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RESEARCH ARTICLE

PENETRATION RESISTANCE OF SANDY LOAM SOILS IN ARID REGIONS AS AFFECTED BY TILLAGE SYSTEMS AND POLYACRYLAMIDE UNDER TWO DIFFERENT PERCENT OF FINE SOIL PARTICLES

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ABSTRACT

A field experiment was carried out at Agriculture Research Station of King Abdulaziz University, Jeddah, Saudi Arabia to study the effect of fine particles, tillage system, and polyacrylamide application rate on the soil penetration resistance during the two seasons (2015/16 – 2016/17). Experimental design was split-split plot with four replications. Main plot included two percent of fine particles, (A = 25.2 silt + clay) and (B = 38.5 silt + clay). Sub-main plots included three tillage systems; no-tillage (NT), moldboard plowing with rotor tiller (CT1), and chisel plowing with disk harrow (CT2). Sub-sub plots were three polyacrylamide (PAM) rates; 0, 10 and 20 kg ha^{-1}. Both locations were cultivated by wheat crop for two consecutive seasons. Results revealed that tillage system affected soil penetration resistance. Penetration resistance results revealed the existence of compacted layer beneath the tilled depth in all treatments in both locations. However, its hardness in location A was higher than in location B. The CT1 treatment had the highest value of cone index; however, the penetration resistance of CT2 and NT treatments was similar. High rate of PAM application improved penetration resistance especially with CT2 tillage system.

INTRODUCTION

Penetration resistance is an indicator for the level of compaction of the soil. Compaction limits root growth and the availability of air and water to the roots (Herrick and Jones, 2002, Lampurlanés and Cantero-Martínez, 2003). Soil compaction is a serious concern for farmers because it reduces crop yields by about 10% and can lead to water and soil quality degradation due to increased runoff and soil structure destruction. Several reasons are responsible for soil compaction as reported by (Handreck and Black, 2010). Fine particles present in the soil can block pores, reducing porosity. These particles may be organic or mineral and may be inherent in the soils' natural makeup, or may constituted from silt laden irrigation water, or by wind or traffic. Soil with a chemical imbalance may be more prone also to compaction. Excessive Na and low Ca means that soil particles will have difficulty flocculating to form aggregates and leads to a dispersive soil that forms a solid mass with minimal air ports. Low microbial activity will result in reduced break down of organic matter and in turn poor nutrient cycling resulted in excessive organic matter in the profile which can clog pores and cause layering. There are two forms of compaction can be found in soils; surface and subsurface. Surface compaction can be partly alleviated with normal tillage operations but subsurface compaction below the normal tillage depth will remain. Fracturing or cutting subsurface compacted soil has, in some cases, resulted in remarkable yield increases (Duiker, 2002). Conventional tillage (CT) is the main tillage practice used in the many regions because CT is good for seedbed preparation, residue and manure incorporation, weed control and alleviation of compaction. In fact several researches investigated the influence of tillage on the structure of soil and its penetration resistance (Abu-Hamdeh, 2003a,b, Abu-Hamdeh, 2014, An *et al*., 2015, Reichert *et al*., 2016, Shekhawat *et al*., 2016; Kargas *et al*., 2016). Conservation tillage methods (reduced and zero tillage) increase cone index compared to the conventional tillage (Afzalinia and Zabihi, 2014). There are also some research results showing no significant effect for conservation tillage on cone index (Rasouli *et al*., 2012). Parihar *et al*. (2016) conducted a long-term study to evaluate tillage practices on physical properties

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of a sandy loam soil in northwestern India. The tillage practices consisted of zero tillage and conventional tillage. They found that compared to conventional tillage plots, the bulk density and penetration resistance showed significant decline (11.0–14.3 and 11.2–12.0%) in zero tillage at 0–15 and 15–30 cm soil layers. Thus, they concluded that conservation agriculture based crop management can be advocated as sustainable intensification strategy in light textured soils of north-western India and other similar agro-ecologies of South Asia. Salem *et al*. (2015) established field experiment on a loamy soil to determine the short term influences of four tillage treatments (zero tillage, reservoir tillage, minimum tillage, and conventional tillage) on some soil physical properties. Soil bulk density and soil cone index were measured during crop growing season and at harvesting time. Their results indicated that there were significant differences between soil bulk density and cone index of zero tillage method and those of reservoir tillage, minimum tillage, and conventional tillage during the growing season; although, this difference was not significant at the time of harvesting in some soil layers. Overall, in most soil layers, tillage practice affected cone index in the order: zero tillage, reservoir tillage, minimum tillage, and conventional tillage. In sandy loam to silt loams soils (<25% clay) that are characterized by an unstable structure, the NT management is expected to be a limited value. In these soils, improving penetration resistance is expected to benefit from practicing tillage and the application of Polyacrylamid (PAM) as a soil conditioner. Therefore, the objective of the current study was to investigate the effects of these parameters (fine particles percent, tillage systems and PAM rate) on soil penetration resistance.

MATERIALS AND METHODS

Field experiment was carried out at the Agricultural Experimental Research Station of King Abdulaziz University (KAU) located at Hada Alsham (110 km north east of Jeddah 21° 79′ N, 39° 70′ E and Altitude of 226 m) to study the effect of fine particles, tillage systems, and poly-acrylamide (PAM) application on soil penetration resistance during two seasons 2015-2016 and 2016-2017. Table (1) shows the initial soil physical properties for both experimental sites. A split-split plot design with four replications was used in this experiment with 72 plots corresponding to a total area of 3300 m^2 in two locations differed in silt and clay contents. The parameters investigated were: two soil fine particles, three tillage systems and three PAM application rates. The main plot included two locations with different clay and silt contents and has not been cultivated for several years. The particle size distribution in the first location (A) was 74.8% sand, 15.5% silt, and 9.7% clay while in the second location (B) was 61.5% sand, 25.7% silt, and 12.8% clay. The sub main plots included three tillage systems (NT = No-tillage, CT1 = Moldboard plowing with rotor tiller, and CT2 = Chisel plowing with disk harrow). The sub-sub main plots were three granular PAM rates (0, 10 and 20 kg/ha PAM). The three levels of PAM were applied before planting and after applying tillage systems. Control plots were not treated by any amount of PAM under each tillage system (0 kg/ha). The entire area of each treated plot was covered completely with PAM and mixed with the upper 15 cm soil layer except for the treatment of no-tillage where the PAM was distributed on soil surface. Both experimental site were cultivated by wheat crop in November 21, 2015 and 2016 for two consecutive season. The recommended cultural practices for wheat crop other than the investigated variables were followed and sprinkler irrigation method was used in irrigation for both growing seasons.

Table 1. Initial physical soil properties at the beginning of the experiments

Parameter	Values	
	Location (A)	Location (B)
Particle size analysis		
Clay %	9.7	12.8
Silt %	15.5	25.7
Sand %	74.8	61.5
Texture grade	Sandy loam	Sandy loam
Penetration resistance		
Layer 0-15	Moderate compacted	Slightly compacted
Layer 15-30	compacted	compacted
Layer 30-45	compacted	compacted

Soil penetration resistance was measured using soil penetrometer at filed capacity at three different locations in each plot. In each location measurements were done for three vertical soil depths: 0-15 cm, 15-30 cm, and 30-45 cm. The penetration measurements were performed based on the ASAE S313.3 standard method. To measure soil resistance, the penetrometer rod was inserted in the soil at a rate of approximately 2.5cm per second when the soil was at the filed capacity. The scale presented by Duiker (2002) was used to interpret penetration resistance readings. Measurements of soil penetration were collected before the start of the experiment and after each growing season.

RESULTS AND DISCUSSION

Initial penetration resistance results before starting the experiment (Table 1) indicated that both soil locations are compacted. however the surface layer (0-15) was less compacted compared to subsurface layers and. Moreover, the compaction was higher in location A than in location B. once the tillage treatments and PAM were applied and the soil was cultivated soil penetration resistance was changed. Results of the effects of differences in location, tillage systems, and PAM rate on cone index (penetration resistance) during the first growing season are shown in Table (2). Results show that the cone index values increased with increasing soil depth in all tillage and PAM treatments in both locations. Furthermore, these values were higher in location A (25.2 clay-silt) compared to location B (38.2 clay-silt). In both soil locations the values of cone index for surface layer (0-15 cm) were 0 which means this surface soil layer become not compacted. Results of cone index for 15-30 soil layer indicated slightly to moderate compaction. It is noted that immediately below the tilled layer (15-30 cm) and 0 kg/ha PAM rate the "moldboard ploughing with rotor tiller" had the greatest value of cone index, followed by the "chisel plowing with disk harrow", and the "no-till" which had the lowest value of cone index in both locations. This trend was repeated under the 10 and the 20 kg/ha PAM rates. As a result, compact rating was "slight" for the "no-till" treatment and "moderate" for both "moldboard plowing with rotor tiller" and "chisel plowing with disk harrow" treatments in the 0 kg/ha PAM rate plots in the first season. The compaction of the 30-45 cm layer was sever under all PAM rates of the location A while was moderate in location B as indicated by cone index presented in Table (2). Continual cultivation in the soil for the second season in both locations led to great change in penetration resistance.

Table 2. Penetration resistance measurements and their interpretation according to Duiker (2002) as affected by locations, tillage systems and PAM rates for the soil after the first growing season of 2015-2016

Tillage sys.	PAM rate (kg/ha)	Soil layers (cm)	Location (A)			Location (B)		
			Cone index >300 psi	Compact rating	Need for Sub soiling	Cone index >300 psi	Compact rating	Need for Sub soiling
NT	0	0-15	0	None	No	0	None	No
		15-30	37	Slight	No	44	Slight	No
		30-45	100	Sever	Yes	62	Moderate	Yes
	10	0-15	0	None	No	0	None	No
		15-30	37	Slight	No	65	Moderate	Yes
		30-45	100	Sever	Yes	56	Moderate	Yes
	20	0-15	0	None	No	0	None	No
		15-30	37	Slight	No	85	Sever	Yes
		30-45	94	Sever	Yes	60	Moderate	Yes
CT1	0	0-15	0	None	No	0	None	No
		15-30	69	Moderate	Yes	54	Moderate	Yes
		30-45	81	Sever	Yes	56	Moderate	Yes
	10	0-15	0	None	No	0	None	No
		15-30	44	Slight	No	54	Moderate	Yes
		30-45	81	Sever	Yes	75	Moderate	Yes
	20	0-15	0	None	No	0	None	No
		15-30	31	Slight	No	54	Moderate	Yes
		30-45	69	Moderate	Yes	75	Moderate	Yes
CT2	0	0-15	0	None	No	0	None	No
		15-30	56	Moderate	Yes	62	Moderate	Yes
		30-45	87	Sever	Yes	69	Moderate	Yes
	10	0-15	0	None	No	0	None	No
		15-30	69	Moderate	Yes	62	Moderate	Yes
		30-45	100	Sever	Yes	62	Moderate	Yes
	20	0-15	0	None	No	0	None	No
		15-30	50	Moderate	Yes	0	None	No
		30-45	100	Sever	Yes	81	Sever	Yes

Location A: (clay and silt = 25.2%), Location B: (clay and silt = 38.5%), NT: no tillage, CT: cultivation tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer

Table 3. Penetration resistance measurements and their interpretation according to Duiker (2002) as affected by locations, tillage systems and PAM rates for the soil after the second growing season of 2016-20117

Tillage sys.	PAM rate (kg/ha)	Soil layers (cm)	Location (A)			Location (B)		
			Cone index >300 psi	Compact rating	Need for Sub soiling	Cone index >300 psi	Compact rating	Need for Sub soiling
NT	0	0-15	0	None	No	0	None	No
		15-30	25	None	No	0	None	No
		30-45	71	Moderate.	Yes	60	Moderate.	Yes
	10	0-15	0	None	No	0	None	No
		15-30	33	Slight	No	15	None	No
		30-45	60	Moderate.	Yes	30	None	No
	20	0-15	0	None	No	0	None	No
		15-30	27	None	No	0	None	No
		30-45	68	Moderate.	Yes	33	Slight	No
CT1	0	0-15	0	None	No	0	None	No
		15-30	47	Slight	No	28	None	No
		30-45	73	Moderate.	Yes	45	Slight	No
	10	0-15	0	None	No	0	None	No
		15-30	37	Slight	No	30	None	No
		30-45	70	Moderate.	Yes	35	Slight	No
	20	0-15	0	None	No	0	None	No
		15-30	22	None	No	33	Slight	No
		30-45	69	Moderate.	Yes	45	Slight	No
CT2	0	0-15	0	None	No	0	None	No
		15-30	35	Slight	No	28	None	No
		30-45	56	Moderate.	Yes	33	Slight	No
	10	0-15	0	None	No	0	None	No
		15-30	45	Slight	No	28	None	No
		30-45	65	Moderate.	Yes	30	None	No
	20	0-15	0	None	No	0	None	No
		15-30	35	Slight	No	25	None	No
		30-45	65	Moderate.	Yes	30	None	No

Location A: (clay and silt = 25.2%), Location B: (clay and silt = 38.5%), NT: no tillage, CT: cultivation tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer

The results of cone index for both locations after the second growing season are presented in Table (3). Results indicated that penetration resistance in the layer of 15-30 cm in location B has been changed from moderate to slight and from sever to moderate in 30-45 cm layer for all PAM rates. The improvement in penetration resistance was higher in location B than in location A. In location B the penetration resistance was None for all soil layer except for the layer of 30-45 cm of NT with 0 kg/ha PAM which was moderate and need sub soiling ploughing to remove. Also the penetration resistance was “Slight” for the layer of 30-45 cm for NT of 20 kg/ha PAM, CT1 of 0, 10 and 20 kg/ha PAM and CT2 of 0 kg/ha PAM. However slight penetration resistance not need for sub soiling ploughing. The results clearly indicated that presence of PAM in soil help to decrease soil compaction by improving penetration resistance.

Generally speaking, the results of penetration resistance measured by cone index reflect more compact soil layer beneath the tilled depth in all treatments. Soil strength increases with axle load and tire inflation pressure of the agricultural equipment. These results reflect a more compacted soil layer at shallow depths in the tillage treatments than in the no-tillage treatment. One possible reason for this is that, tillage can cause the formation of a tillage pan directly beneath the plow. The most damaging form of tillage is moldboard plowing, which forms a compacted subsoil layer just below the plow. Another reason for that, it is known that, soil bulk density increases with axle load and tire inflation pressure. The axle wheel loads and pressures resulted from trafficking the plots during secondary tillage operations and subsequent operations in the field can compact the soil in the tillage zone more than they can in the NT plots due to the increase in both shear and vertical soil stresses (Afzalinia and Zabihi, 2014). Similar results were published by Parihar *et al*. (2016) who found that the penetration resistance showed significant decline in zero tillage compared to conventional tillage at 0–15 and 15–30 cm soil layers. Tillage practice affected cone index in the order: zero tillage, reservoir tillage, minimum tillage, and conventional tillage. Therefore, the impact of soil compaction increase, produced by zero tillage treatment is a potential reason for crop yield reduction in this zero tillage method (Salem *et al*., 2015). A possible reason for the great improvement of penetration resistance in location B compared with location A especially in the second growing season could be PAM application. As the PAM level of the soils increased, the modulus of rupture decreased for the soils of the two locations. With a decrease in the modulus of rupture of the soil, the bulk density of the soil decreased. Since fine textured soils have larger modulus of rupture than coarse textured soil, the amount of decrease of bulk density of the fine textured soil (location B) was less than its value in coarse textured soil (location A) and improved penetration resistance. In general, structural improvement of the soils by adding PAM improves the bulk density of the soils irrespective of the tillage system that the soil is subjected to (Mamedov *et al*., 2010).

Conclusion

The obtained results from this study revealed that tillage system affected soil penetration resistance. Penetration resistance results revealed the existence of compacted layer beneath the tilled depth in all treatments in both locations. However, its hardness in location A was higher than in location B. The CT1 treatment had the highest value of cone index, however, the penetration resistance of CT2 and NT treatments were similar. High rate of PAM application improved penetration resistance especially with CT2 tillage system.

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