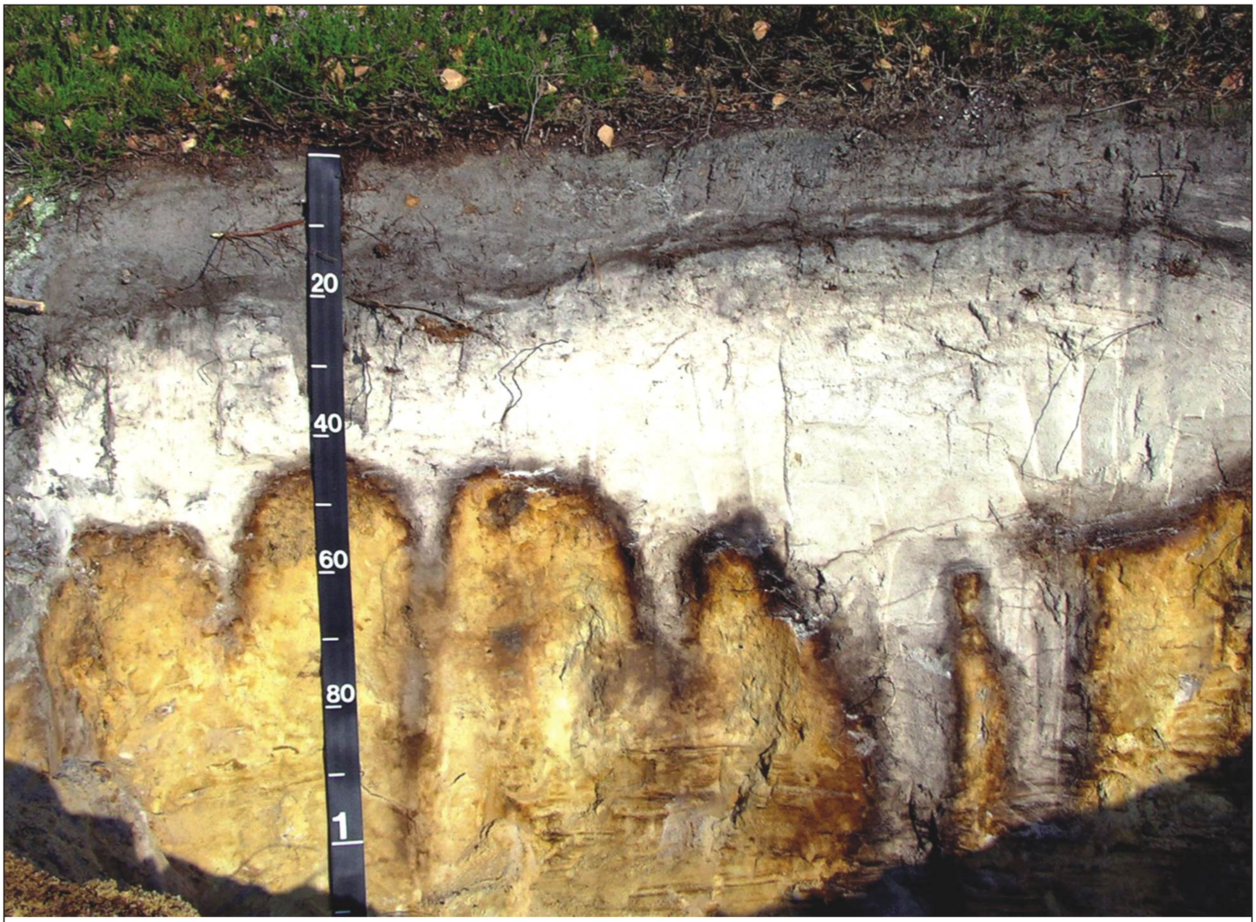

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Movement of Nitrogen, Phosphorus and Potassium Fertilizers in Undisturbed Soil Columns as Affected by Soil Compaction

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Abstract: The objective of this study was to investigate the movement of the added fertilizers to soil as affected by soil compaction. In the experimented soil, three compaction levels were used. The soil was also irrigated for four times and after the each irrigation, Phosphorus (P) and Potassium (K) in the drainage water (effluent) was measured using standard methods. After the fourth irrigation, each soil column was divided to five equal parts and the elements in the columns were measured and finally the data were analyzed using the statistical software. The results showed that as the compaction is increased, the movement of nitrogen (N) and K downward is reduced, but the movement of P is increased. The reason for the movement of N in low compaction is the existence of macropores for preferential flow and suitable conditions for nitrification. The movement of the most of K in low compaction is due to movement through macropores and preferential flow. The increase in P movement in high compaction is caused by high moisture and movement by diffusion.

Key words: Diffusion, preferential flow, hydraulic properties, solute transport, effluent

INTRODUCTION

The compaction of agricultural soil is an important issue that influences root and plant growth (Nevens and Renheull, 2003), soil hydraulic properties (Horton *et al*., 1994), soil and water pollution processes (Van Ouwerkerk and Soane, 1994), required energy for tillage (Larson *et al*., 1994) and movement of solute in soil (Nassar and Horton, 1999). When a soil is compacted, the bulk density of the soil is increased and the porosity is decreased; therefore, the macropores are compressed and changed into micropores (Hakanssaon and Lipiec, 2000) as a result, proportion of macro and micropores will change and there is a greater amount of micropores (Zhang *et al*., 2006). In a compacted soil, due to the increment of micropores, water retentions at high matric potential will increase. When a layer of soil is compacted, it absorbs and retains more moisture. The amount of moisture absorption goes up as the soil compaction increases. However, compaction reduces the infiltration and permeability of the soil. Ponding and weak drainage are signs of soil compaction (Bakker *et al*., 2005). In mechanized agriculture, large agricultural equipments and tractors are used for various agricultural operations. Hence, soil can be compacted by agricultural equipments and their traffic.

Making use of macronutrient fertilizer to produce more is common in agriculture. Soil compaction changes the hydraulic conductivity and water holding capacity of the soil; therefore, it may influence the movement of added fertilizer in the soil. The purpose of the current study is to investigate the effects of compaction on the movement of macronutrients (N, P and K) in soil columns.

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MATERIALS AND METHODS

Undisturbed Soil Columns

The soil samples for this present study were taken in an area of Bijar in Kurdistan Province, west of Iran at 2005 year. The soil was taken from a farm with homogenous soil but various compaction level caused by tractors. The polyvinyl chloride (PVC) pots were 82 mm in diameters and 300 mm in length. The pots were pushed to the soil and injected the foam to inside pots wall. The soil cores were transferred to the lab after 24 h.

Soil Chemical Analysis

Soil electrical conductivity of saturation extract and pH of saturation paste were measured (Rhoades, 1982). Exchangeable potassium was extracted by ammonium acetate and determined by flame photometer (Thomas, 1982). The amount of calcium carbonate was measured using titration (Nelson *et al*., 1982), total N by Kjedahl (Kjeltec 2300 Analyzer) and available P was extracted by sodium bicarbonate solution (Olsen and Summers, 1982). The amount of organic carbon was determined by the potassium dichromate oxidation method (Nelson and Sommers, 1982). Total organic matter was obtained as organic carbon times by 1.724. Table 1 shows the result of analysis.

Soil Mechanical and Physical Measurement

Soil texture was determined by the hydrometer method after sample was dispersed in sodium hexametaphosphate solution and shaken on a horizontal reciprocating shaker for 12 h (Day, 1965). The soil water retention curves for the different soil compaction were measured using a standard pressure plate apparatus. Atterberg limits, viz., liquid limit (LL), plastic limit (PL), were determined using the three-point Casagrande method and 3 mm rod formation (McBride, 1993). Table 2 shows the mechanical properties of experimented soil. The hydraulic conductivity of each soil compaction level was measured by falling head method (Table 3).

Experimental Design, Irrigation and Application of the Fertilizer

The experimental design was a complete randomized design with three replicates for each treatment. There were three compaction treatments (levels). Soil compaction levels were soils with the bulk density of 1300, 1650 and 1950 kg m^{-3} corresponds to 1, 2 and compaction 3, respectively. The fertilizers were mixture with acid washed pure sand and applied on the column surface. Rates of applied fertilizer were 200, 150 and 200 mg kg^{-1} for urea, diammonium phosphate and potassium sulfate, respectively. The soil columns were irrigated 4 times during 50 day of experiment. When the soil moisture in compaction 1, was less than 0.6 time of the Field Capacity (FC), the irrigation was

Table 1: Chemical properties of experimented soil

pH	OM (g kg^{-1})	ECe (dS m^{-1})	Extractable K (mg kg^{-1})	Extractable P (mg kg^{-1})	Total N (mg kg^{-1})	$CaCO_3$ (g kg^{-1})
7.4	160	1.2	220	8	205	180

ECe: Electrical conductivity extractable of saturated paste; OM: Organic Matter

Table 2: Some physical and mechanical properties of experimented soil

Texture	PWP	FC	PL	LL	Clay	Silt	Sand
	(g kg^{-1})						
SiL	11	28	18	38	250	490	260

SiL: Silt loam, LL: Liquid Limit, PL: Plastic Limit, FC: Field Capacity, PWP: Permanent Wilting Point

Table 3: The saturated hydraulic conductivity in three compaction levels

	Compaction levels		
	1	2	3
Saturated hydraulic conductivity (cm day^{-1})	110	58	10

repeated. Drainage water was collected for measurement of P and K. At the end of the experiment, soil column was divided to five equal parts, numbered 1 to 5 from the top the column. In the next stage, the samples air-dried, poured into plastic bags and were analyzed. The data were analyzed using the statistical analysis software for analysis of variance (SAS Institute, 1990). Mean were compared by the Least Significant Difference (LSD).

RESULTS AND DISCUSSION

The Moisture Curves

At high suction potential the moisture content of soil with high compaction level (i.e., compaction 3) is more than soil with lower compaction level. However, at lower suction potential the moisture content of low compaction level is more than soil with high compaction level (Fig. 1).

The Saturated Hydraulic Conductivity

The soil with the highest compaction level has the lowest K_{sat}. Furthermore, the K_{sat} in the soil, which has the bulk density of 1.95 Mg m^{-3} (compaction 3), is 10 times smaller than K_{sat} of the soil which has the bulk density of 1.3 Mg m^{-3} (compaction 1). Result showed that increase in compaction level decreased the K_{sat} of the soil (Table 3).

Nitrogen

Result indicates that as compaction increases, the movement of N to lower depth decreases. The total N in the deepest parts of soil columns in compaction 1 is more than other compaction levels ($p<0.05$) and N distribution in compaction 1 is more homogenous (Fig. 2). With increase of compaction level the total N diminish from depth 1 to 3 is drastic ($p<0.05$). At depth 1, compaction 3 there is the highest total nitrogen ($p<0.05$). depth 1 compaction 1 has lowest amount of total N and compaction 2 has medium amount of total N. Depths 2, 3, 4 and 5 are in contrast with depth 1, that is; with the increment of compaction, the amount of total N has decreased. Overlay, with the increase of compaction levels, the amount of N has come down at deepest depths.

In soils that have large and continuous pores, the amount of transitional N is more than the soils with non-continuous large pores, since in soils with consistent structure and macropores, movement of N through large pores is more and reacts less to the soil matrix. In addition, hydraulic conductivity in the soil with macropores is high. Therefore, the increment of hydraulic conductivity causes faster transfer of N. In the experimented soil in this study, there are existed preferential flows in low compaction levels, because the K_{sat} is high there (Table 2). Another factor which causes more

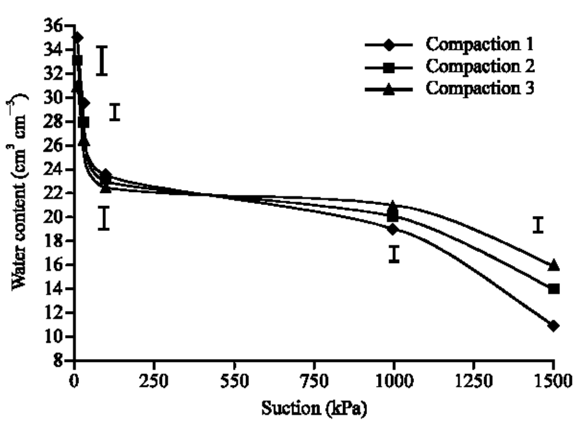

Fig. 1: Soil water curves for four compaction levels

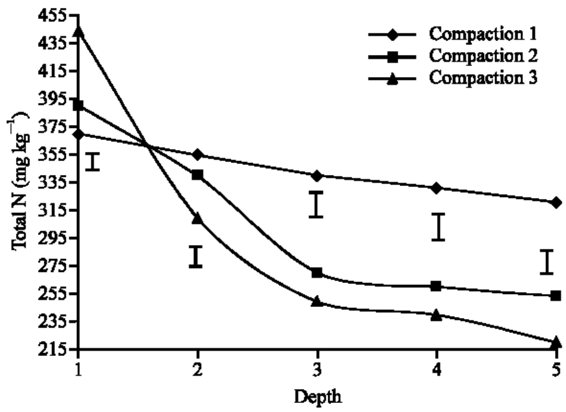

Fig. 2: Total N measured in the different depths of soil column and different soil compaction levels. Bars represent the common LSD ($p<0.05$) by depth for all treatments

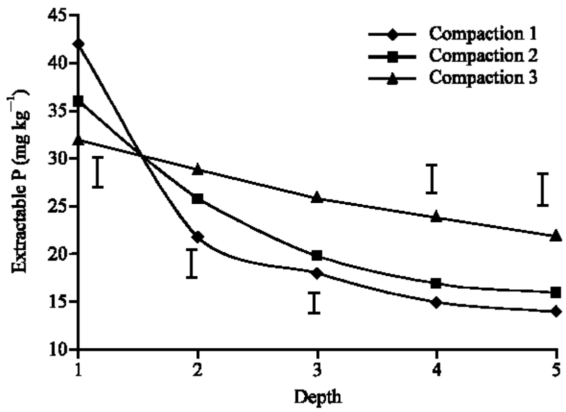

Fig. 3: Extractable P measured in the different depths of soil column and different soil compaction levels. Bars represent the common LSD ($p<0.05$) by depth for all treatments

movement of the N in low compaction (i.e., compaction 1) is the rapid evacuation of water in macropores. In this case, air replaces water and causes more nitrification in the soil (Alva *et al*., 2006). In addition, nitrate is produced in the soil and its movement becomes easier. In highly compacted soil, the amount of soil moisture is high (Fig. 1). In this case, denitrification bacteria are able to do denitrification and a large amount of N is emitted as gas from the soil. Maeda and Bergstrom (2000), studied on N mobility in the soil as affected by preferential flow. They showed, if there was the possibility of preferential flow in the soil, N transferred rapidly in the form of nitrate or ammonium. In present study, results showed that in high compacted soil (i.e., compaction 3), downward movement of N is little and a may be large amount of added N fertilizer goes into the atmosphere in the form of gas.

Phosphorus

There are significant differences for P in soil columns. At the first depth, the amount of P in compaction 1 is more than compaction 3, but at other depths, the amount of P in compaction 3 is higher ($p<0.05$). In the lowest depth of highly compacted soil columns (compaction 3), amount of P is more than other compaction treatment ($p<0.05$), moreover, the distribution of P is more homogenous than other compaction (Fig. 3). The amount of P is more in the lower depth of compaction 3. In

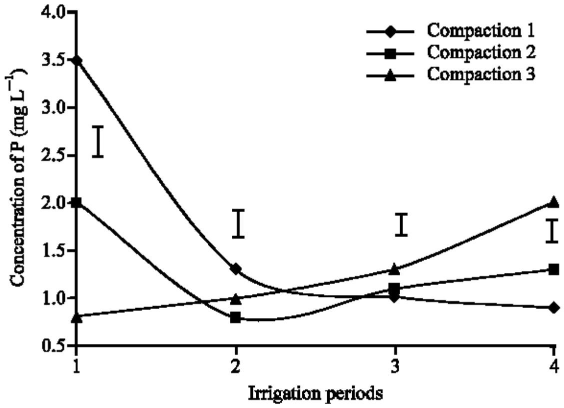

Fig. 4: Concentration of phosphorus in effluent during various irrigation periods and different soil compaction. Bars represent the common LSD (p<0.05) by depth for all treatments

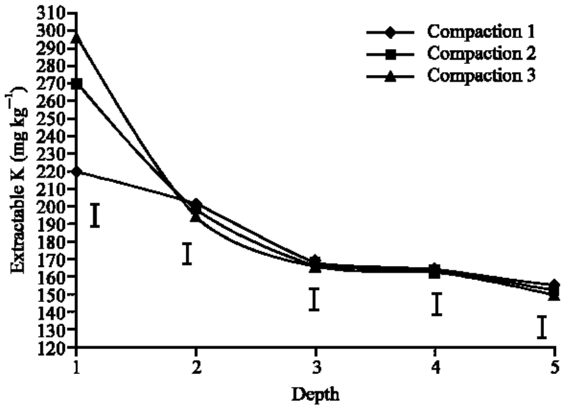

Fig. 5: Extractable K that measured in the different depths of soil column and different soil compaction levels. Bars represent the common LSD (p<0.05) by depth for all treatments

compactions 1, 2 and 3 there are a significant difference in this respect, that is, with the increment of compaction, the amount of P has also increased in lower depths.

At first irrigation drainage, the concentration of P in compaction 1 is several times more than compaction 3 and compaction 2 has middle concentration of P (Fig. 4). This process does not exist for other irrigation period, so that, at irrigation 4 the result is in opposite with irrigation 1.

These results show that P in low compaction has been under the influence of preferential flow, but in highly compacted soil, P has moved under the diffusion (Olsen and Watanabe, 1963) due to the high soil moisture. Although, P moves under the influence of preferential flow (Gjettermann *et al*., 2004), in the soil with micropores, it moves under the impact of diffusivity because there is a lot of carbon dioxide (CO_2) and as result, precipitation of P in the form of calcium phosphate dissolve. The results show that compaction causes better solution of P, the reason of which could be P solution and its diffusivity in wet soil. In the first irrigation, the influence of the preferential flow was prominent.

Potassium

Looking at Fig. 5, one can understand that the amount of potassium in soil columns with various compactions in different depths does not differ significantly (excepted first depth of compaction 1 and

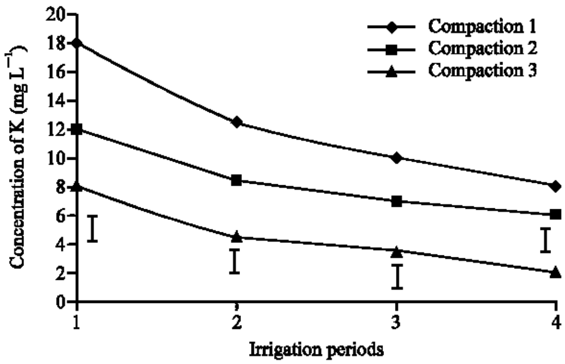

Fig. 6: Concentration of K in the drainage water of columns with different compaction levels. Bars represent the common LSD ($p<0.05$) by depth for all treatments

2). If soil columns considered as criteria for K movement, it will be conclude that K movement has not been affected by soil compaction. However, this conclusion has not a solid base, because the amount of K in water drainage, resulted from the various compactions bears a significant difference ($p<0.05$) and as the compaction goes up, the amount of K in the drainage water goes down (Fig. 6). In the first irrigation, there is the most amount of K in water drainage. As the irrigations were repeated, the amount of measured K has decreased in water drainage. In each irrigation, the highest amounts of K exist in drainage water of soil columns with compaction 1 and the next compactions are two and three respectively. In these compactions, the amount of effluent K has decreased by increase of compaction. According to the result, it can conclude that, K movement has decreased while the compaction increased. Corresponding to the K movement (Black, 1968) indicated that the amount of K in water drainage and K movement depend on soil texture and soil structure. Movement of K in sandy soil and soil with consistent structure was high. In soil with heavy texture and low permeability a great amount of K was absorbed (fixed) by soil colloids.

CONCLUSION

In low compaction, the N movement in soil is very much due to the existence of macropores and preferential flow and goes to lower depth of soil columns. The movement of P in low compaction and in the first irrigation has been very high regarding the preferential flow. While in the third and fourth irrigation in highly compaction, the movement of P has been more than other, because of the more moisture in these columns and diffusivity process and finally the P movement has been more in highly compacted soil. The movement of K in low compaction has been due to the macropores and the preferential flow.

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