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

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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 (CaSO₄·2H₂O) 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 Youssif (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 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°04’ N, Long. 31°6’ 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                          | 1st season | 2nd 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 m³/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 (T₁) was conducted as conventional tillage for wheat production by using two pass of a disc, while T₂ was done by using subsoiler (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.

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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-Sherif 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 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 |
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 |
|------------|------------|------------|
|            | pH (m/ha)  | EC (m/ha)  | pH (m/ha)  | EC (m/ha)  |
|            |            |            |            |            |
| 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       |
| 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 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       | 8.473      | 1.065      | 8.36       | 0.985      |
| Mean of FYM (m/ha) |            |            |            |            |
| 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      |
| Mean       | 8.429      | 1.300      | 8.28       | 1.49       |
| 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

| Tillage | 2015 /2016 | 2016 /2017 |
|---------|------------|------------|
|         | FYM (m³/ha) | Organic matter (mg/g) | Bulk density (g/cm³) | Total porosity (mg/g) | Organic matter (mg/g) | Bulk density (g/cm³) | Total porosity (mg/g) |
| Shallow | Gypsum (0.0) | 9.95 | 12.35 | 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) | 9.95 | 12.20 | 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) | 9.95 | 12.20 | 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) | 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) | 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) | 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) | 11.97 | 1.198 | 548.82 | 12.43 | 1.164 | 561.04 |
| Mean of FYM (m³/ha) | 9.52 | 12.42 | 1.181 | 554.48 | 13.04 | 1.151 | 569.77 |
| 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 |
|         | AC | 0.024 | 0.010 | 0.294 | 0.035 | 0.011 | 0.323 |
|         | 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-Sherif 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 | Gypsum (t/ha) | FYM (m³/ha) | 2015/2016 | 2016/2017 |
|------------|--------------|-------------|-----------|-----------|
|            | N mg kg⁻¹ | P mg kg⁻¹ | K mg kg⁻¹ | N mg kg⁻¹ | P mg kg⁻¹ | K mg kg⁻¹ |
| 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 | 33.125 | 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 | 32.792 | 13.585 | 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 | 33.125 | 12.965 | 350.817 | 41.431 | 15.488 | 381.883 |
| 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 | 32.134 | 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 | 38.797 | 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 | 230.00 |
|            | 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 | 38.958 | 13.361 | 365.217 | 42.025 | 15.935 | 380.800 |
| 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 |
|            | 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 |
| Mean | 49.500 | 49.500 | 16.674 | 522.267 | 53.833 | 18.501 | 546.600 |
| Mean of FYM (m³/ha) | A | 2.177 | 0.223 | 9.613 | 3.015 | 0.211 | 10.216 |
| | B | 4.457 | 0.713 | 10.237 | 5.570 | 0.825 | 11.174 |
| | C | 0.019 | 0.816 | 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 |
 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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