

YIELD OF WHEAT IS INCREASED THROUGH IMPROVING THE CHEMICAL PROPERTIES, NUTRIENT AVAILABILITY AND WATER PRODUCTIVITY OF SALT AFFECTED SOILS IN THE NORTH DELTA OF EGYPT

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Abstract. The lysimeter experiment was carried out twice in consecutive two years (2014-15 and 2015-16) at Sakha Agricultural Research Station, Kafrelsheikh, Egypt to study the effect of three irrigation levels water (i.e., 100, 110 and 120% field capacity (FC), two rates of gypsum (G) (i.e., 50 and 100% G) and three sources of nitrogen (90 kg nitrogen (N), 10 t compost (C) and 7.5 t C + 45 kg N (CN) fed⁻¹ (fed = 4200 m²)) on grain yield of wheat, water relations and soil chemical properties. Water consumptive use (WCU) was markedly increased due to the increase of the level of irrigation, rate of gypsum (G) and CN source (7.5 t C + 45 kg N fed⁻¹). Irrigation with water amount equal to 120% FC recorded the highest values of WCU 1433 and 1570 m³fed⁻¹ in both seasons. Water productivity (kg grain m⁻³ water) for either water application (WA) in both seasons or WCU in the second season was decreased by increasing level of irrigation from 100 to 120% FC in the second season, while the inverse was true for WCU in the first season. The highest mean values of water productivity for WCU 1.816 and 1.791 kg m⁻³ were obtained with the irrigation level of 120% FC in the first season and 100% FC in the second season, respectively. Gypsum rate and N source have an effect on the productivity of irrigation water (WP) for WA and WCU, where the highest mean values for both the two irrigations efficiency were recorded under 100% G requirements and CN (7.5 t C + 45 kg N fed⁻¹). The interaction of 110% FC × 100% G × 7.5 t C + 45 kg N fed⁻¹ produced the highest values of WP for WA (1.245 and 1.374 kg grain m⁻³ WA) in both seasons. Grain yield fedd.⁻¹ was increased significantly with the irrigation level from 100 to 120% FC in both seasons, G rate and CN source. Grain yield (GY) did not differ significantly due to the levels of irrigation water between 120 and 110% FC in both years. Application of 100% G and 7.5 t C + 45 kg N fed⁻¹ at any irrigation level were among those treatments having high GY, being insignificant. The mean values of electrical conductivity (acidity; ECe) and soil sodicity (SARe) were affected by irrigation treatments, G rates and nitrogen sources. A stronger reduction in soil ECe and SARe were recorded under the irrigation level of 120%FC, 100% G and 10 t compost in both seasons. While the soils ECe and SARe were increased by application of chemical N fertilizer alone or with compost. Therefore, it can be concluded that irrigation with water amount equal to 110 or 120% FC, 100% G requirements and 7.5 t C and 45 kg N fed⁻¹ was the best treatment for getting high GY, improving the soil chemical properties, nutrients availability and increasing the water productivity of salt-affected soil in North Delta of Egypt.

Keywords: *irrigation, lysimeter, soil salinity, soil sodicity, gypsum*

Abbreviations: C: compost; CN: carbon & nitrogen; ECe: electrical conductivity (soil salinity); FC: field capacity; fed.: feddan (fed = 4200 m²); G: Gypsum; GY: grain yield K: potassium; N: nitrogen; OM: organic matter; P: phosphorus; SARE: sodium adsorption ratio (soil sodicity); t: ton; WA: water applied; WCU: water consumptive use

Introduction

Wheat (*Triticum aestivum*, L.) is a vital cereal across the globe and it is the most widely grown food cereal crop and its demand is increasing with the increasing population (Hossain et al., 2018; Jahan et al., 2019). It is considered a strategic crop and has played a major role on the national economy and it is one of the widely adapted cereals, grown in different environments (Barutcular et al., 2017; Yildirim et al., 2018). In Egypt, it is also the main food crop, as the current production of wheat does not meet the consumption demand. Recently US' Foreign Agricultural Service (FAS) in Cairo estimated that the wheat production in Egypt reaches 8.45 million metric tons (MMT) in the year in 2018-19, which was 4.3% higher than 2017-18 (Egypt Today, 2018; IndexMundi, 2018). Although in the year 2017, 60.2% of Egypt's total wheat consumption was imported. Concerning wheat consumption, FAS Cairo forecasts Egypt's total wheat consumption in the marketing year (MY) 2018-19 was 20 MMT, which was 1.5% more than the MY 2017-18 (Egypt Today, 2018; IndexMundi, 2018). Therefore, it is confirmed that the demand for wheat in Egypt is increasing day by day, but domestic production could not meet the current demand. As a result, to meet the food security of increasing population, the government of Egypt has taken several initiatives such as increase the area of production, development of high yield potential and stress resistance wheat cultivars, and also to find out improved management practices for reduction the imported percentage to be less than 50% (McGill et al., 2015; IndexMundi, 2018).

Wheat production depends on several factors including environmental condition, cultivars and management factors, such as irrigation and soil fertility. Among the management approaches, irrigation and fertilization and their interaction are considered the most important factors for increasing wheat production (Shaaban, 2006). For example, application of one irrigation increases the yield of wheat by more than 40%, whereas two to three irrigations with proper water and fertilizer management practices increase wheat yield by 50-100% (Hossain et al., 2006). However, to assist the efficient water use, plant-soil-water positive and negative interaction should be well understood under various environmental conditions, particularly in arid and semi-arid regions, where irrigation water is limit due to lack of rainfall (Musick et al., 1994; Wiedenfeld, 2000; Halitigil et al., 2000).

On the other hand, as Egypt is situated under the arid and semi-arid region of the Mediterranean environment, heat, drought and salinity are the major abiotic stress which decreases the productivity of wheat (Al-Naggar et al., 2015a, b; Abdelaal et al., 2018). Among the abiotic stresses, salinity is the most important one that adversely affects the productivity and quality of wheat through altering the physiological and biochemical activity of plants (Otu et al., 2018; Yassin et al., 2019) by accelerating osmotic stress and ion cytotoxicity in plants' cell (Chen and Jiang, 2010; Islam et al., 2011). It is anticipated that the consequence of soil salinity may be increased in future due to the scarcity of annual rainfall, rising of sea water, irrigation with saline water,

excessive use of fertilizers and absence of a good drainage system, particularly in the Mediterranean environment (El-Hendawy et al., 2005).

Therefore, to improve or reclaim the sodic soil for sustainable crop production, it is important for replacing the most of the Na^+ by the most favourable Ca^{++} followed by removal/leaching of salts derived by the reaction of the amendment from sodic soil. While many chemical compounds such as amendments are known in this respect of effective salts reclamation. For example, amendments directly or indirectly supply soluble Ca^{++} and improve the soil productivity by escaping Na^+ from saline soils. Sodic soil reclamation by using amendment will largely depend on the nature of the soil, effectiveness and cost considerations. Among the amendments, gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is a typical soil amendment, which replaces Na^+ ions by the calcium (Ca^{++}) ions (Hanay et al., 2004).

However, the presence of organic matter (OM) through the management of crop residues, using different types of organic manures in the soil is a fundamental option for maintaining soil fertility and productivity. It improves the physical properties, biological activity, water holding capacity and soil's aeration for better seed germination and seedling stand establishment (Edwards and Hailu, 2011). Considering the above important issues for the sustainability of crops production, the research was aimed to study the effect of different requirements of irrigation water, soil amendments and nitrogen fertilization on wheat yield, water relations and some soil chemical properties.

Materials and methods

Location and duration of the study

The lysimeter study was established during the wheat grown season of 2014-15 and 2015-16 at Sakha Agricultural Research Station, Kafr ElSheikh-Egypt. The location lies in 134 km north Cairo, Egypt under North Delta-Egypt. The location is situated at $31^{\circ}07'N$ latitude and $30^{\circ}57'E$ longitude. The study aimed to study the effect of irrigation water level, soil amendments and nitrogen fertilizer sources on wheat yield, water relations and some soil chemical properties.

Physical and chemical properties of lysimeters' soil

Soils in the North Delta of Egypt are characterized by saline and sodic. For determination of soils' chemical and physical soil properties, soil samples were taken from each lysimeter at the depth of 0-15, 15-30, 30-45 and 45-60 cm before sowing and after harvesting in both seasons (*Table 1*). Soil reaction (pH) was determined according to Cottenie et al. (1982), electrical conductivity (ECe) according to Page (1982) and sodium adsorption ratio (SAR) was calculated. Soil OM status was estimated through Walkally Black method according to Hesse (1971). Available N and K were determined according to Jackson (1967). Phosphorus (P) availability was observed according to Olsen et al. (1954), by following sodium bicarbonate method. Mechanical soil analysis was determined according to the international pipette method (Piper, 1950). Gypsum requirement was calculated according to Schoonover method (1952). Soil bulk density was measured by using the core sampling technique as described by Campbell (1994). The chemical composition of compost used in the study is amiable in *Table 2*. The

lysimeters were fertilized with 15.5 kg P₂O₅ feddan⁻¹ in the form of calcium superphosphate (15.5% P₂O₅) during soil preparation.

Table 1. Physical and chemical properties of the lysimeters' soil recorded before sowing during the 2014-15 season

| Properties | Soil depth (cm) | | | | |
|--|-----------------|-------|-------|-------|-------|
| | 0-15 | 15-30 | 30-45 | 45-60 | Mean |
| Particle size (%) | | | | | |
| Sand | 13.35 | 14.72 | 12.5 | 16.33 | 14.23 |
| Silt | 26.89 | 28.58 | 27.3 | 27.85 | 27.66 |
| Clay | 59.76 | 56.7 | 60.2 | 55.82 | 58.12 |
| Texture class | Clay | Clay | Clay | Clay | Clay |
| Soil moisture (%) | | | | | |
| Field capacity | 42.65 | 40.2 | 39.83 | 38.45 | 40.28 |
| Wilting point | 22.87 | 20.65 | 19.89 | 19.36 | 20.69 |
| Available water | 19.78 | 19.55 | 19.94 | 19.09 | 19.59 |
| Bulk density (kg m ⁻³) | 1.21 | 1.26 | 1.31 | 1.34 | 1.28 |
| Chemical properties | | | | | |
| pH (1:2.5) | 8.36 | 8.45 | 8.54 | 8.67 | 8.51 |
| ECe (dS m ⁻¹) | 5.84 | 6.46 | 7.19 | 8.89 | 7.1 |
| SAR (%) | 11.83 | 13.03 | 14.23 | 15.76 | 13.71 |
| OM (%) | 1.76 | 1.54 | 1.45 | 1.15 | 1.48 |
| Available N (mg kg ⁻¹) | 36.21 | 31.87 | 26.45 | 18.96 | 28.37 |
| Available P (mg kg ⁻¹) | 9.28 | 8.92 | 8.56 | 8.19 | 8.74 |
| Available K (mg kg ⁻¹) | 365 | 348 | 297 | 248 | 314.5 |
| Gypsum requirements (meq 100 g⁻¹ soil) | 2.3 | | | | |

Table 2. The chemical composition of compost used in the experiment

| EC dS/m | pH 1:5 | Total N % | C % | C/N ratio | OM % | Total P% | Total K% | Fe ppm | Zn ppm | Mn ppm | Moisture % |
|---------|--------|-----------|-------|-----------|-------|----------|----------|--------|--------|--------|------------|
| 3.76 | 8.23 | 1.79 | 29.78 | 16.64 | 51.34 | 1.68 | 1.28 | 142 | 51 | 132 | 26.80 |

Meteorological information during growing seasons

The meteorological data on mean monthly temperature, relative humidity, wind speed and pan evaporation as well as rainfall in both seasons (2014-15 and 2015-16) from Sakha Station were recorded and presented in *Table 3*.

Experimental treatments and design

Treatments of the present study were arranged in a split-split plot design and repeated four times in both seasons. Where main plots were arranged in levels of irrigation, sub-plots were in rates of gypsum (G) and sub-sub-plots were in sources of nitrogen. Irrigation was done five times at all irrigation treatments: first irrigation was done at each of sowing, the second was tillering, third at jointing, fourth at heading and final one (fifth irrigation) were done at milking stages. Irrigation treatments were started

after the sowing irrigation. Amounts of applied irrigation water were equal to 100, 110 and 120% of field capacity (FC) in the root zone (0-60 cm depth) of the plants. The second and third irrigation were increased 10 and 20% than FC as leaching requirement. Gypsum (G) requirements were used in two rates, i.e., 2.21 and 4.42 t fed⁻¹ (for maintaining 50 and 100% G requirements). Nitrogen (N) sources were 90 kg N (N), 10 t compost (C) and 7.5 t C + 45 kg N (CN) fed⁻¹.

Table 3. Mean monthly of temperature, relative humidity, wind speed and pan evaporation as well as rainfall quantity in both seasons

| Month | Temperature (°C) | | Relative humidity (%) | | Wind speed (km day ⁻¹) | | Pan-evaporation (mm month ⁻¹) | | Rainfall (mm month ⁻¹) | |
|----------|------------------|---------|-----------------------|---------|------------------------------------|---------|---|---------|------------------------------------|---------|
| | 2014-15 | 2015-16 | 2014-15 | 2015-16 | 2014-15 | 2015-16 | 2014-15 | 2015-16 | 2014-15 | 2015-16 |
| November | 19.05 | 19.41 | 74.15 | 75.60 | 67.3 | 70.3 | 277 | 319 | 24.60 | 52.40 |
| December | 15.99 | 14.03 | 76.05 | 77.90 | 46.03 | 57.9 | 172 | 250 | 5.70 | 25.00 |
| January | 12.63 | 12.38 | 74.60 | 74.05 | 70.80 | 69.2 | 271 | 252 | 52.55 | 43.21 |
| February | 13.35 | 15.97 | 74.75 | 69.05 | 72.91 | 58.8 | 290 | 252 | 38.80 | - |
| March | 17.19 | 18.05 | 70.59 | 69.90 | 87.64 | 63.2 | 323 | 359 | 6.25 | 13.2 |
| April | 18.17 | 24.33 | 63.40 | 61.70 | 95.70 | 87.1 | 607 | 594 | 23.90 | - |

Experimental procedure and data collection

Seeds of wheat variety 'Sids 13' was seeded by hand in rows 12.5 cm apart at the rate of 50 kg seeds fed⁻¹, sown on 18 and 23 November in both years (2014 and 2015 seasons), respectively. While each lysimeter was included 8 rows. Phosphorus (P) and potassium (K) fertilizers were added according to the recommended doses of North Delta area of Egypt. For the source of N, fertilizer urea (46% N) was applied in two equal splits, before sowing irrigation and at the tillering stage. G and C were added before planting. The different agricultural practices were done as recommended. At harvest (158 and 154 days after sowing), the central of 6 rows were harvested and threshed to determine grain and straw yield. The weight of GY was adjusted to 14.5% moisture content.

Water measurements

Amount of irrigation water applied (WA) was measured by a portable pump equipped with a water meter for each lysimeter. Amount of irrigation water applied (WA) was determined according to Phocaides (2001) as follows:

$$WA = \frac{FC - \theta_1}{100} \times BD \times DS \quad (\text{Eq.1})$$

where, WA: water applied (cm³); FC: soil moisture percentage at field capacity; θ_1 : soil moisture percentage before irrigation; BD: bulk density (g cm⁻³) and DS: soil layer (cm).

Water consumptive use by growing plants was calculated based on soil moisture depletion (SMD) according to Israelsen and Hansen (1962):

$$Cu = SMD = \sum_{i=1}^{i=4} \frac{\theta_2 - \theta_1}{100} \times D_{bi} \times D_i \times 4200 \quad (\text{Eq.2})$$

where, Cu: water consumptive use ($\text{m}^3/\text{fed.}$) in the effective root zone; Θ_2 : soil moisture percentage after irrigation; Θ_1 : soil moisture percentage before next irrigation; D_{bi} : soil bulk density (g cm^{-3}); D_i : soil layer depth (cm) and i : number of soil layer (1-4).

Soil moisture (%) was determined by drying the soil samples at 105°C to constant weight and the moisture content was calculated according to Singh (1980).

Water productivity (WP) was calculated as the ratio of GY with the amount of irrigation water applied (PIW) and water consumptive use (PW) according to Ali et al. (2007) as follows:

$$PIW = \frac{\text{Yield (kg/ feddan)}}{\text{Applied water (m}^3 \text{ / feddan)}} \quad (\text{Eq.3})$$

$$PW = \frac{\text{Yield (kg/ feddan)}}{\text{water consumptive use (m}^3 \text{ / feddan)}} \quad (\text{Eq.4})$$

Statistical analysis

Data in the present study were arranged and all statistical analysis was subjected to analysis according to Gomez and Gomez (1984) by using "MSTATC" computer software package. Treatment means were compared by Duncan's Multiple Range Test at 5% level of significance (Duncan, 1955).

Results and discussion

Seasonal water applied

Applied seasonal water (WA) consisted of two sources such as irrigation water delivered to lysimeter and effective rainfall. In both seasons, the total amounts of the effective rainfall were recorded 446 and 393 $\text{m}^3 \text{ fed}^{-1}$, respectively (*Table 3*). At the same irrigation treatment, lysimeters of all combinations between gypsum rates and nitrogen sources were received an equal amount of irrigation during the growing season.

Figure 1 shows that the amounts of WA from sowing to harvesting of wheat were gradually increased by increasing the level of irrigation from 100 to 120% FC in both seasons. Wheat plants irrigated with the water amounts equal to 120% FC recorded the highest values of WA 2320 and 2207 $\text{m}^3 \text{ fed}^{-1}$ (55.24 and 52.54 cm) in the two seasons, while the 100% FC recorded the lowest levels of WA i.e., 2095 and 1972 $\text{m}^3 \text{ fed}^{-1}$ (49.88 and 46.95 cm) in both growing seasons, respectively. Such increased in the amount of WA by increasing irrigation level may be attributed to a considerable increase in vegetative growth and leaf area, which resulted in greater transpiration and in turn water requirement. These findings are in close harmony with the findings of Hossain et al. (2006), Sarker et al. (2007), Inamullah et al. (2011) and El-Agrodi et al. (2016).

Seasonal water consumptive use

Data in *Table 4* show that the amount of water lost as evapotranspiration (seasonal water consumptive use, WCU) was increased by increasing irrigation level in the two

seasons. WCU was markedly increased by an increasing the amount of irrigation water from 100 to 120% FC in both seasons. The irrigation level of 120% FC recorded the highest values of WCU followed by 110 and 100% FC. As the soil moisture level increased the water consumptive use was increased due to more improved growth and perhaps luxury consumptive of water. Also, this may be due to an increase in leaching water by increasing the amount of water applied than field capacity.

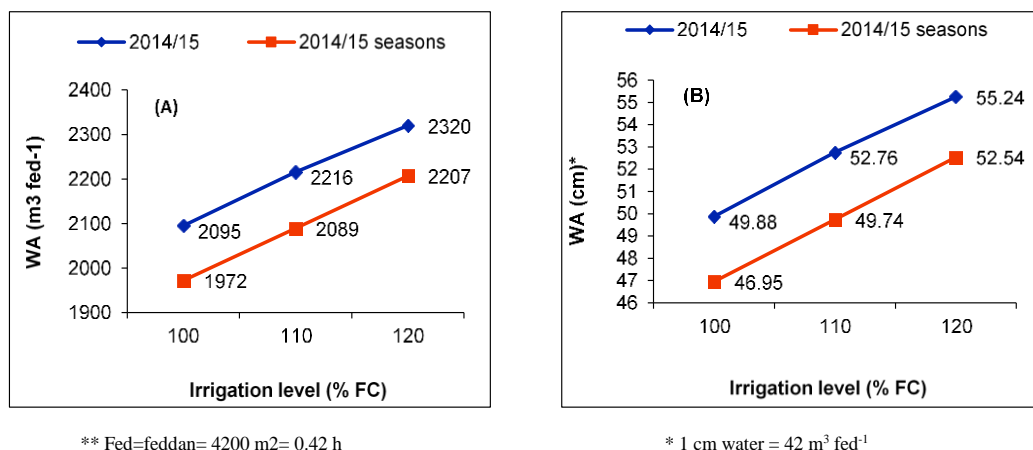


Figure 1. WA in $m^3\ fed^{-1}$ (A) and in cm (B) as affected by irrigation level in both seasons

Incorporation of gypsum in the soil at the rate of $4.42\ t\ fed^{-1}$ (100% of requirements) resulted in the greater WCU than the rate of $2.21\ t\ fed^{-1}$ (50% of requirements) in both seasons. This may be due to more water applied for leaching the exchangeable sodium.

Source of N had a substantial effect on WCU in both seasons. Whereas, application of $7.5\ t\ C + 45\ kg\ N\ fed^{-1}$ (CN) exceeded the application of $90\ kg\ N$ (N) or $10\ t\ compost\ fed^{-1}$ (C) alone in WCU in both seasons. Nitrogen sources were arranged in descending order $CN > N > C$ in this trait in both seasons. While, the application of C and chemical N fertilizer (urea), enhanced the availability of the nutrients in the soil solution. The available nutrients might have helped in enhancing leaf area, which thereby resulted in higher transpiration and more water consumptive.

The interaction between irrigation levels and gypsum rate exerted a substantial effect on WCU. Data show that WCU was increased by increasing each of irrigation level and G rate alone or together in both seasons.

The highest values of WCU 1454 and $1587\ m^3\ fed^{-1}$ were recorded by the irrigation level of 120% FC along with 100% G requirements, while the lowest ones 1349 and $1391\ m^3\ fed^{-1}$ were recorded by the irrigation level of 100% FC along with 50% G requirements in both seasons. The integration between chemical nitrogen ($45\ kg\ N\ fed^{-1}$) and C fertilizer ($7.5\ t\ compost\ fed^{-1}$) along with the irrigation level of 120% FC consumed greater water than the irrigation level of 100% FC and $10\ t\ C\ fed^{-1}$ in both seasons (Table 4). The second order of interaction (irrigation level \times G rate \times nitrogen source) had a markedly effect on WCU (Table 4).

Increasing irrigation level and G rate increased WCU at the same nitrogen source. However, application of both compost and chemical N ($7.5\ t\ C + 45\ kg\ N\ fed^{-1}$), resulted in a markedly increased in WCU, as compared with application $90\ kg\ N$ or $10\ t\ compost\ fed^{-1}$ alone at the same combination of irrigation level and G rate. Wheat plants

received 120% FC WA, 100% G and 7.5 t C + 45 kg N fed⁻¹ recorded the highest values of WCU (1491 and 1603 m³ fed⁻¹), while those received 100% FC WA, 50% G and 7.5 t C fed⁻¹ recorded the lowest ones (1344 and 1394 m³ fed⁻¹) in both seasons. Results demonstrated that water consumptive use increased as soil moisture content was highly maintained by increasing amount of water applied due to increasing leaching requirements. Also, the higher frequent irrigation provides a chance for more water consumption, ultimately resulted in increasing plant transpiration and evaporation from the soil surface. These results are in great harmony with those obtained by Ali et al. (2007).

Table 4. Water consumptive use (WCU), WP for WA and WCU and GY of wheat as affected by levels of irrigation, the rate of gypsum and nitrogen source in both seasons

| Irrigation level | Gypsum rate | N source fed ⁻¹ | WCU (m ³ fed ⁻¹) | | WP for WA (kg grain m ⁻³ water) | | WP for WCU (kg grain m ⁻³ water) | |
|------------------|-------------|----------------------------|---|---------|--|---------|---|---------|
| | | | 2014-15 | 2015-16 | 2014-15 | 2015-16 | 2014-15 | 2015-16 |
| 100% FC | | | 1370 | 1415 | 1.724 | 1.787 | 1.129 | 1.283 |
| 110% FC | | | 1398 | 1491 | 1.779 | 1.755 | 1.122 | 1.229 |
| 120% FC | | | 1433 | 1570 | 1.816 | 1.754 | 1.125 | 1.249 |
| | 50% | | 1379 | 1473 | 1.766 | 1.749 | 1.103 | 1.234 |
| | 100% | | 1422 | 1510 | 1.78 | 1.782 | 1.146 | 1.289 |
| | | 90 kg N | 1396 | 1491 | 1.763 | 1.795 | 1.114 | 1.282 |
| | | 10 t compost | 1378 | 1471 | 1.673 | 1.639 | 1.156 | 1.154 |
| | | 7.5t C + 45 kg N | 1427 | 1514 | 1.885 | 1.862 | 1.217 | 1.339 |
| 100% FC | | 90 kg N | 1367 | 1415 | 1.697 | 1.809 | 1.489 | 1.297 |
| 100% FC | | 10 t compost | 1351 | 1391 | 1.636 | 1.66 | 1.056 | 1.172 |
| 100% FC | | 7.5t C + 45 kg N | 1393 | 1439 | 1.839 | 1.891 | 1.223 | 1.379 |
| 110% FC | | 90 kg N | 1395 | 1490 | 1.769 | 1.793 | 1.113 | 1.279 |
| 110% FC | | 10 t compost | 1373 | 1472 | 1.674 | 1.617 | 1.037 | 1.139 |
| 110% FC | | 7.5t C + 45 kg N | 1427 | 1512 | 1.894 | 1.855 | 1.217 | 1.342 |
| 120% FC | | 90 kg N | 1428 | 1570 | 1.822 | 1.784 | 1.121 | 1.269 |
| 120% FC | | 10 t compost | 1410 | 1549 | 1.707 | 1.64 | 1.037 | 1.151 |
| 120% FC | | 7.5t C + 45 kg N | 1462 | 1591 | 1.921 | 1.839 | 1.211 | 1.326 |
| 100% FC | 50% | | 1349 | 1391 | 1.704 | 1.782 | 1.098 | 1.257 |
| 100% FC | 100% | | 1391 | 1438 | 1.744 | 1.791 | 1.159 | 1.308 |
| 110% FC | 50% | | 1375 | 1476 | 1.782 | 1.738 | 1.106 | 1.229 |
| 110% FC | 100% | | 1421 | 1506 | 1.776 | 1.771 | 1.138 | 1.228 |
| 120% FC | 50% | | 1412 | 1553 | 1.813 | 1.726 | 1.104 | 1.215 |
| 120% FC | 100% | | 1454 | 1587 | 1.819 | 1.783 | 1.141 | 1.282 |
| | 50% | 90 kg N | 1375 | 1476 | 1.767 | 1.791 | 1.099 | 1.265 |
| | 50% | 10 t compost | 1358 | 1451 | 1.667 | 1.611 | 1.025 | 1.119 |
| | 50% | 7.5t C + 45 kg N | 1403 | 1493 | 1.866 | 1.844 | 1.184 | 1.317 |
| | 100% | 90 kg N | 1417 | 1507 | 1.758 | 1.799 | 1.128 | 1.298 |
| | 100% | 10 t compost | 1397 | 1490 | 1.678 | 1.667 | 1.061 | 1.189 |
| | 100% | 7.5t C + 45 kg N | 1451 | 1534 | 1.904 | 1.879 | 1.249 | 1.361 |
| 100% FC | 50% | 90 kg N | 1344 | 1394 | 1.691 | 1.803 | 1.085 | 1.274 |
| 100% FC | 50% | 10 t compost | 1332 | 1372 | 1.629 | 1.637 | 1.036 | 1.139 |
| 100% FC | 50% | 7.5t C + 45 kg N | 1374 | 1407 | 1.791 | 1.905 | 1.172 | 1.359 |
| 100% FC | 100% | 90 kg N | 1389 | 1435 | 1.703 | 1.814 | 1.129 | 1.32 |
| 100% FC | 100% | 10 t compost | 1370 | 1410 | 1.643 | 1.684 | 1.075 | 1.204 |
| 100% FC | 100% | 7.5t C + 45 kg N | 1415 | 1470 | 1.886 | 1.877 | 1.274 | 1.399 |

| | | | | | | | | |
|---------|------|------------------|------|------|-------|-------|-------|-------|
| 110% FC | 50% | 90 kg N | 1369 | 1476 | 1.798 | 1.791 | 1.111 | 1.265 |
| 110% FC | 50% | 10 t compost | 1351 | 1460 | 1.672 | 1.59 | 1.019 | 1.112 |
| 110% FC | 50% | 7.5t C + 45 kg N | 1406 | 1492 | 1.876 | 1.834 | 1.189 | 1.309 |
| 110% FC | 100% | 90 kg N | 1420 | 1504 | 1.739 | 1.795 | 1.115 | 1.292 |
| 110% FC | 100% | 10 t compost | 1395 | 1483 | 1.676 | 1.643 | 1.055 | 1.167 |
| 110% FC | 100% | 7.5t C + 45 kg N | 1448 | 1531 | 1.912 | 1.875 | 1.245 | 1.374 |
| 120% FC | 50% | 90 kg N | 1412 | 1557 | 1.811 | 1.778 | 1.102 | 1.255 |
| 120% FC | 50% | 10 t compost | 1392 | 1522 | 1.7 | 1.606 | 1.019 | 1.107 |
| 120% FC | 50% | 7.5t C + 45 kg N | 1433 | 1579 | 1.93 | 1.793 | 1.192 | 1.283 |
| 120% FC | 100% | 90 kg N | 1443 | 1582 | 1.832 | 1.79 | 1.139 | 1.283 |
| 120% FC | 100% | 10 t compost | 1427 | 1576 | 1.714 | 1.674 | 1.054 | 1.195 |
| 120% FC | 100% | 7.5t C + 45 kg N | 1491 | 1602 | 1.912 | 1.886 | 1.229 | 1.369 |

Generally, WCU values were greater in the second season than in the first season (Table 4). This may be due to increase temperature and decrease relative humidity at the most growing months in the second seasons, which increased evaporation and transpiration and in turn more water consumptive.

Water productivity

GY per unit of applied irrigation water (WA) or water consumptive use (WCU) in kg grain m⁻³ water were used to determine water productivity. Data in Table 4 show that WP (kg grain m⁻³ water) for either WA in both seasons or WCU in the second season was decreased by increasing irrigation level from 100 to 120% FC. The inverse was true in WP for WCU in the first season. The WP for WA and WCU was increased by increasing the gypsum (G) rate in both seasons. Application of 7.5 t C along with 45 kg N fed⁻¹ recorded the highest values of WP for WA and WCU followed by 90 kg N and 10 t compost fed⁻¹ alone in the two seasons. Incorporation of 100% G requirements and integration of compost with chemical nitrogen resulted in an increase in WP for WA and WCU through increasing GY in both seasons.

The first and second order of interaction had a substantial effect on WP for WA and WCU in both seasons. The relative ranking of the interaction among irrigation level, G rate and nitrogen source in was WP for WA and WCU inconsistent in both seasons. The interaction of 110% FC × 100% G × 7.5 t compost + 45 kg N fed⁻¹ produced the highest values of WP for WA (1.245 and 1.374 kg grain m⁻³ WA), while the interaction of 110% FC × 50% G × 10 t compost fed⁻¹ produced the lowest values (1.019 and 1.112 kg grain m⁻³ WA) in the two seasons. The interaction of 120% FC × 100% G × 7.5 t compost + 45 kg N fed⁻¹ produced the highest values of WP for WCU (1.922 and 1.886 kg grain m⁻³ WCU) in both seasons. However, the lowest value of WP for WCU was 1.629 kg grain m⁻³ WCU recorded from the interaction of 100% FC × 50% G × 10 t compost fed⁻¹ in the first seasons, while the interaction of 110% FC × 50% G × 10 t compost fed⁻¹ recorded the lowest value 1.590 kg grain m⁻³ WCU in the second season. Results of the present study could be attributed to the great differences between GY of wheat as well as differences between water applied and water consumed also confirmed by the findings of Ali et al. (2007), Liu et al. (2013), Ali (2016) and El-Shawy et al. (2017).

Grain yield

Grain yield fed^{-1} was significantly increased by increasing the level of irrigation from 100 to 120% FC in both seasons (Table 5). While no significant difference was recorded for GY due to the levels of irrigation water of 120 and 110% FC in both seasons. This may be due to the increase in growth and yield components. In this connection, adequate water not only allowed the wheat plant to increase photosynthetic rate but also give extra time to translocate the carbohydrates in grains, which enhanced grain size and ultimately causes higher GY. This trend in agreement with Ali et al. (2007), Liu et al. (2013); Ali (2016) and Abdrabbo et al. (2016) and Rashwan et al. (2016). The high rate of G (100%) out yielded the low rate (50%) in GY in both seasons. This trend could enhance with Abdel-Fattah (2012), and Hafez et al. (2015). The combination of compost and chemical nitrogen resulted in a significant increase in GY compared with each of the two sources alone in both seasons. Application of organic (compost) and chemical N fertilizer to wheat enhanced the availability of nutrients in the soil solution. The available nutrients might have helped in the stimulation of various physiological processes including cell division and cell elongation of internodes resulting in more tillers formation, leaf numbers and photosynthetic area (leaf area), which resulted in more photosynthetic production and consequently increased dry matter accumulation and GY. Similar results were reported by Ayadi et al. (2012), Yousef et al. (2014), Mehasen et al., (2015), Abd El-Lattief (2016) and Gharib et al. (2016).

Table 5. Grain yield, soil salinity (EC) and sodium adsorption ratio (SAR) after wheat harvest as affected by irrigation level, gypsum rate and nitrogen source in both seasons

| Irrigation level | Gypsum rate | N source fed^{-1} | Grain yield (t fed^{-1}) | | EC (ds m^{-1}) | | SAR (%) | |
|------------------|-------------|----------------------------|-------------------------------------|----------|---------------------------|---------|---------|---------|
| | | | 2014-15 | 2015-16 | 2014-15 | 2015-16 | 2014-15 | 2015-16 |
| 100% FC | | | 2.364 b | 2.529 b | 6.40 | 6.07 | 13.35 | 12.09 |
| 110% FC | | | 2.489 ab | 2.618 ab | 6.05 | 5.73 | 11.91 | 11.29 |
| 120% FC | | | 2.604 a | 2.756 a | 5.77 | 5.36 | 11.49 | 11.17 |
| | 50% | | 2.438 b | 2.576 b | 6.21 | 5.86 | 12.48 | 12.11 |
| | 100% | | 2.533 a | 2.692 a | 5.93 | 5.57 | 12.02 | 10.92 |
| | | 90 kg N | 2.462 b | 2.676 a | 6.30 | 6.07 | 12.64 | 12.00 |
| | | 10 t compost | 2.305 c | 2.41 b | 5.82 | 5.73 | 11.93 | 11.11 |
| | | 7.5t C+45 kg N | 2.691 a | 2.816 a | 6.10 | 5.36 | 12.18 | 11.44 |
| 100% FC | | 90 kg N | 2.319 de | 2.558 cd | 6.70 | 6.46 | 13.66 | 12.48 |
| 100% FC | | 10 t compost | 2.21 e | 2.31 e | 6.11 | 5.75 | 13.03 | 11.79 |
| 100% FC | | 7.5t C+45 kg N | 2.563 bc | 2.72 abc | 6.39 | 6.00 | 13.37 | 11.99 |
| 110% FC | | 90 kg N | 2.466 cd | 2.671 bc | 6.32 | 5.98 | 12.33 | 11.91 |
| 110% FC | | 10 t compost | 2.299 de | 2.379 de | 5.81 | 5.41 | 11.73 | 10.97 |
| 110% FC | | 7.5t C+45 kg N | 2.703 ab | 2.803 ab | 6.02 | 5.79 | 11.68 | 11.01 |
| 120% FC | | 90 kg N | 2.6 abc | 2.8 ab | 5.89 | 5.69 | 11.94 | 11.60 |
| 120% FC | | 10 t compost | 2.406 cde | 2.541 cd | 5.54 | 5.00 | 11.04 | 10.59 |
| 120% FC | | 7.5t C+45 kg N | 2.808 a | 2.926 a | 5.89 | 5.38 | 11.48 | 11.33 |
| 100% FC | 50% | | 2.3 c | 2.48 c | 6.56 | 6.16 | 13.51 | 12.48 |
| 100% FC | 100% | | 2.428 bc | 2.578 bc | 6.24 | 5.98 | 13.19 | 11.69 |
| 110% FC | 50% | | 2.453 b | 2.567 bc | 6.20 | 5.86 | 12.29 | 12.11 |
| 110% FC | 100% | | 2.526 ab | 2.669 ab | 5.89 | 5.59 | 11.53 | 10.47 |
| 120% FC | 50% | | 2.563 ab | 2.681 ab | 5.88 | 5.56 | 11.64 | 11.75 |
| 120% FC | 100% | | 2.646 a | 2.83 a | 5.66 | 5.15 | 11.33 | 10.60 |

| | | | | | | | | |
|---------|------|----------------|-----------|-----------|------|------|-------|-------|
| | 50% | 90 kg N | 2.431 cd | 2.641 bc | 6.41 | 6.16 | 12.89 | 12.52 |
| | 50% | 10 t compost | 2.265 d | 2.337 d | 5.99 | 5.86 | 12.24 | 11.73 |
| | 50% | 7.5t C+45 kg N | 2.62 ab | 2.749 ab | 6.23 | 5.56 | 12.32 | 12.09 |
| | 100% | 90 kg N | 2.493 bc | 2.711 ab | 6.19 | 5.98 | 12.40 | 11.47 |
| | 100% | 10 t compost | 2.345 cd | 2.483 cd | 5.64 | 5.59 | 11.62 | 10.50 |
| | 100% | 7.5t C+45 kg N | 2.763 a | 2.883 a | 5.96 | 5.15 | 12.04 | 10.80 |
| 100% FC | 50% | 90 kg N | 2.273 de | 2.513b-f | 6.82 | 6.58 | 13.68 | 12.93 |
| 100% FC | 50% | 10 t compost | 2.17 e | 2.246 f | 6.29 | 5.78 | 13.23 | 12.08 |
| 100% FC | 50% | 7.5t C+45 kg N | 2.456 b-e | 2.681a-d | 6.56 | 6.11 | 13.52 | 12.45 |
| 100% FC | 100% | 90 kg N | 2.365 cde | 2.603b-e | 6.57 | 6.33 | 13.53 | 12.03 |
| 100% FC | 100% | 10 t compost | 2.251 de | 2.374 def | 5.92 | 5.72 | 12.83 | 11.52 |
| 100% FC | 100% | 7.5t C+45 kg N | 2.669 abc | 2.759abc | 6.22 | 5.89 | 13.22 | 11.53 |
| 110% FC | 50% | 90 kg N | 2.462 b-e | 2.643b-e | 6.52 | 6.11 | 12.86 | 12.66 |
| 110% FC | 50% | 10 t compost | 2.259 de | 2.322ef | 5.96 | 5.49 | 12.21 | 11.77 |
| 110% FC | 50% | 7.5t C+45 kg N | 2.637 abc | 2.736abc | 6.12 | 5.98 | 11.80 | 11.91 |
| 110% FC | 100% | 90 kg N | 2.47 b-e | 2.699 a-d | 6.12 | 5.85 | 11.80 | 11.15 |
| 110% FC | 100% | 10 t compost | 2.338 cde | 2.437 c-f | 5.65 | 5.32 | 11.24 | 10.16 |
| 110% FC | 100% | 7.5t C+45 kg N | 2.769 ab | 2.871 ab | 5.91 | 5.59 | 11.59 | 10.11 |
| 120% FC | 50% | 90 kg N | 2.557 a-d | 2.769 abc | 5.90 | 5.78 | 12.02 | 11.98 |
| 120% FC | 50% | 10 t compost | 2.366 cde | 2.444 c-f | 5.73 | 5.22 | 11.28 | 11.36 |
| 120% FC | 50% | 7.5t C+45 kg N | 2.765 ab | 2.831 ab | 6.02 | 5.68 | 11.63 | 11.90 |
| 120% FC | 100% | 90 kg N | 2.643 abc | 2.831 ab | 5.89 | 5.60 | 11.86 | 11.22 |
| 120% FC | 100% | 10 t compost | 2.446 b-e | 2.638 b-e | 5.34 | 4.78 | 10.80 | 9.82 |
| 120% FC | 100% | 7.5t C+45 kg N | 2.851 a | 3.021 a | 5.75 | 5.07 | 11.33 | 10.76 |

Means of each factor in grain yield columns designated by the same latter are not significantly different at 5% level using DMRT

All the first and second order interactions had a significant effect on GY in both seasons. Increasing irrigation level and G rate along with compost and nitrogen together substantially increased GY. Application of 100% G and 7.5 t compost + 45 kg N fed⁻¹ at any irrigation level were among those treatments having high GY, being insignificant, in both seasons. These results go with those reported by Attia et al. (2013), Abdel-Fattah, (2012), Hafez et al. (2015) and Gharib et al. (2016).

Salinity and sodicity

Salinity (ECe) and sodicity (SARe) of the soil after harvesting as affected by irrigation level, G rate, nitrogen source and their interactions under wheat crop are shown in *Table 5*. The initial value of ECe before the experiment was 7.10 dS m⁻¹ (*Table 1*). Data show that the values of salinity and sodicity were decreased after harvesting compared with those before the beginning of experiment at any studied treatment in both seasons. Increasing irrigation level, G rate and compost alone resulted in a substantially decrease salinity and sodicity of soil after harvesting. Data show that application N fertilizer alone or with compost increased these traits compared with compost alone at any combination between irrigation and G in both seasons. The lowest values of ECe (5.34 and 4.78 dS m⁻¹) and SARe (10.80 and 9.82%) were obtained from the irrigation level of 120% FC, 100% G and 7.5 t compost fed⁻¹ in both seasons.

Application of 10 t compost alone with 100% G reduced Ec greater than 16% at any irrigation level in both seasons (*Figs. 2 and 3*). The highest values of reduction percentage 24.8 and 32.7% were recorded by the interaction of 120% FC × 100% G × 10 t compost fed⁻¹ in the two seasons. The application of G and compost had a positive effect on the soil

properties and the present investigations have addressed the combined effect of compost and G on the saline-sodic soils under semi-arid conditions. The effect of G application on saline-sodic soil reclamation have shown that the soil receiving G at higher rate since it removes the greatest amount of Na^+ from the soil columns and causes a substantial decrease in soil electrical conductivity (EC) and sodium adsorption ratio (SAR) (Hamza and Andrsson, 2003; Rasouli et al., 2013).

Application of 10 t compost alone with 100% gypsum reduced SAR greater than 18% at irrigation levels of 110 and 120% FC in both seasons (Figs. 2 and 3). The highest values of reduction percentage 21.2 and 28.4% were recorded by the interaction of 120% FC \times 100% gypsum \times 10 t compost fed^{-1} in the two seasons.

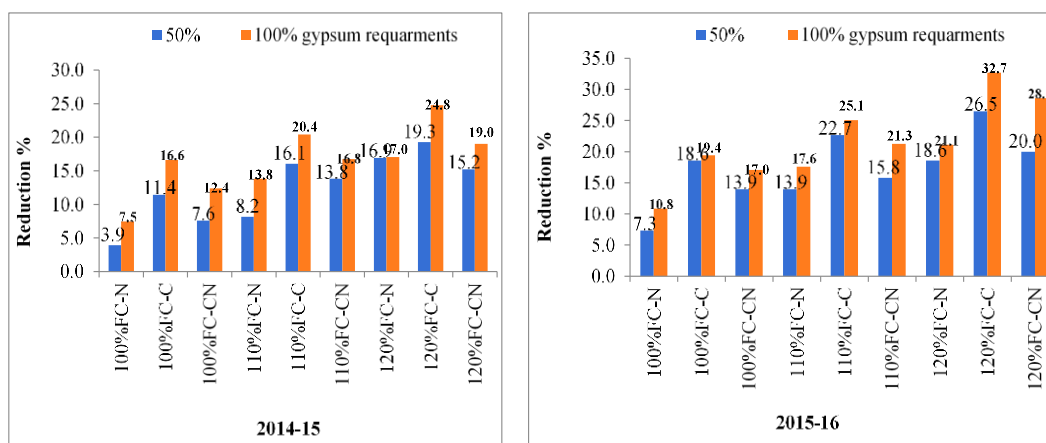


Figure 2. The percent reduction of EC after harvest based on its initial value (7.10) as affected by the interaction of irrigation level, gypsum rate and nitrogen source in both seasons

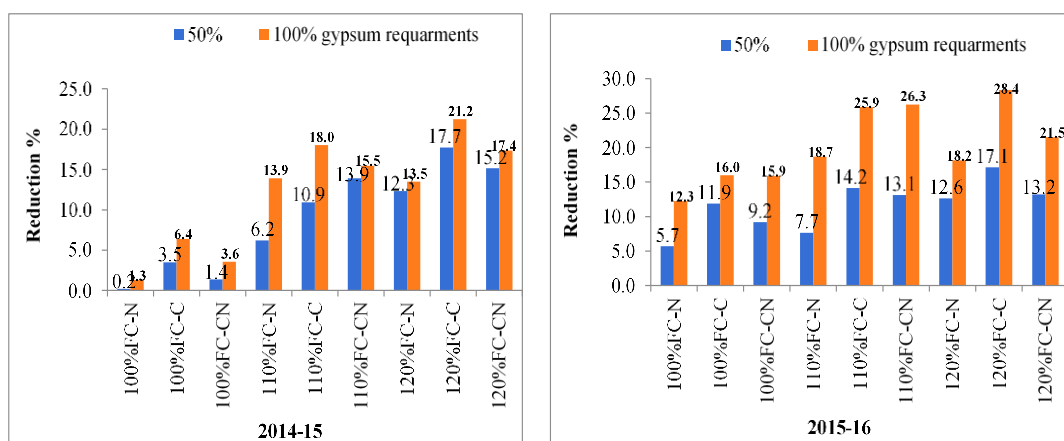


Figure 3. The percent reduction of SAR after harvest based on its initial value (13.71) as affected by the interaction of irrigation level, gypsum rate and nitrogen source in both seasons

Conclusion

In summary, it can be concluded that irrigation with water amount equal to 110 or 120% FC, 100% G requirements and 7.5 t C and 45 kg N fed^{-1} was the best treatment for getting high GY, improve the soil chemical properties, nutrients availability and increase water productivity of salt-affected soil in North Delta of Egypt.

Disclaimer. We hereby declare that the manuscript contains no material which has been accepted for the award of any degree or diploma in any university and that, to the best of our knowledge and belief, the review contains no copy of any material previously published or written by another person except where due reference is made in the text.

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