Effect of Fine Soil Particles, Tillage Systems and Polyacrylamide on Wheat Production and Some Soil Chemical Properties in Arid Regions

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***Abstract*—A field experiment was carried out at the Agriculture Research Station of King Abdulaziz University located at Hada Alsham, Saudi Arabia to study the effect of fine soil particles, tillage system and polyacrylamide on what production and some soil chemical properties. The design of the experiments was a split-split plot with four replications. The main plot included two soil locations A and B, (A with 25.2 silt & clay while B with 38.5 silt & clay). Sub plot included three tillage systems namely No-tillage (NT), Moldboard ploughing with rotor tiller (CT1) and Chisel ploughing with disk harrow (CT2). The sub-sub plot included polyacrylamide (PAM) rates and were 0, 10 and 20 kg/ha. The obtained results indicated that location B was better than location A because wheat production under location B was significantly higher than that of location A. Chisel ploughing with disk harrow (CT2) produced the highest grain yield for wheat crop followed by NT and CT1 tillage system respectively. Application of different rates of PAM (10 and 20 kg/ha) increased yield production compared with 0 kg/ha PAM. Soil nutrients including N, P and K were significantly increased in location B compared to those in location A. The nutrients also increased by increasing PAM rates in both locations.**

***Keywords*—Tillage system , soil amendments , soil texture , field crops, Polyacrylamide, irrigation system.**

I. INTRODUCTION

Use of non-toxic, anionic polyacrylamide (PAM) in the last couple of decades is often considered as an effective soil conditioner (Sojka et al., 2006). It has been known to improve soil aggregate stability (Agassi and Ben-Hur 1992), improve infiltration rate and soil water retention (Flanagan et al. 2003), and reduce runoff (Letey 1996) and soil erosion (Sojka et al. 2007). Sojka et al. (2007) reported that PAM improves the soil quality by altering the physical, chemical and biological properties of soil, thereby improving aeration, water and root penetration and erosion resistance. PAM application reduced the nitrogen losses from soil and enhanced the yield of irrigated corn. However, less attention is given on its effectiveness on properties of soils such as pH, electrolyte level, and organic matter and concentration of nutrient (N, P and K) in the rhizosphere.

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No-till is routine practice in countries like USA, Brazil, Argentina, Canada, and Australia, but in contrast farmer blindly rely on conventional tillage in developing countries. No-till agriculture is considered one of the important tool that increase food safety by rising production and decreasing supply degradation (FAO, 2012). Rainfed agriculture accounts for almost 82% of world's total cropland and rainfed farmers in semiarid regions are highly vulnerable to weather uncertainties and climate change. In arid and semi-arid region, for instance, water stress can be expected to affect rainfed crop yield once every three (Raju and Chand, 2010).

Tillage system affect on important soil chemical characteristics and differences between no-till and conventional tillage with regard to pH, EC, OM and the concentration of nutrients have been observed (Rosolem and Calonego, 2013). The fate of the nutrients in the soil depends on plant roots, plant demand, export through harvesting, and soil type. Soil management can affect nutrient (N, P and K) concentration in soil and availability to plant roots (Rosolem and Calonego, 2013). Crop cover under no-till system greatly reduced the N losses and P fixation in the soil, increasing nitrogenous and phosphate fertilization efficiency and maintaining the nutrients balance in the system. This increase in N and labile P is a result of different interacting factors, such as minimal mixing and soil disturbance, increased residue return, reduced surface soil temperature, higher moisture content and decreased risk of erosion (Logan et al., 1991; Blevins and Frye, 1993). Fuentes et al. (2014) reported that zero tillage in both monoculture and rotation have significant effect on total nitrogen content, soil organic C, pH and EC, therefore enhanced the grain yield of maize and wheat. These tillage effects, however, are environmentally dependent and different results have been reported under different types of soil and climate (Limousin and Tessier, 2007; Thomas et al., 2007).

Individual effect of no-till system and PAM on soil and plant growth has been investigated thoroughly, however, little information is available on its combined use and subsequent effects on plant and soil. Therefore, this study aimed to investigate the short-term effect of tillage and PAM application on yield and yield components of wheat and on some chemical properties of soil.

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II. MATERIAL AND METHODS

A. *Experimental location, design, treatment and cultural practices*

The experiment was conducted at the Agriculture Experimental Station of King Abdulaziz University located at Hada Alsham, northeast of Jeddah (21° 48′ 3″ N, 39° 43′ 25″ E), Saudi Arabia. A split-split block design with four replications was used in this experiment with a total of 72 plots corresponding to the two soil texture, three tillage systems and three PAM rates. The main blokes included two different locations with different clay and silt contents. Both location have not been cultivated for several years. Table (1) presents the experimental soil analysis before starting. The sub plot included three tillage systems (NT = No-tillage, CT1 = Moldboard ploughing with rotor tiller, and CT2 = Chisel ploughing with disk harrow). The sub-sub plots included three granular PAM rates (0, 10 and 20 kg/ha). The three rates of granular polyacrylamide (PAM) were applied before planting and after applying tillage systems. 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. After applying tillage systems and PAM rates, wheat seed was sown in rows spaced at 20 cm apart using a 10 cm-wide seed drill in all treatments and the seeding rate was 135 kg ha^{-1}. After germination the plants was fertilized by the recommended doses of NPK fertilizers. Moreover, the recommended cultural practices for wheat crop were followed until the harvesting.

B. *Measurements of crop yield and yield components data*

Yield and yield component include: stem length at harvesting, number of spikes/m2, spike length, number of grains/spike, seed yield, straw yield and seed index were measured. The measurement and determination procedures were performed as described in Kumar et al (2012) where the plant height, spike length, and number of grains per spike were recorded from ten randomly selected plants from each plot. Total number of spikes was measured in 1 m^2 in each plot. Crop harvest was completed by using a plot combine and air dried. Total straw and grain yield of wheat crop were measured from each plot and then converted into t ha^{-1}. Seed index was obtained by taking the weight of 1000 seeds.

C. *Soil organic matter (SOM)*

Determination of soil organic matter involved the reduction of potassium dichromate ($K2Cr_2O_7$) by organic carbon compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulfate.

D. *Soil chemical properties*

For initial soil analysis, four random soil samples from surface layer (0-30 cm depth) were collected from each experimental site before planting. For the soil analysis after the end of each growing season, one homogeneous sample from each plot was collected air dried, sieved and analyzed different chemical properties. Soil pH and EC (dS m^{-1}) was measured in 1:1 soil suspension and extraction as described by Jackson (1973). Determination of total nitrogen was done according to the Kjeldahl method (Jackson, 1973) using Kjeltec auto 1030 analyzer. Available P was determined as described in Olsen and Sommers (1982). Available K was determined as described in Carson (1980), and was measured using flame emission spectrophotometry.

E. *Statistical Analysis*

The obtained data were statistically analyzed after applying the analysis of variance assumptions using SAS software. The mean separation was performed using LSD test (Steel et al., 1997).

III. RESULTS

A. *Effects of location, tillage system and PAM on growth and yield parameters of wheat*

Results presented in Table (2) show the effects of different tillage system and PAM rates in both locations (A and B) on growth and yield parameters of wheat. Results revealed that, main effects of location, tillage system and PAM were significantly affected on number of spike m^{-2}, number of grains $spike^{-1}$ and grain yield (t ha^{-1}). No significant improvement in plant height was observed as affected by in location, tillage systems and PAM rates. Spike length was only varied significantly by different tillage systems. Tillage system did not show any significant effect on seed index. Results also revealed that, location did not significantly contribute in promoting straw yield (t ha^{-1}). All the second and third level interactions were found non-significant in plant height and spike length. Second level interaction between location and tillage systems was observed significant in case of number of spike m^{-2}, number of grains $spike^{-1}$, and straw yield. Interaction between location and PAM rate was found significant in number of spike m^{-2}, number of grains $spike^{-1}$, grain yield and seed index. Second level interaction between tillage system and PAM significantly affected number of spike m^{-2}, number of grains $spike^{-1}$, grain yield, straw yield, and seed index. Only number of spike m^{-2} and number of grains $spike^{-1}$ were significantly different with third level interaction (location*tillage systems* and PAM).

Mean comparison of growth and yield parameters under two locations (A and B) clearly indicated that maximum plant height (66.3 cm), number of spike m^{-2} (358), spike length (9.22 cm), number of grains $spike^{-1}$ (34), grain yield (4.59 t ha^{-1}), straw yield (7.27 t ha^{-1}), and seed index (37.71 g) was observed under location B (clay and silt = 38.5%). All the other parameters except plant height, spike length and straw yield showed significantly higher values at location B than location A (clay and silt = 25.2%).

Different trends were observed for maximum mean values of growth and yield parameters under tillage systems. No till (NT) treatment was statistically superior to moldboard ploughing with rotor tiller (CT1) and chisel ploughing with disk harrow (CT2) by producing maximum straw yield (7.90 t ha^{-1}). CT1 was better than NT and CT2 by inducing maximum plant height (67.06 cm) and seed index (39.5 g). CT2 was statistically better than NT and CT1 by yielding maximum numbers of spikes m^{-2} (353), spike length (9.43 cm), numbers of grains $spike^{-1}$ (33) and grain yield (4.53 t ha^{-1}).

Improvement in growth and yield parameters by the application of (PAM) was depend on PAM. Application rates. Increasing PAM rate increased all the measured parameters. Tallest plant height (67.45 cm), number of spike m^{-2} (344), spike length (9.30 cm), number of grains $spike^{-1}$ (33), grain yield (4.60 t ha^{-1}), straw yield (7.57 t ha^{-1}), and seed index (41.27 g) were obtained from the application of 20 kg ha^{-1} PAM followed by 10 kg ha^{-1} PAM and 0 kg ha^{-1} PAM respectively (table 2).

B. Effects of 2nd and 3rd level interactions on growth and yield attributes of wheat

a. Interaction effect of location and tillage system (2nd level interaction)

Effect of 2nd level interaction between location and tillage system on number of spikes m^{-2}, number of grains $spike^{-1}$, and straw yield (t ha^{-1}) is shown in figure (1). Results indicated that the highest number of spikes m^{-2} obtained under chisel ploughing with disk harrow (CT2) in both location however, spike number in location B with higher than that of location B. the least number of spike in location A (262) and location B (345) were produced under moldboard ploughing with rotor tiller (CT1). Numbers of grain/spike were the highest in CT2 where it was higher in Location B than that of location A. The least numbers of grains (29 and 32) at locations A and B respectively were found under no tillage (NT) treatment. Maximum straw yield at location A and B was achieved under NT while minimum was under CT2.

b. Interaction effect of location and PAM (2nd level interaction)

Significant interaction between location and polyacrylamide (PAM) for their effect on number of spikes m^{-2}, number of grains $spike^{-1}$, grain yield (t ha^{-1}), and seeds index (g) are presented in Table (3). Increasing the rate of PAM at both locations increased all investigated parameters. However, highest numbers of spikes (388), numbers of grains (35), and grain yield (5.29 t ha^{-1}) was obtained at location B (clay and silt = 38.5%) with 20 kg PAM ha^{-1}. Only maximum value of seed index (42.96) was observed at location A (clay and silt = 25.2%) with 20 kg PAM ha^{-1}.

c. Interaction effect of tillage system and PAM (2nd level interaction)

Results presented in table (4) showed an improvement in numbers of spike m^{-2}, number of grains $spike^{-1}$, grain yield, straw yield, and seed index by the interaction of tillage system and polyacrylamide. Enhancement in growth and yield parameters by the application of PAM under each tillage system was dependent on the rate of PAM. Increasing the amount of PAM showed additive effect on all the studied parameters under each tillage system. Maximum numbers of spikes (376) and number of grains (35) were obtained from chisel ploughing with disk harrow (CT2) along with 20 kg PAM ha^{-1}. Highest grain yield (4.91t ha^{-1}) and straw yield (8.74 t ha^{-1}) was recorded in the treatment of 20 kg PAM ha^{-1} under no tillage (NT) treatment. Seed index was the highest under 20 kg PAM ha^{-1} of moldboard ploughing with rotor tiller (CT1).

d. Interaction effect of location, tillage system and PAM (3rd level interaction)

The mean values number of spikes m^{-2}, and number of grains $spike^{-1}$ as affected by 3rd level interaction among location, tillage system and PAM are presented in Table (5). Results clearly indicated that, the enhancement in growth parameters under all tillage systems at each location is increasing with increasing the rate of PAM. Highest numbers of spikes (419) and numbers of grains (38) were recorded in 20 kg PAM ha^{-1} under CT2 (chisel ploughing with disk harrow) tillage system at location B (clay and silt = 38.5%).

C. Effect of location, tillage system and PAM on soil organic matter

Results of soil organic matter presented in Figure (2) revealed that, both locations were significantly different from each other in organic matter contents. Location B (clay and silt = 38.5%) had higher organic matter content than location A (clay and silt = 25.2%) under all tillage systems and PAM rates. Different tillage systems also showed significantly different effect on soil organic matter. However, maximum organic matter in both locations and at all the levels of PAM was observed under control treatment followed by CT1 (moldboard ploughing with rotor tiller). Different rates of PAM (0, 10 and 20 kg ha^{-1}) showed insignificant difference on soil organic matter in both locations and under all the tillage systems.

D. Effects of location, tillage system and PAM on soil pH, EC, total N and available P and K

Results of the effect of tillage system and PAM on soil EC, pH, total N and available P and K at both locations are presented in Table (6). Results indicated that, only the locations were significantly different in soil EC. Location B (clay and silt = 38.5%) was having remarkably higher EC (4.04) than location A (clay and silt = 25.2%). pH insignificantly affected by the investigated parameters. However, 2nd level interaction between tillage system and PAM was significantly affected on soil pH.

Comparing means of total N and available P and K in both locations revealed that, the highest total N (0.053%), available P (34 mg kg^{-1}) and K (713 mg kg^{-1}) were found in location B. When means of total N and available P and K were compared under different PAM rates, it was observed that, increasing the rate of PAM application increased nutrients availability. Maximum value of total N (0.055%), available P (42 mg kg^{-1}) and K (618 mg kg^{-1}) was recorded under the application of 20 kg PAM ha^{-1}.

a. Interaction effect of tillage system and PAM on soil pH and available K

Means of soil pH and available K as influenced by the interaction between tillage systems and PAM rates are shown in Figure 3. Increasing PAM application rate increased soil pH and available K under all the tillage systems. The highest pH (7.59) was observed under chisel ploughing with disk harrow (CT2) and 20 kg ha^{-1} PAM. Lowest pH (7.36) was also observed under CT2 but with 0 kg ha^{-1} PAM. Soil available K was also varied significantly under the interaction effect of tillage systems and PAM rates. Highest available K (643 mg kg^{-1}) was recorded under no tillage (NT) with the application of 20 kg ha^{-1} PAM. Lowest available K contents (515) were observed under CT2 with 0 kg ha^{-1} PAM.

IV. DISCUSSION

Promotion of all the growth and yield parameters of wheat except seed index has been observed at Location B (clay and silt = 38.5%) than location A (clay and silt = 25.2%). The improvement in growth and yield of wheat at location B could be attributed to larger percentage of fine particles (silt and clay) especially clay in location B compared with that of location A. presence of fine soil particles have been reported to improve water retention, water holding capacity and reduce plant nutrient losses (Reuter, 1994; Ismail and Ozawa, 2007) which ultimately enhance crop growth and yield (Obst, 1989; Carter et al., 1998). Besides this, fine soils also retain more organic matter which play great role in improving crop growth and yield. The presence of significantly higher organic matter in location B than in location A can further strengthen this premise. Improvement in soil structure, aggregation, water holding capacity and nutrient availability were always accompanied with increasing the contents of soil organic matter, (Tanaka et al., 2005; Narayan and Lai, 2006, Ismail 2013).

Regarding tillage systems, chisel ploughing with disk harrow (CT2) was better compared with the other. It was produced the maximum growth parameters because the enhancement in numbers of spikes m^{-2}, spike length, numbers of grains $spike^{-1}$, and grain yield was observed under this system. As a result, high yield was produced. Higher grain yield obtained under CT2 might be resulted due to concomitant improvement in yield related attributes such as numbers of spikes m^{-2}, spike length and numbers of grains $spike^{-1}$ under CT2. Dependence of grain yield on yield related parameters like number of plants per unit land area, spikes per plant, spikelets per spike, grains per spikelet, and single grain weight is confirmed by many researchers, (Stoddard, 1999; Duggan and Fowler, 2006; Royo et al., 2006). Another possible reason for the enhancive effect of CT2 on yield and yield related parameters could be positive influence of CT2 on soil fertility properties. Chisel ploughing increased nitrate concentration by about 42% compared to 29% under moldboard ploughing and to non-plowed soil (Calderon and Jackson, 2002). Increasing nitrate concentration in soil increased plant growth and productivity.

Increasing PAM rate increased yield and yield components of wheat crop compared to control Presence of PAM in soil improved soil physical properties like hydraulic conductivity, infiltration rate, aeration, root penetration, and aggregate stability, thereby boosts plant establishment and growth (Flanagan et al. 2003). Also, incorporated PAM in soil can reserve available water and maintain sufficient soil moisture for plants, therefore decreases water stress during drought events and increase the efficiency of water use by increasing crop production (Lentz and Sojka, 2009; Awad et al., 2013; Lee et al., 2015).

The relatively higher organic matter contents recorded at location B might be due to intrinsic nature of fine particles. The soils having higher proportion of fine particles (clay and silt) may retain more organic matter than course particle soils. On the other hand, low organic matter is generally found in sandy soils due more oxidation of organic matter through high aeration. Tillage treatment significantly affected the organic matter content of the soils in the two locations. Tillage reduces SOM by different ways. Tillage removes plant residue from the soil, thus limiting the normal cycling of material in the system. Tilling may provide air that enhances the rate of microbial decomposition. Furthermore, tillage breaks up soil aggregates, which have a significant function in stabilizing SOM. When soil aggregates are split up, SOM becomes much more susceptible to degradation and succeeding loss.

Significantly higher EC at location B (clay and silt = 38.5%) than location A generally attributed to higher clay contents. Charge bearing property of clay particles can bind different cations and anions resulting in higher EC. Whereas in soils with high proportion of sand particles, cations and anions of salts can be leached due to poor binding capacity of sand particles. Similarly, significantly more total N and available P and K at location B could be also associated with high fine particles and mainly due to two reasons. Firstly, due to high nutrient retention by fine soil particles and secondly due to high organic matter contents in such soils. Similar results reported by Franchini et al. (2003); Pavinato and Rosolem (2008),who reported that, organic matter increases the percentages of calcium (Ca), magnesium (Mg), and K in the soil cation exchange capacity (CEC) due to the complexation of ions, which can reduce nutrient losses due to leaching, especially K.

In this study PAM with a rate of 20 kg ha^{-1} enhanced total N and available P and K of soil. Increase in soil nutrient contents by PAM is associated with improved soil physical, chemical and biological properties of soil, thereby improving aeration, water and root penetration and erosion resistance (Sojka et al., 2007). Several studies showed that, small rate of synthetic organic polymers, including anionic polyacrylamide (PAM), can improve soil structure and aggregate stability, bonding between adjacent aggregates and clay flocculation (Graber et al., 2006, Peterson et al., 2002). Application of PAM improved vertical movement of soil water and major/minor nutrients (NH_3-N, P, K, Ca, Mg, and Fe) which enhanced the nutrient availability for plants (Kim et al. 2015).

V. Conclusion

The obtained results showed significant improvement in growth and yield parameters of wheat in Location B compared with those of location A. Chisel ploughing with disk harrow (CT2) significantly improved number of spike m^{-2}, spike length, number of grains $spike^{-1}$ and grain yield compared with NT and CT1 tillage systems. The highest rate of PAM (20 kg ha^{-1}) was the best compared with 10 and 0 kg ha^{-1}. Number of spikes m^{-2}, number of grains $spike^{-1}$ and straw yield were increased as affected by the interaction between location and tillage system and the interaction between tillage system and PAM. However, the interaction between location and PAM increased number of spikes m^{-2}, number of grains $spike^{-1}$, grain and seed index. Significantly higher organic matter contents, EC, total N and available P and K were observed in location B compared with location A. Tillage systems did not show significant effect on any of the soil chemical property and soil nutrient. Application of PAM (20 kg ha^{-1}) improved total N and available P and K in soil. In conclusion, using of Chisel ploughing with disk harrow (CT2) and high rate of PAM (20 kg ha^{-1}) could be a potential strategy to improve wheat production in arid regions.

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TABLE 1: INITIAL PHYSICAL AND CHEMICAL SOIL ANALYSES BEFORE THE STARTING OF THE EXPERIMENT.

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
Bulk density	(g/cm^3)	1.87	1.71
Air porosity	(%)	29.4	35.4
Basic infiltration rate	(cm/hour)	16.0	7.0
Organic matter	(%)	0.65%	1.10%
EC $_{(1:1\ soil\ extraction)}$	($dS\ m^{-1}$)	0.366	9.16
pH$_{(1:1\ soil\ suspension)}$		7.70	7.32
Nitrogen	(%)	0.03	0.08
Phosphorus	($mg\ kg^{-1}$ soil)	6	13
Potassium	($mg\ kg^{-1}$ soil)	475	1140

TABLE 2: EFFECT OF LOCATION, TILLAGE SYSTEM AND PAM RATE ON GROWTH AND YIELD ATTRIBUTES OF WHEAT.

Treatments	Plant height (cm)	Number of spike m^{-2}	Spike length (cm)	Number of Grains/ $spike^{-1}$	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Seed index (g)
Location (L)							
A	65.55	308.5^{b}	9.12	30.05^{b}	3.75^{b}	7.13	40.37^{a}
B	66.30	357.9^{a}	9.22	33.84^{a}	4.59^{a}	7.27	37.71^{b}
LSD	ns	4.39	NS	0.50	0.28	NS	1.61
Tillage system (TS)							
NT	66.25	343.4^{b}	9.34^{a}	31.05^{c}	4.16^{b}	7.90^{a}	38.6
CT1	67.06	303.4^{c}	8.73^{b}	31.83^{b}	3.82^{c}	6.43^{c}	39.5
CT2	64.47	352.8^{a}	9.43^{a}	32.96^{a}	4.53^{a}	7.27^{b}	39.0
LSD	NS	8.53	0.346	0.721	0.14	0.189	NS
Polyacrylamide (PAM) rates (kg ha^{-1})							
0.0	64.93	314.3b	9.07	30.80^{b}	3.39^{b}	6.82^{c}	35.32^{b}
10.0	65.40	341.1a	9.13	32.25^{a}	4.51^{a}	7.22^{b}	40.54^{a}
20.0	67.45	344.2a	9.30	32.80^{a}	4.60^{a}	7.57^{a}	41.27^{a}
LSD	NS	8.35	NS	0.698	0.149	0.327	0.149
Significance							
L	NS	**	NS	**	**	NS	*
TS	NS	**	**	**	**	**	NS
PAM	NS	**	NS	**	**	**	**
L*TS	NS	**	NS	**	NS	**	NS
L*PAM	NS	**	NS	**	**	NS	**
TS*PAM	NS	**	NS	**	**	**	**
L*TS*PAM	NS	**	NS	*	NS	NS	NS

A: clay and silt = 25.2%, B: clay and silt = 38.5%, NT: no tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, ns: not significant ($p \leq 0.05$), * and ** significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. Means followed by the same letter(s) are not significantly different according to least significant difference (LSD) test at $p \leq 0.05$.

TABLE 3: INTERACTION EFFECT OF LOCATION AND PAM RATE ON NUMBER OF SPIKES M-2, NUMBER OF GRAINS SPIKE-1, GRAIN YIELD (T HA-1), AND SEEDS INDEX (G)

Location	PAM rate (kg ha^{-1})	Number of spikes m^{-2}	Number of grains $spike^{-1}$	Grain yield (t ha^{-1})	Seed index (g)
	0	300	28	3.14	37.44
A	10	302	31	3.74	40.71
	20	324	31	4.37	42.96
	0	327	33	3.64	33.20
B	10	358	34	4.83	39.58
	20	388	35	5.29	40.37
LSD		*11.88*	*0.99*	*0.21*	*1.15*

A: clay and silt = 25.2%, B: clay and silt = 38.5%. LSD = least significant difference at $p \leq 0.05$

TABLE 4: NUMBER OF SPIKES, NUMBER OF GRAINS/SPIKE, GRAIN AND STRAW YIELDS AND SEEDS INDEX (G) AS AFFECTED BY THE INTERACTION EFFECT OF TILLAGE SYSTEM AND PAM RATE

Tillage system	PAM rate (kg ha^{-1})	Number of spikes m^2	Number of grains $spike^{-1}$	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Seed index (g)
NT	0	331	28	3.02	7.39	32.95
	10	337	32	4.55	7.57	41.09
	20	361	33	4.92	8.74	41.76
CT1	0	289	31	3.17	6.11	35.17
	10	302	31	4.13	6.55	41.10
	20	319	33	4.15	6.64	42.22
CT2	0	322	33	3.99	6.77	37.83
	10	360	34	4.73	7.33	38.76
	20	376	35	4.86	7.72	40.49
LSD		*14.55*	*1.22*	*0.26*	*0.57*	*1.41*

NT: no tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow. LSD: least significant difference at $p \leq 0.05$

TABLE 5: NUMBER OF SPIKES AND NUMBER OF GRAINS PER SPIKE AS AFFECTED BY THE INTERACTION AMONG LOCATION, TILLAGE SYSTEM AND PAM RATE.

Location	Tillage system	PAM rate (kg ha^{-1})	Number of spikes m^2	Number of grains $spike^{-1}$
A	NT	0	302	24
		10	338	30
		20	347	32
	CT1	0	242	30
		10	265	31
		20	279	32
	CT2	0	324	30
		10	334	31
		20	344	32
B	NT	0	325	32
		10	373	34
		20	375	35
	CT1	0	325	32
		10	336	33
		20	372	35
	CT2	0	319	34
		10	375	36
		20	419	38
	LSD		*20.47*	*1.71*

A: clay and silt = 25.2%, B: clay and silt = 38.5%, NT: no tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow. LSD = least significant difference at $p \leq 0.05$

TABLE 6: EFFECT OF LOCATION, TILLAGE SYSTEM AND PAM ON SOIL EC, PH, TOTAL NITROGEN AND AVAILABLE PHOSPHORUS AND POTASSIUM UNDER WHEAT CROP.

Treatments	Soil EC ($dS\ m^{-1}$)	Soil pH	Total N (%)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)
Location (L)					
A	1.31[b]	7.47[a]	0.016[b]	25[b]	442[b]
B	4.04[a]	7.51[a]	0.053[a]	34[a]	713[a]
LSD	*0.46*	*NS*	*0.032*	*7.01*	*67.22*
Tillage system (TS)					
NT	2.47[a]	7.51[a]	0.025[a]	26[a]	675[a]
CT1	2.91[a]	7.47[a]	0.030[a]	31[a]	636[a]
CT2	2.65[a]	7.48[a]	0.039[a]	26[a]	644[a]
LSD	*NS*	*NS*	*NS*	*NS*	*NS*
Polyacrylamide (PAM) rates ($kg\ ha^{-1}$)					
0.0	2.578[a]	7.40[a]	0.017[b]	20[b]	555[b]
10.0	2.712[a]	7.48[a]	0.032[a]	21[b]	559[b]
20.0	2.760[a]	7.52[a]	0.055[a]	42[a]	618[a]
LSD	*NS*	*NS*	*0.025*	*7.41*	*51.36*
Significance					
L	**	*NS*	*	*	**
TS	*NS*	*NS*	*NS*	*NS*	*NS*
PAM	*NS*	*NS*	*	**	*
L*TS	*NS*	*NS*	*NS*	*NS*	*NS*
L*PAM	*NS*	*NS*	*NS*	*NS*	*NS*
TS*PAM	*NS*	**	*NS*	*NS*	**
L*TS*PAM	*NS*	*NS*	*NS*	*NS*	*NS*

A: clay and silt = 25.2%, B: clay and silt = 38.5%, NT: no tillage, CT1: moldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, ns: not significant ($p \leq 0.05$), * and ** significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. Means followed by the same letter(s) are not significantly different according to least significant difference (LSD) test at $p \leq 0.05$.