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Effect of subsoil compaction constraints on some morphological, physiological and agronomic properties of wheat (*Triticum aestivum* L.) under rain-fed farming

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Abstract

Soil compaction has become a widespread problem in the world and is one of the factors involved in land degradation and declining crop yields, especially in the arid and semi-arid agriculture. The purpose of this study was to investigate the effects of subsoil compaction on morphological, physiological and agronomic aspects of wheat. The research was carried out in the experimental farms of Anbar Ulum city. The treatments were applied in the form of the completely randomized block design with four independent variables and three replicates. The study treatments included: control treatment (no artificial compression), treatment 2 (two passes of a heavy tractor), treatment 3 (4 times passes of a heavy tractor) and treatment 4 (6 times passes of a heavy tractor. In this study data was analyzed by means of the SAS software package. The type of mean comparison method applied is the LSD test. Results showed that different levels of soil compaction had a significant reducing effect on plant morphological characteristics such as plant height and tiller number. Likewise, soil compaction significantly reduced the agronomic characteristics of wheat like grain weight, biological yield and grain yield, but not so much effect was observed for the harvest index (HI). As for plant physiological characteristics, soil compaction imposed a significant effect such that the concentration of chloride, sodium and potassium concentration in the leaves significantly decreased and so did the leaf area index.

Key words**:** soil compaction, wheat, arid and semi-arid areas, morphology, physiology, yield

1. Introduction

Wheat as an agricultural pivotal and key product has special position on production and consumption of food in world nations. Self-sufficiency in wheat production has been one of the most important economic aims of Iran in recent years. Since the one of the principles of food security is self-sufficiency, achieving this goal will be possible only through increasing food production. Wheat is the most important plant of cereal family that is allocated the greatest cultivation area among grain product in Iran. Wheat cultivation is mostly performed in the form of rain fed in our country. One of the most effective stages in rain fed

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wheat yield is cultivation stage. In recent years, due to mechanization of agricultural and increasing weight of cultivation and harvesting machinery, soil compaction has been raised as a serious problem in agriculture and is considered as interaction effects of machinery, soil, plant and climate. The excessive use of machinery often leads to soil compaction. Today, population growth and the need of human society to produce more food using agricultural machinery (mechanization) are more important in crop production (Ishaq et al, 2001., Al-adawi and Reeder, 1996., Oussible et al, 1992).

Subsoil compaction has become a widespread problem in the world and is considered as one of the effective factors in to land degradation. The vast majority of soil compaction in modern agriculture is often attributed to heavy machinery and traffic load. In the global scale, the total area affected by this process is estimated 68 million hectares (Flowers and Lal, 1998). Over use of natural resources, the lack of suitable lands for agriculture, lack of attention to soil conservation and expansion of agricultural activities In the marginal lands along with the ecological problems and arid and semi arid condition of our country have caused degradation trend in natural ecosystems (Hosseini Araghi, 1997). Soil compaction is occurred in wide areas of soil types and different climate condition. There are strong evidences that showed agricultural compression and production systems led to significant changes in the soil chemistry and physics and also have caused creating balance between vegetation and diversity of soil organisms. It is clear that increase in production per unit area in many parts of the world is causing deterioration of soil resources. Soil erosion is a major concern in this category (Kamkar and Mahdaui Damghani, 2008). Soil compaction due to using different cultivation machinery may causes adverse effects on plant growth and crop yield (Miransery et al, 2009). Taken low-tillage in rainfed condition of semi arid region causes increasing wheat yield (Zare, 2010, Ozon Pyer and Ki, 2006, Douita et al, 2007). Conflicting results have been published which show a decrease in yield of barley and chickpea (Lopez-Fandou et al, 2007). Although it is reported that there is yield reduction of some plants under rainfed cultivation and conservation tillage, but under such conditions, economic efficiency has been high (Benskansa et al, 2006).

Soil compaction is created by increasing bulk density and soil penetration resistance. Reducing the size of large porosity, blocking soil pores, formation of soil surface crust and reduction of aggregate stability, soil structure degradation, and reduction in soil porosity and water permeability are Negative consequences of soil compaction (Al-Adawi and Reeder, 1996). These negative consequences required to additional fertilizer and increasing production costs and creating these conditions will be causes reducing plant growth and less input of fresh organic matters to soil subsequently, reducing recycling cycles of organic matters and mineralization process, reducing micro organisms activity, increasing erodability and depreciation of agricultural machinery. Soil compaction in dry condition causes water stress, reducing soil ventilation in high humidity condition, reducing nutrient availability, reducing metabolic activity of roots and ultimately reducing plant growth and crop yield. Soil compaction reduces available nitrogen and potassium for plant and increases incidence of pests and causes stress for crops subsequently and ultimately reduce crops yield (Ahmad et al, 2006). Soil compaction negatively affects on growth and production of all crops by reducing the supply of air and water in the lower layers of the soil profile. For favorable germination and growth of plants, soil must be including appropriate levels of water and nutrient availability. In addition, the soil for root penetration and germination must have enough porosity (Mosadeghi et al, 2000). Signs of soil compaction can be found often with observation of crop growth in compacted soil. Compacted soil has a high moisture capacity because existed water on soil is not able to drain freely and air movement in the soil is limited. This reduction of internal drainage leads to water logging which may causes flooding, product rehabilitation and ultimately its degradation. Considering to reducing size and number of soil large pores and then reducing ventilate, decreases microbial activity.

Soil microbes have an important role in decomposition of organic materials and fertilizers, and prepare them for the plant root absorption (Ahmad et al, 2006). Today, conservation of environment and achieving to sustainable development is one of the main topics that have been agenda for various countries of the world such as our country. This aim is accessible with implementation the integrated plans of economic, social and cultural (Services of a bureau Educational Technology, 2002). Therefore, quantitative evaluation of soil density for improving agricultural management methods is necessary to decrease derived problems from compaction in environment and crop production systems but low scientific research in relation to various aspects of surface and subsurface compaction has been done. Therefore, quantitative effects of this subject are less tangible for the agricultural community. The aim of this study is survey the effects of subsurface compaction on wheat morphologic, physiologic and agronomic aspects that are important parameters in sustainable production.

2. Material and methods

The study area is located in the North West of Golestan province. A part of the northern fields of Aq qala Township was selected as the case study. The farms expand from 37° 04' 36'' northern latitude to 54° 27' 24'' eastern longitudes. The relief of the area ranges between 46 to 21 meters above the sea level (Abarsajy, 1996).

In the first experiment, artificially subsurface compaction was performed by means of a tractor of the SAME LASER 150 model, weighing 5,700 kg with 26 in 52 meters in diameters (the land was completely flat with no gradient). Next, the 0.1m of topsoil was prepared by soft disking for seeding. The experiment with 4 treatments and 3 replications was conducted as follows:

i) control treatment (without artificial compression): chiseling + shallow disking to a depth of 10 cm ii) two passes of a heavy tractor + shallow disking to a depth of 10 cm iii) four passes of a heavy tractor + shallow disking to a depth of 10 cm and iv) six passes of a heavy tractor + shallow disking to a depth of 10 cm. At the time of the creation of artificial compaction, soil moisture was 21%. Use of agricultural inputs (chemical fertilizer application rates, herbicides, etc.) was the same for all treatments. Prior to cultivation and based on the recommendation made by the extension commissioners, 160 $kg.ha^{-1}$ phosphorus, 160 $kg.ha^{-1}$ potassium and 50 $kg.ha^{-1}$ nitrogen fertilizers were applied to the fields. Because dry farming is the common agricultural practice in the study area, so the precipitation received to all parts of treatment plots was the same.

some morphological characteristics (number of tillers, plant height), some agronomic traits (grain yield, biological yield and harvest index) and some physiological characteristics (the rate of accumulation Na^+, K^+, Cl^- in the leaves) of wheat.

2.1. Plant Sampling

Plant height was measured during the seed's milky stage. In this case, 10 plants from each plot were randomly selected and measures from the ground to the tip of the plant.

Measuring the number of tillers was done during the onset of wheat jointing in spring so that the number of 10 plants from each plot were identified. Tillers per plant were counted separately, and the average number of tillers for the ten plants was assigned to each plot.

Grain weight was measures by selecting three different plants from each plot and counting the grains. Then, using a digital, the grains were weighed and the obtained value was taken as the average thousand grain weight of each plot. Biological yield was determined after harvesting wheat from each plot of 2*2 m diameter. Once transferred to the laboratory, the plants were left in the oven at 60 ° C for 36 hours. Then by weighing, the value obtained was generalized to the surface of one hectare. To obtain the yield of wheat, grains of sample plants were separated by small threshers and after weighing he value obtained were generalized to the surface of one hectare.

The harvest index (Equation 1) was calculated as given:

(Biological yield / yield) * 100 = HI eq. 1

For obtaining leaf area index, during the milky stage, ten plants per plot were randomly sampled. Then the leaves were removed and placed in the oven at 70 ° C for 24, dried and weighed. In succession, average weight of each sample's leaves was calculated. From the established relationship between the average dry leaf weight of each plant with the leaf area (eq.2), leaf area was calculated. (Bakhshandeh et al, 2011). Leaf area index (LAI) was obtained by multiplying the number of plants in an area within a one square meter of each plot by the leaf area obtained in the precious step.

Y=3.91+212.27X eq. 2

Where Y denotes leaf area and X denotes dry weight of green leaf.

To obtain the concentration of potassium and sodium in wheat flame photometer instrument was used. Finally, sodium and potassium levels in each sample was calculated using (Equation 3) in terms of mg per g of dry matter (Rahnema, 2009).

$$AE = \frac{C \times D \times V}{۱۰^{۶} \times DM} \times ۱۰۰۰$$

eq.3

Where AE indicates value in millimeters of the desired element, in which the C shows the concentration of the element of interest in gram per gram of dry matter; V stands for the total volume; D denotes dilution factor in $mg.l^{-1}$; DM is the dry weight of prepared extract in ml per gram of samples. Chlorine concentration in wheat leaves was measured by precipitation titration method.

The final experimental data obtained were analyzed by SAS statistical software. Treatment means were compared with LSD test at 1% level.

3. Results and discussion

3.1 The effect of subsurface on morphological properties

Variance analysis indicated compaction effects of subsurface soil on plant height is significant at level 1% and also showed a very significant difference among compaction levels in view number of tiller.

Table1. Variance analysis of wheat morphological properties in subsurface compaction treatments

		Mean squares	
Sources variation	Degree of freedom	Number of tillers	height Plant
frequency	2	0.003	5.957
soil Compaction	3	2.37^{**}	55.318^{**}
Error	6	0.045	6.25

** Significant at 1% level, * significant at 5% level, ns: non-significant

The results of plant height and number of tiller mean comparison showed that there is significant difference among different levels of compaction. Maximum plant height (93.67 centimeters) and number of tiller (3.03) belonged to control treatment and there are minimum plant height (82.33 cm) and number of tiller (1.97) for treatment 4 (6 times to-and-fro). Not observed significant difference between the effect of 2times to-and-fro and 4times to-and-fro treatments on plant height and the effect of all treatment on the number of tiller have significant difference (Figure 1 and 2).

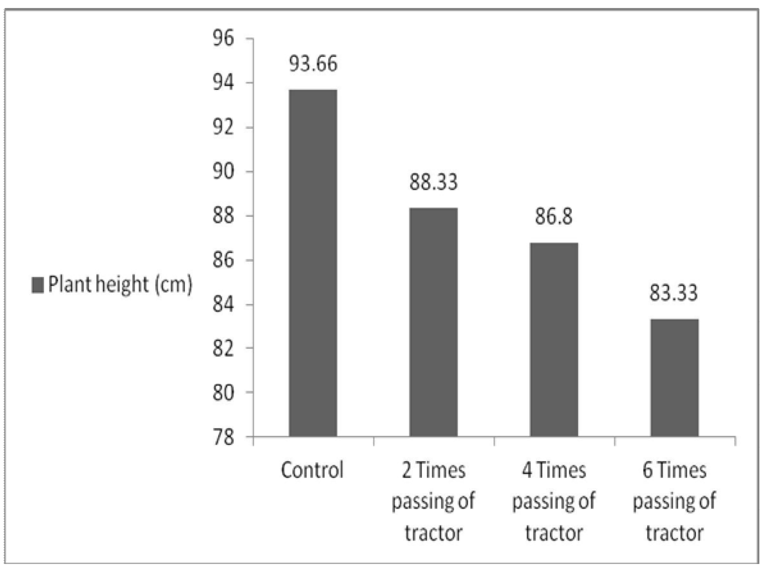

Figure1. Diagram of the changes in wheat height (cm) in different levels of subsurface compaction

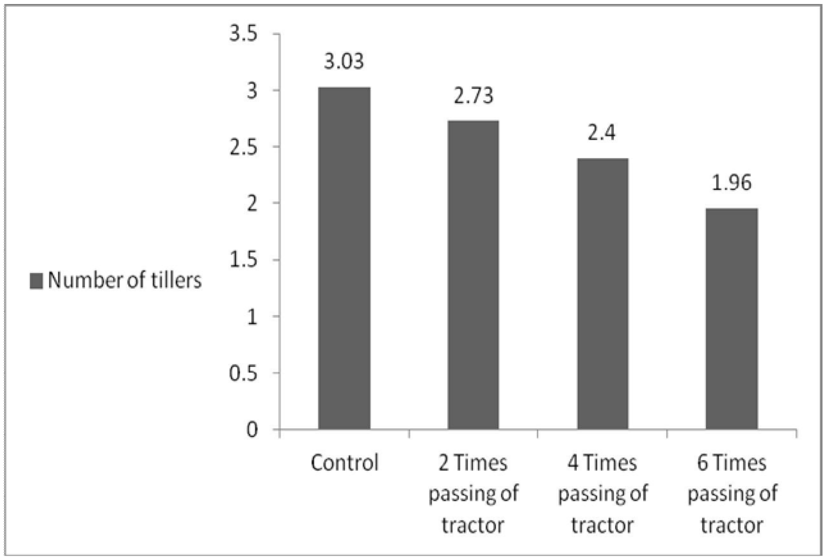

Figure2. Diagram of the changes in the number of wheat tiller in different levels of subsurface compaction

Wheat height in 2, 4 and 6 times to-and-fro treatments of heavy tractor decreased 6, 7 and 11 percent in comparison to control treatment respectively. Also the number of tiller in two times to-and-fro treatments decreased 9% in comparison to control treatment. In 4 and 6 times to-and-fro treatments, the number of tiller decreased 20 and 35 percent respectively. Ahmad et al (2006) achieved to similar results in their researches. They reported wheat height decreased 6% due to compaction of soil subsurface and their reason for significant effect of soil subsurface compaction on plant height has been changing soil physical condition. With increasing soil bulk density, soil particles are attached together and are reduced soil porosity. Increasing soil bulk density and decreasing soil porosity causes reducing root ability in more penetration for water and nutrient absorption that ultimately affects the growth and development of the wheat plant.

3.2 The effects of subsurface compaction on agronomic properties

The results of variance analysis for agronomic properties showed subsurface compaction treatments have a significant difference at the 1% level on grain and biological yield. Harvest index (grain yield/biological yield) not showed significant difference under effect compaction treatments. The effect of compaction on thousand grain weight was significant at the 1% level (Table 2).

Table2. Variance analysis of wheat agronomic properties in subsurface compaction treatments

Sources variation	Degree of freedom	Mean squares		
		biological yield	grain yield	Harvest index
frequency	2	31825	7564.58	1.509
soil compaction	3	4371896**	664856.52**	0.081 ns
Error	6	17636.11	2967.36	0.353

** Significant at 1% level, * significant at 5% level, ns: non-significant

Mean comparison results of biological yield, and grain yield showed maximum and minimum biological and grain yield are belong to control and 6times to-and-fro treatments respectively (Figure 4, 5). Maximum biological and grain yield are 6926.7 and 2733.3 kg/ha respectively. Minimum biological yield is 4081.7 kg/ha and Minimum grain yield is 4081.7 kg/ha that these low amounts achieved for 6times to-and-fro treatment. The effect of different levels of compaction on measured properties is significant and effect of all treatment on biological and grain yield have a significant difference together.

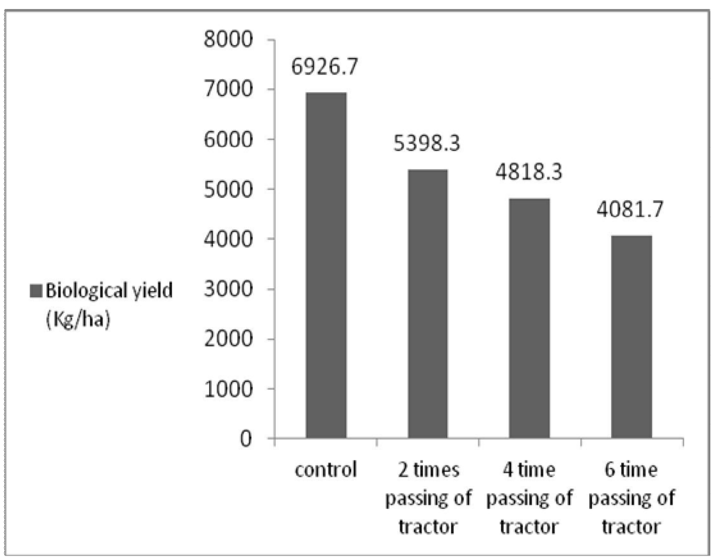

Figure3. Diagram of the changes in the wheat biological yield (Kg/ha) in different levels of subsurface compaction

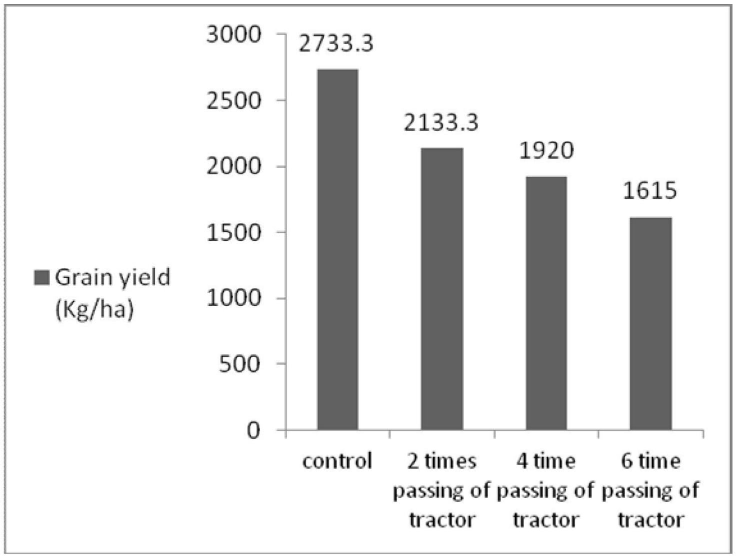

Figure4. Diagram of the changes in the wheat grain yield (Kg/ha) in different levels of subsurface compaction

The effect of different treatments of subsurface compaction on harvest index not show significant difference statistically (Figure 5).

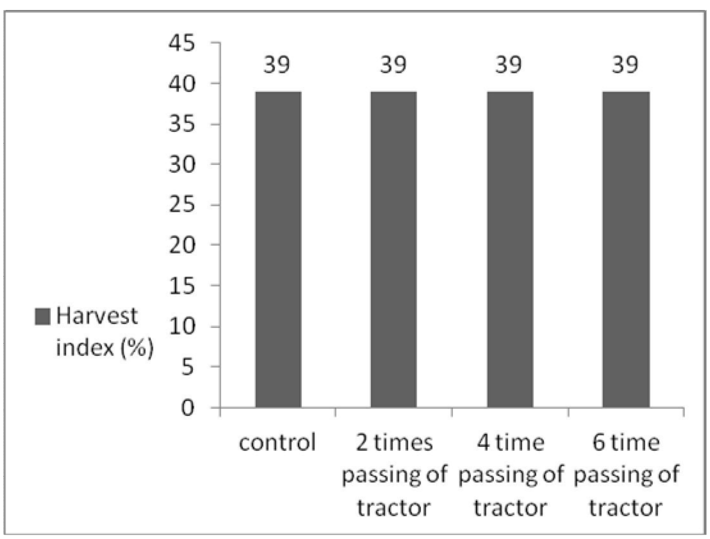

Figure5. Diagram of the changes in the wheat harvest index (based on percent) in different levels of subsurface compaction

Wheat biological yield in 2, 4 and 6 times to-and-fros of a heavy tractor decreased 22, 30 and 41 percent in comparison to the control treatment respectively. Also wheat grain yield in 2, 4 and 6 times to-and-fros of a heavy tractor decreased 22, 29 and 40 percent in comparison to the control treatment respectively and these decreasing percent for thousand grain weight has been 4, 7 and 14 percent in comparison to the control treatment for mentioned treatments respectively. Oussible et al (1992) showed that 4 times to-and-fros of a heavy tractor (7.5 tons tractor), decreased biological yield by a range of 12-23% and grain yield by a range of 9-20% and stated this reduction was associated with a decrease in the number of shrub per unit area. Their reason for decreasing number of shrubs is limiting root access to soil nitrogen. Ishak et al (2001) found grain yield decreased 38 percent with increasing soil bulk density from 1.65 to 1.93. The effect of subsurface compaction on wheat yield is comparable to Mahli and Nibourg (1993) by a range of 9-23% reduction and to Galeteni (1980) with over 45 percent reduction. Hasan et al (2007) indicated that subsoil compaction adversely affected the bulk density, total porosity of soil and root length during both the years. They showed that wheat grain and thousand grains weight yield decreased about 18 and 28 percent with increasing soil bulk density from 1.4 to 1.7gr/cm^2 and reported soil compaction in root region due to changing soil physical properties is the rational reason for this reduction. The change of soil physical properties has affect on growth and development of root and prevents of the normal growth and natural development. The limit of root growth disrupts the water and nutrient absorption from soil and ultimately decreases wheat yield.

Soil compaction reduces the absorption of water and nutrients by changing the physical condition of the soil and restricting root growth subsequently (Abbasi and Adamz, 1992 and 2000). Asgari et al (2008) and Soghaib et al (2004) using spot experiment reported that salinity factor together soil compaction causes reduction in biological yield, grain yield and thousand grain weights that results of this experiment are in agreement with the findings of them. Grain yield in compacted and salinity soil decreased 66 and 76 percent in comparison to control treatment respectively (Asgari et al, 2008 and Soghaib et al, 2004). This reduction is stated due to decreasing permeability and accessibility water and nutrients resulting from soil compaction. Achieved results showed that different levels of subsurface compaction have not effects on harvest index that may be because of very high relation between grain and biological yields. These yields have been decreased with the same ratio in different levels of soil compaction.

3.3 Subsurface compaction effects on physiological characteristics

An overview of the table of the analysis of variance (Table 3) shows the significant effect (at the 1% level) of various levels of subsurface compaction on the concentration of chloride, sodium and potassium in leaves.

Table 3 - Analysis of variance of the physiological characteristics of wheat in subsurface soil compaction treatments

Sources variation	Degree of freedom	Mean squares		
		Cl^-	Na^+	K^+
frequency	2	0.002	0.001	0.0001
soil compaction	3	0.3966**	0.2430**	0.0941**
Error	6	0.001	0.0012	0.0005

** Significant at 1% level, * significant at 5% level, ns: non-significant

Results of the mean comparison (Figures 7, 8 and 9) show that the concentration of chloride, sodium and potassium levels in the leaves were significantly affected by subsurface soil compaction. Here, the maximum concentrations of chloride, sodium and potassium in leaves (respectively 3.29 and 3.05 and 2.77 %) were observed in the case of the control treatment while the lowest values (2.49 and 2.38 and 32.35%) were obtained at treatment 3 (with six times of tractor passage), respectively. Different levels of compaction on the traits measured were statistically significant. On the other hand, the effects of all treatments on the concentrations of these elements in leaves were significantly different.

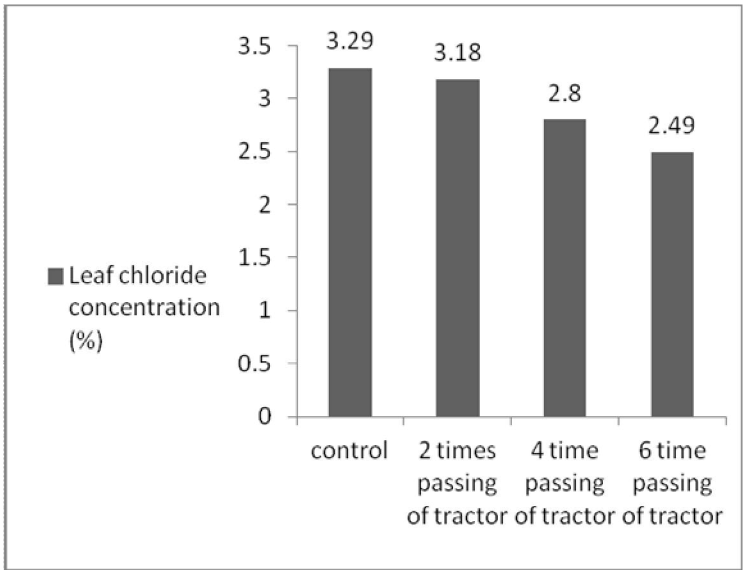

Figure 7- percentage change in total chloride concentration in wheat leaves at different subsurface soil compaction levels

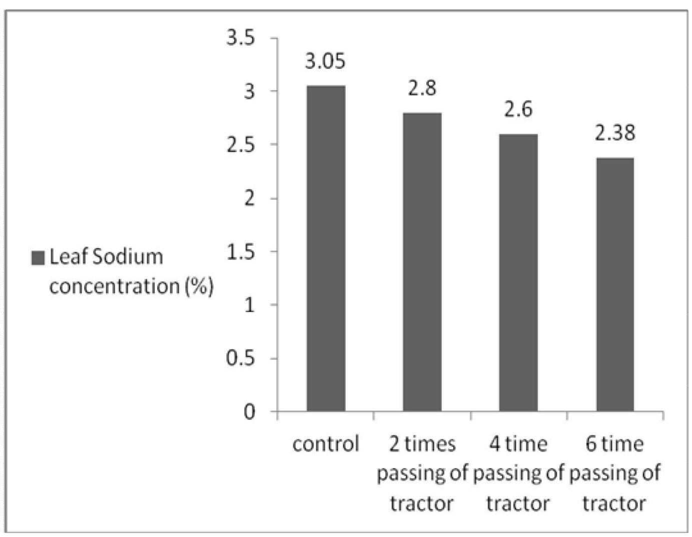

Figure 8 - percentage change in total sodium concentration in wheat leaves at different subsurface soil compaction levels

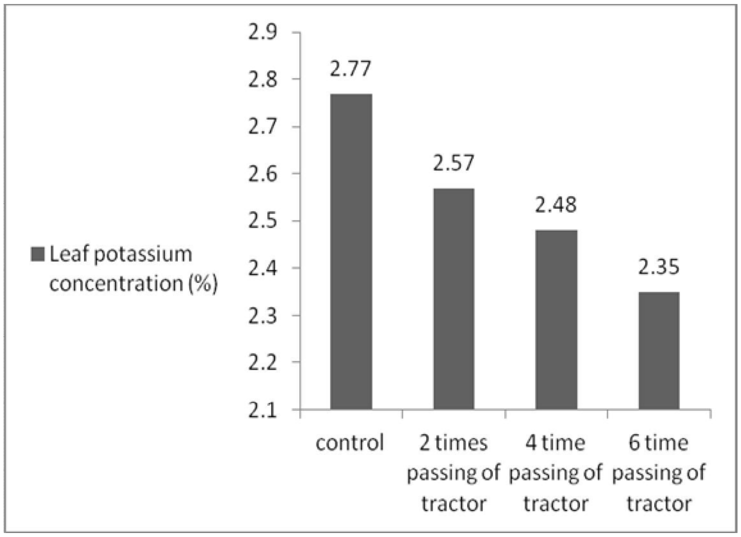

Figure 9 - percentage change in total potassium concentration in wheat leaves at different subsurface soil compaction levels

Ahmad and colleagues (2009) considered the effect of subsurface soil compaction on absorption of nitrogen, phosphorus and potassium by wheat and concluded that with 12-15% increase in soil bulk density will results in 11-28% decrease in plant's potassium which is a testimony to the findings of the current paper. Shahraini et al (2009) also examined the interaction of soil compaction and salinity on potassium uptake by wheat in a pot experiment at 1% level and found that potassium uptake had decreased which further corroborates our findings. Asgari et al. (2008) with a pot experiment showed that the concentrations of sodium, potassium and chloride in wheat leave decreases under soil compaction and salinity at 1% level. The latter is due to the reduced permeability, water availability and nutrient constraints under soil compaction and increased salinity.

With increased subsurface compaction and increasing bulk density, the ability of roots to penetrate deep into the soil decreases. As a result, available water and nutrients content shrinks for plants (Hasan et al, 2001).

4. Conclusion

In this study it was shown that the existence of subsurface soil compaction in arable lands up to which extent is able to significantly affect wheat yield and yield components (number of tillers, plant height, biological yield, grain yield, thousand grain weight, sodium, chloride and potassium content of leaves and leaf area index). Given that the most important criteria considered by farmers is grain yield it is well illustrated that in the subsurface soil compaction by tractor traffic: by increasing soil bulk density at the depth of 10-30cm, grain yield decreased in treatment two (by 1.53 $gr.cm^{-3}$), four (by 1.61 $gr.cm^{-3}$) and finally six (by 1.69 $gr.cm^{-3}$) compared with the control (by 1.33 $gr.cm^{-3}$). This could be expressed in percentages as 21, 29 and 40% decrease in treatments two, four and six, respectively.

Since soil compaction, especially in the deeper layers is not easily resolved, prevention is the best way to tackle the problem (Zhang et al, 2001). To prevent soil compaction as much as possible, tractors and machinery traffic must be avoided to an acceptable level and this is of high priority during the time which soil is wet. It is more preferable to perform the operations with lighter machineries. As much as possible in a sophisticated agricultural plan these recommendations must be considered:

Increasing soil organic matter, leaving crop residue from the previous crop at the soil surface, using crops with deep-and-vertical-penetrating roots during crop rotation, tillage depth variation in different years, using super absorbent for better ventilation and reduces soil compaction, implementing no-tillage system to reduce traffic of farming machineries, maintaining plant residues at the soil surface, applying lacking nutrients to the soil, and subsoil operations to reduce the detrimental effects.

As a field-based study, the results could be transferred to the local farmers. Authorities have to remove the obstacles to deliver the message to the farmers in order to enhance production and reach nation self-sufficiency.

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