V_s^2}$	kPa
Bulk Modulus	$K = \rho (V_p^2 - \frac{4}{3} V_s^2)$	kPa

Electrical resistivity surveys create an electrical current in the ground using two dedicated electrodes, and measure the resulting electrical potential field using a further electrodes. Vertical electrical sounding (VES) is a geophysical method for investigation of a geological medium. The method is based on the estimation of the electrical conductivity or resistivity of the medium. The estimation is performed based on the measurement of voltage of electrical field induced by the distant grounded electrodes (current electrodes). The recorded values were calculated to determine apparent resistivity of soil, ρa (Ω m) using equation.

$$\rho_a (\Omega m) = k \frac{\Delta V}{I} \tag{1}$$

K: geometric factor, I: measured voltage and ΔV :observed potential difference can be defined.

Electrical resistivity method utilized Vertical Electrical Sounding in the survey site. The VES entatiled 1-D vertical probing of the surface. Electrical resistivity imaging system, ABEM SAS 4000, were used in present study. Calculated apparent resistivity were interpreted quantitatively by partial curve matching and computer iteration technique using IPES6 (Başokur, 1999) software.

Bearing capacities along tracks were calculated by the using seismic method (Imai and Yoshimira, 1976; Tezcan, 2006; Keçeli, 2010), depending on triaxial compression test, cohesion and angle of internal friction which were found from laboratory tests (Terzaghi, 1943; Broms, 1964) and SPT (N) values (Terzaghi and Peck, 1948; Meyerhof, 1956; Meyerhof, 1974).

Based on Terzaghi's bearing capacity theory, column load (P) is resisted by shear stresses at edges of three zones under the footing and the overburden pressure, q (=γD) above the footing. The first part in the equation is related to the cohesion of the soil. The second part is related to the depth of the footing and overburden pressure.

The third part is related to the width of the footing and the length of the shear stress area. Equation 1 was used for Terzaghi's bearing capasity calculations. K_1, k_2: coefficients of foundation shape, *c*: cohesion, *B*: width of footing, γ : unit weight of soil can be determined. The bearing capacity factors, *Nc*, *Nq*, *Nγ*, are functions of internal friction angle.

$$q_u = k_1 c N_c + P_0 ' N_q + k_2 \gamma B N_\gamma \tag{2}$$

The Broms approach to computing bearing capacity is equation 3. When the rail-tie system is considered as a contiguous unit placed on the ballast and subgrade, the Broms approach provides a reasonable estimate of the general bearing capacity failures that occur under field conditions. The Equation 3 for bearing capacity equation as total cohesion (*c*), subballast material (*γ*), width of footing (*B*), surcharge loading (q_0) is defined as

$$q_u = cN_c + q_0 N_q + 0.5\gamma B N_\gamma \qquad (3)$$

Terzaghi and Peck (1948, 1967) method is for settlement of 25 mm. It relates blow counts *(N')*, width of footing *(B)* and groundwater level *(C_w)*. The equation for bearing capacity equation is as (equation 4);

$$q_{ult} = 11xN'xC_w \qquad (4)$$

According to the Terzaghi approach, Meyerhof has improved the ultimate bearing capacity $q_{net(all)=}q_{all} - (\gamma D_f))$ for 25 mm settlement. Bearing capacity formula was renewed using N_{70} in 1974 (Meyerhof, 1974).

Imai and Yoshimura (1976) method is based on the relationship between longitudinal seismic wave velocity *(V_p)* and bearing capacity *(q_u)*. Their bearing capacity formula is given in equation 5.

$$q_u = 10V_p^3 \qquad (5)$$

Tezcan (2006) which includes calculation of bearing capacity theory will be explained as follows. In order to set a practical upper ceiling for allowable bearing capacity, q_u which includes rock formations the empirical expression (equation 6) is adjusted to yield gradually reduced values through a factor S_v, for shear wave velocities (V_s), greater than 500 m/s and unit weight of soil (γ) as follows :

$$q_u = 0.024\gamma V_s s_v \geq 30.6\gamma$$

$$(6)$$

$$s_v = 1 - 3x10^{-6}(V_s - 500)^{1.6}$$

Keceli (2010)'s approach is based on the relationship between longitudinal seismic wave velocity (V_p), transverse wave velocity (V_s) and bearing capacity. ρ is density. Keceli's formula is given in equation 7.

$$q_u = \frac{1}{100} * \frac{\rho V_s^2}{V_p} \qquad (7)$$

Results and Discussion

Applications of geophysical surveys, geological and geotechnical

Seismic and electrical resistivity methods were used in evaluating the subsurface integrity of a 6.8 km stretch of railway track in southeastern Sivas basin Boundaries of formations and groundwater levels were searched by using electrical resistivity distribution of subsurface which were found from electical resistivity surveys at 59 points. Ru-4 and Ru-5 of electrical resistivity measurements taken from the Segment-I can be seen in Figure 2.

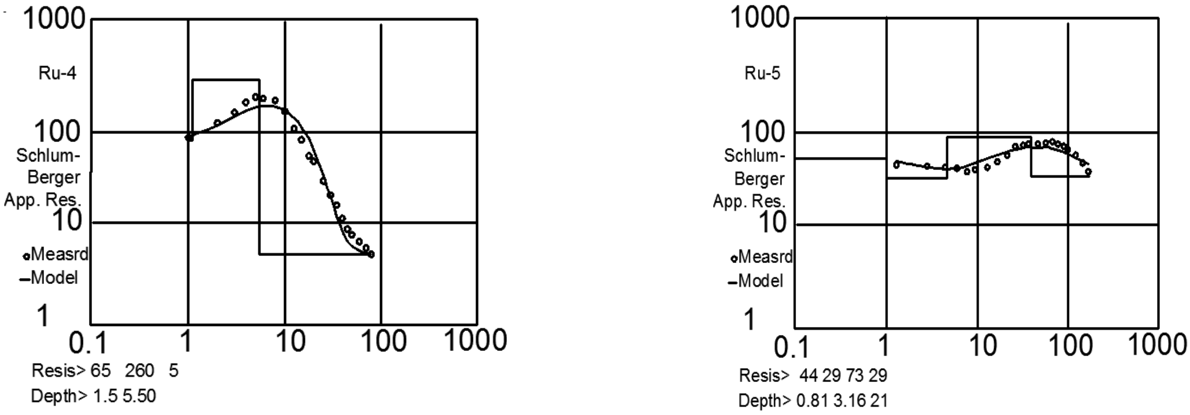

Figure 2. Resistivity sections from examples of electricial measurements (Ru-4 and Ru-5) for Schlumberger array. Yellow circles are defined as measured resistivity values. Red line is for our subsurface resistivity model. After iteration, resistivity values and depths can seen in red colour on the screen.

Seismic P wave and S wave records were measured at 62 and 56 points, respectively. Elastic parameters and thickness of layers were calculated from calculated seismic velocities whereupon done soil's classifications were derived. After these procedures, the bearing capacities of the soils were analyzed by using seismic wave velocities and geotechnical approaches. Su-4 of seismic refraction measurements taken from the Segment-I were given an example. Seismic record, time-distance graph drawn by first arrivals, calculated subsurface model and velocities were given in Figure 3a,b.

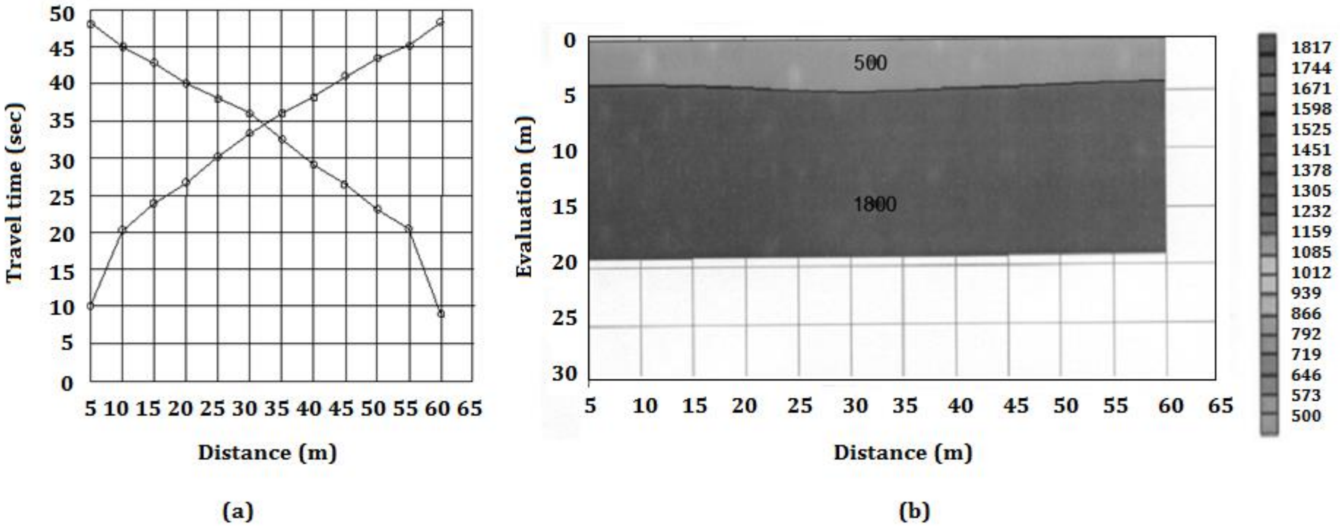

Figure 3. a) Time (sec) – distance (m) graph b) Subsurface model with time-inversion method

Furthermore, boreholes at 11 points and 3 test pits were drilled to estimate geotechnical properties of soil-rock units, soil classification regard as physical engineering parameters, and to investigate groundwater level's. SPT was taken from fundamental boreholes and laboratory tests were done on samples and cores are taken from test pits. 11 boreholes totalling 178.82 m were drilled on the survey site (see Table 2); their depths vary between 10 and 27 meters. Lithology and groundwater levels of the wells drilled are given in this table.

Table 2. Depth, lithology and groundwater level of study areada drilled boreholes

Location	Depth (m)	Lithology	Groundwater Level (m)
USK 0+420	10.95	Clayey Gravel Sand	4.50
KSK 1+068	12.31	Sand	4.30
ASK 1+915	18.45	Clay – Sand - Gravel	4.40
ASK 2+580	13.55	Sand	4.30
YSK 2+900	27.00	Jips – Mudstone - Sandstone	-
USK 4+635	10.95	Clay-Sand	3.00
USK 5+250	13.60	Clay – Sand - Gravel	6.10
USK 6+305	10.10	Sand - Conglomera	4.35
SISK 5	12.18	Clay - Sand	10.00
SISK 8	15.20	Gravel Clay	10.00
SISK 13	16.95	Clay	2.40
SISK 14	16.95	Clay - Sand	2.75

Undisturbed soil samples were taken from 2.5-3.0, 4.0-4.5, 5.5-6.0, 7.0-7.5 and 7.5-8.0 m, respectively. Standard Penetration Tests were done each 1.5 m and disturbed soil samples were taken. Laboratory tests (According to Atterberg limits, content of water permeability and sieve analysis) were determined on disturbed samples. Undisturbed samples were used for triaxial compressive strength tests. Seven triaxial compressive strength tests were done on samples taken from boreholes on the survey site. Minimum and maximum values of cohesion are 62 KPa and 85 KPa. The stiffness of the soil can be determined as Medium Stiff depending on unconfined compressive strength.

62 P waves and 56 S waves measurements were recorded with using a 12 channel shallow exploration seismograph. A hammer with a weight of 8 kg was chosen as a source. Shots were done at the beginning and the end of spread. If the conditions of survey area were avaible, lengths of spread of 60 m, 120 m and spaces of geophones of 5 m and 10 m, respectively, were selected.

The distrubition of seismic velocities and subsurface structure was estimated by evaluating seismic records for measured profiles. Collected seismic measurements for six profiles chosen from on the survey site were used for calculating the soil's dynamic density (ρ) (Gradner, 1974), Shear Modules (G) (Kramer, 1996), Young Modules (E) (Bowless, 1988) and Poisson Ratio (υ). These results are given in Table 3. When the velocities and elastic parameters seen in Table 3 are examined, according to Eurocode-8 soil classification tables, types of the survey area are classified as from loose to hard soils.

Furthermore, Vertical Electrical Sounding method (VES) was used on the survey site where the the Schlumberger electrode array configuration were utilized at 59 points. The distances between electrodes were set from 1 to 80 m (AB/2) and from 0.25 to 10 m (MN/2). VES curves were interpreted quantitatively by partial curve matching and computer iteration technique so that information on the resisvitiy distrubition underground could be obtained.

Table 3. Seismic velocities and dynamic-elastic parameteres for six profiles chosen from survey site randomly

Spread Name	Layer Name	Vp (m/s)	Vs (m/s)	ρ (gr/cm^3)	G (kg/cm^2)	E (kg/cm^2)	υ	K (kg/cm^2)
Su-10	1	408	259	1.39	933	2169	0.16	1071
	2	1649	801	1.97	12655	34057	0.35	36760
Su-20	1	601	285	1.53	1244	3373	0.35	3876
	2	2242	901	2.13	17290	48540	0.40	84006
Su-30	1	541	262	1.49	1024	2760	0.35	3002
	2	1656	629	1.97	7812	22119	0.42	43732
Su-40	1	363	159	1.35	342	944	0.38	1325
	2	1732	562	2.00	6307	18178	0.44	51491
Su-50	1	413	151	1.40	318	905	0.42	1956
	2	1880	712	2.04	10332	29266	0.42	58259
Su-60	1	396	145	1.38	290	826	0.42	1778
	2	1732	753	2.00	11322	31327	0.38	44804

The railway tracks were examined in seven segments and Seven underground sections were prepared by using the data obtained from seismic cross-sections, vertical electrical soundings and mechanic drilling studies for clear and easy interpretation.

Segment-I is on the eastern boundary of survey site (0+000-0+640 km). The length of section is 640 meters. This section obtains five resistivity soundings, four seismic refraction measurements and one mechanical borehole which is called USK-0+420. As a result of the this section which is drawn from collected measurements, it has been found out that the examined track route road has a layered structure. Layers are named according to their depth as Layer 1, Layer 2. The topsoil has resistivity values ranging from 15 to 202 Ωm corresponding to clay and sandy gravel respectively; the top soil thickness varies between 0.0 m and 4.00 m. The topsoil has longitudinal waves values ranging from 410 m/sn to 500 m/s, shear waves values are between 220 m/sn and 356 m/s. Layer 2 is the weathered basement with resistivity and depths values varying between 11-362 Ωm and from 4.00 m to 16.00 m, respectively. Maximum and minimum P and S wave velocities range from 1378 m/sn to 2370 m/s and from 666 m/sn to 934 m/s. Elastisite Modulus are 2038-53056 kg/cm^2 and shear modules are 725-18839 kg/cm^2. According to Eurocode-8 soil classification tables, soil of alignment is B and C which mean very dense sand or gravel or very stiff clay and dense sand or gravel or stiff clay, respectively. Values of Poisson Ratio were calculated between 0.01-0.43. Called USK-0+420 borehole's lithology is clayey-gravel sand, groundwater level is 4.50 m. According to collected and calculated data, Section-I can be seen in Figure 4a and Figure 4b.The dashed line indicates groundwater level, the continous line shows the boundary of seismic layer. Su_1 is the start point for seismic spread. Ru_1 is one - dimensional resistivity point. The USK-0+420 indicates the place of borehole.

Segment-II occurs on 1400 meters of the survey site (0+640-1+880 km). On the investigation site 12 resistivity soundings, 12 seismic refraction measurements and one mechanical borehole, which is called KSK-1+068, were conducted. According to the underground structure estimated, the topsoil has resistivity values ranging from 13 Ωm to 45 Ωm corresponding to clay and sandy gravel respectively; the top soil thickness varies between 0.0 m and 5.00 m. Layer 1's longitudinal and shear waves values range from 346 m/sn to 550 m/s and 152 m/sn to 286 m/s, respectively. This layer can be affected by groundwater level. The weathered basement called Layer 2 has resistivity and thickness values varying between 2 Ωm and 31 Ωm and 5.00-16.00 m, respectively, under the first layer, respectively. It's primary and secondary wave velocities vary between 1261m/sn and 1943 m/s and 415 m/sn and 822 m/s. Its lithology is stiff clayey sand gravel. According to Eurocode-8, bearing capacitiy of this segment which Elasticitiy Modules lie between 1258 kg/cm² and 31069 kg/cm² and whose shear modules are 347-13482 kg/cm² are determined as loose, medium and stiff with increasing depth. This layer has Poisson Ratio values ranging from 0.04 to 0.44. The well formation called KSK-1+068 is sandy clay with groundwater level at 4.20 m.

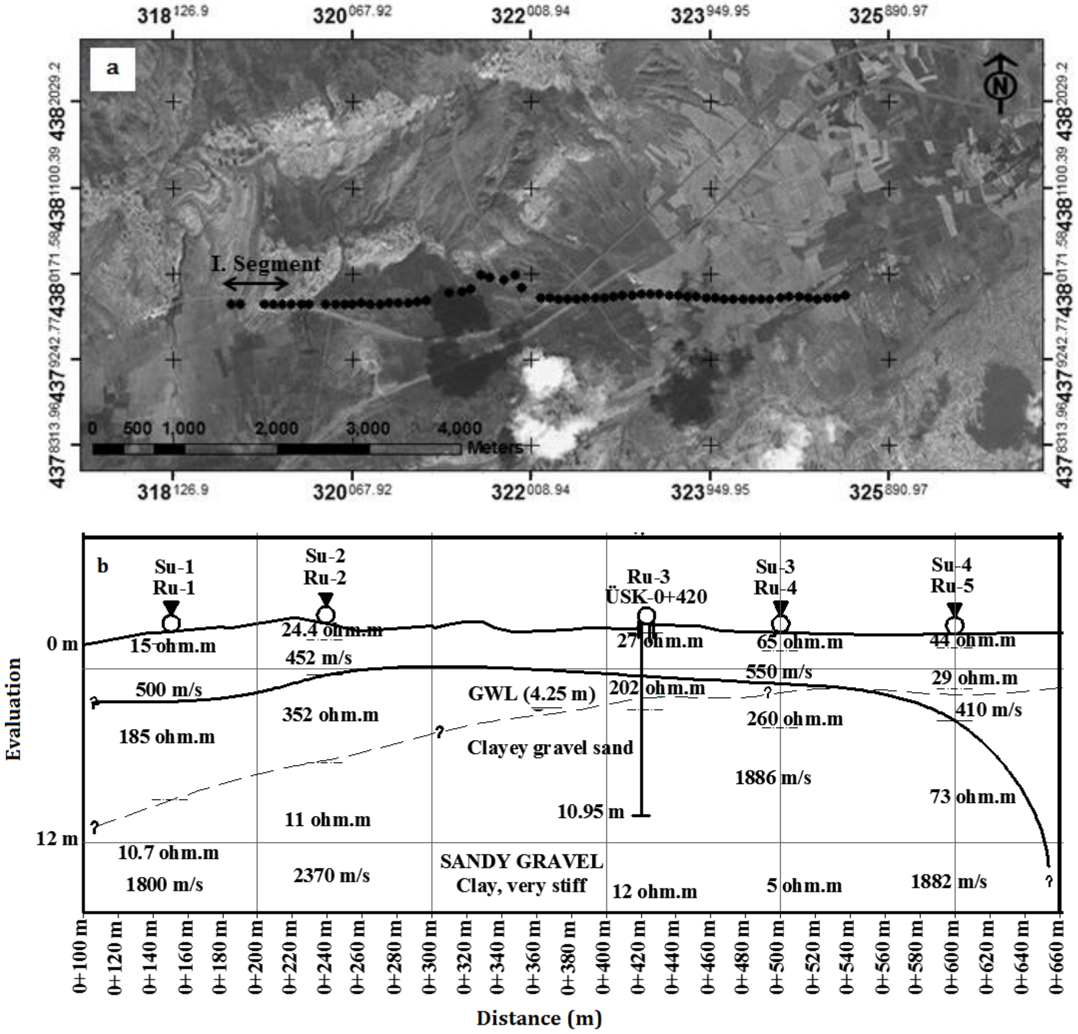

Figure 4. a) Map of route for Section-I b) Section-I drawn using measurements. Boreholes, seismic and electrical data shown in this section. Route of section can be seen on map above mentioned section. Points of geophysical measurement were marked as black point.

Segment-III lies between 1+880 km and 2+750 km. It underwent six resistivity soundings, six seismic refraction measurements and two mechanical boreholes called ASK-1+195 and ASK-2+580. The length of section is 870 metres. It is specified as two layers according to seismic measurements. Groundwater levels varies between 5.80-6.30 meters. Seismic measurements were named from Su_17 to Su_22. The first layer has resistivity values ranging from 3.2 Ωm to 20 Ωm corresponding to sandy hard clay. The topsoil's thickness varies between 0.0 m and 5.00 m. Its values of longitudinal and shear waves range from 403 m/sn to 601 m/s and 168-287 m/s. The resistivity and thickness values of the weathered basement vary between 2.90-57 Ωm and 5.00-16.00 m under Layer 1. The second layer has longitudinal waves value ranging from 1792 m/sn to 2251 m/s. Shear wave velocities vary from 637 m/sn to 901 m/sn. Layer 2 can be determined as sandstone formation. This segment which has elasticity modules as 1258-31069 kg/cm² and shear modules between 426 kg/cm² and 18470 kg/cm². According to Eurocode-8 and Bowless soil classification for dynamic properties, this segment can be determined as "B" and "medium and stiff soil". Calculated Poisson values are ranging from 0.35 to 0.45. It can be understood that layers are of porous structure. Sandy clay gravel formations can be seen during called ASK-1+195 and ASK-2+580 wells. Groundwater levels are 4.30-4.40.

Segment-IV includes a stretch of rail cutting. The width of the cutting is 550 meters, lying, between 2+750 km and 3+300 km (Figure 5). This section has five seismic refraction measurements and one well which is called YSK-2+900 for geotechnical properties. Two layers are determined in accordance with seismic investigation. The top soil thickness varies between 0.0m and 5.00 m as claystone and gypsum. Their form is decayed rock. Thickness values of the weathered basement where is under top soil vary between 5.00-16.00 m. The second layer has longitudinal waves value ranging from 1696 m/sn to 2251 m/s, shear waves values are 637-901 m/s. These can be determined as possible sandstone layers. Shear waves record could not be taken in this area. Mechanical borehole of lithology is gypsum - sandstone and siltstone. Seismic velocities of this section indicates soil with high bearing capacity. According to collected and calculated data, Section-IV can be seen in Figure 5a and Figure 5b.

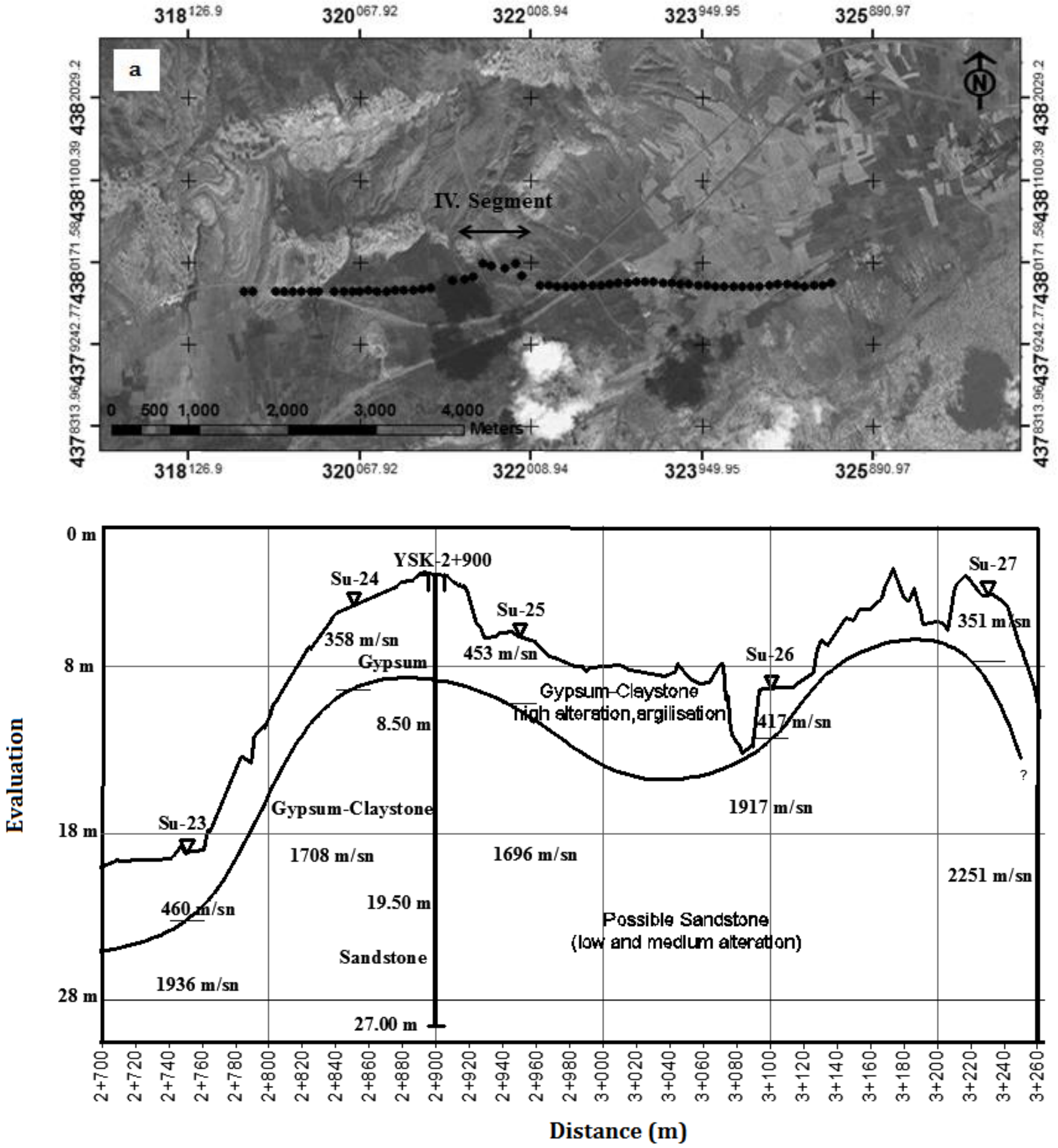

Figure 5. a) Map of route for Section-IV b) Section-IV drawn using measurements. Boreholes, seismic and electrical data shown in this section. Route of section can be seen on map above mentioned section. Points of geophysical measurement were marked as black point.

Segment-V lies between 3+300 km and 4+900 km. The length of this section is 1600 m. There were 15 resistivity soundings, 16 seismic refraction measurements, five mechanical boreholes which were called as SİSK_5, SİSK_8, SİSK_13, SİSK_14, ÜSK 4+635 and a test pit. The depth of the top layer, consisting of silty sand units, ranges from 0.00 to 5.00 meters values of P and S velocity vary between 236 m/sn and 694 m/s, and 150-314 m/sn, respectively. Resistivity values range between 8 Ωm and 20 Ωm. This layer is weathered. The weathered basement with the resistivity, P waves, S waves and thickness values vary between 3 Ωm and 40

Ωm, 1308-1785 m/sn, 520-791 m/sn and 5.00-16.00 m under the first layer, respectively. The groundwater level varies between 3.00 m and 5.20 m. According to Eurocode-8, the soil of the aligment ranges from B to C. According to Bowless soil classification for dynamic properties, this segment which has elasticity modules as 646-31906 kg/cm² and shear modules between 325-12314 kg/cm² can be determined as loose and stiff soil. Poisson Ratio ranges from 0.02 to 0.47. Formations of SİSK_5, SİSK_8, SİSK_13, SİSK_14 and ÜSK-4+635 are clayey sand. Boreholes data and geophysical data match each others.

Segment-VI of track in this region lies between 4+900 km and 5+300 km. Four resistivity soundings, four seismic refraction measurements and one well called ÜSK+520 were done on this section. The length of section is 400 m and two seismic layers were formed with seismic measurements. According to mechanical boreholes, ÜSK-5+250, between Su_44 and Su_47, the depth of the top layer is between 0.00 m and 5.00 m, being silty sand gravel stiff units. P and S wave values vary between 506 m/sn and 769 m/s, and 132-219 m/sn, respectively. Resistivity values range from 6 Ωm to 22 Ωm. Resistivity, velocity of P waves, velocity of S waves and thickness values of weathered basement vary between 6-54 Ωm, 1522-1692 m/sn, 591-648 m/sn and 5.00-16.00 m, respectively, under the first layer. The type of this layer can be determined as stiff, sandy gravel units. Groundwater level is 5.30 m. The soil of this section can be classified from B to C, especially as regards Eurocode-8. According to Bowless soil classification for dynamic properties, this segment which has elasticity modules as 748-28940 kg/cm² and shear modules between 528-11468 kg/cm² can be determined as medium and stiff soil. The Poisson Ratio changes 0.34-0.47. The lithology of the borehole called ÜSK 5+250 is very stiff and suggests sandy gravel units. According to collected and calculated data, Section VI can be seen in Figure 6.

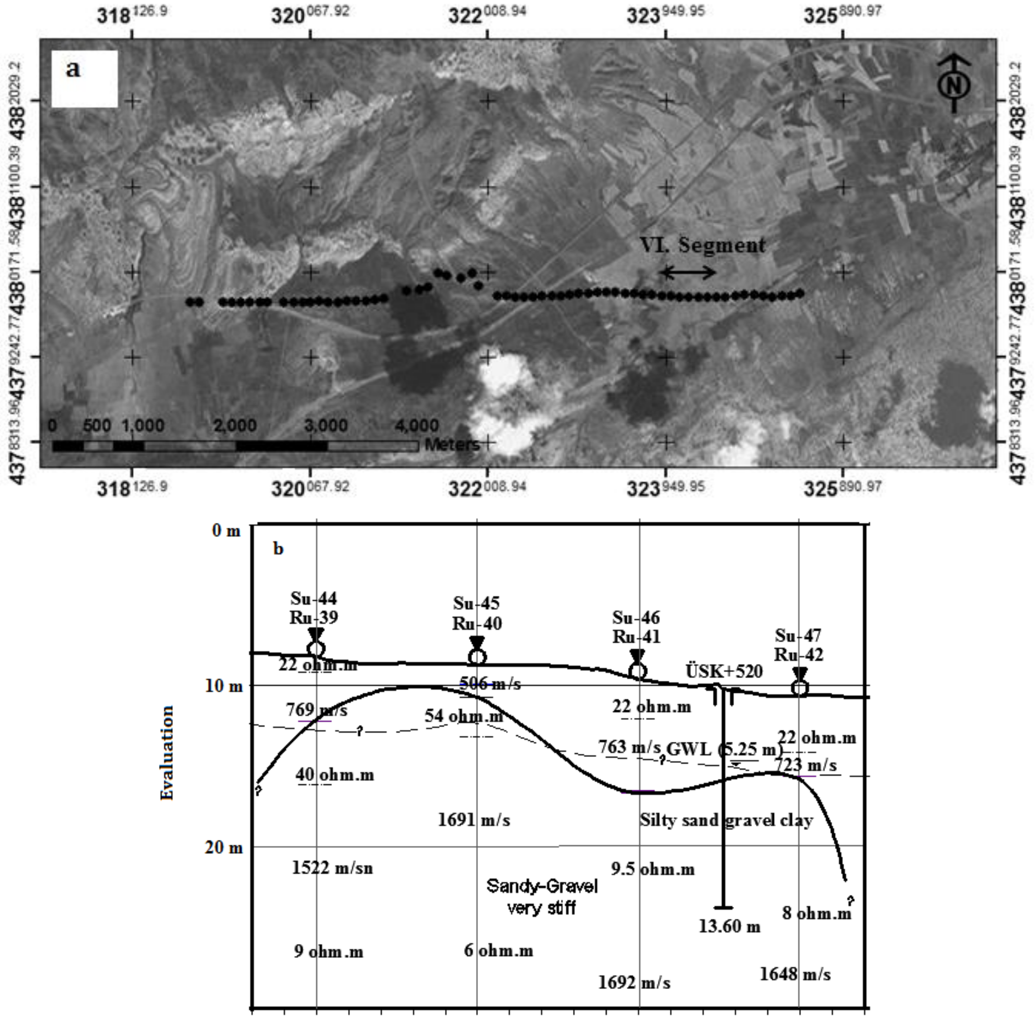

Figure 6. a) Map of route for Section-IV b) Section-VI drawn using measurements. Boreholes, seismic and electrical data shown in this section. Route of section can be seen on map above mentioned section. Points of geophysical measurement were marked as black point.

Segment-VII includes 5+300 km - 6+800 km of study area. 15 resistivity soundings, 15 seismic refraction measurements called Su_48-Su_62 and one mechanical borehole called ÜSK-6+305 and a test pit called AÇ-6+910 were done on this field. The section length is 1400 meters. According to all seismic shot points, ÜSK-6+305 of mechanical borehole, depth of top layer ranges between 0.00 m and 5.00 m as stiff silty sand gravel units. Values of P and S wave vary between 381 m/sn and 794 m/s, and 164-321 m/sn, respectively. Resistivity values range from 14 Ωm to 27 Ωm. Resistivity, P waves velocity, S waves velocity and thickness values vary between 4-70 Ωm, 1738- 3001 m/sn, 444-1532 m/sn and 5.00-16.00 m, respectively, in the weathered basement under the first layer. The type of this layer could be determined as medium weathered rock. Soil of aligment can be classified B and C, according to Eurocode 8. Conglomera gaps can approximately be found within 5.00 m between the Su_57 and Su_60 seismic shot points. This layer is waterlogged soil. According to the Bowless soil classification for dynamic properties, this segment which has elasticity modules as 826-14235 kg/cm^2 and shear modules between 290-53768 kg/cm^2 can be determined as medium and stiff soil. Poisson Ratio ranges from 0.23 to 0.47. Formations of ÜSK-6+305 and AÇ+910 are silty sand and conglomera.

Bearing capacities which were calculated by use of laboratory tests and seismic methods can be seen in Table 4. Bearing capacitiy values calculated by using shear wave velocity range between 19.95 KPa and 97 KPa. According to USA soil classification standards, values of bearing capacities can be determined as D (stiff soil). Bearing capacity values calculated by using laboratory results range between 19.52 KPa and 161 KPa. Stiffness of soil is medium hard with regards to the values of unconfined compressive test.

Table 4. Bearing capacities calculated by using laboratory tests and seismic methods

Name of Borehole	Groundwater Level	Soil Classification	q_{soil} (Terzaghi) KPa	q_{soil} (Broms) KPa	q_{soil} (V_p-V_s) KPa	q_{soil} (Triaxial Compression Test) KPa
USK_0+420	4.50	SM	-	-	78.0	-
KSK_1+068	4.30	SM	-	-	62.0	-
ASK_1+915	4.40	CL	46.26	46.05	58.5	128
ASK_2+580	4.30	SC	-	-	59.0	-
SİSK_5	10.0	CH	-	-	46.0	-
SISK_8	10.0	CL	-	-	97.0	-
SISK_13	2.40	CH	48.16	33.93	57.0	161
SISK_14	2.75	CH	19.95	19.92	51.0	151
USK_4+635	3.00	CH	35.30	34.55	45.0	144
USK_5+250	6.10	CH	52.00	52.00	79.0	132
USK_6+305	4.35	SM	-	-	77.0	-

11 boreholes given with specific levels have minimum and maximum SPT (N) values of between 18 and 30 (see in Table 4). Bearing capacities calculated by using SPT blow counts (N) are between 223 KPa and 438 KPa (see table 5). According to the Eurocode - 8 soil classification tables, which include SPT blow count (N) values. Calculated bearing capacities used all SPT blow counts (N). The soil can be classified as C.

Conclusion

In this study, high speed track planned between the cities of Sivas and Erzincan was investigated with special regard to underground structure and bearing capacities of soils. Subsurface structure was determined by seismic velocities and resistivity distrubition calculated from seismic and electric resistivity methods on survey site. The total length of reviewed track was 6+800 km. The maximum and minimum P wave and S wave velocities vary 273 m/s-3001 m/s, 132 m/s-1532 m/sn. Elasticity and shear modules range from 646 to 53056 kg/cm^2 and from 290 to 53768 kg/cm^2. As a result of the investigation, it has been identified that the soil beneath the aligment examined has a layered structure. Layers were named according to depth as Layer 1 and Layer 2. The average thickness of layers are 0-5 m, and 5-16 m, respectively. According to calculated elastic parameters on track route, the bearing capacities of the soil depend on horizontal and vertical movements was determined as very weathered, weathered soils and stiff soils in some areas. Bearing capacitiy values calculated by using shear wave velocity range between 19.95 and 97 KPa Bearing capacitiy values calculated by using laboratory results range between 19.52 and 161 KPa. Bearing capacities calculated by using SPT blow counts (N) show values between 223 and 438 KPa. Bearing capacities calculated by using results of laboratory and seismic velocities are similar each other.

Table 5. Bearing Capasities calculated by using Standard Penetration Test Blow Counts (N)

Name of Borehole	Depth (m)	Soil Classification	SPT (N) Blow Counts	q_{ult} Terzaghi-Peck KPa	q_{ult} Meyerhof (1974) KPa	q_{ult} Average KPa
ÜSK_0420	1.70	SM	26	351.7	386.9	353
	3.20	SM	28			
KSK_1068	1.70	SM	21	297.7	335.6	301
	3.20	SM	23			
ASK_1915	1.70	CL	24	311.3	376.4	323
	3.20	CL	25			
ASK_2580	1.70	SC	18	214.8	276.5	226
	3.20	SC	18			
SISK_5	1.70	CH	24	469.8	414.9	438
	3.20	CH	30			
SISK_8	1.70	CL	20	450.7	399.6	421
	3.20	CL	22			
SISK_13	1.70	CH	18	221.9	291.9	236
	3.20	CH	20			
SISK_14	1.70	CH	21	242.2	307.2	253
	3.20	CH	19			
USK_4635	1.70	CH	21	233.8	299.6	248
	3.20	CH	18			
USK_5250	1.70	CH	23	300.7	314.5	296
	3.20	CH	20			
USK_6305	1.70	SM	13	210.3	272.8	223
	3.20	SM	19			

Bearing capacity results which is calculated by SPT is different from other results because The SPT is affected by several factors, such as overburden stress, rod length, and equipment type and so the N value measured in the field should be corrected to N60 or (N1)60, which is computed by multiplying the N value by the correction factors of overburden stress, energy ratio, borehole diameter, sampling method, and rod length. Ultimate bearing capacity results which is found by seismic measurements is dynamic parameters. For this reason, results of bearing capacity can be lower values. Liquefaction problems can be seen on the survey site because of existing groundwater. The bearing capasities of examined weak zones should be strengthened and groundwater should be removed from the media.

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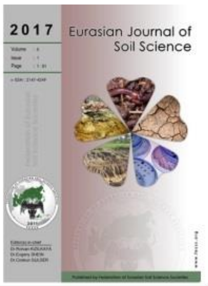

Nutrient release dynamics of an accelerated compost: A case study in an Alfisol and Ultisol

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Abstract

Acceleration of composting process could influence fertilizer-efficiency of the accelerated composts. This study therefore evaluated the nutrient release dynamics of different rates of a commercial accelerated compost (*OBD-plus*) in two soils described as Alfisol and Ultisol, under laboratory incubation study, in order to generate information for simulation under field conditions. Accelerated compost (AC) at the rates of 30, 60, 90, 120, 150 kg N ha^{-1}, mineral fertilizer (NPK 15-15-15) and conventional compost (CC) at 60 kg N ha^{-1}, were each mixed with 2 mm sieved soil (Alfisol and Ultisol) in cups, and arranged in a completely randomised design with three replications. Soils without amendment served as control. The treated soils were retrieved at 2, 4, 6, 8, 10 and 12 weeks of incubation (WOI), air dried and analysed for pH, organic C, N, P and K, and data analysed using regression test. The results revealed that the 60 kg N ha^{-1} AC improved the pH, OC, N. P, K by -2%, 11%, 3%, 141% and 4% respectively, across the WOI, on the average of performance in the two soils, comparable with mineral fertilizer (-5%, 8%, -1%, 76%, 4% respectively) and CC (11%, 40%, 3%, 773%, 10% respectively). The 60 kg N ha^{-1} AC significantly correlated ($p<0.05$) with time of incubation only with respect to P (0.934) and gave a similar nutrient release pattern compared with mineral fertilizer and CC, in terms of C, N, P and K in both soils. It therefore showed that the accelerated compost evaluated could mineralize in a way similar to conventional compost and mineral fertilizers, despite its shorter composting duration to maturity.

Keywords: Accelerated compost, Alfisol, incubation study, Ultisol.

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Introduction

Nutrient release from applied fertilizer is the process by which the plant nutrients from fertilizer materials become available in the soil for plants uptake. It has been widely reported that mineral fertilizers could release their nutrients in the soil almost immediately after application (Adediran et al., 2004), whereas, composts release their nutrients gradually. This is because compost would first go through decomposition (mineralization) before the release of the nutrients (Eghball et al., 2004; Tejada and Gonzalez, 2007). The soil organisms would first breakdown the fertilizer materials before nutrients are mineralized by eventual death of soil organisms (Abou El-Magd et al., 2005; Deenik, 2006). The rate of mineralization by compost could be affected by some factors such as climate, soil moisture, soil type, the composition, formulation and characteristics of the raw materials, maturity of the compost, as well as the composting technology (FAO, 2005; Gutser et al., 2005; Diacono and Montemurro, 2010).

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The potential of conventional (traditional) compost to mineralize nutrients for crop use has been widely reported (Molindo, 2008; Ipinmoroti, 2013). Although, there is a campaign for the use of compost all over the world due to its benefits over the mineral fertilizers (Koning and Smaling, 2005; Pender et al., 2006), the duration of composting is a limiting factor to its adoption. The conventional composting procedures take as long as two – eight months to produce matured compost, depending on the nature of the materials involved and methodology in use (Cooperband, 2002). This led to the development of the new technologies aiming at reducing the composting duration. There are now rapid composting methods, which offer the possibilities of reducing the composting period to three weeks and such are referred to as rapid (accelerated) compost (FAO, 2003). However, there is a need to evaluate accelerated compost (AC) in respect of mineralization of its constituent nutrients, considering its shortness in the time to maturity. There is a dearth of information on the pattern of release of nutrients by accelerated compost in Alfisols and Ultisols, which are major agricultural soil types in the world. Alfisols and Ultisols constitute 9.7% and 8.5%, respectively of the global soil, based on soil order (Blum and Eswaran, 2004).

The two soil types are highly weathered, leached and inherently low in soil nutrients, hence, they usually require soil amendments to improve their productivity (FFD, 2012). Laboratory soil incubation studies give opportunities to properly understudy soil properties or amendments with less environmental interference, which then generate results that could be highly useful in simulation of the performance of the understudied factor or soil amendment. Meanwhile, different crops have different nutrient requirement ranging from low to very high (FAO, 2006), hence, the need to consider fertilizer amendment at different rates in incubation study. This study therefore evaluated the nutrient release dynamics of different rates of an accelerated compost in a typical Alfisol and Ultisol of Southwest Nigeria.

Material and Methods

The experiment was carried out at the Federal College of Agriculture, Moor Plantation, Ibadan. The two soils used for this study were described as Alfisol (Smyth and Montgomery, 1962) and Ultisol (Periaswamy and Ashaye, 1982). The Alfisol was collected from the experimental site of the Federal College of Agriculture, Moor Plantation, Ibadan, Nigeria (Lat. 7^0 22’ 27.95’’ and Long. 3^0 50’ 20.62’’). The Ultisol was collected from the Institute of Agricultural Research and Training sub-Station, Ikenne, Nigeria (Lat. $6^0$51’ 21.11’’ and Long. 3^0 42’ 20.23’’). The soils were air-dried and sieved with 2 mm mesh. The accelerated compost; *OBD-plus* evaluated in this study was a commercial product, obtained from Gateway Fertilizer Company, Abeokuta, Ogun State, Nigeria. The method of composting involves the artificial introduction of some microorganisms, which speed up the rate of decomposition of organic materials. The compost matures in three weeks instead of the two to eight months period in conventional composting. The particle size was ≤2 mm. The conventional compost used as a check was also a commercial product, obtained from Alesinloye Compost Company, Alesinloye market, Ibadan, Nigeria.

The accelerated compost (AC) at the rates of 30, 60, 90, 120, 150 kg N ha^{-1}, mineral fertilizer (NPK 15-15-15) and conventional compost (CC) at 60 kg N ha^{-1} each, were thoroughly mixed with 80 g of the sieved Alfisol or Ultisol in cups, and arranged in a completely randomised design with three replications. Cups without amendment served as control. A total of 144 (8 treatments x 3 replicates x 6 weeks) filled incubation cups were involved for each of the two soils and each of the cups served as an experimental unit. The surface diameter and depth of each cup were 8 cm and 4 cm, respectively. The treated soils were moistened with deionized water to field capacity and each cup was covered and made air-tight. The cups were set up in the laboratory at temperature of 26 ± 2 ^{0}C.

Chemical analysis of the composts were carried out using standard procedures (Olsen and Dean, 1965; Okalebo et al., 1993; Bremner, 1996; Thomas, 1996). The physical and chemical analysis of the pre- and post-incubated soils were also carried out using standard procedures (Bray and Kurtz, 1945; Murphy and Riley, 1962; Hendershot et al., 1993; Bremner, 1996; Nelson and Sommers, 1996; Thomas, 1996). The chemical analysis of the accelerated and conventional composts is shown in the Table 1. The soil analysis before incubation showed that the Alfisol was low in N (0.4 g kg^{-1}), but marginal in K (0.4 cmol kg^{-1}) and P (8 mg kg^{-1}). The pH was 6.2, soil organic carbon (SOC) of 7.2 g kg^{-1} was low and the textural class was loamy sand. The Ultisol was low in N (0.7 g kg^{-1}), P (7 mg kg^{-1}) and K (0.2 cmol kg^{-1}), pH was 5.9, SOC (10.2 g kg^{-1}) was medium and the textural class was loamy sand (FFD, 2012). The treated soils were retrieved at 2, 4, 6, 8, 10 and 12 weeks of incubation (WOI), air dried and analysed for pH, SOC, N, P and K, and data analysed using regression test.

Table 1. Chemical analysis of the accelerated and conventional composts

Parameter	pH (H_2O)	Total C	N	P	K	Ca	Mg	Na	C:N	Fe	Cu	Mn	Zn
		------------------------- (g kg^{-1}) -------------------------								--------------- mg kg^{-1} -----------			
AC	6.2	170	12.3	46	5	3.1	1.1	2	140	2860	71	495	464
CC	9.7	170	12.0	8	17	3.2	1.0	4	140	1670	78	393	186

AC; Accelerated compost, CC; Conventional compost

Results

The effects of the different rates of AC on soil pH across 12 WOI (Figure 1) showed that the change of pH per week was similar for all the fertilizer treatments in each of the two soil types. However, 60 kg N ha^{-1} CC led to the highest pH (Alfisol; 7.3 – 7.6, Ultisol; 6.5 – 8.0) across the WO1, followed by the various rates of AC and control treatment. The 60 kg N ha^{-1} NPK gave the lowest pH value (Alfisol; 6.2 – 6.6, Ultisol; 5.5 – 6.5). The result also showed that coefficient of determination (CD) (R^2) for each treatment was low in both soil types.

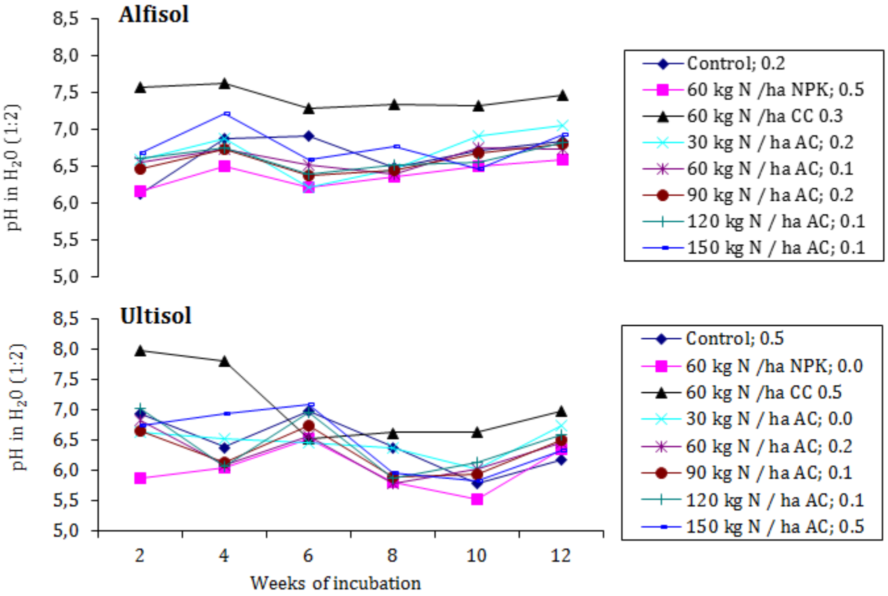

Figure 1. Comparative effects of the fertilizer treatments on soil pH across weeks of incubation
AC; Accelerated Compost, CC; Conventional Compost; the values in front of treatments legends are R^2.

The result of the values of the SOC recovery in Alfisol (Figure 2) showed that all the different rates of AC gave irregular pattern across WOI, which was similar with that of the control (3.0 – 13.6 g kg^{-1}), NPK (4.2 – 11.5 g kg^{-1}) and CC (6.3 – 11.0 g kg^{-1}) treatments. A similar trend was also observed in Ultisol. The CD for each treatment was low in both soil types, except with respect to 60 kg N ha^{-1} NPK (0.7) and 60 kg N ha^{-1} CC (0.7) treatments in Ultisol.

The result of the nitrogen release is shown in Figure 3. In Alfisol, all compost treatments resulted into less N values from 2 – 6 WOI (average of 0.6 g kg^{-1}), but higher values from 8 – 12 WOI (average of 0.7 g kg^{-1}), when compared with NPK, which had average of 0.7 and 0.5 g kg^{-1} values for 2 – 6 and 8 – 12 WOI, respectively. Also, CC released more N (0.7 g kg^{-1}) compared to various rates of AC at 2 - 6 WOI, but less compared to 90 and 150 kg N ha^{-1} AC at 8 – 12 WOI. In the Ultisol, all the various rates of AC and the CC resulted into similar pattern of release of N across the WOI, though in a trend different to what was obtained in Alfisol. On the average across the WOI, 60 kgN/ha AC gave highest value of N (1.6 g kg^{-1}), followed by 60 kg N ha^{-1} CC (1.5 g kg^{-1}), both higher than 60 kg N ha^{-1} NPK (1.1 g kg^{-1}). However, the AC and CC had similar N release pattern across the WOI. The CD for each treatment was low in both soil types, except for 60 kg N ha^{-1} CC (0.7) and 150 kg N ha^{-1} AC (0.9) treatments in Alfisol.

The result of available phosphorus release (Figure 4) showed that all various rates of AC (except 30 kg N ha^{-1}) followed a similar pattern, with a higher value of available P (average of 42 mg kg^{-1} over WOI) compared to NPK (average of 17 mg kg^{-1}). Although the different rates of AC had a similar pattern of release with CC (average of 48 mg kg^{-1}), the values were less across the WOI. A similar pattern was obtained in Ultisol. The CD were high for 60 kg N ha^{-1} AC (0.88) and 120 kg N ha^{-1} AC (0.70), but low for other treatments in Alfisol. The CD were also high for 60 kg N ha^{-1} CC (0.79), 120 kg N ha^{-1} AC (0.80) and 150 kg N ha^{-1} AC (0.68), but low for others in Ultisol.

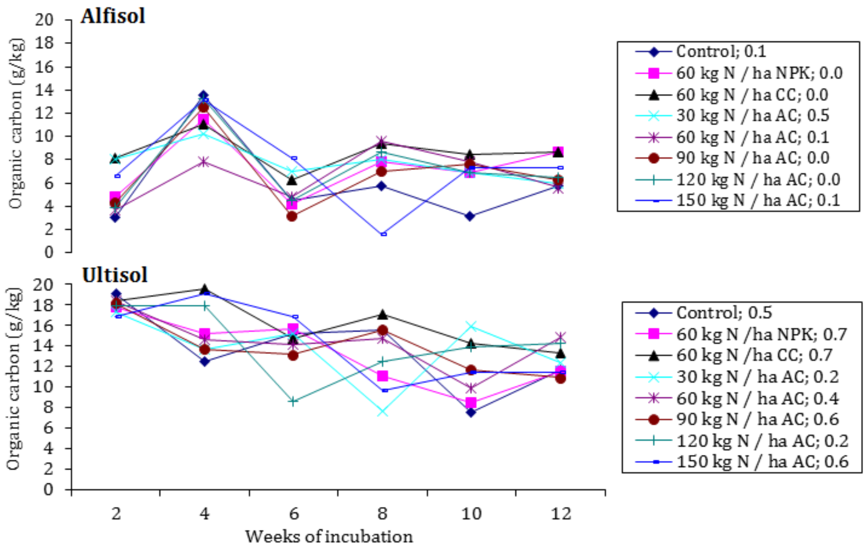

Figure 2. Effects of the fertilizer treatments on soil organic carbon across weeks of incubation
AC; Accelerated Compost, CC; Conventional Compost; the values in front of treatments legends are R^2.

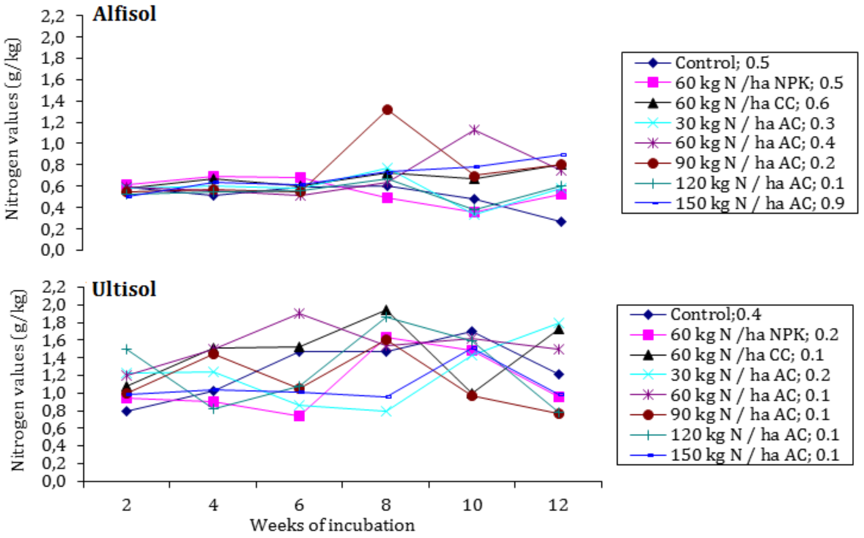

Figure 3. Comparative N release pattern by the various treatments across weeks of incubation
AC; Accelerated Compost, CC; Conventional Compost; the values in front of treatments legends are R^2.

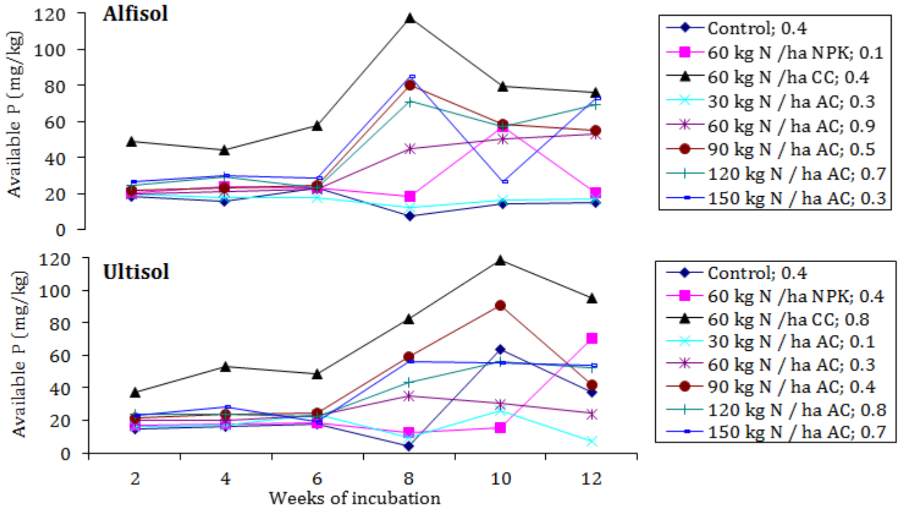

Figure 4. Comparative effects of the fertilizer treatments on available P across weeks of incubation
AC; Accelerated Compost, CC; Conventional Compost; the values in front of treatments legends are R^2.

The result of potassium release (Figure 5) showed that all the various rates of AC gave a similar pattern across WOI compared with CC and NPK in Alfisol. However, the result showed that CC gave the highest potassium release (average of 2 cmol kg^{-1}), except at 12 WOI. In Ultisol, all the various rates of AC, the CC and NPK treatments gave a similar pattern of potassium release across WOI, except that NPK dropped at 8 WOI (0.1 cmol kg^{-1}), while CC (2 cmol kg^{-1}) gave the highest value across the WOI. The CD were high for the control (0.74) and 150 kg N ha^{-1} AC (0.84), but low for others in Alfisol. The CD were also high for the control (0.68), 30 kg N ha^{-1} AC (0.86), 90 kg N ha^{-1} AC (0.76) and 120 kg N ha^{-1} AC (0.92), but low for others in Ultisol.

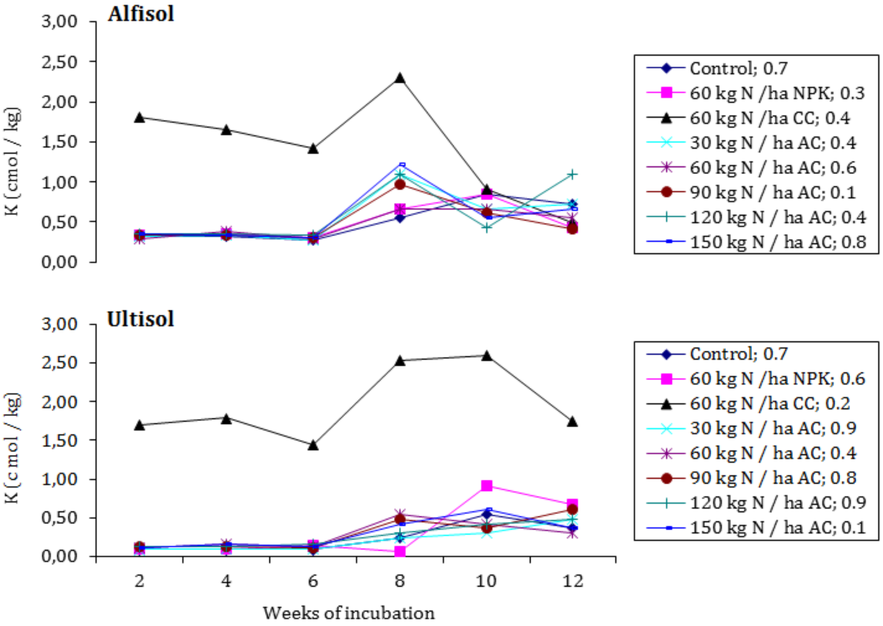

Figure 5. Comparative effect of the fertilizer treatments on K across weeks of incubation
AC; Accelerated Compost, CC; Conventional Compost; the values in front of treatments legends are R^2.

Discussion

The soil pH values obtained across the WOI of the fertilizer treatments are in the order of CC > AC > NPK (NPK 15-15-15 mineral fertilizer) in both Alfisol and Ultisol. This showed that the AC used for this study resulted into low soil pH compared with CC, but higher than that of NPK in both soils. This could be alluded to the fact that the pH 6.2 of the AC at application was much less than that of the CC (9.7). The Coefficient of determination (R^2) values for each treatment being low for all the treatments in both soil types showed that the effect of each fertilizer treatment on the soil pH was not time dependent.

The organic carbon (OC) recovery pattern of the various rates of AC was similar to that of the control, NPK and CC treatments in each of the two soil types. While it generally increased at 12 weeks relative to 2 WOI in Alfisol, it decreased with Ultisol. This suggested the influence of soil types on mineralization of the soil amendments (Diacono and Montemurro, 2010). The OC been highest at 2 WOI with Ultisol and lowest at 12 WOI suggested that mineralization of organic matter was at lag phase initially, while material could have been transformed in the soil at later period. This result confirmed the findings of Abbasi et al. (2015), where the applied organic amendments endured immobilization with little mineralization during the early period of incubation. The application of AC lowered OC relative to CC across the WOI, suggesting that the OC might have formed chelate and organic complexes with Fe and Mn (Voss, 1998). The AC used in this study had higher Fe and Mn than CC, as revealed by the results of chemical analysis of the two composts.

The N release pattern of the different rates of AC was similar and within the same range compared with CC and NPK across the WOI, in both Alfisol and Ultisol. This showed that AC compared favourably with NPK and CC in terms of N release. All compost treated soils had less N values from 2 – 6 WOI, but higher values from 8 – 12 WOI, when compared with NPK in Alfisol. This confirmed the reports of Tejada and Gonzalez (2007) and AyanfeOluwa et al. (2015) that composts release their nutrients gradually, compared to mineral fertilizers. This is because soil organisms will first act on the composts, before the release of the nutrients, while the nutrients from mineral fertilizer could be readily available to the plant almost immediately after application (Adediran et al., 2004). This, therefore confirmed the need for composts to be applied before planting so as to allow for mineralization and aid plant uptake of the nutrients (Paulin and O'Malley, 2008; Nwaogu et al., 2013). The rate of release of nitrogen by the 60 kg N ha^{-1} CC and 150 kg N ha^{-1} AC increased with the time of incubation in Alfisol. Also, in Ultisol, the AC and CC at 60 kg N/ha resulted into more nitrogen (across the WOI) than 60 kgN/ha NPK. This result showed that the shortness in the duration of composting of AC did not affect its rate of nitrogen release. The result of the available P release of the different rates of AC showed that all the various fertilizer rates (except 30 kg N ha^{-1}) gave a similar P release pattern comparable with the CC and NPK in both Alfisol and Ultisol. However, while CC gave the highest value, AC at various rates (except 30 kg N ha^{-1} which is a lower rate compared to that of NPK) gave higher values across the WOI compared with the control and NPK in both Alfisol and Ultisol. The high value of P obtained from compost treatments relative to NPK could be due to the ability of organic materials to reduce the P adsorption capacity of soils, and the potential of chemical fertilizers to reduce soil pH, thus increasing P fixation (von Wandruszka, 2006; Hepperly et al., 2009; Yu et al., 2013). This is in line with the findings of Ipinmoroti (2013) that compost released higher amount of available P than the control. This result showing that AC had similar pattern of release of P compared with CC and NPK when applied at the same rate of 60 kg N ha^{-1}, indicate that AC could be a suitable fertilizer for crop production.

The K release of the various rates of AC also gave a pattern comparable with CC and NPK treatments in both Alfisol and Ultisol, with the same range of K values observed in AC and NPK, but higher values in CC. The high K recorded in the soil treated with CC is traceable to the high K present in the CC, compared with AC. The higher K value recorded in Alfisol compared with Ultisol could also be linked to the difference in the amount of initial K present in the two soil types, however, the pattern of release was similar. It therefore showed that AC compared favourably with NPK and CC as it gave a similar pattern of release of K.

Conclusion

The focus of this study was to investigate the nutrient release dynamics of an accelerated compost, in relation to that of the conventional compost and commonly used NPK fertilizers, as possibility of simulating the performance of the commercial compost in Alfisols and Ultisols. The result showed that the accelerated compost used for this study gave a similar nutrient release pattern, compared with mineral fertilizer NPK 15-15-15 and conventional compost as revealed by the result of organic C, N, P and K. As much as the accelerated compost seemed better than the mineral NPK, application of conventional compost still seemed to be preferred in release of N, P and K.

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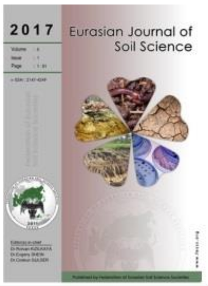

Effect of salt stress on concentration of nitrogen and phosphorus in root and leaf of strawberry plant

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Abstract

In this study the effect of salt stress on the concentrations of nitrogen (N) and phosphorus (P) in the leaves and the roots of two strawberry (*Fragaria vesca* L.) cultivars (Camarosa and Sweet Charlie) was investigated on cold stored bare-rooted seedlings grown in buckets filled with coarse sand. The treatments consisting of no-NaCl control, 1760, 2400, and 3040 mg L^{-1} of NaCl in half-strength Hoagland nutrient solution were applied to the plants for six months. During the experiment, leaf and root sampling were performed two times with five months interval. Roots and leaves of the plants were analyzed for Na, Cl, N and P. Analysis of variance (ANOVA) procedures was performed in Three Factors Completely Randomized Design for plant analysis results. Additionally orthogonal comparison was applied to the significant salinity effects. Cultivar and sampling time affected N, P, Na and Cl concentrations of the roots significantly. Cultivar-sampling time and sampling time-salinity interactions were significant for the N, P and Na concentrations of the roots. Salinity solely affected Cl concentrations of the roots significantly. All the treatments affected the concentrations of P, Na and Cl of the leaves significantly. The N concentrations of the leaves were affected significantly by only sampling time. Cultivar-salinity and sampling time-salinity interactions were found significant in the leaf N concentrations of the plants. The results show that the cultivars probably have different strategies in arrangement of N and P composition under salinity.

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Introduction

The increasing urbanization has expedited the demand of out-of-season strawberry growing all over the world. Aforesaid production has been mainly realized in greenhouse conditions and provided a momentous economic contribution to the growers. However, the pressure on the limited sources of good quality irrigation water has promoted the usage of relatively low quality, mostly saline, irrigation water in the production. Additionally higher yield expectation increased the excessive fertilizer application. These phenomena increased the salinity hazard in the soils of the production areas.

An increase in soil salinity commonly results in a reduction of water intake of plants. Passive nutrient uptake of the plants is related to water intake and any decrease in water availability causes to a reduction in uptake of many plant nutrients. Additionally the imbalance in composition of saline soil solution can also cause to uptake of some ions in excessive amounts such as Cl, Na and Mg. An increase in the concentration of these ions either has a toxic effect directly to the plants or promotes imbalance in plant nutrient metabolism

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(Ghafoor et al., 2004). According to Orcutt and Nielsen (2000) the most interesting interaction between salinity and macronutrient uptake is that between salinity and N accumulation. Botella et al. (1997) reported that NaCl reduced the accumulation of nitrate and ammonium when provided together to the plant. On the other hand limitations of P can occur in glycophytes like strawberry exposed to high salinity (Gorham, 1992). According to Kalifa et al. (2000) crop tolerance to high NaCl concentrations is partly related to inorganic P availability. High NaCl caused reduced P uptake in several crop species. Both root uptake and translocation of P to shoots were depressed. All these processes result in lower crop yields. Strawberry species are very salt sensitive (Larson, 1994) and suffer reductions in growth, quality, and yields (Awang et al., 1993 a,b) at soil electrical conductivities (EC_e) of above 1 dS m^{-1} (Carter, 1981). The species however, differ in their salt tolerance (Awang et al., 1993 a,b). The objectives of this research were to evaluate the effect of increasing NaCl-induced salinity on the concentrations of N and P in strawberry. In particular how salinity interferes with N and P concentrations of root and leaf, and how these changes are related to time.

Material and Methods

Plant material and salinity treatments

Two strawberry cultivars, Camarosa and Sweet Charlie were grown in high plastic tunnel at 25 ± 10 °C, 75 ± 25% Rh and natural photoperiod during Fall 2004 and Spring 2005. Cold stored bare-rooted strawberry seedlings were planted in 5–L buckets filled with coarse sand (0.6–0.8 mm particle size) on September 30, 2004. Three plants were planted in each bucket.

The treatments consisted of control (no-NaCl) and 1760 mg L^{-1}, 2400 mg L^{-1}, 3040 mg L^{-1} of NaCl (which are equal to 2.75 dS m^{-1}, 3.75 dS m^{-1} and 4.75 dS m^{-1} salinity respectively) in half-strength Hoagland nutrient solution. Tap water used in the preparation of the treatments contains approximately 109.57 mg L^{-1} Na and 7.1 mg L^{-1} Cl. Salinity treatments were started 30 days after planting. The pots irrigated with an amount of NaCl-enriched half concentrated Hoagland solution accounting for a leaching factor of 20–25% (Hoagland and Arnon, 1950) for six months. Each treatment was replicated 3 times with 2 buckets, 3 plants per bucket, hence 6 buckets and 18 plants per replicate.

Sampling and chemical analyses

Leaf and root sampling were performed two times with five months interval in full bloom periods of the plants. For this purpose the first three buckets in the each replication were emptied on January 2, 2005 and the second three buckets were emptied on May 1, 2005. The plants were gently removed from the sand and partitioned into roots and leaves. The roots were selected by hand mechanically from the sand. For plant analysis, physiologically mature leaves of the same physiological age, free of damage or defects, were sampled. The samples were immediately transported to the laboratory in closed polyethylene bags and carefully washed with tap water, rinsed in deionized water, and dried in a forced-air oven at 70°C for 72 h in paper bags. Dried samples were ground in a stainless steel coffee grinder. The ground samples were wet digested in a mixture of nitric acid/perchloric acid (HNO_3/$HClO_4$) (4/1, v/v) solution (Westerman, 1990). Sodium contents in the digest were determined using flame photometry (Jenway PFP7, Staffordshire, UK), P by the vanadomolybdophosphoric method (Westerman, 1990). The total N content of the dried samples were analyzed by Kjeldahl digestion method (Westerman, 1990). For the N analysis, 0.25 g of the samples was wet digested in a heating digester (Velp Scientifica, DK20, Milano, Italy) and then distilled in a distillation unit (Velp Scientifica, UDK126A, Milano, Italy). Aliquots were titrated by 0.1 N HCl. The results were expressed as the % N in the dry matter. The Cl was extracted from 0.1 g of the ground sample with 10 ml of deionized water by shaking the mixture for 2 h. The Cl concentrations of the extracts were measured by a chloridmeter (Jenway PCLM3, Staffordshire, UK). The results were expressed as the % Cl in the dry matter (Brown and Jackson, 1955).

Analysis of variance (ANOVA) procedures were performed in Three Factors Completely Randomized Design for plant analysis results according to Little and Hills (1978). Additionally orthogonal comparison was applied to the significant salinity effects.

Results

Variance analyses results of the effects on the cultivars, sampling time and salinity on N, P, Na and Cl concentrations of the roots and the leaves were given in Table 1. Cultivar and sampling time affected N, P, Na and Cl concentrations of the roots significantly. Cultivar-sampling time and sampling time-salinity interactions were significant for the N, P and Na concentrations of the roots. Salinity solely affected Cl concentrations of the roots significantly. All the treatments affected Cl concentration of the roots however the interactions between the treatments were nonsignificant.

Table 1. Variance analysis results of the effects of cultivar, sampling time and salinity on N, P, Na and Cl concentrations of the roots and the leaves

Treatments and interactions	Nutrients in the roots				Nutrients in the leaves			
	N	P	Na	Cl	N	P	Na	Cl
A-Cultivar	**	**	**	**	ns	**	*	**
B-Sampling Time	**	**	**	**	**	**	**	**
C-Salinity	ns	ns	ns	**	ns	**	**	**
AxB Interaction	*	**	**	ns	ns	**	ns	ns
AxC Interaction	ns	ns	ns	ns	**	ns	ns	ns
BxC Interaction	*	*	**	ns	*	**	ns	ns
AxBxC Interaction	ns	ns	ns	ns	ns	ns	ns	ns

* $P \leq 0.05$, ** $P \leq 0.01$, ns: nonsignificant

All the treatments affected the concentrations of P, Na and Cl of the leaves significantly. In other words, different levels of P, Na and Cl concentrations of the cultivars altered according to sampling time and salinity levels. The N concentrations of the leaves were affected by only sampling time. Cultivar-salinity and sampling time-salinity interactions were found significant in the leaf N concentrations of the plants.

Cultivar-sampling time and sampling time-salinity interactions were significant for the leaf P concentrations of the plants. None of the interactions between the treatments were significant for Na and Cl concentrations of the leaves. Interaction between the cultivar and sampling time for N, P and Na concentrations of the roots were seen in Table 2. Nitrogen and P concentrations of the cultivars decreased, and Na concentration increased with time.

Table 2. Interaction between cultivar and sampling time in respect to root N, P and Na concentrations

Cultivar	Root N (%)		Root P (%)		Root Na (%)	
	January	May	January	May	January	May
Camarosa	3.25*	1.71	0.33	0.06	0.31	0.39
Sweet Charlie	3.87	2.08	0.35	0.13	0.56	0.76

Interaction and orthogonal comparisons between the sampling times and the salinity levels for the root N, P and Na concentrations were given in Table 3 and Table 4 respectively. Root N and P concentrations of the cultivars decreased and root Na concentrations increased with time (Table 3). Compared to the control treatment, increasing salinity levels enhanced the N and P concentrations of the roots in the first sampling time. This effect was linear for the N concentration. However aforesaid relations were nonsignificant in the second sampling time. Salinity treatments increased the concentration of Na of the roots linearly. Nitrogen and P concentrations of the roots were affected in the first sampling time (Table 4).

Table 3. Interaction between sampling time and salinity in respect to root N, P and Na concentrations

Plant Nutrients (%)	Sampling Time	Salinity (dS m^{-1})			
		Control	2.75	3.75	4.75
N	January	3.41*	3.41	3.68	3.74
	May	1.93	1.87	1.91	1.87
P	January	0.31	0.34	0.34	0.37
	May	0.10	0.10	0.09	0.09
Na	January	0.15	0.31	0.54	0.76
	May	0.45	0.52	0.50	0.84

Table 4. Orthogonal comparison of sampling time-salinity interaction in respect to root N, P and Na concentrations

Sampling Time	Comparison	N	P	Na
January	Control vs. other Treatments	*	**	**
	Salinity-Linear	**	ns	**
	Salinity-Quadratic	ns	ns	ns
May	Control vs. other Treatments	ns	ns	**
	Salinity-Linear	ns	ns	**
	Salinity-Quadratic	ns	ns	**

* $P \leq 0.05$, ** $P \leq 0.01$, ns: nonsignificant

Interaction between the cultivar and the salinity for the leaf N concentration, and their orthogonal comparisons were given in Table 5 and Table 6 respectively. The salinity affected leaf N concentrations of the cultivars in different ways. The leaf N concentration of Camarosa was stable, but the leaf N concentration of Sweet Charlie increased (Table 5). Probably the difference between the cultivars made the main effects of the salinity on leaf N concentration nonsignificant (Table 1). Compared to the control treatment, salinity levels increased the leaf N concentrations of Sweet Charlie, additionally salinity treatments affected the leaf N concentrations of this cultivar quadraticly. In other words, the second salinity level (3.75 dS m^{-1}) increased the leaf N concentration compared to the first salinity level (2.75 dS m^{-1}), however the third salinity level (4.75 dS m^{-1}) decreased the leaf N concentration of Sweet Charlie compared to the second salinity level (3.75 dS m^{-1}) (Table 6).

Table 5. Interaction between cultivar and salinity in respect to leaf N concentrations (%)

Cultivar	Salinity (dS m^{-1})			
	Control	2.75	3.75	4.75
Camarosa	2.24*	2.26	2.18	2.27
Sweet Charlie	2.18	2.16	2.37	2.34

Table 6. Orthogonal comparison of cultivar-salinity interaction in respect to leaf N concentrations

Cultivar	Comparison	
Camarosa	Control vs. other Treatments	ns
	Salinity-Linear	ns
	Salinity-Quadratic	ns
Sweet Charlie	Control vs. other Treatments	*
	Salinity-Linear	**
	Salinity-Quadratic	*

* P ≤ 0.05, ** P ≤ 0.01, ns: nonsignificant

Interaction between the sampling time and the salinity for the leaf N and P concentrations, and their orthogonal comparisons were given in Table 7 and Table 8 respectively. In general, the leaf N concentration of the cultivars increased with time, the leaf P concentration of the cultivars decreased with time (Table 7). The effects of the salinity levels on the leaf N and P concentrations of the cultivars disappeared in the second sampling times (Table 8). Salinity treatments increased the leaf N and P concentrations linearly in the first sampling time (Table 8).

Table 7. Interaction between sampling time and salinity in respect to leaf N (%) and P concentrations (%)

Plant Nutrients (%)	Sampling Time	Salinity (dS m^{-1})			
		Control	2.75	3.75	4.75
N	January	2.13*	2.10	2.19	2.31
	May	2.30	2.33	2.37	2.30
P	January	0.40	0.41	0.44	0.48
	May	0.20	0.22	0.20	0.21

Table 8. Orthogonal comparison of sampling time-salinity interaction in respect to leaf N (%) and P concentrations (%)

Sampling Time	Comparison	N	P
January	Control vs. other Treatments	ns	**
	Salinity-Linear	**	**
	Salinity-Quadratic	ns	ns
May	Control vs. other Treatments	ns	ns
	Salinity-Linear	ns	ns
	Salinity-Quadratic	ns	ns

** P ≤ 0.01, ns: nonsignificant

Interaction between the cultivar and sampling time for the leaf P concentration were given in Table 9. The leaf P concentrations of the cultivars decreased with time.

Table 9. Interaction between cultivar and sampling time in respect to leaf P concentrations (%)

Cultivar	Sampling Time	
	January	May
Camarosa	0.39*	0.20
Sweet Charlie	0.47	0.21

The effects of salinity on leaf Na, leaf Cl and root Cl concentrations, and their orthogonal comparisons were given in Table 10 and Table 11 respectively. The salinity treatments increased the concentrations of the related plant nutrients linearly.

Table 10. Effect of salinity on root Cl and leaf Na and Cl concentrations

Plant Nutrients (%)	Salinity (dS m^{-1})			
	Control	2.75	3.75	4.75
Leaf Na	0.01*	0.02	0.04	0.06
Leaf Cl	0.42	0.54	0.73	0.84
Root Cl	0.24	0.32	0.38	0.53

Table 11. Orthogonal comparison of salinity effect on root Cl, leaf Na and Cl concentrations

	Comparison of the nutrients in the leaves		Comparison of the nutrients in the roots
Interaction	Na	Cl	Cl
Control vs. other Treatments	**	**	**
Salinity-Linear	**	**	**
Salinity-Quadratic	ns	ns	ns

** P ≤ 0.01, ns: nonsignificant

Discussion

The results of the mineral analyses showed that the cultivars probably have different strategies in point of the organization of Na in plants. Compared to the Camarosa, the root Na concentrations of the Sweet Charlie were approx. 45% and 49% higher for the sampling times of the January and the May respectively (Table 2). But it has slightly lower leaf Na concentration than that of Camarosa (The data not shown). Probably Camarosa tended to limit the entry of Na into the roots while Sweet Charlie tended to prevent translocation of Na to the leaves. In other words, Sweet Charlie has low translocation potential or a feedback control, from demand by vegetative growth that regulates the uptake and translocation from root to aerial parts. According to Jacoby (1979), ions accumulate in the root or in the basal part of the shoot, from where return to the root system and excreted into the medium. The efficiency of these exclusion processes varies among soybean (Durand and Lacan 1994) and olive (Demiral, 2005) cultivars, and can be considered as one of the mechanisms for maintenance of low leaf-Na concentration in plants.

Salt-tolerant plants differ from salt-sensitive ones in having a low rate of Na and Cl transport to leaves (Munns, 2002). Ulrich et al. (1980) report Na toxicities with concentrations greater than 0.1% Na in strawberry. Although there were differences in the root and leaf concentrations of Na between the cultivars, the leaf Na content of the cultivars did not exceed 0.05% in the study. Hence, the cultivars showed similar response in this point.

Chloride should also be appreciated in determination of salinity resistance level of plants. This element is absorbed by cell membranes and translocated easily to the upper plant parts compared to Na. Therefore, its level is generally higher than that of Na in upper plant parts although it is a trace element (Marschner, 1995). In this study, the cultivars significantly differed in the concentrations of Cl in their tissues (Table 1). Compared to the Sweet Charlie, Cl concentrations of root and leaf of Camarosa were lower both in the January and in the May sampling (Figures 1,2). Hence Camarosa can be rated as more tolerant cultivar to Cl in soil solution or in irrigation water. According to Grieve et al. (2003), the salt tolerance of soybean is positively correlated with Cl exclusion from the leaves and salt-sensitive cultivars' leaves are severely injured due to Cl toxicity and contained 10–15 times more Cl than the tolerant Cl excluding varieties. As reported by Demiral et al. (2005), salt-sensitive barley cultivar Kaya accumulated more Cl in leaves than salt-tolerant barley cultivar Scarlet.

Strawberry plant is sensitive to high Cl contents in root area (Lieten, 1997). Leaf Cl contents higher than 0.5% causes necrosis in leaves and yield reduce for most of the strawberry cultivars (Ulrich et al., 1980). In the study, increase in duration of salinity led the cultivars to exceed this limit in the second sampling period. Lieten (1997) stated that leaf Cl content of cv. Elsanta does not exceed 0.5% and shows no any toxicity symptoms in leaves under salinity.

Compared to the Camarosa, the root N concentrations of Sweet Charlie were approx. 18% and 16% higher for the sampling times of the January and the May respectively (Table 2). This phenomenon probably deals with the higher tissue Cl concentrations of Sweet Charlie than that of Camarosa (Figures 1, 2). Inhibition of

NO_3^- translocation to the leaves by Cl^- would result in an accumulation of NO_3^- in the roots (Rubinigg et al., 2003). According to the authors there might be a negative effect of NaCl on the translocation of NO_3^- from root to the aerial parts of the plants. As reported by Köhler and Raschke (2000) the anion channels with similar permeability for both NO_3^- and Cl^- in xylem parencyhma cells play a significant role in the xylem loading of NO_3^- and Cl^-. In the presence of high Cl^- concentrations, root to aerial parts translocation of NO_3^- could therefore be decreased at the site of entrance into the xylem via competition for the same channel.

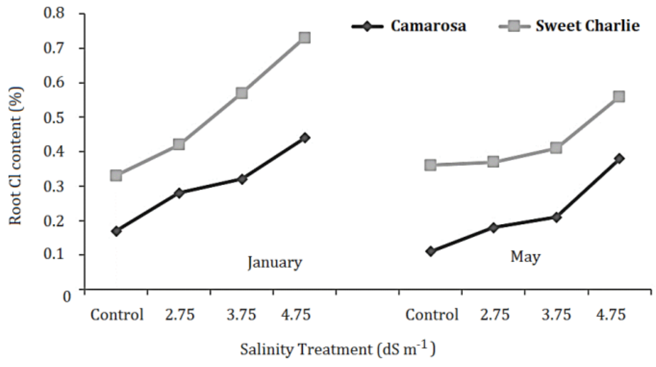

Figure 1. Variation in root Cl content of the cultivars under salinity in different sampling times

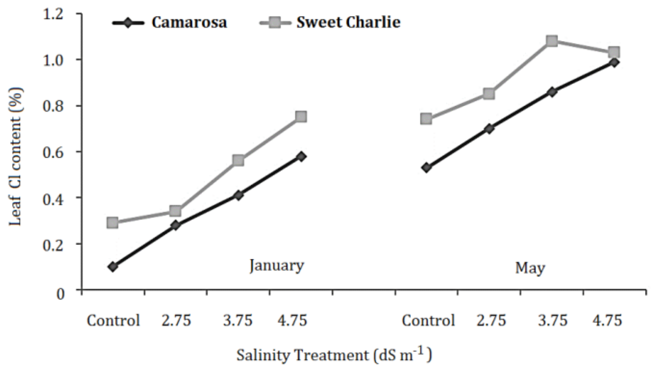

Figure 2. Variation in leaf Cl content of the cultivars under salinity in different sampling times

Another probable reason of high N concentration in plant tissues is increased synthesis of amino-N compounds as a plant response to salt stress. Probably increasing sensitivity of the plants to the salinity increased the synthesis of this kind of biochemical compounds in plants (Storey and Wyn-Jones, 1977). According to Loupassaki et al. (2002) salt sensitive olive cultivars have higher N concentration in their tissues. In the light of the data given above it can be concluded that Sweet Charlie is more salt sensitive cultivar than that of Camarosa and more salt sensitive plants have higher N concentrations in their roots than salt tolerant ones.

Salinity increased the N concentrations of the roots (Table 3). However this tendency disappeared in the second sampling time (Tables 3, 4). Compared to the sampling time of the January, the root N concentrations of the cultivars were approx. 47% lower in the sampling time of the May (Table 2). This might be a result of decreased NO_3^- influx under increasing Cl^- concentrations in plant tissues with time. According to Botella et al. (1994) Cl^- exerted a negative effect on NO_3^- uptake in *Triticum aestivum*, but could not specify whether the observed interaction was due to competitive inhibition or not.

The cultivars have lower concentrations of N in their leaves than that of their roots (Tables 2, 5). The lower N concentrations of the leaves of the plants could be the consequence of a generally lower rate of solute flow in the xylem as a result of a reduced transpiration rate for NO_3^- or amino acids, a lower requirement for NO_3^- in the aerial parts of the plants, or a decreased NO_3^- influx (Rubinigg et al., 2003). The concentrations of N of Sweet Charlie leaves significantly increased with the salinity (Table 5, 6). However this interaction was nonsignificant for Camarosa (Table 6). This result might be related to the different response of the cultivars to the salinity.

Compared to the sampling time of January, the N concentrations of the cultivars' leaves increased in the sampling time of May (Table 7). This might be related to the high amounts of the organic solutes synthesized under increased salinity stress resulted from increasing salinity level and salinity duration or a concentration effect due to growth depression. This tendency was significant in the January but in the May (Table 8).

The cultivars have more or less similar concentrations of P in their roots in the sampling time of January. However root P concentrations of the cultivars decreased significantly in the sampling time of May (Table 2). A similar tendency was also seen in the leaf P concentrations of the cultivars (Table 9).

Controversy, concerns about the effect of salinity on P concentrations of plants is reflected in the literature. Some researchers reported that salinity decreased P concentrations of plant tissues. According to Cangi and Tarakçıoğlu (2006) compared to control, 40 mM NaCl application decreased P in roots but increased in both leaves and shoots of kivifruit. Shibli et al. (2001) reported decreased of P in the shoots of *Saintpalia* *ionantha*. Our results disagree with the aforementioned reports. On the other hand the results of some other studies indicated that salinity may increase P concentrations of the plants (Navarro et al., 2001; Loupassaki et al., 2002). Keutgen and Pawelzik (2009) found increased concentrations of P in roots and petioles of salt stressed strawberry cultivars Korona and Elsanta. Our results confirmed this increase of root (Tables 3) and leaf P concentrations in both cultivars in the sampling time of January but in the sampling time of May (Table 7). Sweet Charlie has both higher concentration of Cl (Figure 1, 2) and higher concentration of P in its tissues than that of Camarosa (Tables 2 and 9). Salinity imposed by Cl salts stimulated P uptake in plants (Cerda et al., 1977; Kasırğa and Demiral, 2016) and such increase of P levels is not a result of concentration effect due to growth depression (Roberts et al., 1984). According to Furihata et al. (1992) plants have two different P uptake systems: one with a high affinity (uptake of P at low P concentrations) and one with a lower affinity (uptake of P at higher P concentrations). The low affinity system is considered constitutive (Dunlop et al., 1997) and its activity is connected with the existence of multiple transporters of P in the plasma membrane and tonoplast (Schachtman et al., 1998). The transporters are regulated by the external P concentration (Leggewie et al., 1997) and high cytosol pH (Martinez and Lauchli, 1994). Most likely salinity increased the P uptake of the experimental plants through low affinity system and the salt-induced alkalinization of cytosols contributed to the process.

In conclusion; the results of the study showed that the cultivars and sampling times affected N, P, Na and Cl concentrations of the plants significantly. Under increasing salinity Camarosa suppressed better the concentrations of Na and Cl of the plant tissues than that of Sweet Charlie. Therefore Camarosa is rated as more tolerant cultivar to Na^+ and Cl^- ions in soil solution or in irrigation water. The effects of increasing salinity on plant nutrients tested have lost its significance over time. This is probably related to the increasing damage constituted by the extended stress to the plant metabolism. The cultivars showed different responses in terms of N and P contents under increasing salinity. Sweet Charlie had higher N concentrations in their tissues than that of the Camarosa. This reaction is evaluated as a sign of higher sensibility to salt stress. Salinity increased the P concentrations of the experimental plants and the cultivars had more or less similar concentrations of P in their tissues under salinity. This tendency is attributed to the changes in P uptake system of the plants that arising from the salinity.

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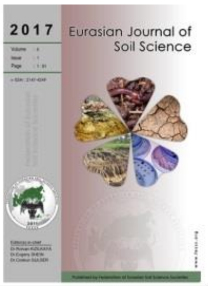

Prediction of soil organic carbon using VIS-NIR spectroscopy: Application to Red Mediterranean soils from Croatia

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Abstract

The objectives of this research were: (i) to assess the accuracy of diffuse reflectance spectroscopy (DRS) in predicting the soil organic carbon (SOC) content, and (ii) determine the importance of wavelength ranges and specific wavelengths in the SOC prediction model. The reflectance spectra of a total of 424 topsoils (0-25 cm) samples were measured in a laboratory using a portable Terra Spec 4 Hi-Res Mineral Spectrometer with a wavelength range 350-2500 nm. Partial least squares regression (PLSR) with leave-one-out cross validation was used to develop calibration models for SOC prediction. The accuracy of the estimate determined by the coefficient of determination (R^2), the concordance correlation coefficient (ρc), the ratio of performance to deviation (RPD), the range error ratio (RER) and the root mean square error (RMSE) values of 0.83, 0.90, 2.42, 15.1 and 2.47 g C kg^{-1} respectively, indicated successful model for SOC prediction. The near infrared (NIR) and the short-wave infrared (SWIR) spectrums were more accurate than those in the visible (VIS) and short-wave near-infrared (SWNIR) spectral regions. The wavelengths contributing most to the prediction of SOC were at: 1925, 1915, 2170, 2315, 1875, 2260, 1910, 2380, 435, 1960, 2200, 1050, 1420, 1425 and 500 nm. This study has shown that VIS-NIR reflectance spectroscopy can be used as a rapid method for determining organic carbon content in the Red Mediterranean soils that can be sufficient for a rough screening.

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Introduction

Soil organic carbon content (SOC) is a fundamental constituent of the soil. It governs physical, chemical and biological processes in soils. The decline of SOC content in soils is one of the main threats for soil degradation. There is an increasing interest for large amounts of the accurate SOC data to be used in protection and enhancement of the global environment, soil quality assessment and precision agriculture.

In last few decades diffuse reflectance spectroscopy (DRS) due to its cost-efficiency, ease of handling, rapidity, minimal sample preparation and the development of chemometrics is being considered as a possible alternative to the conventional soil laboratory analyses. The visible-near-infrared (VIS-NIR) spectroscopy provides a large number of information on the organic and inorganic soil components. Absorption in the visible range provides a measure of soil colour, organic matter (Ben-Dor et al., 1999) and Fe minerals, mainly haematite and goethite (Sherman and Waite, 1985). The near-infrared (NIR) portions of the electromagnetic spectrum are associated with the stretching and bending of NH, OH and CH groups (Dalal and Henry, 1986; Clark, 1999; Viscarra Rossel and Behrens, 2010).

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Published data pointed out that different spectral ranges and wavelengths can be responsible for the prediction of the SOC content (Brown et al., 2006; Viscarra Rossel et al., 2006a; Viscarra Rossel and Behrens, 2010). Sudduth and Hummel (1991) reported that near-infrared (NIR) reflectance data provided considerably better predictions of soil organic matter content than visible (VIS). Islam et al. (2003) evaluated the ability of reflectance spectroscopy in the UV, VIS, and NIR ranges to predict several soil properties. They demonstrated that the overall prediction of SOC was better with the whole spectral range (VIS-NIR) than NIR or VIS. Several studies have examined the question of the spectral ranges most suitable for predicting SOC concentration, considering the VIS, VIS-NIR, NIR and mid-infrared (MIR) (Viscarra Rossel et al., 2006b). They indicated that the MIR was more suitable than the NIR or VIS, but also noted that the MIR spectroscopy is more expensive and complex than VIS-NIR measurement.

The contribution of each wavelength of the VIS-NIR reflectance spectra for the SOC prediction was the subject of numerous studies (Ben-Dor and Banin, 1995; Dalal and Henry, 1986; Chang and Laird, 2002; Lee et al., 2009; Stenberg et al., 2010; Sarkhot et al., 2011; Xu et al. 2016). They have identified different wavelengths as important for estimation of SOC.

Numerous studies used VIS-NIR spectroscopy to analyse SOC content on the global (Brown et al., 2006; Viscarra Rossel et al., 2016), continental (Stevens et al., 2013), national (Vasquez et al., 2010; Knadel et al., 2012; Shi et al., 2015; Wijewardane et al., 2016), regional (Ben-Dor and Banin, 1995; Islam et al. 2003; Lee et al., 2009; Summers et al., 2011; Sarkhot et al., 2011; Leone et al., 2012; Shi et al., 2015) and local/field scales Kuang and Mouazen, 2012; Wetterlind et al., 2010; Fontán et al., 2011). The most studies were conducted on the heterogeneous sets of soil samples with respect its geographical origin and varying of soil forming factors (Climate, Organisms, Topography, Parent material and Time). The exposed literature sources showed that the estimates of the SOC have been validated with a substantial range of the accuracy. The possible factors of the relatively large differences in the accuracy of the SOC estimation related with a number of factors (high SOC variability, the heterogeneity of soil types and parent material, land uses and size of the sampling area). Numerous studies have shown that geographically closer and more homogeneous sample sets with similar characteristics resulted in the improved SOC prediction models (Vasques et al., 2010, Wijewardane et al., 2016).

In this context, we decided to explore the accuracy of VIS-NIR spectroscopy for prediction of SOC content using soil samples that are similar with respect to soil types, parent materials and land use. We have chosen Red Mediterranean soils from Dalmatia, Croatia on limestones and dolomites used in agricultural production. The objectives of this work were (i) to assess the accuracy of the diffuse reflectance spectroscopy and PLSR for the SOC measurement and (ii) to determine the importance of different VIS-NIR spectral ranges and the wavelengths for the estimating SOC content.

Material and Methods

Study area and soil data

In our analyses, we used the SOC content data and soil spectra for a total of 424 topsoil samples selected from a Spectral library of soils from Dalmatia (Miloš, 2013). Dalmatia occupies the middle part of the Adriatic coastal zone of Croatia. The SOC content was determined using the Kotzman method (JDPZ, 1966). Selected data belong to soils with a characteristic reddish-brown to red colour what is commonly referred to as a Red Mediterranean soil or Terra Rossa on hard limestone and dolomites. According to the Croatian soil classification system, these soils belong to the class of Cambic soils. The World Reference Base for soil resources (FAO, 2014) equivalents is Chromic Cambisols and Rhodic Cambisols. The climate of the study area is Mediterranean, with dry, hot summers and mild, moderately rainy winters. Agricultural areas of this typical karst environment consists a large number of dislocated smaller areas and parcels of olive groves, vineyards, fruit orchards and abandoned agricultural land.

Spectra measurements and data pre-processing

The reflectance spectra of soil samples were measured in a laboratory using a portable Terra Spec 4 Hi-Res Mineral Spectrometer with a wavelength range 350-2500 nm. Soil samples were air-dried and sieved through 2 mm sieve. The correction with a standardised white Spectralon® panel (Analytical Spectral Devices, Boulder, CO, USA) with 100% reflectance was made prior to the first scan and after every ten samples. All spectra were recorded at 1 nm data spacing interval over the wavelength range of 400-2500 nm. Pre-processing method: first derivative with Savitzky-Golay smoothing (Savitzky and Golay, 1964), with a second order polynomial fit. The spectral range of the soil spectra was first reduced to 400 - 2490 nm to eliminate the noise at the edges of each spectrum. Spectral shortening was followed by averaging of the adjacent 5 nm wavelength. Thus, the total number of wavelengths for VIS-NIR modelling were 419 wavelengths.

Model Calibration and Validation

We used the partial least squares regressions (PLSR) with leave-one-out cross-validation method for calibrating the spectral data with the reference data and SOC model construction. For more details on the PLSR see e.g. Martens and Naes (1989) and Wold et al. (2001). Leave-one-out cross-validation method (Efron and Tibshirani, 1994) we used to determine the optimal number of the factors to retain in the calibration model. The regression coefficients for each of the 419 wavelengths in the range of 400 to 2490 nm were calculated. The best SOC model was generated when the PLS analyses were run using only significant wavelengths ($p<0.05$) identified with Marten's uncertainty test.

Model Performance Evaluation

Predictive performances of the SOC model were evaluated by calculating the root mean square error (RMSEP) of prediction, the ratio of performance to deviation (RPD), range error ratio (RER) the coefficient of determination (R^2) and the concordance correlation coefficient (ρc). RMSEP is defined as the square root of the average of squared differences between predicted and measured Y values of the validation objects and evaluated by Equation (1):

$$\text{RMSEP} = \sqrt{\sum_{i=1}^{N} \frac{(\hat{y}_i - y_i)^2}{N}} \qquad \text{Eq. (1)}$$

where y_i and $\hat{y}_i$ are the measured and predicted values of sample *i*, respectively, and *N* is the number of samples.

The RPD was initially used by Williams (1987) for assessing the goodness of fit for NIR calibrations. The RPD represents the division between the reference data standard deviation and the standard error of the prediction and deduced with Equation (2):

$$\text{RPD} = {}^{\text{SD}}/_{\text{SEP}} \qquad \text{Eq. (2)}$$

where SD is the standard deviation of the validation dataset and SEP (Equation 3), which is standard error of prediction. SEP is the RMSEP corrected for bias (Equation 3). Bias is the average value of the difference between predicted and measured values (Equation 4).

$$\text{SEP} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i - Bias)^2} \qquad \text{Eq. (3)}$$

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i) \qquad \text{Eq. (4)}$$

To interpret the RPD values we adopted the six level interpretations given by Viscarra Rossel et al. (2006b) as follows: RPD<1.0 indicate very poor model/predictions and their use is not recommended; RPD between 1.0 and 1.4 indicate poor model/predictions where only high and low values are distinguishable; RPD between 1.4 and 1.8 indicate fair model/predictions which may be used for assessment and correlation; RPD values between 1.8 and 2.0 indicate good model/predictions where quantitative predictions are possible; RPD between 2.0 and 2.5 indicate very good, quantitative model/predictions and RPD>2.5 indicate excellent model/predictions.

Range Error Ratio (RER, Equation 5) is the ratio of the range of the reference data to the SE in the validation set (Starr et al., 1981).

$$\text{RER} = \frac{\text{Max} - \text{Min}}{\text{SEP}} \qquad \text{Eq. (5)}$$

In Equation 5, Max and Min are the maximum and the minimum values observed in the reference data. The RPD and RER are dimensionless statistics, meaning they can be compared on the same basis between different models. The RER values we interpreted according to the thresholds given by Malley et al. (2004) as follows: RER>20 indicate excellent prediction model; 15≤ RER ≤20 successful; 10≤ RER <15 moderately successful and 8≤ RER <10 indicate moderately useful prediction model.

To interpret the predictive performances of the SOC models calculated by the coefficient of determination (R^2) we adopted threshold values given by Saeys et al. (2005) as follows: a value for R^2 between 0.66 and 0.80 indicates approximate quantitative predictions, R^2 between 0.81 and 0.90 reveals good prediction and R^2 >0.90 is considered to be an excellent prediction. The concordance correlation coefficient (ρc) was proposed by Lin (1989) for assessment of concordance (agreement) between two measures of the continuous data. Like a correlation, Lin's concordance correlation coefficient (ρc) ranges from -1 to 1, where a value of 1 denotes perfect agreement; values >0.90 suggest excellent agreement; values between 0.80 and 0.90 substantial agreement; between 0.65 and 0.80 moderate agreement and values <0.65 poor agreement.

Results and Discussion

The soil organic carbon statistics and soil spectral properties

The descriptive statistics of the soil organic carbon content analysed using conventional laboratory method analysis (reference dataset), and their calibration and cross-validated PLSR predictions for the four spectral regions: VIS (400-700 nm), NIR (700-2490 nm), SWNIR (700-1100 nm), SWIR (1100-2490 nm) and combined VIS-NIR (400-2490 nm) is given in Table 1. The SOC content for the reference dataset varies from 0.81 to 37.87 g C kg^{-1} with an average value of 21.35 g C kg^{-1} (Table 1).

Table 1. Statistical description of the soil organic carbon content (g kg^{-1}) for the reference, calibration and validation datasets for different spectral ranges

Statistics	Reference	Calibration	Validation				
		VIS-NIR	VIS-NIR	NIR	VIS	SWIR	SWNIR
Mean	21.35	21.35	21.36	21.37	21.36	21.37	21.36
Minimum	0.81	0.36	0.25	0.32	0.05	0.25	0.02
Maximum	37.87	35.35	35.28	33.84	31.11	33.51	29.04
Range	37.06	34.99	35.03	33.52	31.06	33.25	28.92
Std.Dev.	5.96	5.52	5.47	5.19	4.37	5.12	4.12
Skewness	-0.55	-0.79	-0.81	-0.84	-1.19	-0.86	-1.51

VIS-NIR – visible and near infrared range (400-2490 nm); NIR – near infrared range (700-2490 nm); VIS – visible range (400-700 nm); SWIR - shortwave infrared range (1100-2490 nm); SWNIR – shortwave near infrared range (700-1100 nm)

The negatively skewed distribution for the reference, calibration and VIS-NIR, NIR and SWIR validation dataset indicate a slightly asymmetrical distribution with a long tail to the left. The skewness for the validation VIS and SWNIR spectral regions are less than -1.0 and indicate substantial skewness and the distribution is far from symmetrical.

Figure 1 and 2 show mean reflectance spectra and mean first-derivative reflectance spectra of the soil samples that were used to develop PLSR calibration model. The shape of the overall reflectance spectra (Figure 1) shows a typical soil spectrum characterised with reflectance increasing with increasing wavelength in the visible range (400–700 nm) and does not contain distinct or sharp peaks that can be directly associated with specific constituents. In the visible range, the mean first-derivative of the SOC reflectance spectra (Figure 2) shows two obvious adsorption bands near 430 and 565 nm which can be attributed to the presence of the chromophorous constituents, mainly iron oxide (Ben-Dor et al., 1999). The mean reflectance spectra (Figure 1), as well as mean first-derivative spectra (Figure 2), show a weak concave shape at the wavelengths around 800-970 nm. This concavity can be attributed mainly to increased iron oxide content since the soil samples contain a low content organic matter which can mask the effect of Fe (Demattê et al., 2004).

Furthermore, soil mean reflectance and first-derivative spectra (Figure 1 and Figure 2) show several important absorptions around 1400, 1900, and 2200 nm. In addition to this, first-derivative spectra shows strong adsorption around 2400 nm (Figure 2). These absorptions can be attributed to water molecule vibrations and OH^- groups (1400 nm), water (1900 nm) and mineral influences (2200 nm and 2400 nm).

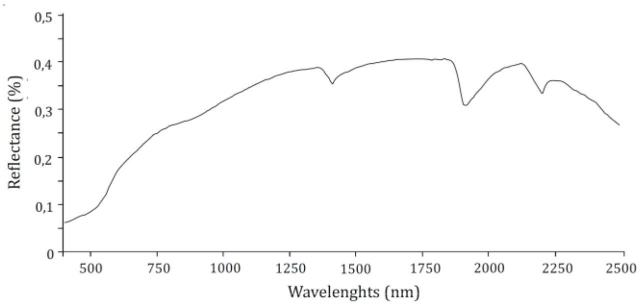

Figure 1. The mean reflectance spectra for 424 soil samples

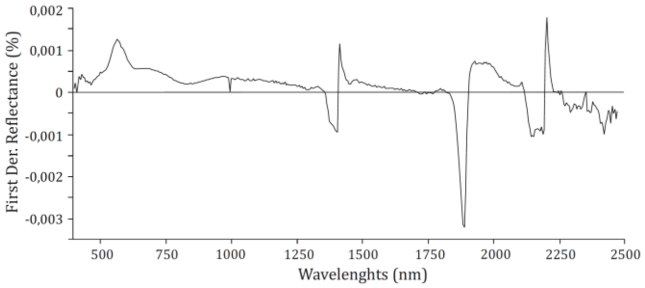

Figure 2. The mean first-derivative spectra for 424 soil samples

Performance assessment of calibration and validation models

Statistical description of the PLSR calibrated and their cross-validated PLSR SOC predictions for different spectral ranges is given in Table 2. The best SOC prediction model for the each spectral range was generated when the PLSR analyses included five factors. The PLSR SOC model with the lowest RMSEP and highest R^2, ρc, RPD and RER is considered as the best model. The best prediction for SOC was obtained from the VIS-NIR spectra with validation R^2, ρc, RPD, RER and RMSEP values of 0.83, 0.90, 2.42, 15.1 and 2.47 g C kg^{-1} respectively.

Table 2. Calibration and validation results of the SOC models diagnostics for the different spectral ranges and combined VIS-NIR spectral range

Spectral	Calibration		Validation						
range	RMSEC	R^2	RMSEP	Bias	SEP	R^2	ρc	RPD	RER
VIS-NIR	2.18	0.88	2.47	-0.01	2.46	0.83	0.90	2.42	15.1
NIR	2.70	0.84	2.99	0.02	3.01	0.75	0.86	1.98	12.2
SWIR	2.96	0.75	3.24	-0.01	3.23	0.70	0.83	1.84	11.3
VIS	4.11	0.52	4.53	-0.01	4.52	0.42	0.61	1.32	8.07
SWNIR	4.23	0.49	4.50	0.01	4.51	0.46	0.61	1.32	8.12

RMSEC - root mean square error of calibration; R^2 - coefficient of determination; RMSEP - root mean square error of prediction; SEP – standard error of prediction, ρc - concordance correlation coefficient; RPD - ratio of performance to deviation; RER - range error ratio

According to threshold values for the coefficient of determination (R^2) given by Saeys et al. (2005) R^2 values of the SOC validation models for the spectral ranges (Table 2) can be interpreted as follows: the SOC model developed using the VIS-NIR spectral range reveals good prediction; NIR and SWIR region indicate approximate quantitative predictions until the calibrations for VIS and SWNIR region are only able to discriminate between high and low SOC values.

Lin's ρc values of the SOC validation models for the VIS-NIR range (Table 2) suggests good agreement; the NIR and SWIR region denote substantial agreement and VIS and SWNIR region suggest a poor agreement between reference data and the cross-validated SOC values.

According to the stated interpretation given by Viscarra Rossel et al. (2006b), follows that the VIS-NIR spectral range with the RPD value of 2.42 (Table 2) indicates very good quantitative model for the SOC prediction; NIR and SWIR regions with the RPD values between 1.8 and 2.0 indicate good prediction model and VIS and SWNIR regions with values of the RPD between 1.0 and 1.4 indicate poor SOC prediction model.

The RER values for different spectral ranges (Table 2) we interpreted according to the thresholds given by Malley et al. (2004) as follows: the SOC model created using VIS-NIR range (15≤ RER ≤20) indicates successful prediction; the NIR and SWIR spectral range with 10≤ RER <15 indicate moderately successful model and model created using the VIS and SWNIR region (8≤ RER <10) indicates moderately useful prediction.

The RMSEP is the most efficient measure of the average uncertainty in spectral predictions that can be expected for future predicting new samples. The future predictions of the samples in the test set can be considered that 2 times RMSEP represents a 95% confidence interval for the real values. Since RMSEP values for the SOC predicted models (Table 2) ranged from 2.47 g C kg^{-1} (VIS-NIR) to 4.53 g C kg^{-1} (VIS) with its mean value of 21.36 g C kg^{-1} (Table 1), then there is a 95% chance that the mean value of the SOC content, as measured in laboratory, lies between 16.42 to 26.30 g C kg^{-1} and 12.30 to 30.42 g C kg^{-1} respectively.

The predictive performance of the SOC prediction model in this study (Table 2) is a similar accuracy as those obtained by Gras et al. (2014), Wijewardane et al. (2016) and Knadel et al. (2012) who achieved similar R^2 values of 0.82, 0.83 and 0.81 and RPD of 2.40, 2.41 and 2.40, respectively. Some authors (Brown et al., 2006; Chang and Laird, 2002 and Viscarra Rossel et al., 2016) reported the higher accuracy of SOC prediction models than our with R^2 values of 0.87, 0.89 and 089, respectively. Leone et al. (2012) obtained a high accuracy (R^2 0.84-0.93 and 2.36-2.53 RPD) for local SOC predictive models in the soils of southern Italy. Study of Kuang and Mouazen (2012) at the farm-scale in four different European countries showed a very wide range of R^2 and RPD, 0.12-0.96 and 1.07-4.95, respectively. Wetterlind et al. (2010) reported a very good prediction of SOM (R^2 = 0.89, RMSE = 4.70 g kg^{-1} and RPD= 3.0) achieved for a farm-scale calibration model using only 25 soil samples. However, numerous studies achieved a less predictive capacity of SOC models than our e.g. Gao et al. (2014), Shi et al. (2015), Summers et al. (2011) and Fontán et al. (2011). In the mentioned studies R^2 ranged from 0.55 to 0.79 and RPD from 1.80 to 2.01. The exposed large differences in the accuracy of the SOC estimates related with a number of factors (high SOC variability, the heterogeneity of soil types and parent material, land uses and size of the sampling area) and it cannot be easily identified.

In general, all parameters of cross-validated predictions diagnostic (R^2, Lin's ρc, RPD, RER and RMSP) given in Table 2, showed that the SOC prediction model created using combined VIS-NIR spectra provides the most accurate predictions. So, the NIR and the short-wave infrared (SWIR) spectrum predictions were more accurate than those in the VIS and short-wave near-infrared (SWNIR) spectral region. Exposed is in accordance with previous findings, e.g. Sudduth and Hummel (1991) who reported that NIR reflectance data provided considerably better predictions of soil organic matter content than those in the visible range. Islam et al. (2003) demonstrated that the overall prediction of SOC was better with the whole VIS-NIR spectral range than in the NIR.

Identification of the important wavelengths for the SOC prediction

The contribution of each wavelength of the VIS-NIR spectral range for the SOC prediction model, marked with PLSR regression coefficient, is shown in Figure 3. The best SOC prediction model included only those wavelengths for which Marten's test of uncertainty showed that significantly contribute (p < 0.01) to the prediction. Figure 3 illustrates that the final SOC model retained a very large number of wavelengths (total number of selected wavelengths were 176) and that the significant wavelengths with large regression coefficients were observed throughout the spectrum.

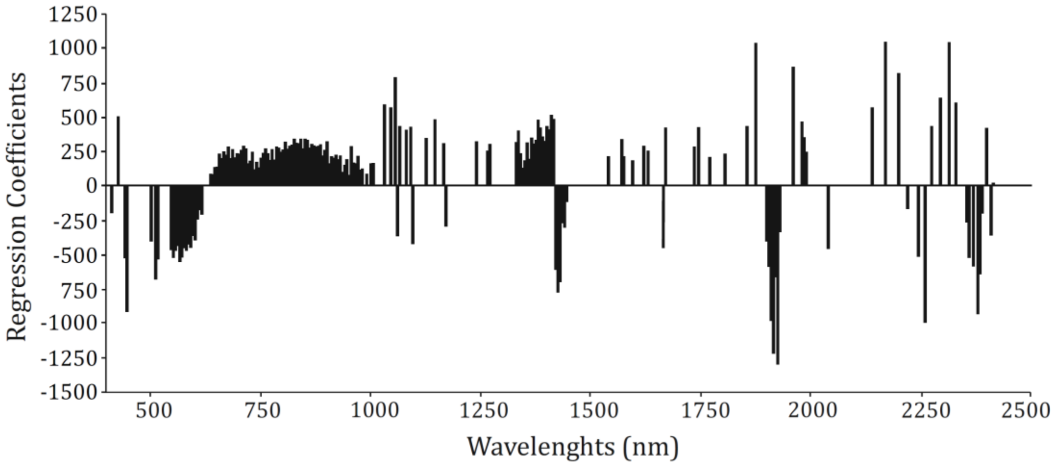

Figure 3. Regression coefficients of the wavelengths retained as a significant (p < 0.01) in the final a fifth-component SOC prediction model for VIS-NIR range

In the visible range the significant wavelengths with the maximum regression coefficients of the SOC prediction model were observed as individual peaks at 430 and 435 nm and a broad spectral range from 500 to 590 nm, with maximum peaks at 500 and 555 nm (Figure 3). In the SWNIR (700-1100 nm) spectral region there is noticeable a broad region around 800 nm with a maximum contribution at 815, 830 and 840 nm. Wavelengths in these spectral regions associated with the chromophorous constituents - iron oxides – mainly haematite and goethite (Sherman and Waite, 1985) and organic matter (Ben-Dor et al., 1999). The highest correlation coefficients were observed in the short-wave infrared (SWIR, 1100-2500 nm) region (Figure 3). This spectral region is characterised with featured absorption bands around 1400 (max. peak at 1420 nm), 1900 (max. peak at 1925 nm), 2200 and 2300 nm due to OH^- and water (1400 nm and 1900 nm) and mineral influences (2200 and 2300 nm). These absorption bands associated also with the overtones and combination absorptions of C–H, O–H, S–H, C=O, and N–H (Dalal and Henry, 1986; Clark, 1999; Viscarra Rossel and Behrens, 2010) and consequently contain information about the concentration of the organic composition of the scanned soil sample. The high contributing wavelengths of the water adsorption features are consistent with research findings by Viscarra Rossel et al. (2006a) and Sarkhot et al. (2011). The wavelengths contributing most to the SOC prediction model are found around 2200 nm (max. peak at 2170 nm) and around 2300 nm (max. peaks at 2315 and 2380) due to Al–OH bend plus O–H stretch combinations, that are diagnostic absorption features in clay mineral identification (Clark et al., 1990). Many other authors (Ben-Dor and Banin, 1995; Dalal and Henry, 1986; Stenberg et al. (2010) and Viscarra Rossel and Behrens (2010) have also identified the bands around 2200 and 2300 nm as being important for SOC calibration.

Ordering 15 wavelengths with the highest regression coefficients in the final a fifth-component SOC model for VIS-NIR range were: 1925, 1915, 2170, 2315, 1875, 2260, 1910, 2380, 435, 1960, 2200, 1050, 1420, 1425 and 500 nm. This is consistent with other research findings. For example, Lee et al. (2009) reported 450–465, 965, 1409, and 1775–2200 nm as important wavelengths for soil organic carbon prediction. Sarkhot et al. (2011) observed the significant wavelengths throughout the spectrum, while the magnitude of PLSR coefficients was higher in the region 400, 1400, 1900 and 2200 or 2300 nm. Chang and Laird (2002) reported that the wavelengths important for organic carbon were in the range between 1770 nm to 2500 nm. This study showed that twelve of the fifteen most significant wavelengths were greater than 1100 nm. The advantage of the wavelengths above 1100 nm is that they are uncorrelated with Fe- oxides that reduced the collinearity problem with organic matter. This is consistent with previous research (Ben-Dor and Banin, 1995; Dalal and Henry, 1986; Stenberg et al., 2010; Xu et al., 2016) which have identified wavelengths around 1100, 1600, 1700 to 1800, 2000, and 2200 to 2400 nm as being particularly important for SOC calibration.

As conclusions, (i) all parameters of cross-validated predictions diagnostic R^2, Lin's ρc, RPD, RER and RMSEP with values of 0.83, 0.90, 2.42, 15.1 and 2.47 g C kg^{-1} respectively indicated successful model for predicting of the organic carbon in Red Mediterranean soil, (ii) the SOC prediction model created using combined VIS-NIR spectra provided the most accurate SOC predictions, (iii) the NIR and the short-wave infrared (SWIR) spectrum predictions were more accurate than those in the VIS and short-wave near-infrared (SWNIR) spectral region and (iv) the wavelengths contributing most to the prediction of SOC content were at 1925, 1915, 2170, 2315, 1875, 2260, 1910, 2380, 435, 1960, 2200, 1050, 1420, 1425 and 500 nm. Taking into account the predictive statistics and accuracy of created model, it can be sufficient for rapid and a rough screening of the organic carbon in Red Mediterranean soils.

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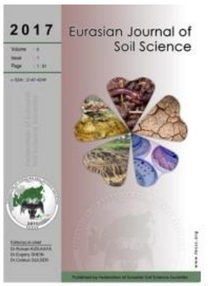

Effect of different irrigation systems on root growth of maize and cowpea plants in sandy soil

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Abstract

A field experiment was conducted at the Experimental Farm, Faculty of Agriculture, Suez Canal University to study the influence of different irrigation systems on root length density and specific root length of maize and cowpea plants cultivated in sandy soil. Three irrigation systems (Surface, drip and sprinkler irrigation) were used in this study. The NPK fertilizers were applied as recommended doses for maize and cowpea. Root samples were collected from the soil profile below one plant (maize and cowpea) which was irrigated by the three irrigation systems by using an iron box (30 cm × 20 cm) which is divided into 24 small boxes each box is (5 × 5 × 5 cm). At surface irrigation, root length density of cowpea reached to soil depth 30-40cm with lateral distances 5-10 cm and 15-20 cm. Vertical distribution of root length density of maize was increased with soil depth till 20-25 cm, and then it decreased till soil depth 35-40cm. Under drip irrigation, root length density of cowpea increased horizontally from 0-5cm to 10-15cm then it decreased till soil depth 25-30 cm and below this depth root length density disappeared. For the root length density and specific root length of maize under drip irrigation, the data showed that root length density and specific root length decreased with increasing in soil depth. The root length density of cowpea under sprinkler irrigation at 0-5cm disappeared from horizontal distance at 25-30 cm. The data showed that root length density of maize under sprinkler irrigation was higher at the soil top layers 0-5 cm and 5-10 cm than other layers from 10-40 cm.

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Introduction

Plant root systems are responsible for plant growth, absorption of water, and nutrients uptake (Lynch, 1995). The root system must adapt to nutrient availability, lack and excess of moisture, and wind shear on the shoot, along with other abiotic factors such as soil compaction and texture. The impact of biotic factors on root systems includes insect pests, diseases, nematodes, weeds, and competition due to high planting densities. Deep rooting is particularly beneficial for allowing water uptake from great soil depths during the drought times (Gaiser et al., 2012). The crop response to water system strategies was different (Lu et al., 2001), and the effect of irrigation on the plant root systems is also different from one irrigation system to another because of differences in soil water regimes. It has been proven that for crop growth, the earlier the irrigation water was applied, the better the root system grew (Carefoot and Major, 1994). Machado et al., (2003) reported that the distribution of water within the soil profile as a result of the level of irrigation affects the development of horizontal and vertical root growth as well as transportation and uptake of nutrients by plant roots in the soil. Similar finding was reported by (Sperry et al., 2002; Song and Li, 2006; Hu et al., 2009).

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Lü et al. (2015) studied the effect of different irrigation methods on root distribution in winter wheat fields. They found that more fine roots were produced in the border irrigation treatment when soil water content was low and topsoil bulk density was high. Root growth restrained in the deep layers in the surface drip irrigation treatment, followed by sprinkler irrigation and border irrigation, which was due to the different water application frequencies. The aim of this research is to study the root length density and specific root length of two crops under different irrigation methods in sandy soil.

Material and Methods

This study was conducted in the experimental site of Agricultural College of Suez Canal University during the summer season in 2015. The soil of the experimental site was sandy in texture, very low in organic matter (0.3%) with pH (7.2) and EC (2.4 dSm^{-1}) as showen at Table 1. The available N, P and K were 35, 7, 70 mg/kg, respectively before the initiation of the experiment according to Page et al. (1982). At summer season, the maize *(Zea mays)* and cowpea *(Vigna unguiculata)* seeds were sowed at the field on 21 May 2015, with the spacing of 30 cm between the rows and 30 cm between plants in a row and irrigated by surface, drip and sprinkler irrigation systems. The level of fertilizers adopted in the study were 47.6 kg N ha^{-1}, 47.6 kg P_2O_5 ha^{-1} and 71.4 kg K_2O ha^{-1} for cowpea plants and 333 kgN ha^{-1}, 71.4 kg P_2O_5 ha^{-1} and 71.4 kg K_2O ha^{-1} for maize plants. The recommended fertilizers which were used in the experiment with the two plants were ammonium nitrate, potassium sulphate and diammonium phosphate. All fertilizers were incorporated into the soil at a depth of 10 cm.

Table 1. Properties of the soil of the experimental site

Texture	Clay, %	2.00			
	Silt, %	3.50			
	Sand, %	94.50			
Chemical property	pH, 1:2.5, w/v	7.20	Soil nutrients, mg kg^{-1}	Available N	35.00
	EC, dSm^{-1}	2.40		Available P	7.00
	Organic matter, %	0.30		Available K	70.00
Soluble cations, mmol$_c$L^{-1}	Ca^{2+}	5.25	Soluble anions, mmol$_c$L^{-1}	CO_3^{2-}	<0.01
	Mg^{2+}	4.00		HCO_3^-	5.00
	Na^+	4.00		Cl^-	10.50
	K^+	2.00		SO_4^{2-}	4.50

Root samples were collected from the soil profile below one plant (maize and cowpea) which was irrigated by the three irrigation systems by using an iron box (30 cm × 20 cm) which is divided into 24 small boxes each box is (5 × 5 × 5 cm) as shown at Figure 1. This iron box which has a sharp edge is pressed horizontally in soil profile to depth of 40cm as shown at Figure 2. To separate roots from soil of each small box, the samples were poured through a sieve 0.2mm. Similar method was carried out (Gao et al., 2010)

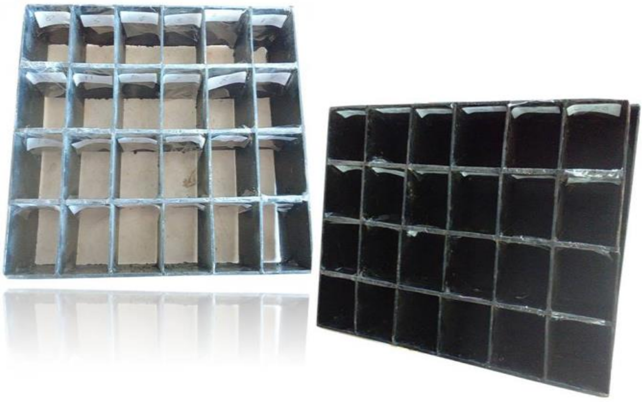

Figure 1. Iron box divided into 24 small boxes; each of them is (5× 5× 5 cm)

Figure 2. The iron box which has a sharp edge is pressed horizontally in the soil profile

Some parameters of root distribution were calculated such as root length was measured by the formula that was simplified and adjusted by Tennant (1976) as following:

$$\text{Root length (R)} = \frac{11}{14} \text{ x Number of intersections (N) x Grid unit.}$$

Root length density (RLD) was calculated with the equation of Fageria et al. (2006)

$$\text{Root Length density (cm cm}^{-3}\text{)} = \frac{\text{Root length in cm}}{\text{Soil volume where roots have been collected cm}^3}$$

Specific root length (SRL) has been widely used as an indicator for the root morphology indicator. It could be calculated with the equation of Zobel (2005)

$$\text{Specific Root Length (cm g}^{-1}\text{ root dry weight)} = \frac{\text{Root Length (cm)}}{\text{Root dry weight (g)}}$$

Results and Discussion

At surface irrigation, water moves with soil gravity so that roots penetrated soil profile to deep depths to uptake available soil water. With respect to this concept, root length density of cowpea reached to soil 30-40 cm with lateral distances 5-10 cm and 15-20 cm as illustrated at Table 2. Root length density decreased with increasing in soil depth. At 10-15 cm, the root length density was 1.51 cm.cm^{-3}at 0-5 cm and decreased to 0.5 cm.cm^{-3}at soil depth 35-40 cm. The lowest root length density was 40 cm.cm^{-3} at soil depth 35-40 cm with lateral distance 5-10 cm. At horizontal distance 25-30 cm, root length density is disappeared.

Table 2. Distribution of root length density (RLD) and specific root length (SRL) of cowpea along soil profile under surface irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	9.81	0.63	21.59	1.38	23.50	1.51	19.63	1.26	15.70	1.00	-	-
5-10	9.36	0.60	13.74	0.88	15.00	0.96	12.76	0.82	14.72	0.94	-	-
10-15	8.75	0.56	11.88	0.76	14.72	0.94	12.50	0.80	13.74	0.88	-	-
15-20	15.70	1.00	13.74	0.88	14.00	0.90	11.88	0.76	13.74	0.88	-	-
20-25	8.13	0.52	11.25	0.72	12.50	0.80	11.50	0.74	12.76	0.82	-	-
25-30	7.50	0.48	10.88	0.70	11.36	0.74	11.00	0.70	11.87	0.75	-	-
30-35	6.25	0.40	9.50	0.61	10.00	0.64	8.30	0.54	11.25	0.72	-	-
35-40	-	-	7.50	0.48	8.00	0.50	6.25	0.40	-	-	-	-

With regard to root distribution of maize, the data at Table 3 showed that root length density and specific root length was higher at soil depth 20-25 cm at all horizontal distances. Vertical distribution of root length density of maize was increased with soil depth till 20-25 cm, and then it decreased till soil depth 35-40 cm. At horizontal distance 10-15 cm and 15-20 cm, the root length density recorded the highest values among the other distance where the maize plant was located at these distances then root length density decreased with the increase in horizontal distance. At horizontal distance 10-15 cm, the root length density of maize increased up to soil depth 30-35 cm. In general, root length density of maize and cowpea decreased with increased with soil depth. Similar findings were obtained by Raj et al. (2013) reported that under surface irrigation, maize roots increased with soil depth to uptake more water, this is because of the depletion of moisture below the root zone and the plants had to extract water from deeper layers.

Table 3. Distribution of root length density (RLD) and specific root length (SRL) of maize along soil profile under surface irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	1.51	8.02	0.75	4.01	1.07	5.68	2.51	13.36	1.16	6.15	1.26	6.68
5-10	1.00	5.34	0.69	3.67	0.88	4.68	2.64	14.03	0.73	3.87	0.75	4.01
10-15	0.98	5.21	0.94	5.01	1.63	8.69	1.70	9.02	0.85	4.54	1.63	8.69
15-20	0.94	5.01	1.63	8.69	1.88	10.02	1.83	9.75	1.80	9.55	0.63	3.34
20-25	2.01	10.69	2.26	12.03	2.51	13.36	2.14	11.36	2.51	13.36	2.01	10.69
25-30	1.00	5.34	1.88	10.02	1.68	8.95	1.26	6.68	1.26	6.68	0.94	5.01
30-35	0.63	3.34	1.51	8.02	2.51	13.36	0.75	4.01	0.63	3.34	0.63	3.34
35-40	1.07	5.68	1.19	6.35	1.00	5.34	0.75	4.01	0.72	3.81	0.63	3.34

Under drip irrigation, root length density of cowpea is higher at the soil surface from 0 to 20 cm as presented at Table 4. The highest value of root length was 2.51 cm.cm^{-3}at 10-15 cm with soil depth 0-5 cm. The lowest root length density was 0.40 cm.cm^{-3} recorded at 15-20 cm with soil depth 25-30 cm. At lateral distance 25-

30 cm, root length density and specific root length disappeared along soil profile. In general, root length density increased horizontally from 0-5cm to 10-15cm then it decreased till soil depth 25-30 cm and below this depth root length density disappeared. Similar findings were observed by Moroke et al. (2005) who found that root growth in the soil profile for cowpea, sunflower and grain sorghum were characterized by the highest root length density found in the upper 0.5 m of the soil profile and decreasing with depth.

Table 4. Distribution of root length density (RLD) and specific root length (SRL) of cowpea along soil profile under drip irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	0.88	14.09	1.26	20.13	2.51	40.26	2.26	36.23	1.26	19.63	-	-
5-10	0.82	13.08	1.0	16.10	1.26	20.13	1.51	23.55	0.88	13.78	-	-
10-15	0.72	11.25	0.82	12.76	0.88	13.74	1.38	21.59	0.75	11.78	-	-
15-20	0.63	10.06	0.75	12.08	0.82	12.76	0.94	14.78	0.69	10.79	-	-
20-25	0.44	7.05	0.61	9.74	0.63	10.06	0.75	11.78	0.63	10.06	-	-
25-30	-	-	-	-	0.56	8.97	0.40	6.41	-	-	-	-
30-35	-	-	-	-	-	-	-	-	-	-	-	-
35-40	-	-	-	-	-	-	-	-	-	-	-	-

For root distribution of maize, Table 5 presented the root length density and specific root length of maize under drip irrigation. The data showed that root length density and specific root length decreased with increasing in soil depth. The highest values of root length density and specific root length were 5.02 cm.cm^{-3} and 25.12 cm.g^{-1}root at horizontal distance 15-20 cm with soil depth 0-5 cm. Root length density increased with the increase in horizontal distance from 0-5 cm till 10-15cm 15-20 cm then it decreased from 5.02 cm.cm^{-3} to 2.14 cm.cm^{-3} with increasing in horizontal distance. The lowest root length density was 0.63 cm.cm^{-3} observed at the horizontal distance 0-5 cm with the soil depth 35-40cm. These results are compatible with Gao et al. (2010) who found that the peak horizontal spread of maize roots occurred in the 16-22 cm layer of the soil and root depth increased with the increase in soil depth.

Table 5. Distribution of root length density (RLD) and specific root length (SRL) of maize along soil profile under drip irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	2.51	12.56	4.14	20.27	4.65	23.24	5.02	25.12	2.89	14.44	2.14	10.68
5-10	1.88	9.42	1.63	8.16	2.32	11.62	2.80	14..0	1.07	5.34	1.19	5.97
10-15	1.51	7.54	2.01	10.05	2.14	10.68	2.26	11.30	1.26	6.28	2.14	10.68
15-20	1.38	6.91	1.26	6.28	1.51	7.54	4.02	20.10	2.26	11.30	2.64	13.19
20-25	1.26	6.28	2.51	12.56	1.00	5.02	3.77	18.84	2.07	10.36	2.01	10.05
25-30	1.88	9.42	1.26	6.28	1.88	9.42	2.14	10.68	0.50	2.51	2.26	11.30
30-35	1.38	6.91	0.63	3.14	0.94	4.71	1.44	7.22	0.88	4.40	0.75	3.77
35-40	0.63	3.14	0.50	2.51	0.63	3.14	0.82	4.08	0.75	3.77	0.69	3.45

The data at Table 6 showed that the root length density and specific root length of cowpea cultivated under sprinkler irrigation. The root length density at 0-5 cm was 0.75 cm.cm^{-3} and increased to 1.26 cm.cm^{-3} at 10-15 cm then it decreased to 20-25 cm and disappeared from horizontal distance at 25-30 cm. The lowest root length density was 0.50 cm.cm^{-3} recorded at horizontal distance 0-5 cm with soil depth 20-25 cm. The root length density is founded at horizontal distance 10-15 cm from soil depth 0-5 cm to soil depth 30-35 cm. This is may be due to the shortage of water through soil profile because of the movements of irrigation water by gravity. At horizontal distance 15-20 cm, the root length density at the soil surface was 1.07 cm.cm^{-3} then it decreased to 0.63 cm.cm^{-3}at soil depth 25-30 cm. The data showed that root length density disappeared from soil profile 25-30 cm. The same results were obtained by Steel and Summerfield (1985) who found that cowpea had a rapid root growth to gain available soil water in arid and semiarid regions.

With regard to root length density and specific root length of maize under sprinkler irrigation. The data at Table 7 showed that root length density was higher at the soil top layers 0-5 cm and 5-10 cm than other layers from 10-40 cm. The highest root length was 2.22 cm.cm^{-3} recorded at horizontal distance 10-15 cm at the top layer from 0-5cm. The lowest value was 0.63 cm.cm^{-3} at horizontal distance 25-30 cm with soil depth 35-40cm. The data showed that root length density increased horizontally from 1.63 cm.cm^{-3} at 0-5 cm then it began to decrease to 0.79 cm.cm^{-3}at 25-30 cm. This result was observed at all depths with horizontal distances. Talking of vertical distribution of roots, root length density decreased with the increase in soil depth. This is because of sprinkler irrigation is attributed to be higher frequency. Correspondingly, Lv et al. (2010) found that the maize root length density is high at the top layer of soil.

Table 6. Distribution of root length density (RLD) and specific root length (SRL) of cowpea along soil profile under sprinkler irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	0.75	10.47	0.88	12.21	1.26	17.44	1.07	14.83	0.82	11.34	-	-
5-10	0.69	9.59	0.82	11.34	1.13	15.70	0.88	12.21	0.75	10.47	-	-
10-15	0.63	8.72	0.79	11.0	1.07	14.83	0.82	11.34	0.69	9.59	-	-
15-20	0.75	7.85	0.75	10.47	0.94	13.08	0.79	11.0	0.65	9.09	-	-
20-25	0.50	6.88	0.69	9.59	0.85	11.86	0.69	9.59	0.63	8.72	-	-
25-30	-	-	0.63	8.72	0.78	10.82	0.63	8.72	-	-	-	-
30-35	-	-	-	-	0.65	9.07	-	-	-	-	-	-
35-40	-	-	-	-	-	-	-	-	-	-	-	-

Table 7. Distribution of root length density (RLD) and specific root length (SRL) of maize along soil profile under sprinkler irrigation

Soil depth, cm	Horizontal Distance (cm)											
	0-5		5-10		10-15		15-20		20-25		25-30	
	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}	SRL, cm.g^{-1} root	RLD, cm.cm^{-3}
0-5	1.63	5.67	1.00	3.49	2.22	7.72	1.88	6.54	0.82	2.83	0.79	2.75
5-10	1.19	4.14	0.88	3.05	1.0	3.49	0.98	3.40	0.85	2.97	0.75	2.62
10-15	0.95	3.34	0.75	2.62	1.07	3.71	0.88	3.05	0.79	2.75	0.69	2.40
15-20	0.94	3.27	0.63	2.18	0.82	2.83	0.78	2.70	0.70	2.44	0.67	2.31
20-25	0.94	3.27	0.88	3.05	1.00	3.49	1.13	3.93	1.07	3.71	0.69	2.40
25-30	0.85	2.97	0.80	2.79	0.88	3.05	1.26	4.36	0.69	2.40	0.67	2.31
30-35	0.78	2.70	1.26	4.36	1.88	6.54	0.75	2.62	0.67	2.31	0.64	2.19
35-40	0.65	2.20	0.68	2.35	0.70	2.42	1.00	3.49	0.75	2.62	0.63	2.18

Conclusion

Understanding the plant root length density and specific root length are an important consideration when using different irrigation methods. This study was conducted at the experimental site of Agricultural College of Suez Canal University during the summer season using two crops maize and cowpea growing under three irrigation systems. The data showed that the root length density and specific root length of cowpea under surface irrigation decreased vertically with soil depth and it disappeared horizontally at 25-30 cm. At all soil depths and distances, the root length density was found. At drip irrigation, root length density of cowpea is higher at the soil surface from 0 to 20 cm. For maize crop, the data showed that root length density and specific root length decreased with increasing soil depth. At sprinkler irrigation, the root length density at 0-5 cm was 0.75 cm.cm^{-3} and increased to 1.26 cm.cm^{-3} at 10-15 cm then it decreased to 20-25 cm and disappeared from horizontal distance at 25-30 cm. For maize crop under sprinkler irrigation, the lowest value was 0.63 cm.cm^{-3} at the horizontal distance 25-30 cm with soil depth 35-40 cm.

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