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Original Research Article



Some agricultural practices for improving the productivity of moderately sodic soil I: soil properties and wheat vegetative growth

Taha, M.B.¹, Abd Elhamed, A. S.²

¹Soils, Water and Environment (SWERI), Agricultural Research Center, Giza, Egypt.

²Agricultural Crop Research Institute, Agricultural Research Center, Egypt.

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Abstract

The present investigation was conducted in two successive seasons of 2015/2016 and 2016/2017 at Sids Agric. Station, ARC to determine the effect of two tillage systems, i.e. shallow and subsoiling tillage as well as three gypsum levels (0.0, 4.76, and 9.52 t/ha) and four farmyard manure (FYM) levels (0.0, 11.9, 23.8, and 35.7 m³/ha) on the properties of moderately sodic soil and wheat growth. The results reveal that subsoiling tillage improved soil bulk density, total porosity, and soil fertility while increasing gypsum and FYM levels had a positive effect on soil reaction, soil organic matter, total porosity, soil available N, P, and K as well as wheat vegetative growth namely, plant height, number of spikes/m², number of grains/spike and 1000-grain weight. In contrast, soil salinity was increased by increasing FYM levels. The highest values of wheat growth parameters were achieved under the treatment of 9.52 t/ha gypsum combined with 35.7 m³/ha FYM under subsoiling tillage. From these results, it could be recommended to use subsoiling tillage and add 9.52 t/ha gypsum and 35.7 m³/ha FYM to improve the moderately sodic soil as well as enhance wheat growth.

Keywords Farmyard manure, Successive seasons, Sodic soil, Wheat growth

Introduction

Wheat is one of the most important crops all over the world. It is the greatest source of food for a large number of people. Also, wheat is the main source of fodder for animal nutrition to developing animal production. To meet the tremendous increasing of the local consumption, the policy of our country aims to maximizing wheat production. This can be performed by two ways: increasing the area cultivated by wheat and improving the different processes related to wheat production such as introducing high yielding varieties, fertilization, tillage and improving chemical and physical properties, etc.

Tillage is one of the most agricultural practices for crop production and soil properties. It is defined as mechanical operations of the soil for plant growth, which influence various soil properties, e.g., soil temperature, water retention, infiltration, soil salinity, soil reaction, and soil organic matter (Strudley et al., 2008). In general, there are two types of tillage, conservation tillage (surface or no tillage) and

conventional tillage include many operations aimed to mixed plant residues and organic manure into the soil. On the other hand, Lal et al. (1994) mentioned that the conservation or surface tillage is concerned with the method of preparation of seedbed that contains plant residues as mulch and left the soil surface roughness. The selection of suitable tillage type overcame many edaphic constraints, while the inopportune one resulted in many problems, such as the destruction of soil structure, enhancing erosion, loss of organic matter, and plant nutrients leaching (Lal, 1993). Reducing tillage has a beneficial effect on many soil properties, while excessive tillage gave negative effects on soil erosion (Iqbal et al., 2005). In addition, Khan et al. (2001) indicated that reducing tillage improved the size and the distribution of pores, consequently increasing the soil to store and diffuse the air, water, and nutrients. Additionally, several problems of soil properties were appear due to long-term conventional tillage, e.g. plough bottom thickening, a shallow soil tillage layer, reducing water holding capacity, poor permeability, and

decreasing in soil structure (Van Wie et al., 2013). Liu et al. (2016) reported that conventional tillage can increase the penetration resistance beneath the tilled layer. Furthermore, Guan et al. (2014) indicated that subsoiling improved crop production. In this concern, Wang et al. (2019) stated that tillage at 20-50 cm depth, soil bulk density, and the soil compaction were decreased, while it improved each of macro aggregation (> 0.25 cm), the structure stability, and soil water storage, consequently increased maize yield. Inversely, many investigators reported the favorable effect of subsoiling one, such as Jiao et al. (2017) and Soltanabadi et al. (2018). Unfortunately, heavy agricultural equipment resulted in soil compaction and formation in many hard pans which decrease root growth, limiting access to nutrients and water in subsoil, consequently reducing crop production (Tahir et al., 2018).

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is the most important amendment for sodic soils due to its being cheaper. It is considered the main source of calcium and sulfur for plant nutrition (Chen et al., 2005). The geological deposits are the traditional source of gypsum. Gypsum contains about 23 % calcium and 19 % sulfur. It is used for treating the sodic soil, where calcium present in gypsum can displacement of sodium on the cation exchange capacity of the soil. This process needs a good drainage system to leach the salts accumulated in the root zone by irrigation (Stephen, 2002). Many workers stated the beneficial effect of gypsum on improving physical and chemical properties of soil, e.g., decreasing each of soil reaction, soil salinity, total porosity, exchangeable sodium percentage, and bulk density as well as increasing the soil hydraulic conductivity, total porosity, and aggregates water stability such as Abou Youssef (2001), Manzoor et al. (2001), Sarwar et al. (2011) and Abdel-Fattah et al. (2015).

Farmyard manure has been increasingly used by farmers in Egypt in the past many decades. The using of farmyard manure is used as soil conditioners and as fertilizer. In this concern, Ali et al. (2009) reported that using organic fertilizer resulted in improving physical, chemical, and nutritional soil properties as well as vegetative growth of wheat grown in sandy soil. In addition, Chun et al. (2007) and Rajendran et al. (2009) reported that organic manure decreased sodium, carbonates, and bicarbonates in soil solution as well as increased the availability of the nutrients in the soil. Organic manure application, improved the soil exchange capacity, consequently results in leaching the excess cations from the root zone (Clark et al., 2007). Ndiaye et al. (2000) and Madejón et al. (2001) mentioned that organic manure enhanced soil microbial activity. Importantly, Madejón et al. (2001) and Sarwar et al. (2011), and Abbas and Hussain (2020) reported that combined gypsum with organic manure resulted in enhancing the effect of organic manure alone on soil properties, especially in sodic soil.

Accordingly, this work aims to investigate the effect of gypsum and farmyard manure under different tillage systems on soil properties and the growth of wheat plants grown in moderately sodic clay soil.

Materials and methods

Set up of the experiment

To evaluate the effect of different levels of gypsum and farmyard manure under two tillage systems, i.e., shallow and subsoiling on wheat growth and soil properties after wheat harvest, two field experiments were conducted at the Agricultural Farm of Sids Agricultural Research Station, ARC, Beni-Suef Governorate (Lat. $29^{\circ}04'$ N, Long. $31^{\circ}06'$ E and 30.4 m above sea level) in 2015/2016 and 2016/2017 seasons. A representative surface soil sample before sowing was taken to determine some chemical and physical soil properties according to A.O.A.C. (1990) and listed in Table 1. Also, surface soil samples from each plot after wheat harvest were taken to determine some soil properties according to A.O.A.C. (1990).

Table 1. Physico-chemical characteristics analysis of soil before sowing

Characteristics	1 st season	2 nd season
Particle size distributions %:		
Coarse sand	0.36	0.55
Fine sand	18.73	15.17
Silt	29.12	31.09
Clay	51.79	53.19
Textural class	Clay	Clay
ESP (%)	14.70	14.35
Field capacity (%)	44.31	46.15
Available water (%)	22.72	21.22
Wilting point (%)	21.59	24.93
pH (1:2.5 soil-water suspension)	8.43	8.45
EC (dSm^{-1}), 1:5 soil-water extraction	1.42	1.49
Total carbonate (mg/g)	11.1	15.7
Organic matter (mg/g)	10.6	10.5
Available N mg/kg soil	19.35	21.27
Available P mg/kg soil	12.14	13.39
Available K mg/kg soil	176.4	186.1

The design of the experiment

The design of the experiment was a split-split design in four replications in complete randomized blocks. The factors were: tillage system (A), namely, shallow and sub-soiling tillage; gypsum (B), i.e., 0.0, 4.76 and 9.52 t/ha and farmyard manure (C), i.e., 0.0, 11.9, 23.8 and 35.7 m^3/ha . The tillage system was arranged in the main plots and gypsum was located in sub-plots, while farmyard manure treatments were applied in sub-subplots. The shallow tillage (T_1) was conducted as conventional tillage for wheat production by using two pass of a disc, while T_2 was done by using sub-soiler (about 90 cm depth). Representative sample was taken from the used FYM in both seasons to determine some chemical analysis according to A.O.A.C. (1990) and listed in Table 2.

Table 2. Some chemical analysis of FYM used in the experiments in both growing seasons.

Chemical properties	2015/2016	2016/2017
EC (1:15, soil-water extraction)	5.90	6.20
Organic carbon (mg/g)	169.0	184.0
Organic matter (mg/g)	291.4	317.2
Total N (mg/g)	16.2	17.4
Total P (mg/g)	3.3	3.6
Total K (mg/g)	14.0	14.4
C/N ratio	10:1	11:1

Gypsum and FYM treatments were added before sowing during land preparation.

Wheat sowing

Wheat (*Triticum aestivum*, variety Beni Suef 5) grains were sown on 15 and 20 November at the rate of 142.8 kg/ha in both seasons, respectively in plots (4 x 5.25 m = 21 m² = 1/476 ha) in rows (15 cm between). All treatments supplied with 178.5 kg N/ha as urea (46.0% N), 54.74 kg P₂O₅/ha as mono-calcium superphosphate (15.5 % P₂O₅), and 57.12 kg K/ha as potassium sulphate (48 % K₂O). All other cultural practices for wheat production were done as in the district.

Data recorded

At harvest ten wheat plants were randomly taken to determine plant height, number of spikes/m², number of grains/spike, and 1000-grain weight.

Statistical analysis

The results were subjected to statistical analysis according to the method described by [Snedecor and Cochran \(1980\)](#). The differences between the studied treatments were compared by using LSD at a 5 % level of probability.

Results and discussion

Soil physical properties

The effect of tillage systems, gypsum, and farmyard manure application on some physical properties after wheat harvest are given in [Tables 3 and 4](#). As for the main effect of tillage systems, the data clearly show that tillage systems were significantly affected soil properties except for soil pH and organic matter, where subsoiling tillage decreased soil salinity, soil bulk density, and increased soil porosity than shallow tillage. After wheat harvest, soil EC and bulk density were declined by about 8.5 and 1.3 % and soil porosity increased by about 1.1 % due to deep tillage than shallow one in the first season, respectively. Similar results were obtained in the second one. The beneficial effect of deep tillage on decreasing both soil salinity and soil bulk density and increasing total soil porosity may be due to its positive effect on decreasing soil compaction ([Thomas et al., 2007](#)). In this

concern, [Sasal et al. \(2006\)](#) mentioned that soil porosity is closely related to soil aeration, water movement, and root growth, consequently plant growth. Also, increasing soil porosity resulted in improving the leaching processes, in turn reducing soil salinity. These results are in harmony with those obtained by [Sharma et al. \(2016\)](#) and [Jiao et al. \(2017\)](#) who stated that subsoiling tillage improved some physical soil properties.

Concerning the main effect of gypsum, the data indicate that gypsum application had promotive effects on improving the studied soil properties, where its application was significantly reduced soil reaction, soil salinity, and bulk density as well as increased soil organic matter and soil porosity. It is obvious to observe that the positive effect of gypsum on soil properties increased as the gypsum levels increased. Compared with no gypsum, added 9.52 t/ha gypsum reduced pH, EC, and bulk density values by about 0.71, 26.88, and 1.42 % as well as increased soil organic matter and total soil porosity by about 3.76 and 1.03 % in the first season, respectively. The same trends were obtained in the second season. The enhancement of physical soil properties due to gypsum application can be explained by gypsum considered as acid-forming substances, hence reduced soil reaction ([Stamford et al., 2015](#)). Also, [Bairagi et al. \(2017\)](#) and [Andrade et al. \(2018\)](#) mentioned that gypsum application increased the soil water infiltration rate by improving the soil structure, consequently increasing soil porosity and reducing soil salinity by leaching during irrigation water. On the other hand, the beneficial effect of gypsum on soil organic matter and bulk density may be due to the positive effect of gypsum on improving soil properties, consequently increasing root growth, which its residues after harvest increased soil organic matter and decreased soil bulk density. These results are in line with those obtained by [Sarwar et al. \(2011\)](#), [Abdel-Fattah et al. \(2015\)](#), and [El-Sheref et al. \(2019\)](#) who reported that gypsum application improved the chemical and physical properties.

With regard to the main effect of farmyard manure, the data clearly reveal that FYM application improved all studied soil properties, except soil salinity which increased by farmyard manure application. It is obvious to notice that the effect of FYM on soil properties was increased as FYM levels increased. The increasing of FYM from 0.0 to 35.7 m³/ha reduced pH and bulk density from 8.473 to 8.382 and 1.220 to 1.159 (g cm⁻³) as well as increased soil salinity, soil organic matter, and total porosity from 1.065 to 1.632 dSm⁻¹, 0.998 to 1.429 %, and 53.962 to 56.258 % in the first season, respectively. Similar trends were obtained in the second season. The promotive effect of organic manure on improving soil properties may be due to organic manure improved the granulation, flocculation, and stability of aggregates which resulted in a reduction in soil SAR, consequently reducing soil pH and bulk density and increasing soil porosity ([Hussain et al., 2001](#) and [Zia et al., 2007](#)).

Table 3. pH and EC values after wheat harvest as affected by FYM and gypsum applications under different tillage systems

Treatments			2015 /2016		2016 /2017	
Tillage	Gypsum (t/ ha)	FYM (m ³ /ha)	pH	EC	pH	EC
Shallow	Gypsum (0.0)	0.0	8.530	1.300	8.43	1.24
		11.9	8.480	1.723	8.38	1.64
		23.8	8.447	1.820	8.32	1.68
		35.7	8.400	2.100	8.30	1.96
	Mean		8.464	1.741	8.36	1.63
	Gypsum (4.76)	0.0	8.460	1.080	8.36	1.02
		11.9	8.430	1.380	8.33	1.28
		23.8	8.400	1.550	8.28	1.45
		35.7	8.373	1.580	8.33	1.52
	Mean		8.416	1.400	8.33	1.32
	Gypsum (9.52)	0.0	8.440	0.920	8.32	0.92
		11.9	8.400	1.100	8.28	1.00
		23.8	8.380	1.150	8.24	1.05
		35.7	8.360	1.350	8.22	1.21
	Mean		8.395	1.130	8.27	1.05
Mean			8.425	1.421	8.32	1.331
Subsoiling	Gypsum (0.0)	0.0	8.500	1.077	8.40	0.96
		11.9	8.470	1.380	8.35	1.22
		23.8	8.440	1.550	8.30	1.41
		35.7	8.420	1.840	8.32	1.66
	Mean		8.458	1.459	8.34	1.31
	Gypsum (4.76)	0.0	8.460	1.040	8.34	0.90
		11.9	8.450	1.160	8.25	1.04
		23.8	8.400	1.380	8.20	1.22
		35.7	8.380	1.350	8.24	1.15
	Mean		8.423	1.230	8.26	1.08
	Gypsum (9.52)	0.0	8.450	0.970	8.31	0.87
		11.9	8.420	1.050	8.26	0.93
		23.8	8.400	1.250	8.20	1.05
		35.7	8.360	1.570	8.20	1.37
	Mean		8.408	1.210	8.24	1.06
Mean			8.429	1.300	8.28	1.49
Mean of gypsum (t/ha)		0.0	8.461	1.600	8.35	1.470
		4.76	8.419	1.315	8.295	1.200
		9.52	8.401	1.170	8.255	1.055
Mean of FYM (m ³ /ha)		0.0	8.473	1.065	8.36	0.985
		11.9	8.442	1.299	8.308	1.185
		23.8	8.411	1.450	8.257	1.310
		35.7	8.382	1.632	8.268	1.478
L.S.D at 0.05		A	NS	0.085	NS	0.091
		B	0.022	0.157	0.037	0.162
		AB	NS	0.392	NS	0.396
		C	0.031	0.365	0.033	0.365
		AC	NS	0.411	NS	0.452
		BC	0.046	0.436	0.0490	0.461
		ABC	NS	0.480	NS	0.493

Table 4. Soil organic matter, bulk density and total porosity after wheat harvest as affected by FYM and gypsum applications under different tillage systems

Treatments			2015 /2016			2016 /2017		
Tillage	Gypsum (t/ha)	FYM (m ³ /ha)	Organic matter (mg/g)	Bulk density (g/cm ³)	Total porosity (mg/g)	Organic matter (mg/g)	Bulk density (g/cm ³)	Total porosity (mg/g)
Shallow	Gypsum (0.0)	0.0	9.95	1.235	533.96	10.10	1.200	547.17
		11.9	11.72	1.212	542.64	12.13	1.178	555.47
		23.8	12.40	1.188	551.70	12.84	1.152	565.28
		35.7	13.60	1.175	556.60	14.21	1.140	569.81
	Mean		11.93	1.203	546.23	12.32	1.168	559.43
	Gypsum (4.76)	0.0	9.95	1.220	539.62	10.33	1.185	552.83
		11.9	11.50	1.205	545.28	11.83	1.165	560.38
		23.8	13.00	1.185	552.83	13.48	1.150	566.04
		35.7	14.10	1.170	558.49	14.84	1.132	572.83
	Mean		12.17	1.195	549.06	12.62	1.158	563.02
	Gypsum (9.52)	0.0	9.95	1.220	539.62	10.46	1.180	554.72
		11.9	11.72	1.200	547.17	12.26	1.160	562.26
		23.8	13.21	1.175	556.60	13.79	1.144	568.30
		35.7	14.79	1.160	562.26	15.48	1.125	575.47
	Mean		12.35	1.189	551.41	13.00	1.152	565.19
Mean			12.15	1.196	548.90	12.65	1.159	562.55
Subsoiling	Gypsum (0.0)	0.0	9.95	1.220	539.62	10.50	1.185	552.83
		11.9	11.40	1.205	544.72	11.90	1.166	560.00
		23.8	12.90	1.180	554.72	13.34	1.150	566.04
		35.7	13.79	1.165	560.38	14.40	1.135	571.70
	Mean		12.01	1.193	551.41	12.54	1.159	562.64
	Gypsum (4.76)	0.0	10.10	1.215	541.51	10.90	1.175	556.60
		11.9	12.00	1.190	550.94	13.00	1.148	566.79
		23.8	13.84	1.160	562.26	14.64	1.135	571.70
		35.7	14.79	1.145	567.92	15.48	1.122	576.60
	Mean		12.68	1.178	555.66	13.51	1.144	567.92
	Gypsum (9.52)	0.0	10.00	1.210	543.40	10.62	1.170	558.49
		11.9	11.76	1.185	552.83	12.29	1.158	563.02
		23.8	13.50	1.155	564.15	14.36	1.140	569.81
		35.7	14.65	1.140	569.81	15.00	1.128	574.34
	Mean		12.48	1.173	557.55	13.07	1.149	574.34
Mean			12.39	1.181	554.87	13.04	1.151	568.30
Mean of gypsum (t/ha)		0.0	11.97	1.198	548.82	12.43	1.164	561.04
		4.76	12.43	1.187	552.36	13.07	1.151	565.47
		9.52	12.42	1.181	554.48	13.04	1.151	569.77
Mean of FYM (m ³ /ha)		0.0	9.98	1.220	539.62	10.49	1.183	553.77
		11.9	11.68	1.200	547.26	12.24	1.153	561.32
		23.8	13.14	1.174	557.04	13.74	1.145	567.86
		35.7	14.29	1.159	562.58	14.90	1.130	575.13
L.S.D at 0.05		A	NS	0.012	0.321	NS	0.017	0.362
		B	0.026	0.011	0.304	0.036	0.012	0.325
		AB	NS	0.020	0.421	NS	0.026	0.436
		C	0.028	0.034	0.967	0.039	0.390	1.007
		AC	NS	0.042	1.135	NS	0.044	1.166
		BC	0.385	0.045	1.207	0.406	0.047	1.254
		ABC	NS	0.052	1.411	NS	0.055	1.439

the positive effect of organic manure on reducing soil pH is mainly due to the production of organic acids throughout the decomposition of organic manure. These results are in accordance with those obtained by [Qadir et al. \(2017\)](#) and [Sarhan and Abd El-Gayed \(2017\)](#). Unfortunately, farmyard manure had a negative effect on soil salinity, which was mainly due to the used FYM having relatively high salinity values (5.90 and 6.20 dSm⁻¹ in both seasons, respectively, [Table 2](#)) as indicated by [Ahmed \(2009\)](#). Similar results were obtained by [Ahmed \(2017\)](#) and [Galal et al. \(2017\)](#).

As for the interaction effect, the data show that the soil properties after wheat harvest were significantly responded to the interaction between treatments. In general, mixed inorganic gypsum with organic manure under subsoiling tillage enhanced its effect on improving soil properties. The treatment of 9.52 t/ha gypsum + 35.7 m³/ha FYM under subsoiling tillage recorded the best values of soil properties after harvest, except soil salinity. In these connections, [Chen et al. \(2010\)](#) and [Sarwar et al. \(2011\)](#) mentioned that the application of gypsum enhanced the effect of organic manure on reclamation salt-affected soil.

Soil fertility

The data of the effect of studied factors on soil fertility, in term of soil available N, P, and K in the soil after wheat harvest are given in [Table 5](#). As for the main effect of tillage system, the data showed that subsoiling tillage increased soil fertility after harvest. The relative increasing in soil available N, P and K after wheat harvest due to subsoiling method reached to 16.9, 3.1 and 4.1 % when compared with shallow tillage in the first season. Similar trends were obtained in the second season. The improvement of soil fertility caused by subsoiling tillage may be attributed to subsoiling practice break up the high-density layer of soil, increased the infiltration rate, enhanced the microbiological activity, and consequently enhanced nutrient availability in soil ([Bennie and Botha, 1986](#)). These results are in line with those obtained [Memon et al. \(2013\)](#).

Regarding the main effect of gypsum, the obtained results show that the postharvest soil fertility was positively responded to gypsum application. Increasing gypsum levels were significantly increased soil available N and P, while soil available K increased as gypsum increased up to 4.76 t/ha thereafter decreased. Compared with no gypsum, added 9.52 t/ha gypsum increased soil available N and P by about 36.0 and 9.6 % in the first season and 20.6 and 5.2 % in the second one, respectively. On the other hand, added 4.76 t/ha gypsum increased soil available K after harvest by about 11.5 and 11.1 % over without gypsum application in both seasons, respectively.

Whereas, the highest level of gypsum, i.e. 9.52 t/ha decreased soil available K by about 5.7 and 8.1 % than 4.76 t/ha in the two studied seasons, respectively. The beneficial effect of increasing gypsum levels up to 9.52 t/ha on the soil available N and P as well as increasing gypsum up to 4.76 t/ha on soil available K may be due to the positive effect of gypsum on

improving physical soil properties, especially pH, EC and organic matter as discussed before in [Table 3](#) and [4](#). While, the decreasing in potassium availability under the highest gypsum rate may be attributed to the antagonistic relationship between potassium and calcium as mentioned by [Jones et al. \(1991\)](#) who stated that under the high level of calcium, the availability of potassium in soil decreased. These results are in harmony with many authors such as [Rashid et al. \(2008\)](#) for nitrogen, [El-Sheref et al. \(2019\)](#) for phosphorus, and [Sarwar et al. \(2011\)](#) for potassium.

Considering the main effect of farmyard manure, the data clearly show that soil fertility after wheat harvest was positively affected by added organic manure, where increasing FYM levels were significantly increased soil available N, P, and K. Over without manuring, added 35.7 m³/ha FYM resulted in increasing soil available N, P, and K by about 109.2, 63.0 and 144.2 % in the first season, respectively. Similar trends were obtained in the second season. The improvement in N, P, and K availability caused by FYM application could be explained by the positive effect of FYM on reducing soil reaction as mentioned before in [Table 3](#) ([Galal et al., 2017](#)). In addition, [Mekail et al. \(2006\)](#) reported that farmyard manure contains sufficient amounts of the essential nutrients. Also, [Reddy and Aruna \(2008\)](#) stated that FYM play an important role in plant production not only by it consider as main source of nutrients, but also improving soil chemical and physical properties, consequently increasing nutrients efficiency in soil. These results agree with those obtained by [Sarwar et al. \(2011\)](#), [Galal et al. \(2017\)](#), [Qadir et al. \(2017\)](#), and [Mekawy and Abd El-Hafeez \(2020\)](#).

The data of the interaction between treatments or among them reveal that soil fertility was significantly affected by the interaction between the studied treatments, where added farmyard manure enhanced the effect of gypsum, especially under subsoiling tillage on increasing nutrients availability in the soil after harvest. In general, the highest values of available N and P in postharvest soil were recorded under the treatment of subsoiling tillage + 9.52 t/ha gypsum + 35.7 m³/ha FYM, while the highest potassium availability was achieved under the treatment of subsoiling tillage + 4.76 t/ha gypsum + 35.7 m³/ha FYM. On the other hand, the treatment of shallow tillage + no gypsum + without manuring possessed the lowest values of nutrient availability. Similar results were obtained by [Singh et al. \(2001\)](#), [Mikanová et al. \(2012\)](#), [Verma et al. \(2012\)](#), [Shaaban et al. \(2013\)](#), and [Qadir et al. \(2017\)](#) who indicated that added gypsum with organic manure induces a positive effect on nutrients availability.

Vegetative growth

The data in [Table 6](#) represent the response of wheat vegetative growth, namely plant height, number of spikes/m², number of grains/spike and 1000-grain weight to tillage system as well as gypsum and FYM application. Put the main effect of tillage system in consideration, the results show that tillage system had a positive effect on the studied vegetative growth parameters. Subsoiling method surpassed shallow

tillage on its effect on wheat growth. The relative increasing of plant height, number of spikes/m², number of grains/spike and 1000-grain weight due to subsoiling tillage reached to 2.1, 1.3, 0.3 and 0.8 % over shallow tillage in the first season,

Table 5. Available N, P and K in soil after wheat harvest as affected by FYM and gypsum applications under different tillage systems

Treatments			2015 /2016			2016 /2017		
Tillage	Gypsum (t/ha)	FYM (m ³ /ha)	N mg kg ⁻¹	P mg kg ⁻¹	K mg kg ⁻¹	N mg kg ⁻¹	P mg kg ⁻¹	K mg kg ⁻¹
Shallow	Gypsum (0.0)	0.0	20.000	9.480	200.000	30.000	12.480	221.000
		11.9	23.500	11.325	231.100	31.500	14.325	271.000
		23.8	30.000	13.091	400.900	40.000	16.095	446.900
		35.7	37.000	16.835	500.700	43.000	16.830	530.700
	Mean		27.625	12.683	333.175	36.125	14.933	367.400
	Gypsum (4.76)	0.0	22.500	9.800	216.000	32.500	12.825	235.000
		11.9	27.000	12.315	245.200	35.000	14.820	277.000
		23.8	38.000	13.275	464.000	52.000	16.280	506.000
		35.7	45.000	15.780	509.000	55.000	18.785	569.000
	Mean		33.125	12.792	358.550	43.625	15.678	396.750
	Gypsum (9.52)	0.0	25.500	10.500	210.900	30.000	12.850	230.000
		11.9	28.000	12.866	250.600	32.000	14.766	278.600
		23.8	48.500	14.175	476.200	56.167	16.675	496.200
		35.7	55.000	16.125	505.200	60.000	19.125	521.200
	Mean		39.250	13.416	360.725	44.542	15.854	381.500
	Mean			33.333	12.965	350.817	41.431	15.488
Subsoiling	Gypsum (0.0)	0.0	25.000	9.671	210.030	30.000	12.660	230.030
		11.9	30.000	10.481	246.200	35.000	14.480	266.200
		23.8	35.000	13.125	420.700	40.000	16.125	432.700
		35.7	45.000	15.980	503.000	50.000	18.990	523.000
	Mean		33.750	12.314	344.983	37.750	15.564	362.983
	Gypsum (4.76)	0.0	22.000	10.685	225.070	28.000	13.185	239.070
		11.9	33.500	12.480	260.600	33.300	14.985	268.600
		23.8	45.000	14.325	500.000	50.000	16.800	526.000
		35.7	55.000	17.625	605.600	55.000	19.125	625.600
	Mean		38.875	13.779	397.817	41.575	16.024	414.818
	Gypsum (9.52)	0.0	27.000	11.250	221.000	28.000	13.397	230.000
		11.9	35.000	12.551	240.100	35.000	15.176	262.100
		23.8	55.000	14.460	440.200	60.000	16.991	456.200
		35.7	60.000	17.700	510.100	60.000	19.307	510.100
	Mean		44.250	13.991	352.850	45.750	16.218	364.600
	Mean			38.958	13.361	365.217	42.025	15.935
Mean of gypsum (t/ha)	0.0	30.688	12.498	339.079	37.438	15.249	365.191	
	4.76	36.000	13.286	378.184	42.600	15.476	405.784	
	9.52	41.750	13.703	356.788	45.146	16.036	373.050	
Mean of FYM (m ³ /ha)	0.0	23.667	10.232	213.833	29.750	12.333	230.850	
	11.9	29.500	12.003	245.633	33.633	14.196	270.583	
	23.8	41.917	13.742	450.333	49.694	15.879	477.333	
	35.7	49.500	16.674	522.267	53.833	18.501	546.600	
L.S.D at 0.05	A	2.117	0.223	9.613	3.015	0.211	10.216	
	B	4.457	0.713	10.237	5.570	0.825	11.174	
	C	7.002	1.816	13.165	7.689	1.952	14.452	
	AB	11.335	1.215	30.251	12.008	1.962	34.163	
	AC	13.155	1.621	35.661	14.215	2.113	39.952	
	BC	8.711	1.602	34.101	9.825	2.235	40.357	
	ABC	13.251	1.961	39.651	14.619	2.771	42.118	

Table 6. Plant height and yield component as affected by FYM and gypsum applications under different tillage systems

Treatments			2015 /2016				2016 /2017			
Tillage	Gypsum (t/ha)	FYM (m ³ /ha)	Plant height (cm)	Number of spikes /m ²	Number of grains /spike	1000-grain weight	Plant height (cm)	Number of spikes /m ²	Number of grains /spike	1000-grain weight
Shallow	Gypsum (0.0)	0.0	102.00	360	44.00	53.040	109.00	370	44.10	56.00
		11.9	103.00	375	44.12	55.700	110.80	386	44.15	58.00
		23.8	107.00	392	44.54	56.523	112.00	400	44.18	59.50
		35.7	107.00	413	44.70	58.380	112.80	412	44.20	62.00
	Mean		104.75	385	44.34	55.91	111.15	392	44.16	58.88
	Gypsum (4.76)	0.0	104.00	365	44.11	54.240	110.40	378	44.53	56.00
		11.9	105.00	385	44.36	56.000	111.00	395	44.56	58.26
		23.8	108.00	400	44.69	57.800	111.70	410	44.69	59.00
		35.7	107.00	418	44.83	58.850	113.20	425	44.72	62.00
	Mean		105.75	392	44.50	56.720	111.58	402	44.63	58.82
	Gypsum (9.52)	0.0	103.00	370	44.22	54.540	110.00	380	44.62	57.00
		11.9	106.00	388	44.41	56.210	111.90	395	44.70	58.81
		23.8	107.00	399	44.73	56.830	113.40	413	44.79	60.43
		35.7	108.00	415	44.85	58.140	112.40	420	44.85	64.00
	Mean		106.00	393	44.55	56.430	111.90	402	44.74	60.06
	Mean			105.50	390	44.46	56.354	111.54	399	44.55
Subsoiling	Gypsum (0.0)	0.0	105.00	368	44.17	53.560	108.70	380	44.26	57.00
		11.9	107.00	380	44.21	55.240	109.00	393	44.32	59.00
		23.8	107.00	396	44.69	56.800	113.50	418	44.39	60.04
		35.7	109.00	415	44.82	58.700	113.40	423	44.46	62.32
	Mean		107.00	390	44.35	56.08	111.15	404	44.36	59.59
	Gypsum (4.76)	0.0	105.00	372	44.31	55.000	109.10	380	44.35	57.60
		11.9	107.00	388	44.46	57.480	111.30	398	44.46	59.08
		23.8	110.00	405	44.74	57.960	113.90	430	44.52	59.76
		35.7	111.00	425	44.92	58.660	114.70	435	44.69	62.40
	Mean		108.25	398	44.61	57.28	112.25	411	44.51	59.71
	Gypsum (9.52)	0.0	105.00	370	44.69	55.877	110.40	377	44.69	57.80
		11.9	108.00	392	44.75	56.373	111.60	402	44.79	60.00
		23.8	108.00	410	44.81	56.950	113.40	428	44.86	60.55
		35.7	111.00	420	44.96	59.260	113.20	435	44.93	60.80
	Mean		108.00	398	44.81	57.11	112.15	411	44.82	59.79
	Mean			107.75	395	44.59	56.792	111.85	409	44.56
Mean of gypsum (t/ha)	0.0	105.875	375	44.35	55.993	111.15	398	44.26	59.233	
	4.76	107.00	395	44.55	56.999	111.92	407	44.57	59.263	
	9.52	107.00	396	45.68	56.727	112.03	407	44.78	59.965	
Mean of FYM (m ³ /ha)	0.0	104.00	368	44.25	54.376	109.60	378	44.43	56.956	
	11.9	106.00	385	44.39	56.167	110.93	395	44.50	58.858	
	23.8	107.83	400	44.70	57.084	112.98	417	44.57	59.880	
	35.7	108.83	418	44.85	58.665	113.28	425	44.64	62.253	
L.S.D at 0.05	A	0.361	1.214	0.006	0.114	0.420	1.425	0.007	0.136	
	B	0.314	7.702	0.663	0.227	0.441	8.266	0.715	0.248	
	AB	0.465	9.614	0.813	0.286	0.502	10.364	0.825	0.317	
	C	1.214	11.651	0.236	1.152	1.405	12.265	0.247	1.238	
	AC	1.612	13.114	0.295	1.417	1.673	14.002	0.303	1.509	
	BC	1.635	14.251	0.335	1.431	1.704	16.610	0.346	1.524	
	ABC	1.913	16.214	0.376	1.557	2.007	18.823	0.392	1.592	

respectively. Same trends were obtained in the second season. The superiority of deep tillage than shallow one on

vegetative growth of wheat is mainly due to its positive effect in physical soil properties and soil fertility [Tables 3, 4 and 5](#).

In this concern, Alam et al. (2014) found that deep tillage enhanced root mass density of wheat than no tillage or conventional tillage. These results are similar to those obtained by Irshad et al. (2017) who stated that maximum cotton growth was achieved under deep tillage. Also, Alam et al. (2014), Jiao et al. (2017) and Soltanabadi et al. (2018) reported that deep tillage increased sunflower, wheat and maize growth than shallow tillage, respectively.

Irrespective of tillage and farmyard manure, the data in Table 6 clearly reveal that gypsum application had positive effect on the vegetative growth of wheat. Increasing gypsum levels were significantly increased the studied wheat vegetative growth parameters. Added 9.52t gypsum/ha gave the tallest plant, greatest number of spikes/m², the highest number of grains/spike and the heaviest grain weight in both seasons. The promotive effect of gypsum on wheat growth may be due to gypsum application improved some chemical and physical properties as mentioned before Tables 3, 4 and 5. In this connection, Genaidy (2011) mentioned that added gypsum prior to crops planting in slightly to moderately sodic soil enhanced crop growth by modifying some soil properties, such as physicochemical properties as well as improved nutrient availability. These results were in agreement with many workers such as Bello (2012) and El-Sheref et al. (2019) who reported that increasing gypsum levels increased vegetative growth of wheat plant.

As the main effect of FYM, the obtained data show that wheat vegetative growth parameters were significantly affected by farmyard manure application, where increasing its levels increased these parameters. The relative increasing in plant height, number of spikes/m², number of grains/spike and 1000-grain weight due to added 35.7 m³/ha FYM reached to 4.6, 13.6, 1.4 and 7.9 % when compared with no manuring in first season. Similar results were obtained in the second season. The beneficial effect of FYM on wheat growth is mainly due its effect on improving soil physical properties and its fertility as discussed former Tables 3, 4 and 5. Tisdale et al. (2002) indicated that added farmyard manure to soil supply an additional of NH₄-N and enhancing the solubility of phosphorus and micronutrients. These results are confirmed by many authors such as Ali et al. (2009) and Galal et al. (2017) who stated that farmyard manure application enhanced wheat growth.

The data of the interaction between any two treatments or among them reveal that all studied wheat vegetative growth parameters were responded to these interactions. The using of organic manure enhancing the positive effect of gypsum on wheat growth, especially under subsoiling tillage. In general, the highest values of vegetative growth were recorded under the treatment of subsoiling tillage + 9.52 t/ha gypsum + 35.7 m³/ha FYM. On the other hand, the treatment of shallow tillage without both gypsum and organic manure exhibited the lowest values of these parameters. Similar results were obtained by Irshad et al. (2017) for the interaction between tillage and FYM and Genedy et al. (2018) for interaction between organic manure and gypsum.

Conclusions

From the results of this study, under slightly to moderately sodic soil it could be concluded to integrated gypsum with organic manure under subsoiling tillage to improved soil properties and wheat growth. Therefore, for maximizing wheat yields grown in moderately sodic soil, it could be recommended to using subsoiling tillage system and incorporated 9.52 t/ha gypsum +35.7 m³/ha farmyard manure before wheat planting. In economic view subsoiling tillage + without or 4.76 t/ha gypsum +35.7 m³/ha FYM is the best for attain highest net income.

Conflict of Interest

The author hereby declares no conflict of interest.

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