13 Egypt. J. Soil Sci. **Vol. 63,** No. 2, pp: 163 - 176 (2023)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Integrated Effect of Mole Drains Systems and Planting Methods on Saline Soil Chemical Properties and Wheat Productivity

Wael M. Nada[a*], Manal F. Tantawy[b], Mohamed M. H. Hamad[b], and **Esam G. Abo-Elela[b]**

[a]*Department of Soil Science, Faculty of Agriculture, Menoufia University, Shebin El-Kom 32514, Menoufia, Egypt;* [b]*Soils, Water and Environment Research Institute (Agric. Res Center) Giza, Egypt*

TWO fieldexperiments were carried out at El-Serw Agricultural Research Station, Damietta Governorate, Egypt during two successive winter growing seasons of 2018/ 2019 and 2019/2020 to study the effect of mole drains (with 2 and 4 m distance and 30 and 40 cm depth) and two planting methods (basins and furrows) on saline soil chemical properties, fertilely and productivity of wheat (*Triticum aestivum* L., cv. Sakha 93) productivity. The obtained data showed that, increasing in mole depth and decrease the distance between the moles reduced sail pH, EC, ESP and the content of OM and available N, P and K. These decreases with furrows planting method were higher than those found with basins planting method. In addition, the high straw and grains yields (kgfed^{-1}) of wheat plants as well as its content and uptake of N, P, K and protein were found with 2 m distance and 40 cm depth of mole drains in furrow planting methods. These results concluded that, under saline soil conditions, furrows planting method performed than basins one with applying mole drains as well as application of both organic and mineral fertilizer in suitable amounts and forms.

Keywords: Saline soil, Mole drains, Planting methods, Wheat, Yield parameters.

1. Introduction

In Egypt, the lack of agricultural land and the increase in the population led to an increase in the demand for agricultural products. Therefore, the reclamation and cultivation of saline-alkaline soils is one of the major challenges facing decision makers to provide the population's requirements of these products (Godfray et al., 2010).This problem prompted researchers to find suitable solutions to treat soil salinity and cultivate it with crops that have high resistance to salinity (Mahdy, 2011).

Saline non-sodic and saline sodic soils especially in heavy clay soil of Nile Delta need leaching processes, in their reclamation where these soils characterized by low permeability (Antar, 2000; Abdalla et al., 2010; Antar et al., 2014).It also has poor physical properties, low water infiltration and drainage, high osmotic effect, ionic imbalance and toxicity, all of which are adverse results of salinity and sodicity, which inhibit plant growth and productivity (Abdel-Fattah and Merwad, 2016; Amer and Hashem, 2018). Therefore, a good drainage system is considered one of the most important and necessary procedure to improve clayey saline soil so that it is suitable for crop production in a short time with a cheap cost (Aiad, 2014; El-Dein and Galal, 2017).

Mole drains are circular, unlined subsoil channels, which function like pipe drains.It has highly effective in removing excess irrigation water, and it is used with clay soils especially in the temperate regions. Although its cost is low, its short life is acceptable (Singh et al., 2022). Mole drains are excavated with a mole plow, which consists of a cylindrical base attached to a narrow stem, followed by a cylindrical expander of slightly larger diameter.The foot and extender build the drainage

*Corresponding author e-mail: wael_nada22@yahoo.com
Received: 08/02/2023; Accepted: 25/02/2023
DOI: 10.21608/EJSS.2023.192612.1571

channel while the stem prevents the lumps of topsoil associated with tillage from falling down into the channel (Kolekar et al., 2011).Mole drains (pipeless) was used on a large scale with heavy clay soils to reclaim it and improve their productivity (Antar et al., 2008; El-Adl, 2011; El-Sanat et al., 2017; Bayoumi, 2019).Deep plowing will improve the movement of irrigation water downward, carrying the salts from the surface layers, decreasing soil pH, EC, and ESP in combination with compost applications (El-Sanat et al., 2017; Abou Hussien et al., 2020). Distance between mole drains and their depth were the most important factors that affecting the efficiency of mole drains in improving saline soil properties. Decreasing distance and increasing depth lead to decreasing soil EC and ESP (Aiad, 2014; El-Sanat et al., 2017; Bayoumi, 2019).

Furthermore, planting methods may be instrumental practice in improving and overcoming the properties of extremely poor saline soils. In comparison to the Basin method, raised bed cultivation (furrows) improves water distribution and its efficiency without decreasing the yield (Freeman et al., 2007; Kumar et al., 2010). This is probably due to the low number of plants per area unit and the high efficiency of water distribution (Aboelsoud et al., 2020). Zhang et al.(2007) indicated that the decrease in water consumption and increase its productivity, and increase the wheat yield accompanied the furrows cultivation compared to the traditional basin method. Hassan et al. (2008) reported that wheat grown in furrows achieved 13% and 50% higher in grain yield, and irrigation water productivity, respectively, than those in basin planting.

In addition, reclamation saline soil can be achieved to mitigate the effects of salinity through the application of soil amendments like gypsum and compost (Saied et al., 2017; Sahakyan et al., 2022).Many researchers have proven that adding compost and gypsum to saline soils had a great role in increasing wheat yield and reducing soil salinity (Bayoumi, 2019; Awwad et al., 2022; Hussein et al., 2022).

From other wise, wheat plant (*Triticum aestivum* L.) is considered one of the most important cereal crops in the world. Egypt produces half of its needs (20 million tons) of wheat and import the other (Asseng et al., 2018). Therefore, compensation of this production shortfall should be by increasing the cultivated area in both old and newly reclaimed soils, growing diseases-resistant cultivars (Raza et al., 2019), and improving agriculture practices (Datta et al., 2009; Bowman et al., 2013).
Therefore, this study aims mainly to define the best planting method of wheat plants as well as the good system of mole drains under saline soil conditions and their effects on these soil chemical properties, fertility and the productivity of wheat plant.

2. Materials and Methods

2.1. Experimental location and soil sampling

The current study was carried out at Elserw Agricultural Research Station, Damietta Governorate (31° 14' 37.3" N, 31° 47' 57.1" E), Agricultural Research Center (ARC), Egypt. In order toRepresent saline soil,two field experiments were carried out during two successive growing winter seasons 2018/2019 and 2019/2020 to evaluate mole drainage systems which carried out on two distance (2 and 4 m) and two depths (30 and 40 cm) under two planting methods (basins and furrows) on salt-affected soil properties fertility and productivity of wheat plant (*Triticum aestivum* L., cv Sakha 93). Before planting of each season, five surface (0 – 30 cm) weretaken from different sites of the experimental soil. These samples, air dried, good mixed, sieved through a 2 mm sieve and analyzed for some soil properties and fertility as described by (Cottenie et al., 1982; Page et al., 1982; Klute 1986). The obtained results are listed in Table (1).

2.2. Field experiment

In the two experiments, the studied treatments (10 treatment) were arranged within the experimental units (30 unit) in strip plot design in threereplicates (Figure 1). The experimental plots were divided into five main groups or main factor (6 plot/ main group) representing the mole drain systems, i.e. without mole drains (M0), with 2 m distance and 30 cm depth (M1), with 2 m distance and 40 cm depth (M2), with 4 m distance and 30 cm depth (M3), and with 4 m distance and 40 cm depth (M4). The plots of each main group was divided into two sub-groups (2 plots / subgroup) representing the basin and furrows planting methods. The area of each plot was 120 m^2 (12 m length x 10 m wide).Based on the commonly use in such soil (Abou Hussien et al., 2020; Aid et la., 2021), before planting and with soil preparation, all plots were treated by compost (as organic fertilizer) and ordinary super-phosphate (15.5% P_2O_5) at rates of 10 ton fed^{-1}(2.4 kgm^{-2}), 100 $kgfed^{-1}$ (2.4 gm^{-2}), respectively.

TABLE 1. Some physical and chemical properties of the experimental soil (values are average of two growing seasons).

Particle size distribution (%)				Texture class	BD (Mg m^{-3})	PD (Mg m^{-3})	TP (%)	FC (%)	pH	ECe (dS m^{-1})
C. sand	F. sand	Silt	Clay						-	
2.1	10.5	22.5	64.9	Clay	1.35	2.55	47.06	32.5	8.72	11.25
CEC (cmol kg^{-1})	ESP (%)	OM (%)	$CaCO_3$ (%)	Available macronutrients (mg kg^{-1})			Available micronutrients (mg kg^{-1})			
				N	P	K	Fe	Mn	Zn	Cu
40.3	20.85	0.95	2.85	33.50	7.65	140.88	2.13	2.70	0.72	0.55

BD= Bulk density, **PD**= Particle density, **TP**= Total Porosity, **FC**= Field capacity, **pH** = Soil reactionmeasured in 1:2.5, soil: distilled water suspension, **EC**= electrical conductivity(measured in soil paste extraction), **CEC**= Cation exchange capacity**, ESP**= Exchangeable sodium percentage**, OM**= organic matter, n=5.

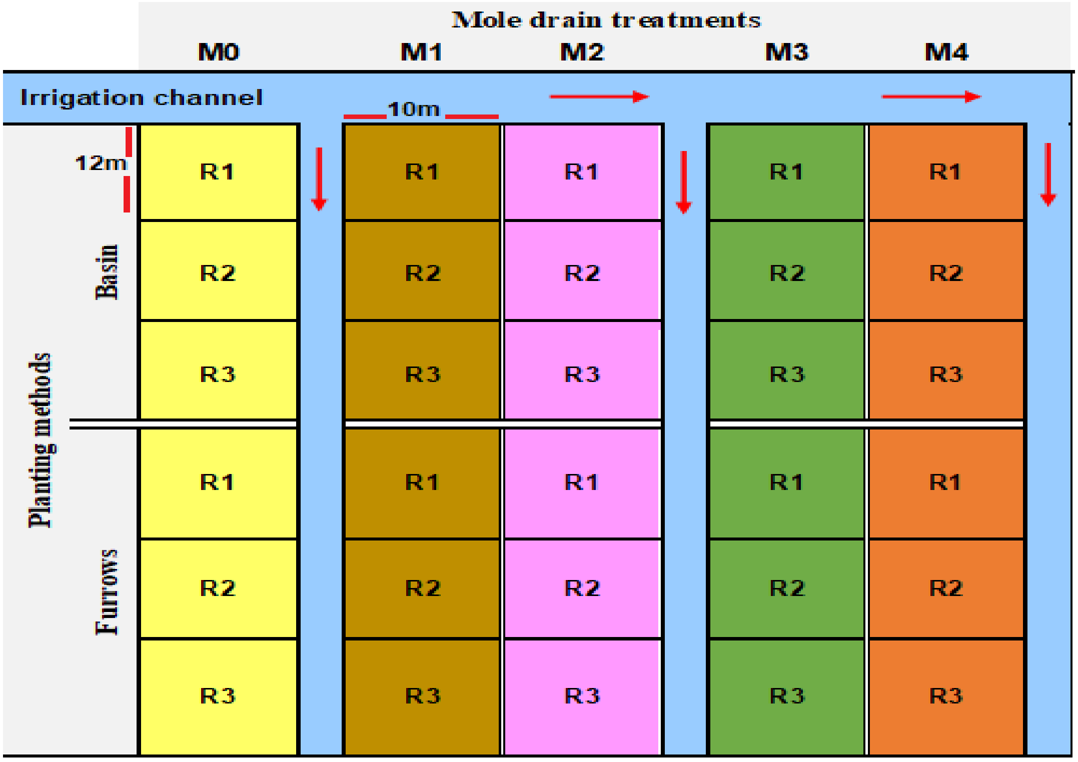

Fig. 1. Design of the studied treatments (M0=control without mole, M1=2m mole space with 30 cm depth, M2= 2m mole space with 40 cm depth, M3= 4m mole space with 30 cm depth, M4= 4m mole space with 40 cm depth, R= replicate).

Also, a protective dose of agricultural gypsum (4.0 tonfed^{-1}) was added to all of the studied plots. All plots were ploughed according to the traditional methods by using the surface plow (8 to 10 cm depth). The treatments of mole drains were carried out by using mole ploughinstalled at a depth of 30 and 40 cm and spacing of 2 and 4 m. After plowing, leveled, the desired planting methods were established. For furrows planting methods, each plot was divided into 10 lines with 120 cm wide, 10 m length and height of 15 cm. While, the basin plots were prepared and divided according to the traditional used methods (12 m length x 10 m wide).

Grains of wheat (*Triticum aestivum* L., cv Sakha 93) were obtained from field Crops Research Institute, ARC, Egypt. In both growing seasons the grains were planted in rows with 10 and 5 cm (between the rows and heels) at the first week ofNovember 2018 and 2019. All farming processes of wheat plant under soil conditions were carried in the two seasons according to the recommendations pointed by Agriculture Ministry of Egypt. Nitrogen and K fertilization were carried out at rates of 130 kg fed^{-1} (30.95 g m^{-2}) and 100 kg fed^{-1} (23.81 g m^{-2}) amnion nitrate (33.5% N) and potassium sulfate (48.1% K_2O), respectively. Bathe N and K fertilizers were added in two equal doses after 20 and 50 days of planting.

2.3. Plant and soil measurements

At harvesting stage, (the third week of April in both seasons), the plant in each plot were harvested above the soil surface, air dared, separated to straw and gains and weighted to obtained grains, straw and biological yields (kgfed^{-1}). A portion of grains from each plot was taken, oven-dried at 70^o C for 48 hr, weighted, ground and kept for chemical analysis. A 0.5 g of ground grains was digested in 10 ml mixture of concentrated H_2SO_4 and $HClO_4$ at mixed ration of 3: 1 according to the method of Chapman and Pratt (1961). The clear digest was dallied up to 100 ml using distilled water. The digest grains content of N, P and K was determined according to the methods mentioned by Cottenie et al. (1982). Grains protein content was calculated by multiplying its N content (%) by 5.83 as pointed out by Jones (1931). Moreover, biological yield (BY, kgfed^{-1}) was calculated by the following equation (Eq. 1) according to Fischer et al. (1978), where GY and SY are the Grain and straw yields (kgfed^{-1}), respectively. Furthermore, Eq. 2 was used to calculate the productivity of irrigation water (PIW, kgm^{-3}) according to Ali et al. (2007), where IW is the applied irrigation water (m^{3}fed^{-1}).

$$BY = GY + SY \quad \text{Eq. 1}$$

$$PIW = GY/ IW \quad \text{Eq. 2}$$

Also, after harvesting in the two growing seasons, surface soil sample (0 – 30 cm) was taken separately from each plot and prepared to chemical analysis as described by Cottenie et al. (1982) and Page et al. (1982). These analysis include soil pH, EC, and the OM content as well as the soil content of available N, P, and K. Soil soluble cations of Na^+, Ca^{2+}, and Mg^{2+} (Data not recorded) were estimated to calculate values of soil SAR (Eq. 3), which used to predicate the values of soil ESP by the following formula (Eq. 4) according to Rashidi and Seilsepour (2008).

$$SAR = Na / [(Ca + Mg)/2]^{1/2} \quad \text{Eq. 3}$$

$$ESP = 1.095 + 1.03\ SAR \quad \text{Eq. 4}$$

2.4. Statistical analysis

The obtained data for plant and soil analysis were statically analysis (ANOVA) according to the method mentioned by Snedecor and Cochran (1989). The least significant difference (LSD) testwas used to compare different means of the examined treatments, as it was considered significant at the 5% level of probability.

3. Results and Discussion

3.1. Soil chemical properties

Soil reaction (pH)

The presented data in Table (2) show that, soil pH in all experimental plots were slightly alkaline, where its ranged between 8.70 in zero tillage treatment in basins planting method (M0) to 8.14 with tillage treatment of 2 m distance and 40 cm depth under furrows planting method (M2). Generally, with the treatments of drainage system and planting methods, soil pH was decreased compared with the initial soil pH (Table 1) which resulted from the improve effect of farming processes such as organic manure application on soil chemical properties (Abou Hussien et al., 2020; Abou Hussien et al., 2022). The highest significant decrease in soil pH appeared with M2 (8.17) treatment, while the lowest one was in M0 (8.70). Regarding to the effect of planting methods on soil pH, the data in Table (2) show that, with the same treatment of mole drains system, soil pH of furrows plots (8.33) was significantly lower than that of basin treatments (8.43). These results attributed high leaching amounts of irrigation water in furrow method compared with those occurred with basins planting method. In this respect before that, Kumar et al. (2010), Aboelsoud et al. (2020) and Abou Hussien et al. (2022) obtained on similar results.

Also, the soil treated with mole drains showed a significant decrease in pH values compared to the untreated soils. The soil treated with mole drains that have a 2 m distance (M1 and M2). Soils that had drains at a distance of 2 m (M1 and M2) had significantly lower pH than those that had drains at a distance of 4 m (M3 and M4). In the same context, the drains that were executed at depths of 30 cm had a great effect in reducing the pH values compared to those that were dug at a depth of 40 cm. For example, soil pH with mole drains treatments of 2 m distance and 40 cm depth (M2) were 8.20 and 8.14 with the planting method of basins and furrow, respectively. This means that, soil pH was decreased significantly with the decrease in the distance between the two types as well as with the increase in the depth of mole drains. Before that and under saline soil conditions, El-Sanat (2018), Abou Hussien et al. (2020) and Abou Hussien et al. (2022) obtained on similar results, where they attributed those decreases to the increase in the leaching amounts of irrigation water resulted from increase in soil total porosity with deep tillage.

Soil electrical conductivity (EC)

The data of soil EC (dSm^{-1}) presented in Table (2) show a clear decrease under both treatments of mole drains system and planting methods. The highest EC value (11.09 dSm^{-1}) in the zero treatment of mole drains system with basin planting method (M0), while the lowest one (8.50 dSm^{-1}) was appeared in the furrow planting method with 2 m distance and 40 cm depth (M2) of mole drains recorded relative decrease of 23.35%. For example, in furrows cultivation method, soil EC was decreased from 10.81 dSm^{-1} with zero tillage treatment to 8.95 and 8.50 dSm^{-1} under the treatment of 2 m distance with the increase in mole drains depth from 30 to 40 cm recorded relative decrease of 17.21 and 21.37%, respectively.

TABLE 2. Saline soil pH, EC, SAR, ESP and OM content as affected by different studied treatments(values are average of two growing seasons).

Treatments		pH	EC	SAR	ESP	OM
Mole drain systems	Planting methods	-	(dS m^{-1})	-	(%)	(%)
M0	Basin	8.76a ± 0.016	11.09a ± 0.01	17.82a ± 0.01	20.31a ± 0.01	0.969a ± 0.011
	Furrow	8.65b ± 0.008	10.81b ± 0.01	17.18b ± 0.06	19.65b ± 0.06	0.943bc ± 0.012
M1	Basin	8.37de ± 0.038	9.04g ± 0.06	15.32e ± 0.08	17.73e ± 0.08	0.940bcd ± 0.010
	Furrow	8.22fg ± 0.031	8.95h ± 0.02	14.67g ± 0.09	17.07g ± 0.09	0.960ab ± 0.010
M2	Basin	8.20g ± 0.011	8.85i ± 0.05	14.35h ± 0.07	16.73h ± 0.08	0.918d ± 0.008
	Furrow	8.14h ± 0.016	8.50j ± 0.02	13.95i ± 0.06	16.32i ± 0.07	0.886e ± 0.015
M3	Basin	8.50c ± 0.013	9.62c ± 0.04	16.41c ± 0.11	18.85c ± 0.12	0.950abc ± 0.010
	Furrow	8.41d ± 0.033	9.40d ± 0.01	15.69d ± 0.01	18.12d ± 0.01	0.930 ± 0.010
M4	Basin	8.34e ± 0.011	9.32e ± 0.02	15.68d ± 0.05	18.11d ± 0.05	0.937cd ±0.015
	Furrow	8.26f ± 0.005	9.10f ± 0.01	15.10f ± 0.09	17.50f ± 0.09	0.921d ± 0.010
F-test		**ns**	**	**ns**	*	**
LSD 0.05		**0.004**	**0.051**	**0.214**	**0.216**	**0.022**
Mole drain systems						
M0		8.70a ± 0.063	10.95a ± 0.15	17.51a ± 0.35	19.98a ± 0.36	0.956a ± 0.017
M1		8.29c ± 0.087	8.99d ± 0.06	14.99d ± 0.36	17.39d ± 0.37	0.950ab ± 0.014
M2		8.17d ± 0.035	8.67e ± 0.20	14.15e ± 0.23	16.52e ± 0.24	0.903d ± 0.020
M3		8.45b ± 0.055	9.51b ± 0.12	16.05b ± 0.40	18.48b ± 0.41	0.940bc ± 0.014
M4		8.30c ± 0.046	9.21c ± 0.12	15.39c ± 0.33	17.81c ± 0.34	0.928c ± 0.014
F-test		**	**	**	**	**
LSD 0.05		**0.024**	**0.046**	**0.84**	**0.088**	**0.016**
Planting methods						
Basin		8.43a ± 0.197	9.58a ± 0.82	15.92a ± 1.20	18.34a ± 1.24	0.943a ± 0.020
Furrow		8.33b ± 0.188	9.35b ± 0.81	15.32b ± 1.13	17.73b ± 1.17	0.928b ± 0.027
F-test		**	**	**	**	*
LSD 0.05		**0.022**	**0.0229**	**0.096**	**0.097**	**0.010**

M0=control without mole, **M1**=2m mole space with 30 cm depth, **M2**= 2m mole space with 40 cm depth, **M3**= 4m mole space with 30 cm depth, **M4**= 4m mole space with 40 cm depth, ns= non-significant, **EC**= electrical conductivity(measured in soil paste extraction), **SAR**= Sodium adsorption ratio, **ESP**= Exchangeable sodium percentage, **OM**= organic matter, *= significant at 0.05 probability level; **= significant at 0.01probability level**.** Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

The applied treatments of mole drains either the distance or the depth have a high decrease effect of soil EC (Table 2). The highest significant decrease in EC value (8.67 dSm-1) was in favor of the treatment of drains at a distance of 2 m and 40 cm depth (M2).Also, with the same mole drains depth, the found decrease of soil EC in the treatments that have a 2 m distance (M1 and M2) was higher than that have 4 m distance (M3 and M4). Moreover, with the same distance between drains, soils that were plowed at depths of 40 cm were more effective in reducing EC values than those that were drained at depths of 30 cm. For example, soil EC with 2 m distance between the drains were 8.99 and 8.67 dSm^{-1} with mole drains depth of 30 and 40 cm, respectively. The decrease of EC as a result of increase in mole drains depth and the decrease in the distance between the mole drains was attributed to high leaching amounts of irrigation water with these treatments, where such these treatments decreased soil bulk density and increased its total porosity (Kolekar et a., 2011; El-Sanat, 2018, Bayoumi, 2019; Abou Hussien et al., 2020).

Also, data in Table (2) show that, with the same treatment of mole drains (distance and depth) EC value with furrows planting method was lower than that found with basins planting method. For example, with the mole drains treatment of 2 m distance and 30 cm depth were 9.04 and 8.95 dSm^{-1} with basins and furrow planting methods, respectively. Regarding to the individual effect of planting methods, the EC values of the furrows treatments were significantly lower than the basin treatments, which it were 9.35 dSm^{-1} and 9.58 dSm^{-1}, respectively.The superior effect of furrow cultivation method on the decrease of soil EC compared with basins methods may be explained by the large amounts of soluble salts leached with drainage water with furrows planting method. These results are in harmony with this obtained by Ghane et al. (2009), Kumar et al. (2010), and Aboelsoud et al. (2020).

Sodium sodicity (SAR and ESP)

Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are very important, where it is used as good parameters for soil alkalinity (Richards, 1954). Also, these parameters influenced greatly on all soil physical, chemical and biological properties as well as on plant growth. Data in Table (2) cleared that, according to Richards (1954), the experimental soil classified as sodic alkaline soil (ESP > 15%). Generally, soil SAR and ESP were decreased significantly as a result of the studied treatments. In details, the highest values of soil SAR (17.82) and ESP (20.31%) were recorded to the soil untreated with drains and planted in basin method, while the lowest significant values (13.95 and 16.32%, for SAR and ESP, respectively) were in soil excavated by 2 m spacing mole at 30 cm depth and integrated by furrows planting method. Data also demonstrated that, increasing depth of mole drains up to 40 cm and decrease in the distance between the moles resulted in a more decrease in soil SAR and ESP with the two planting methods. The lowest significant SAR (14.15) and ESP (16.52%) values were found with 2 m spacing and 40 cm depth of mole drains treatment under furrow planting method. In comparison with control treatment (M0), the reduction of soil SAR and ESP were higher under mole drain with 2 m spacing and 40 cm depth (M2), respectively about 19.19 and 17.32%.

Concerning planting methods, results in Table (2) showed that, using furrows as planting method resulted in more decrease of soil SAR and ESP compared with that found with basins method. Therefore, furrows methods recorded the lowest significant values for both SAR (15.32) and ESP (17.73%), as compared with the highest one (15.92 and 18.34%) appeared in basin method, respectively. These findings are resulted from the high leached amounts of soluble sodium (Na^+) with drainage which increased with the increase in moles depth and decrease in the distance between the drains especially with furrows planting method. These results are in similar with those obtained before that Antar (2000) and Elsanat (2003), Kumar et al. (2010), and Aboelsoud et al. (2020).

Soil organic matter (SOM)

Soil content (%) of organic matter (SOM) considered important properties of agricultural soil, where it has a greater effect on many physical and chemical soil properties especially under saline soil conditions. Under all experimental treatments in this study, SOM was lower than 1.0% where this content ranged between 0.969% with zero tillage treatment in basins planting method and 0.886% under furrows planting method with 2 m distance and 40 cm depth of mole drain treatment (Table 2). This low content may be resulted from soil alkaline conditions that resulted in an increase of organic matter solublization and des-reduction (Stevenson, 1994). More decrease of SOM was found as a result of applying mole drains system, where this content was decreased with the increase in moles depth and the rate of this decrease was increased with the decrease distance between the drains.Increasing tillage depth and decreasing the distance among moles may be increased aeration, which led to high oxidation and decomposition of soil OM (El-Sanat et al., 2017; Abou Hussien et al. 2020). For example, the content of SOM was decreased from 0.956% with zero mole drains system (M0) to 0.950 (M1) and 0.903% (M2) with 2 m spacing mole drain at 30 and 40 cm depth, respectively. This recorded relative decrease of 0.63 and 5.54% in M1 and M2 treatments as compared with control (M0). Another example, SOM was decreased from 0.956% with zero tillage to 0.940 (M3) and 0.928% (M4) with 4 m drainage distance, recorded relative decrease by 1.67 and 2.93% at moles depth of 30 and 40 cm, respectively. These results as well as the mentioned examples, may be conducted that, with moles drains system applying especially under salt affected soils, organic materials must be added in sufficient amounts to improve soil health and fertility (Aiad, 2014; El-Sanat et al., 2017; Bayoumi, 2019; Abou Hussien et al. 2020).

Otherwise, either without (zero tillage) or with mole drains system under study, the data in Table (2) show that, the contents of SOM with basins planting method were higher than those found with furrows cultivation method. Soil planted in furrows method showed the lowest significant value (0.928) of OM, while those designed by basin method appeared with the highest OM value (0.943%). Such findings were resulted from good aeration conditions with furrow cultivation method which resulted in more oxidation and degradation for SOM produced high soluble mineral and organic compounds (Ghane et al., 2009; Kumar et al., 2010; and Aboelsoud et al., 2020).

3.2. Soil content of available macronutrients

Nitrogen (N)

In general, the experimental soil characterized by low content of available N, where this content under all experimental treatments ranged from 33.35 $mgkg^{-1}$ in zero tillage treatments with furrows planting method to 28.78 $mgkg^{-1}$ in furrows planting method with 2 m distance spacing and 40 cm depth (Table 3). This Table also show that, all experimental treatments resulted in a decrease in soil content of available N. In other words, increasing moles depths as well as decrease the distance between these moles resulted in a decrease in the soil content of available N. These decreases were from 33.33 mgkg^{-1} in soil zero mole drains (M0) to 30.08 and 29.47 mgkg^{-1} in the soil treated by 2 m spacing moles and depth of 30 and 40 cm (M1 and M2), respectively. Consequently, this recorded relative decreases of 9.75 and 11.58% of M1 and M2 treatments, respectively. Moreover, the rate of these decreases with furrows planting method were higher than those recorded with the planting method of basins. Whereas, it were decrease to 31.34 and 30.45 mgkg^{-1} in basin and furrows planting methods, respectively. The soil content of available N is in harmony with the soil content of OM (Table 1 and 2). These findings means that, establishment of mole drains or deep tillage resulted in a decrease in the soil content of available N which may be resulted from decrease in the soil content of OM, high leaching amounts of available N with drainage water and increase in its uptake by growing plants (El-Sanat, 2003; Aiad, 2014; Abdel-Fattah and Merwad, 2016; Abou Hussien et al., 2020). Therefore, under such these treatments, N fertilizer must be added in suitable amount and form.

TABLE 3. Saline soil available N, P and K contents as affected by different studied treatments(values are average of two growing seasons).

Treatments		N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
Mole drain systems	**Planting methods**			
M0	**Basin**	33.32a ± 0.98	7.63a ± 0.07	139.90a ± 0.96
	Furrow	33.35a ± 0.94	7.62a ± 0.08	139.64a ± 1.08
M1	**Basin**	30.92ab ± 1.20	7.82de ± 0.05	137.32b ± 1.11
	Furrow	29.24ab ± 0.86	6.78def ± 0.08	131.16de ± 1.18
M2	**Basin**	30.16ab ± 1.00	6.64f ± 0.05	129.10f ± 0.92
	Furrow	28.78b ± 1.00	6.69ef ± 0.04	127.51g ± 1.19
M3	**Basin**	31.61ab ± 1.53	7.32b ± 0.07	136.26bc ± 0.72
	Furrow	30.86ab ± 1.00	7.10c ± 0.03	135.69c ± 1.27
M4	**Basin**	30.72ab ± 0.99	7.15c ± 0.10	132.49d ± 1.01
	Furrow	30.01ab ± 1.07	6.85d ± 0.08	130.24ef ± 1.33
F-test		**ns**	**	**
LSD $_{0.05}$		**4.49**	**0.15**	**1.41**
Mole drain systems				
M0		33.33a ± 0.86	7.63a ± 0.06	139.77a ± 0.92
M1		30.08bc ± 1.31	6.79d ± 0.06	134.24c ± 3.53
M2		29.47c ± 1.17	6.67e ± 0.05	128.31e ± 1.29
M3		31.24b ± 1.22	7.21b ± 0.13	135.98b ± 0.97
M4		30.37bc ± 1.00	7.00c ± 0.18	131.37c ± 1.62
F-test		**	**	**
LSD $_{0.05}$		**1.613**	**0.113**	**1.023**
Planting methods				
Basin		31.34a ± 1.49	7.11a ± 0.37	135.02a ± 4.01
Furrow		30.45a ± 1.86	7.01b ± 0.35	132.85b ± 4.56
F-test		**ns**	*	**
LSD $_{0.05}$		**2.008**	**0.068**	**0.633**

M0=control without mole, **M1**=2m mole space with 30 cm depth, **M2**= 2m mole space with 40 cm depth, **M3**= 4m mole space with 30 cm depth, **M4**= 4m mole space with 40 cm depth, ns= non-significant, *= significant at 0.05 probability level; **= significant at 0.01probability level**.** Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

Phosphorus (P)

Phosphorus and its availability in the agricultural soil affected greatly by different soil properties and its management. Soil content of available P was low (lower than 8.0 mgkg^{-1}) and ranged between 7.62 mgkg^{-1} with zero tillage in furrows planting methods and 6.64 mgkg^{-1} under basin planting method in 2 m distance and 40 cm depth of mole drains (Table 3). Regarding to this range may be reported that, in two planting methods, all treatments of mole drains resulted in a significantly decreases in the soil content of available P and this decrease was more clear with furrows planting method. For example,soil content of available P was decreased from 7.63 mgkg^{-1} in zero tillage treatment with the two cultivation methods to 6.79 and 6.67 mgkg^{-1} at 2 m distance and 30 cm (M1) and 40 cm (M2) depth, respectively. The basins and furrows planting method recorded relative decrease by 6.82 and 8.01% of soil available P, respectively, as compared with M0 treatments. This could be due to higher P uptake by plants grown in furrows plots than those planted in basin treatments (Kumar et al., 2010). Furthermore, soil contents of P in the same mole depth were 6.79 and 7.21 mgkg^{-1}, and 6.67 and 7.00 mgkg^{-1} for the treatments ploughed at spacing distance of 2 m and 4 m, respectively. This trends recorded relative soil P decreases of 11.01 and 5.50 (at 2 m distance) and 12.58 and 8.26% (at

4 m mole distance) for the treatments tilled at 30 cm and 40 cm depth, respectively. These findings cleared that, under saline soil conditions, the soil content of available P leached from soil by large amounts with drainage water, therefore to overcome on P deficiency in this conditions, P must be applied in suitable amounts and forms. Before that, similar results were obtained by Elsanat (2003), Aiad (2014), Abdel-Fattah and Merwad (2016), and Abou Hussien et al. (2020).

Potassium (K)

Soil available K content (mgkg^{-1}) as affected by the studied treatments i.e. mole drains (distances and depths) and planting methods (basin and furrows) are shown in Table (3). Data show that the soil content of available K appeared wide range, which ranged between 139.90 mgkg^{-1} in zero tillage treatment in basin planting methods and 127.50 mgkg^{-1} in the 2 m spacing distance and 40 cm depth of mole drain. Also, this Table show the behavior of available K in relation with the experimental factors was in similar with those mentioned and discussed before that with the soil content of available N and P. This mean that, the soil content of available K decreased after mole drains systems application, where the rate of this decrease was increased as moles depth increase and decrease in the distance between the moles. In addition, with the moles drains system, the decrease in the soil content of available K with furrows planting method was higher than that found with basins cultivation method. These results are in agreement with those obtained by Elsanat (2003), Abdel-Fattah and Merwad (2016), and Abou Hussien et al. (2020).

3.3. *Straw, grain, and biological yield*

Data in Table (4) show straw, grains and biological yield (kg fed^{-1}) of wheat plants grown on salt-affected soil of Egypt as affected by both planting methods (basins and furrows) and moles systems (varied in their distances and depths).Generally, the low yields (particularly grains) of wheat may be due to its high sensitivity to the high salinity of the studied soil (Table 1).

TABLE 4. Grains, straw, biological yield and harvest indexof wheat grown in saline soil affected by different studied treatments (values are average of two growing seasons).

Treatments		Grain (kg fed^{-1})	Straw (kg fed^{-1})	Biological yield (kg fed^{-1})
Mole drain systems	**Planting methods**			
M0	**Basin**	874.9f ± 132.1	2250.4i ± 130.8	3125.4h ± 262.7
	Furrow	992.6e ± 90.2	2512.8h ± 95.4	3505.4g ± 185.3
M1	**Basin**	1276.4cd ± 130.1	3173.9f ± 122.7	4450.3e ± 252.6
	Furrow	1450.1b ± 139.1	3552.3b ± 133.9	5002.4b ± 272.2
M2	**Basin**	1325.5c ± 122.4	3339.6d ± 121.8	4665.1c ± 244.0
	Furrow	1528.1a ± 131.7	3666.5a ± 118.5	5194.6a ± 246.3
M3	**Basin**	1215.9d ± 112.6	3105.7g ± 111.4	4321.6f ± 223.6
	Furrow	1437.5b ± 86.9	3487.8c ± 118.0	4925.4b ± 203.8
M4	**Basin**	1286.1cd ± 121.9	3255.2e ± 114.6	4541.3de ± 240.1
	Furrow	1472.2ab ± 105.2	3105.41g ± 104.6	4577.6cd ± 209.9
F-test		**	**	**
LSD $_{0.05}$		**75.15**	**46.58**	**120.66**
Mole drain systems				
M0		933.8d ± 119.9	2381.6e ± 176.5	3315.4e ± 291.0
M1		1363.3b ± 153.5	3363.1b ± 236.9	4726.4b ± 382.9
M2		1426.8a ± 158.8	3460.8a ± 166.3	4929.8a ± 384.4
M3		1326.7c ± 151.1	3296.7c ± 233.1	4623.5c ± 382.1
M4		1379.1b ± 144.1	3222.5d ± 246.5	4559.4d ± 219.9
F-test		**	**	**
LSD $_{0.05}$		**31.52**	**19.81**	**47.57**
Planting methods				
Basin		1195.8b ± 199.7	3024.8b ± 421.6	4220.8b ± 614.6
Furrow		1376.1a ± 222.5	3264.9a ± 445.9	4641.1a ± 641.2
F-test		**	**	**
LSD $_{0.05}$		**33.61**	**20.83**	**53.96**

M0=control without mole, **M1**=2m mole space with 30 cm depth, **M2**= 2m mole space with 40 cm depth, **M3**= 4m mole space with 30 cm depth, **M4**= 4m mole space with 40 cm depth, ns= non-significant, *= significant at 0.05 probability level; **= significant at 0.01probability level. Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

Moreover, low fertility and extreme properties of saline soils may be the other reasons (Richards, 1954; Ghane et al., 2009; Abou Hussien et al., 2020).

Data clearly showed that, all treatments in this study have a high significant effect on the obtained yield (straw and grains) of wheat plants. The highest significant grains, straw, and biological yields (1528.1, 3666.5 and 5194.6 $kgfed^{-1}$) was found in the plants planted under furrows planting method with 2 m distance and 40 cm depth of mole drains, while the lowest yields (874.9, 2250.4 and 3125.4 $kgfed^{-1}$) was obtained from the plants under zero tillage treatment and basin planting method. Data in Table (4) also, demonstrated that decreasing mole drain distance led to increase grain, straw, and biological yields, while increasing depth led to increase all of those yields of wheat plant. Clearly, it can noticed that, the yields of grains, straw and biological at 2 m distance and 30 cm depth (M1) of mole drains were 1363.3, 3363.1, and 4726.4 $kgfed^{-1}$ and were with 4 m distance and the same depth (M3) 1326.7, 3296.7, and 4623.5 $kgfed^{-1}$, that recorded a relative decrease of 2.68, 1.98 and 2.17%, respectively. These values of relative decrease reveals that, expanding mole spacing reduced the yields attributes of wheat crop. Concerning the effect of mole depth, grain, straw, and biological yields at 40 cm depth were higher than those in mole drains digged at 30 cm depth. These findings could be related to high effective of narrow and deeper mole drains on improving soil physical and chemical properties that reflected on plant growth parameters (Kolekar et al., 2011; Antar et al., 2014;Aiad, 2014; El-Sanat et al., 2017; Abou Hussien et al, 2020).

On the other side, wheat plants grown in furrows gave high significant yields of grains, straw, and biological yields of wheat plants than that obtained with basins planting method (Table 4). The mean yields of grains, straw and biological of wheat grown in basin were 1195.8, 3024.8, and 4220.8 kg fed^{-1}, while these yields in furrows were 1376.1, 3264.9, and 4641.1 kg fed^{-1}, which recorded a relative increase of 15.08, 7.93, and 9.96%, respectively. These values of relative increases reveals that, cultivation on furrows increased grains yield by percent more than that for straw. The superior increase effect of furrows cultivation method on yields of wheat plants in compared with that found with basins cultivation methods are attributed to improve saline soil condition (physically and chemically) with furrows planting method where it's have low pH, EC and ESP (Table 2). These trends were in similar with that achieved by Ghane et al. (2009), Kumar et al. (2010), Aboelsoud et al. (2020), Aiad et al., (2021).

3.4. Grain content of N, P and K

Nitrogen (N) content

Data in Table (5) show a narrow range in the grains of wheat plants concentration (%) under salt affected soil conditions affected by mole drains systems (spacing distance and depth) and planting methods, where this concentration ranged between 1.42% in the plants cultivated on basin method with 2 m distance and 30 cm depth of mole drains and 1.29% in the plants planted in furrows method without any mole drains treatments.

On the other hand, N uptake ranged between 20.50 $kgfed^{-1}$ with furrows cultivation method and 2 m between distance and 30 cm depth of mole drain, and 11.34 kg fed^{-1} in basin cultivation method with absence of mole drains. Regarding to the effect of mole drains treatments (distance and depth) on the grains of wheat concentration (%) of N as recorded in Table (5) may be rated that, this concentration was increased with the increase in the depth of the moles as well as with increase in their between distance. This trend is in harmony with the found improve in soil chemical properties under the same treatments. Similar effect was observed on N uptake, which reflect the effect of these treatments on the high grains yields (Bayoumi, 2019; Abou Hussien et al., 2020). This reversible trend may be explained based on the cultivation effect (Marschenr, 2011).

The high N uptake in the grains of wheat plots with applying mole drains system mainly attributed to the found improve physical, chemical and biological soil properties (El-Adl, 2011; Aiad, 2014; Abdel-Fattah et al., 2016; El-Sanat et al., 2017; Abou Hussien et al., 2020). In addition, data in Table (5) also show that, with the same treatment of mole drains, both N concentration (%) and uptake ($kgfed^{-1}$) under furrows planting method were higher than those found with the wheat plants planted in basins planting method which in harmony with the improve in different soil properties and the found yields of grains (Kumar et al., 2010; Aiad et al., 2021).

Phosphorus (P) content

Phosphorus concentration (%) in the grains of wheat plants grown on saline soil in relation with the studied treatments as shown in Table (5) ranged from 0.340% in furrows cultivation method with zero treatment of mole drains to 0.475% in basin cultivation method with mole treatment of 40 cm depth and 2 m between distance. With the same mole depth, concentration (%) of P in the grains were higher in the plants grown under 2 m than that of 4 m spacing distance mole drains. While with the same spacing distance, the highest significant concentrations of P in grains were recorded to the plants grown in soil treated with 40 cm mole depths. Consequently, the highest P uptake were also observed in the grains of wheat plants planted on the furrows with mole drains treatments of 40 cm depth and 2 m between distance, where these findings are in harmony with the obtained yields of grains. These results are in similar with those obtained before that by Bayoumi (2019) and Abou Hussien et al. (2020), and Mohiy et al. (2022).

Potassium (K) content

Data in Table (5) show a similar effect of the studied treatment (mole drains and planting methods) on the grains of wheat plant content of K was similar with those mentioned before that with the content of N and P. This content (% and kgfed^{-1}) varied from treatment to another, where the highest significant K concentration (1.92%) was found in the grains of wheat plants planted on basin with mole drains at 2 m spacing distance and 30 cm depth and the lowest significant one (1.58%) was found in the grains of wheat plants planted in basin, without any application of mole drains. In addition the highest K uptake (26.78 kgfed^{-1}) was found in the grains of wheat plants grown on furrows with mole drains at 2 m spacing distance and 40 cm depth, while the lowest one (14.71 kgfed^{-1}) was observed in the grains of wheat plants planted in basins with absence the treatments of mole drains. Also, data presented in Table (5) reveal that increasing space distance of mole drains led to significant decrease of their plant grains content of K, while soil with deeper drains recorded the lowest significant values of its grain K concentration. But increasing mole depth as well as decrease in the between distance resulted in an increase of K uptake by grains of wheat plants under saline soil condition. These findings means that with the same treatment of mole drains, K uptake in the grains of wheat plants grown on furrows was higher than that found in the plants grown in basins. In this respect before that similar observations were maintained by Kumar et al. (2010), El-Sanat (2018), Bayoumi (2019), Abou Hussien et al. (2020), and Mohiy et al. (2022) and others with different plants.

TABLE 5. Concentration and uptake of N, P, K and protein of wheat grain grown in saline soil affected by different studied treatments (values are average of two growing seasons).

Treatments		N		P		K		Protein	
Mole drain systems	Planting methods	Conc. (%)	Uptake (kg fed^{-1})	Conc. (%)	Uptake (kg fed^{-1})	Conc. (%)	Uptake (kg fed^{-1})	Conc. (%)	Uptake (kg fed^{-1})
M0	**Basin**	1.30d	11.34d	0.348fg	3.043i	1.68d	14.71e	7.57d	66.12d
	Furrow	1.29d	12.82d	0.340g	3.376h	1.58e	15.70e	7.53d	74.73d
M1	**Basin**	1.42a	18.11c	0.423bc	5.393f	1.92a	24.52bc	8.27a	105.59c
	Furrow	1.41a	20.50a	0.401cd	5.822d	1.79b	26.04ab	8.24a	119.51a
M2	**Basin**	1.39ab	18.47bc	0.475a	6.305b	1.80b	23.89cd	8.12ab	107.66bc
	Furrow	1.36bc	20.73a	0.441b	6.750a	1.75c	26.78a	7.91c	120.83a
M3	**Basin**	1.40a	17.03c	0.393de	4.781g	1.81b	21.96d	8.16ab	99.28c
	Furrow	1.38abc	19.82ab	0.370ef	5.323f	1.76c	25.30abc	8.04bc	115.53ab
M4	**Basin**	1.38abc	17.75c	0.437b	5.625e	1.74c	22.38d	8.05bc	103.47c
	Furrow	1.35c	19.83ab	0.407cd	5.988c	1.70d	24.99abc	7.86c	115.59ab
F-test		**ns**	**ns**	**ns**	**ns**	**	**	**ns**	**ns**
LSD $_{0.05}$		**0.038**	**1.516**	**0.026**	**0.136**	**0.029**	**2.097**	**0.192**	**8.877**
Mole drain systems									
M0		1.29d	12.08d	0.345d	3.210d	1.63d	15.20c	7.55d	70.43d
M1		1.42a	19.31ab	0.412b	5.606b	1.86a	25.28a	8.26a	112.55ab
M2		1.38bc	19.59a	0.458a	6.526a	1.78b	25.33a	8.02bc	114.25a
M3		1.39b	18.42c	0.381c	5.051c	1.78b	23.63b	8.10b	107.41c
M4		1.36c	18.79bc	0.421b	5.806b	1.72c	23.68c	7.95c	109.53bc
F-test		**	**	**	**	**	**	**	**
LSD $_{0.05}$		**0.020**	**0.551**	**0.014**	**0.282**	**0.015**	**0.716**	**0.115**	**3.21**
Planting methods									
Basin		1.37a	16.54b	0.416a	5.030b	1.79a	21.49b	8.03a	96.43b
Furrow		1.35b	18.74a	0.391b	5.451a	1.72b	23.76a	7.92b	109.24a
F-test		*	**	*	**	**	**	*	**
LSD $_{0.05}$		**0.017**	**0.678**	**0.012**	**0.061**	**0.013**	**0.938**	**0.086**	**3.97**

M0=control without mole, **M1**=2m mole space with 30 cm depth, **M2**= 2m mole space with 40 cm depth, **M3**= 4m mole space with 30 cm depth, **M4**= 4m mole space with 40 cm depth, ns= non-significant, *= significant at 0.05 probability level; **= significant at 0.01probability level. Means in a column with the same letter are not significantly different at the 5% level.

Protein yield

Protein content (%) in the grins of wheat plants grown on saline soil as listed in Table (5) show that, this content takes the same order found and discussed before that for N content. The highest significant content (8.27%) of protein was found in the grains of wheat plants grown on basin with mole drains of 30 cm depth and 2 m spacing distance and the lowest on (7.53%) was found in the grains of wheat plants grown in furrows with absence any treatment of mole drains. The same

Table also show a wide variations in the yield of protein measured as kgfed^{-1}, where the highest protein yield (120.83 kgfed^{-1}) was found in the grains of wheat plants planted on furrows with mole drains treatment of 40 cm depth and 2 m between distance which attributed to high grins yield found in this treatment, but the lowest protein yield (66.12 kgfed^{-1}) was resulted from absence mole drains in the planting method of basins (Aiad et al., 2021; Mohiy et al., 2022).

3.5. Applied irrigation water and its productivity

The total irrigation water applied and its productivity of wheat grains as affected by mole drain systems and different planting methods are shown in Table (6) and Figure (2). The highest significant volume of applied irrigation (2585.0 m^3 fed^{-1}) were found for plants grown in basin treated by 2 m distance and 40 cm depth mole drain, while the lowest one (1795.0 m^3 fed^{-1}) recorded to the plants planted in furrows treatment without mole drains.

TABLE 6. Individual effect of mole drains systems and planting methods on the applied Irrigation water and its productivity of wheat grain yields (values are average of two growing seasons).

Treatments	Applied water (m^3 fed^{-1})	Productivity of irrigation water (kg m^{-3})
	Mole drain systems	
M0	2112.8e ± 348.2	0.457c ± 0.116
M1	2264.2b ± 282.7	0.615b ± 0.133
M2	2387.5a ± 216.7	0.605b ± 0.113
M3	2145.7d ± 300.9	0.635a ± 0.153
M4	2215.0c ± 307.4	0.638a ± 0.145
F-test	**	**
LSD $_{0.05}$	**19.83**	**0.015**
	Planting methods	
Basin	2490.4a ± 63.7	0.480b ± 0.08
Furrow	1959.7b ± 140.8	0.700a ± 0.10
F-test	**	**
LSD $_{0.05}$	**29.79**	**0.031**

M0=control without mole, **M1**=2m mole space with 30 cm depth, **M2**= 2m mole space with 40 cm depth, **M3**= 4m mole space with 30 cm depth, **M4**= 4m mole space with 40 cm depth, ns= non-significant, *= significant at 0.05 probability level; **= significant at 0.01probability level**.** Means in a column with the same letter are not significantly different at the 5% level (mean values ± Stdev, n=3).

Also, wheat plants grown in plots treated with narrow (2 m distance) and deeper (40 cm depth) mole drains received the highest volume of applied irrigation water, where it were arranged as M0, M3, M4, M2, and M1 treatments. Individually, plants cultivated in basin methods had more amount (2490.4 m^{3}fed^{-1}) of irrigation than those (1959 m^{3}fed^{-1}) planted in furrows method.

Otherwise, the studied treatments (mole drains and planting methods) had a positive impact on the productivity of irrigation water (PIW) for wheat grains are shown in Table (6) and Figure 2. Data clearly showed that the highest significant values(0.769 kgm^{-3}) of PIW recorded to the wheat grains planted in furrows with 4 m distance and 30 cm depth mole drains, while the lowest on (0.360 kgm^{-3}) appeared in the other cultivated in basin without drains systems (Figure 2). Increasing distance between moles led to significant increase of PIW, while increase mole depth did not show significant differences. This is certainly consistent with the volume of applied water and its grain yield in these treatments. Further, the PIW of wheat grains planted in furrows was higher than those cultivated in basin treatments. This probably was due to less irrigation water is sufficient for wider and deeper moles as compared with narrow and shallower drain mole (Ali et al., 2007; El-Adl, 2011; Aiad, 2014; El-Sanat et al., 2017). In addition, these results confirmed previous findings by Hassan et al.(2005), Ghane et al. (2009), and Singh et al. (2022), who emphasized the provision of irrigation water by furrows methods.

4. Conclusion

The effect of mole drains systems and planting methods on saline soil chemical properties, fertility, and some yield attributes of wheat plants were examined under field trial conditions. Under saline soil conditions deep tillage or mole drainage system must be carried to improve these soil conditions, which have a greater effect on soil physicochemical properties, plant yields attributes and productivity of the used irrigation water, especially with using of furrows planting method.

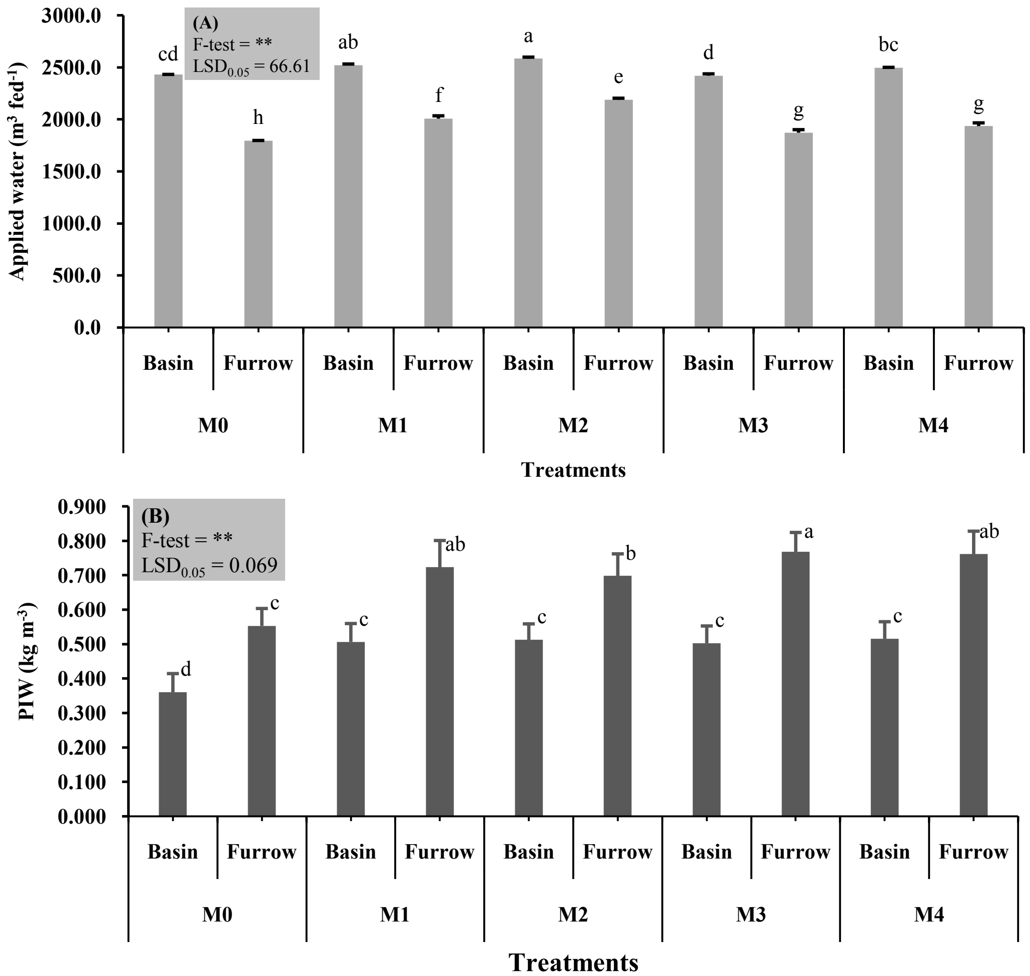

Fig. 2. Integrated effect of mole drains systems and planting methods on the applied water (A) and its productivity (PIW, B) of wheat grain yields (values are average of two growing seasons, M0=control without mole, M1=2m mole space with 30 cm depth, M2= 2m mole space with 40 cm depth, M3= 4m mole space with 30 cm depth, M4= 4m mole space with 40 cm depth, columns labelled with the same letter are not significantly different at the 5% level (error bars represented ± Stdev., n=3).

Conflicts of interest

There is no conflict of interest between the authors or any donor or funding agency.

5. References

Abdalla MA, Mansour SF, Abdel Razek MM (2010). Effect of applying gypsum on some physico-chemical and hydrological properties of a saline-sodic clay soil provided with a tile drainage system. *Fayoum Journal of Agricultural Research and Development*, **24**(2), 89-103.

Abdel-Fattah MK, Merwad AMA (2016). Approach for reclamation and improving fertility of saline-sodic soils. *Egyptian Journal of Soil Science*,**56**(4), 573-588.

Aboelsoud H, Engel B, Gad K (2020). Effect of planting methods and gypsum application on yield and water productivity of wheat under salinity conditions in North Nile Delta. *Agronomy*, **10**(6), 853.

Abou Hussien EA, Abd El Adl M, Omran W, Tawfik S (2022). Effect of Tillage Depth on Some Properties of Saline Soil. *Menoufia Journal of Soil Science*, **7**(5), 81-90.

Abou Hussien EA, Nada WM, Mahrous H (2020). Subsoiling Tillage and Compost Applications in Relation to Saline Soil Properties and its Productivity of Wheat. *Environment, Biodiversity and Soil Security*, **4**(2020), 253-266.

Aiad MA (2014). Effect of Mole Drains and Compost Application on Some Soil Properties, Water Relations and Its Productivity at North Delta. *Journal of Soil Sciences and Agricultural Engineering*, **5**(2), 219-236.

Aiad MA, Amer MM, Khalifa TH, Shabana MM, Zoghdan MG, Shaker EM, Kheir AM (2021).

Combined application of compost, zeolite and a raised bed planting method alleviate salinity stress and improve cereal crop productivity in arid regions. *Agronomy*, **11**(12), 2495.

Ali MH, Hoque MR, Hassan AA, Khair A (2007). Effects of deficit irrigation on yield, water productivity, and economic returns of wheat. *Agricultural water management*, **92**(3), 151-161.

Amer MM, Hashem IM (2018). Impact of some soil amendments on properties and productivity of salt affected soils at Kafr El-Sheikh Governorate. *Egyptian Journal of Soil Science*, **58**(2), 177-191.

Antar ASM (2000). Effect of drainage system on some hydrological, physical and chemical properties of soil in Northern Delta, Egypt. M.Sc. Thesis, Faculty of Agriculture. Menoufia University. Egypt.

Antar SA, El-Henawy AS, Atwa AAE (2008). Improving some properties of heavy clay salt affected soil as a result of different subsurface tillage. *Journal of Soil Sciences and Agricultural Engineering*, **33**(10), 7675-7687.

Antar SA, El-Sanat GMA, Khafagy HA (2014). Improving heavy clay salt affected soil and its production using some amendments application in north delta. *Journal of Soil Sciences and Agricultural Engineering*, **5**(12), 1717-1730.

Asseng S, Kheir AM, Kassie BT, Hoogenboom G, Abdelaal AI, Haman DZ, Ruane AC (2018). Can Egypt become self-sufficient in wheat?.*Environmental Research Letters*, **13**(9), 094012.

Awwad EA, Mohamed IR, El-Hameedb A, Adel M, Zaghloul EA (2022). The Co-Addition of Soil Organic Amendments and Natural Bio-Stimulants Improves the Production and Defenses of the Wheat Plant Grown under the Dual stress of Salinity and Alkalinity. *Egyptian Journal of Soil Science*, **62**(2), 137-153.

Bayoumi M (2019). Impact of mole drains and soil amendments application on management of salt affected soils. *Journal of Soil Sciences and Agricultural Engineering*, **10**(4), 209-217.

Bowman AK (2013). Agricultural production in Egypt. *The Roman Agricultural Economy. Organization, Investment, and Production*, pp: 219-253.

Chapman HD, Pratt PF (1961). Method of analysis for soils, plants and waters, University of California (Riverside) Division of Agriculture Sciences. *Agr. Publ. Office, Univ. Hall Univ. Calif., Berkeley, USA*.

Cottenie A, Verloo M, Kikens L, Velghe G, Camerlynck R (1982). Analytical problems and method in chemical plant and soil analysis. *Hand book Ed. A. Cottenie, Gent, Belgium*, p 190.

Datta JK, Nag S, Banerjee A, Mondai NK (2009). Impact of salt stress on five varieties of wheat (Triticum aestivum L.) cultivars under laboratory condition. *Journal of Applied Sciences and Environmental Management*, **13**(3), 93 – 97.

El-Adl MA (2011). Effect of different types of mole drains composition on some clay soil properties and wheat yield. *Journal of Soil Sciences and Agricultural Engineering*, **2**(1), 109-120.

El-Dein AAS, Galal ME (2017). Prediction of reclamation processes in some saline soils of Egypt. *Egyptian Journal of Soil Science*, **57**(3), 293-301.

El-Sanat GMA (2003). Effect of amelioration processes on nutrients status in salt affected soils. M.Sc. Thesis, Fac. Agric. Menoufia Univ., Egypt.

El-Sanat GMA (2018). Impact of subsoiling, organic manure and nitrogen sources on some soil properties and sugar beet productivity. *Menoufia Journal of Soil Science*, **3**(1), 1-16.

El-Sanat GMA, Aiad MA, Amer MM (2017). Impact of some soil amendments and different tillage depths on saline heavy clay soils properties and its yield water productivity. *International Journal of Plant and Soil Science*, **14**(2), 1-13.

Fischer RA, Turner NC (1978). Plant productivity in the arid and semiarid zones. *Annual Review of Plant Physiology*, **29**(1), 277-317.

Freeman KW, Girma K, Teal RK, Arnall DB, Klatt A, Raun WR (2007). Winter wheat grain yield and grain nitrogen as influenced by bed and conventional planting systems. *Journal of plant nutrition*, **30**(4), 611-622.

Ghane E, Feizi M, Mostafazadeh-Fard B, Landi E (2009). Water productivity of winter wheat in different irrigation/planting methods using saline irrigation water. *International Journal of Agriculture and Biology*, **11**(2), 131-137.

Godfray HCJ, Beddington John R, Crute Ian R, Haddad L, Lawrence D, Muir James F, Pretty J, Robinson S, Thomas Sandy M, Toulmin C (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, **327**, 812–818.

Hassan I, Hussain Z, Akbar G (2005). Effect of permanent raised beds on water productivity for irrigated maize–wheat cropping system. *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico*, *121*.

Hussein M, Ali M, Abbas MH, Bassouny MA (2022). Composting Animal and Plant Residues for Improving the Characteristics of a Clayey Soil and Enhancing the Productivity of Wheat Plant Grown Thereon. *Egyptian Journal of Soil Science*, **62**(3), 195-208.

Jones DB (1931). Factors for converting percentages of nitrogen in foods and feeds into percentages of proteins (No. 183). US Department of Agriculture. pp.22.

Klute A, Dirksen C (1986). Hydraulic conductivity and diffusivity: Laboratory methods. *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*, **5**, 687-734.

Kolekar OL, Patil SA, Patil SB, Rathod SD (2011). Effect of different mole spacing on the yield of summer groundnut. *International Journal of Agricultural Engineering*, **4**(01), 82-85.

Kumar A, Sharma KD, Yadav A (2010). Enhancing yield and water productivity of wheat (Triticum aestivum) through furrow irrigated raised bed system in the Indo-Gangetic Plains of India. *Indian Journal of Agricultural Sciences*, **80**(3), 198.

Mahdy AM (2011). Comparative effects of different soil amendments on amelioration of saline-sodic soils. *Soil Water Res.*, **6**, 205–216.

Marschner H (Ed.). (2011). Marschner's mineral nutrition of higher plants. Academic press, third Edition, p 672.

Mohiy M, Salous MS (2022). Comparison between wheat conventional planting methods and raised beds method using three seeding rates under Upper Egypt conditions. *SVU-International Journal of Agricultural Sciences*, **4**(2), 34-40.

Page AL, Miller RH, Keeney DR (1982). Methods of soil analysis. Part 2. Chemical and microbiological properties. Agronomy, No. 9. *Soil Science Society of America,* Madison, WI, 1159.

Rashidi M, Seilsepour M (2008). Modeling of soil exchangeable sodium percentage based on soil sodium adsorption ratio. *International Journal of Agriculture & Biology*, **3**(4), 22-26.

Raza A, Mehmood SS, Tabassum J, Batool R (2019). Targeting plant hormones to develop abiotic stress resistance in wheat. *Wheat Production in Changing Environments: Responses, Adaptation and Tolerance*, Springer: Berlin/Heidelberg, Germany, pp: 557-577.

Richards L A (1954). Diagnosis and improvement of saline and alkali soils. (Vol. 78, No. 2, p. 154). LWW.

Sahakyan S, Yedoyan T, Eloyan A, Daveyan S (2022). Interaction Features of Some Acid Ameliorants in the Process of Chemical Reclamation of Sodic Solonetz-Solonchaks. *Egyptian Journal of Soil Science*, **62**(3), 209-221.

Saied M, Elsanat GM, Talha N, El Barbary SM (2017). On-farm soil management practices for improving soil properties and productivity of rice and wheat under salt-affected soils at North Delta, Egypt. *Egyptian Journal of Soil Science*, **57**(4), 445-453.

Singh R, Rao KR, Singh RK, Singh KP, Singh SK (2022). Drainage Technologies for Enhancing Productivity of Temporary Waterlogged Vertisols. *Journal of Agricultural Engineering (India)*, **59**(3), 279-292.

Snedecor GW, Cochran WG (1989). Statistical methods, 8^{th} Edn. *Ames: Iowa State Univ. Press Iowa*, **54**, 71-82.

Stevenson FJ (1994). Humus chemistry: genesis, composition, reactions. John Wiley & Sons.

Zhang J, Sun J, Duan A, Wang J, Shen X, Liu X (2007). Winter wheat grain yield and grain nitrogen on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. *Agric. Water Manage*, **92**, 41-47.