J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 15 (10):305 - 311, 2024

Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

Effect of Tile Drain Spacing on Nitrate Losses, Heavy Clay Soil Properties and Wheat Crop Productivity in Egypt

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ABSTRACT

Three field experiments were established at EL-Serw Agricultural Research Station, the Agricultural Research Center, Damietta Governorate, Northeast Delta Egypt, during three winter seasons from 2016 to 2019 to investigate the effect of subsurface drainage system on some soil properties, wheat productivity and nitrate loss from the soil under this study. The experiments were conducted in a randomized complete block design with three replicates. The subsurface drainage lines were divided into three spacings of 15 m, 30 m and 60 m, separated by a buffer zone and installed at a depth of 1.5 m and a slope of 0.1%. The results displayed that reducing drainage distances to 15 m led to decrease ground water level and its salinity, improve of the physical and chemical soil properties. As for promoting the yield and its components, as well as N-uptake of plant and Nitrogen application efficiency (NAE) of wheat plants was realized with narrow spacing compared to wider spacings. Regarding the N-available content of the soil and the loss of nitrates by leaching into the groundwater, they decreased with the reduction of the subsurface drainage spacings, so the nitrogen fertilizer application rate should be divided into 3 doses reduced nitrate losses by leaching. Finally, narrow spacing between tiles drain tends to improve the physical and chemical properties, lower the water table level, and increase production and (NAE) to the wheat crop.

Keywords: Tile drainage spacing, soil properties, nitrate leaching, wheat crop productivity and N-application efficiency.

INTRODUCTION

Agricultural drainage is main to sustainable farmland and thus food productivity around the world. In wet zones, drainage allows site passing the capability to appropriate plant, harvesting and remove extreme water from the root domain. In arid and semi-arid regions, drainage is major for waterlogging and salinity control (Muhammad *et al*., 2021). In areas where natural drainage is not sufficient to remove excess water and salts, drainage can be improved by installing artificial drainage systems in the form of horizontal surfaces, underground drains or tube wells. Salt-affected alluvial agricultural soils are widespread in all northern parts of the Nile Delta and in the Northern Lakes region. The clay cover in this portion reaches about 40 m Moharam *et al.* (1999). These lands are low-lying and heavy clay soils with poor productivity. Therefore, Tile drainage is the process of removing extreme water from the soil to extend appropriate conditions for crop production. (El-Hadidy *et al*., 2003 and Ghane *et al*., 2016). Also, improvement in drainage conditions is acieved gradually over time, especially with the reduced tile drainage spacing.

Moukhtar *et al*., (2003) and Abdel-Mawgoud *et al*., (2007) demonstrated that at the end of the irrigation interval (after three weeks), the groundwater depth increased to 131, 103 and 94 cm below soil surface for tile drain spacings of 15, 30 and 60 m, successively in the same field. On the other hand, they found that the soil moisture content and soil bulk density increased as raising tile drain spacing while, soil total porosity took the opposite trend as augmenting tile drain spacing. Also, tile drainage spacings treatments achieved a positive effect on soil salinity and sodicty. The decrease in the soil salinity and sodicty followed the order of: 15 m > 30 m > 60 m tile drain spacing. Khafagy and Salama (2018) illustrated that, open drainage spacing of 10 m is better than spacing 20 m in reducing soil salinity, sodicty and bulk density particularly in surface layers while the total soil porosity raised. Wasef (2004) demonstrated that improving the hydraulic properties of the soil by lowering the watertable depth was most efficacious under the closed drainage distances compared to the wider spacing. Khafagy and Salama (2018) revealed that the increase in wheat productivity was more obvious with narrow drainage spacing compared to wider drainage spacing. Tile drainage can raise crop productivity and the total economic yield of the soil (Jung *et al*., 2010). The useful influence of tile drainage immediate impact on crop yield (Wang *et al*., 2006), also the effects of water strain and delayed cultivation on yield reduction raised with increasing drainage distances. In other studies, conducted by Moukhtar *et al*., (2004) illustrated that wheat plant height, number of tillers and dry weight of plant were promoted with reduced drainage distances.

Tile drainage is a major water management exercise in a lot of the world's wetlands, but it has negative impact of elevation NO_3^- leaching into the soil (Kladivko *et al.* 2004). Nitrate pollution of agricultural drainage water poses a disturbing intimidation to the environment and economy with the development of intensive farming systems. promoted agricultural drainage water flow provides NO_3^- concentration in the drainage water, which raises the health hazads to humans if it is used as a source of drinking water (Kladivko *et al*., 2010). The results obtained by Abdel Khalik (2000) and Antar (2007) manifested that the depth of groundwater, the

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DOI: 10.21608/jssae.2024.319402.1249

concentration of nitrates in the groundwater, as well as the productivity of the crop and the nitrogen absorbed by the plant augmented with narrow drainage spacings compared to the wide space. Nangia *et al*. (2010) also appeared that NO3-N concentrations in the tile drainage decreased with increasing the distance between tiles. This is because larger spacing between tiles raises soil moisture, promotes the frequency of anaerobic conditions in the root zone and augmented denitrification. The purpose of the current study was to evaluate the influence of tile drainage system with different drain distances on: (1) some soil properties, (2) Nitrate leaching through soil profile to groundwater, (3) yield crop, (4) nitrogen uptake by wheat crop and N-application efficiency.

MATRIALS AND METHODS

Description of the experimental site:

A field trail has been established on heavy clay soils in El-Serw Agriculture Research Station, Agriculture Research Center, Damietta governorate ($31^{0}14$ N and $31^{0}48$ E) in the northeast of the Delta during three successive winter seasons from 2016 to 2019 to study the influence of tile drainage spacings on wheat productivity and nitrate loss. The experiments were conducted in a completely randomized block design, with three replications. The tile drainage lines were divided into three spacings of 15, 30 and 60 m, detached by a buffer zone and composite at a depth of 1.5 m and with a slope of 0.1%. Data presented in tables 1 and 2 show Preliminary data on some physical and chemical characteristic of soil in the study area. The area has a semi-tropical climate with hot, dry summers and cold, wet winters. The climatic conditions (mean rainfall (mm), humidity, maximum and minimum temperature and dew /forest point (C^{o}) at the experimental location through three wheat planting seasons varied completely through the three years of the experiment (Fig. 1a and b):

Table 1. The initial of some soil physical properties of the studied soil.

Soil depth (cm)	Particle size distribution Sand%	Silt%	Clay%	Texture class	O.M. %	Bd (g cm^{-3})	Total porosity %
0 – 30	15.53	22.21	62.26	Clay	1.24	1.31	49.11
30 – 60	16.22	22.22	61.56	Clay	0.45	1.39	47.48

O.M.: Organic matter **Bd: Bulk density**

Table 2. The initial of some soil chemical properties of the studied soil.

Soil depth (cm)	pH	EC (dSm^{-1})	CaCO3 %	Soluble anion and cations (meq L^{-1}) CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	ESP
0 – 30	8..1	5.95	2.40	-	3.64	51.41	6.02	5.59	2.43	51.37	1.68	21
30 – 60	8.2	7.09	2.67	-	3.00	60.57	8.28	6.64	2.99	59.96	2.26	22

pH was determined in the soil water suspensions (1:2.5) **EC was estimated in the soil water extract (1:5)**

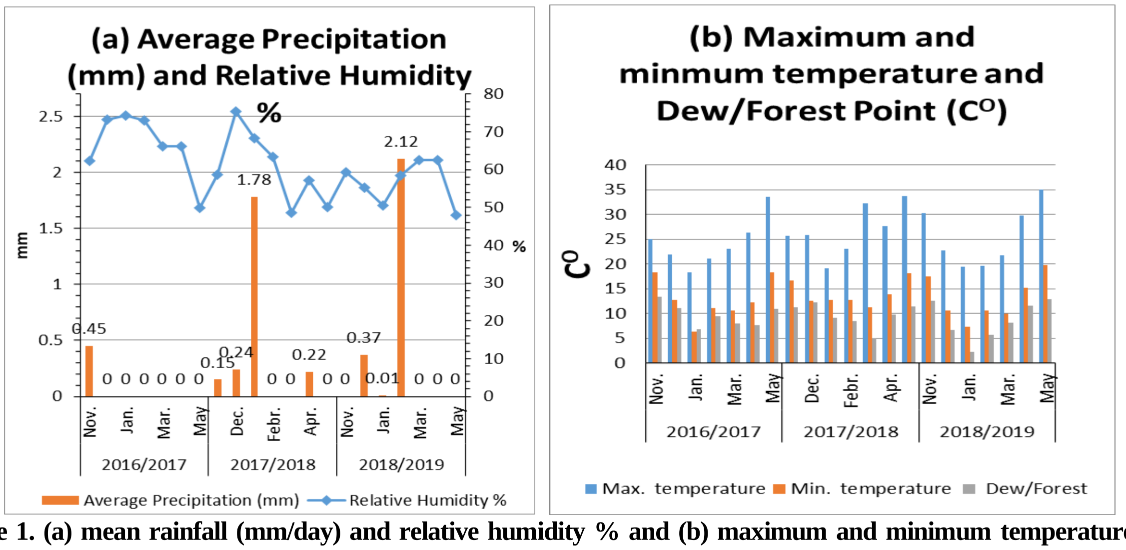

Figure 1. (a) mean rainfall (mm/day) and relative humidity % and (b) maximum and minimum temperature and Dew/Forest Point (C^{o}) of experimental location through the three grown seasons.

The crop grown was wheat (*Triticum aestivum, L*) and the seeds were sown on November 15th during the three seasons. For each experimental plot, 50 kg fed^{-1} of superphosphate (15.5 % P2O5) and 50 kg fed^{-1} of K-sulfate (48 %) were added during the plowing process, and N-fertilizer was added at a level of 75 kg fed^{-1} of nitrogen (Urea 46 %) in three doses before the first, second and third irrigation.

Chemical and physical soil analysis:

At harvest, soil samples were collected at depths of 0 - 30 and 30 - 60 cm from the soil surface from each treatment, air-dried, grinded to pass into a 2 mm sieve and kept for analysis. Particle size distribution and Calcium carbonate were determined according to Piper (1950). Organic matter was determined using Walkley & Black method as described by Jackson (1967). Soil moisture content and bulk density was determined according to Klute (1986). Total soil porosity was calculated from bulk density and average particle size density (2.65 g cm^{-3}). Soil salinity and pH were estimated according to Page *et al*. (1982). Cations and anions were estimated in the soil water extract (1:5) as described by Jackson (1967). Exchangeable sodium was appreciation using flame photometer according to Page *et al*. (1982). A soil sample was taken to estimate N-available after 3 days adding N-fertilizer and before the next irrigation (B). Available N was estimated using micro Kjeldahel as outlined by Page *et al.* (1982).

Ground water monitoring and analysis:

To monitor the groundwater level and take samples, monitoring wells were fixed in the midway between the tile drain lines. Several groundwater samples were combined at different times of the day and compound daily sample was taken for analysis. The groundwater samples were taken to analysis for NO_3^- after 3 days from adding N-fertilizer and before next irrigation (B) using Kjeldahl method (Cottenie *et al.*, 1982).

Wheat yield and total nitrogen content:

The wheat yield was harvested on 11th April in first season, 9th April in second season and 7th April in third seasons to measured plant height (cm), spike length (cm), weight of 1000 grain (g), root volume (cm^3), fresh and dry root weight (g plant^{-1}), straw and grain yields (ton fed^{-1}). Grain and straw samples were taken and dried at 70° C, grinded with a mill and its total N content was determined using Kjeldahl digestion (Cottenie *et al.*, 1982). N-uptake (kg fed^{-1}) was calculated by multiplying dry yield (kg fed^{-1}) by N % (N content in percentage either for grain and straw). Nitrogen application efficiency (NAE) was calculated as follows:

$$NAE = \frac{N\text{-uptake}}{N\text{-native} + N\text{-applied}} \times 100$$

Where:

N-Native: Basic nitrogen content of soil before planting.
N-applied: Synthetic addition of nitrogen.

RESULTS AND DISCUSSION

Watertable level and its salinity:

The average depth and salinity of the groundwater table values for the three tiles drain spacings investigated during the three seasons are illustrated in (Figure 2). The results explicated that the groundwater level rises rapidly over time after irrigation until it reaches the highest values then gradually decline. The decline in groundwater levels was faster with a drainage distance of 15 m compared to tile drainage distances of 30 and 60 m. This may be ascribed to the augmented effectiveness of the tile drainage at a depth of 15 m. Also, the data in (Figure 2) show that the average groundwater table salinity values for three seasons decreased with narrow subsurface drainage spacing (15 m) than wider subsurface drainage spacing (30 and 60 m). These results are the same as the results obtained (El-Hadidy *et al.*, 2003; Moukhtar *et al.*, 2003; Anter, 2007 and Abdel-Mawgoud *et al.*, 2007).

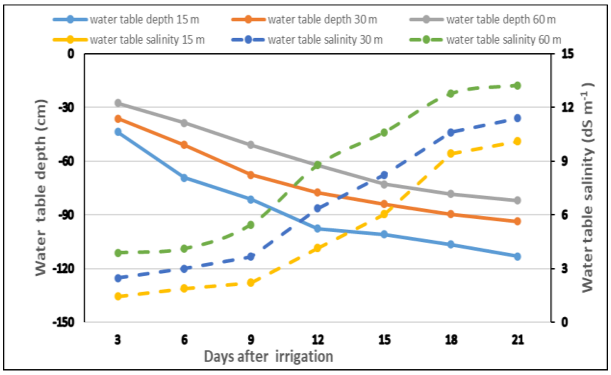

Fig. 2. Average groundwater depth and its salinity during the three studied seasons as affected by tile drainage spacings.

Soil salinity and sodicity:

Data demonstrated in Figures (3 and 4) the influence of tile drainage distance on soil salinity and sodicity. The results appear that narrow tile drainage spacing (15 m) are superior compared to wider tile drainage spacing (30 and 60 m) in minimize soil salinity and sodicity, particularly in the upper layer during the three seasons. The results can be explained that the narrow distances between the drainages gave good drainage efficiency, which improved the physicochemical properties of the soil, which affected the movement of water downward and into the drains carrying dissolved salts. Antar *et al.* (2016) and Khafagy and Salama (2018) obtained similar results.

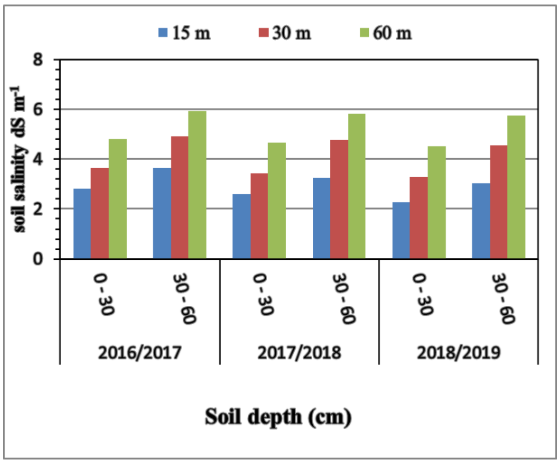

Fig. 3. soil salinity dS m^{-1} for the three studied seasons as affected by tile drainage Spacings.

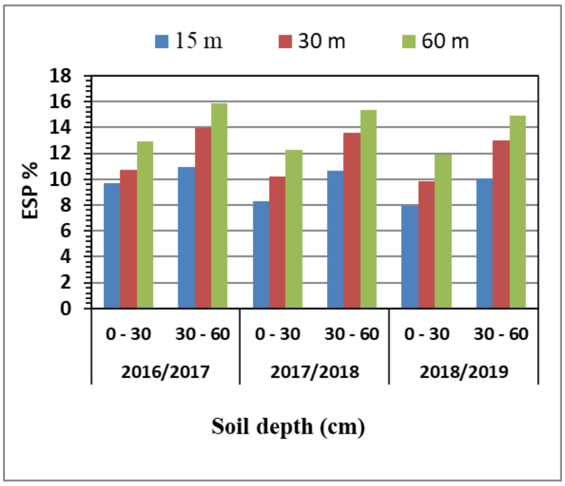

Fig. 4. ESP % for the three studied seasons as affected by tile drainage spacings.

Some soil physical properties:

Soil moisture content:

Soil moisture content at intervals after irrigation and its effect on tile drainage spacings are appeared in Figure (5).

It is clear that the soil moisture content decreases with raising days after irrigation. It is also clear that the treatment of the tile drainage spacing of 15 m is has the most influence on the soil moisture content and also is the best for drying the soil and not reaching waterlogging for a longer period. These data are consistent with the data pooled with Moukhtar *et al.* (2003), Abdel-Mawgoud *et al.* (2007), Antar *et al.* (2016) and Khafagy and salama (2018).

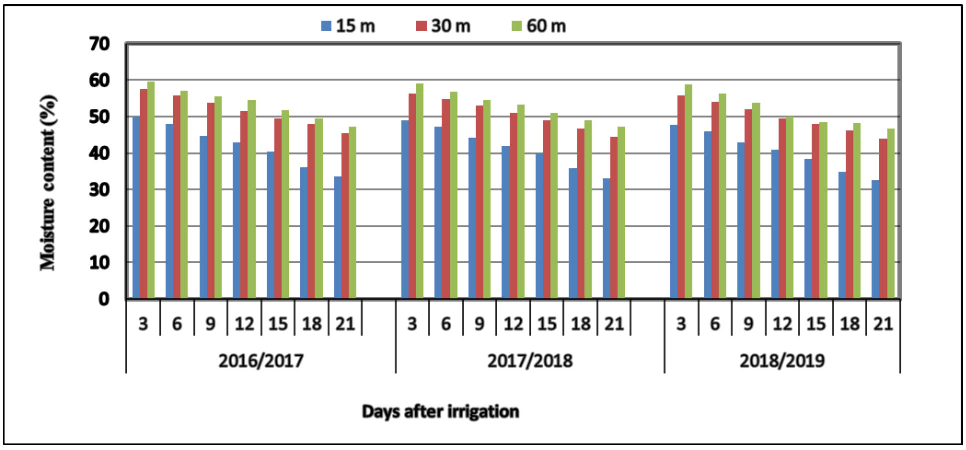

Fig. 5. Soil moisture content (%) for the three studied seasons as affected by tile drainage spacings.

Soil bulk density and porosity:

Data illustrated in Figures (6 and 7) manifested the influence of tile drain distance dealings on soil bulk density in upper and lower soil layers. The data implied that soil bulk density enhanced with soil depth. Also, soil bulk density elevated as tile drain distance raised. On the other hands, total soil porosity values appeared an adverse trend to bulk density values with three tile drainage spacings.

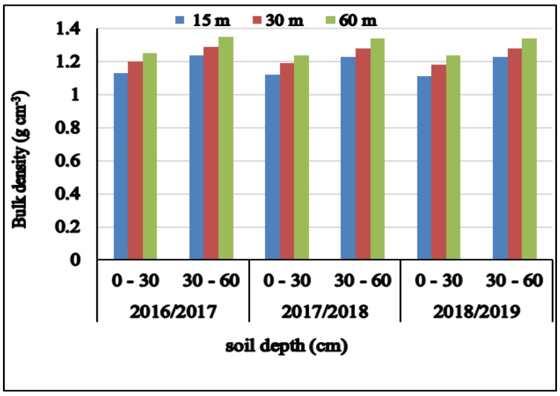

Fig. 6. Bulk density (g cm-3) for the three studied seasons as affected tile by drainage spacings.

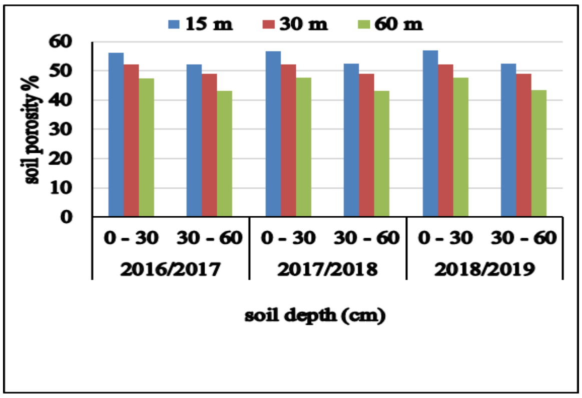

Fig. 7. soil porosity % for the three studied Seasons as affected by tile drainage spacings.

This is probably because the 15 m drainage distance gave a good drainage efficiency, ameliorate soil properties and thus gave better soil structure and better soil permeability (Abdel-Mawgoud *et al*., 2007 and Antar *et al*., 2016).

Available nitrogen in soil:

Available nitrogen in the soil after the first three irrigations following adding N-fertilizer as affected by the tile drainage spacings, is explained in (Figure 8).

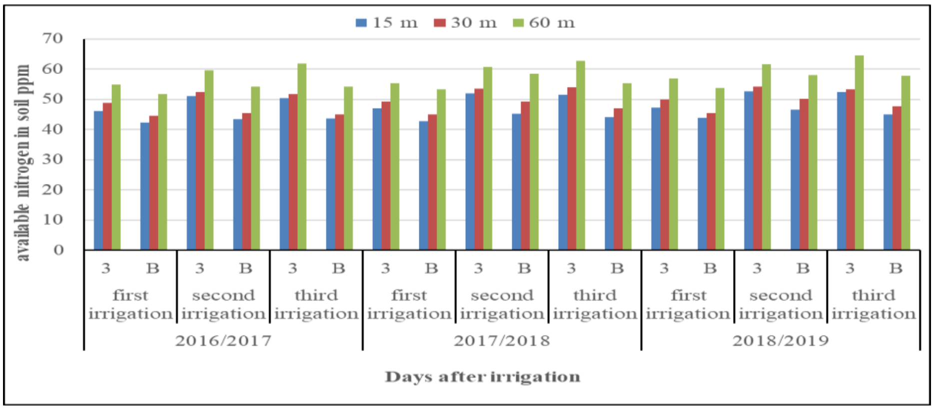

Fig. 8. Available nitrogen in the soil (ppm) for the three studied seasons as affected by tile drainage spacings.

The results displayed that the available nitrogen increased with increasing tile drainage distances. This can be explained by assuming that increasing drainage distances leads to a decrease in the amount of drainage water and an excessing in the quantities of nutrients in the soil solution. Available nitrogen also decreases with increasing time after each irrigation, and this is ascribed to the rapid and increased nitrogen uptake by plants immediately after irrigation, when the soil water tension is very low. These results are identical to the results reported with Abd El-Khalek, (2000) and Antar, (2005 and 2007).

NO_3^- loss in ground water by leaching:

Concentration of NO_3^- lost into ground water by leaching through the three irrigations as affected by tile drainage spacings declared in (Figure 9). The results pointed out that NO_3^- lost elevated with 15 m drainage spacings than

30 and 60 m. This can be ascribed to the drainage distance of 15 m gave better drainage efficiency and improved the physicochemical properties of the soil, thus giving a better structure to the soil and improving hydraulic conductivity, which affects the movement of water downward, carrying a lot of nutrients in dissolvable forms. These data are the same as those collected by Abd El-Khalek, (2000), El-Hadidy *et al.* (2003) and Antar, (2007). Also, the data found that the highest values of nitrogen loss by leaching into groundwater at tile drainage distances of 15, 30 and 60 m, respectively, were obtained 3 days after adding fertilizer and these values were clearly reduced with increasing days after adding fertilizer until reached to the lowest value before the next irrigation. This was ascribed to the fact that the soil after irrigation loses part of the applied water along with soluble nutrients through downward movement due to gravity until a steady state (field capacity) where free water stops. In the EL-Serw area, soils with high clay content reach field capacity after three days of irrigation. After this period, the water holding capacity becomes maximum and then the loss of soluble nutrients is reduced or stopped by water leashing through water infiltration. These data are coincided with that obtained by Abd El-Khalek (2000); Kladivko *et al.* (2004) and Antar (2007).

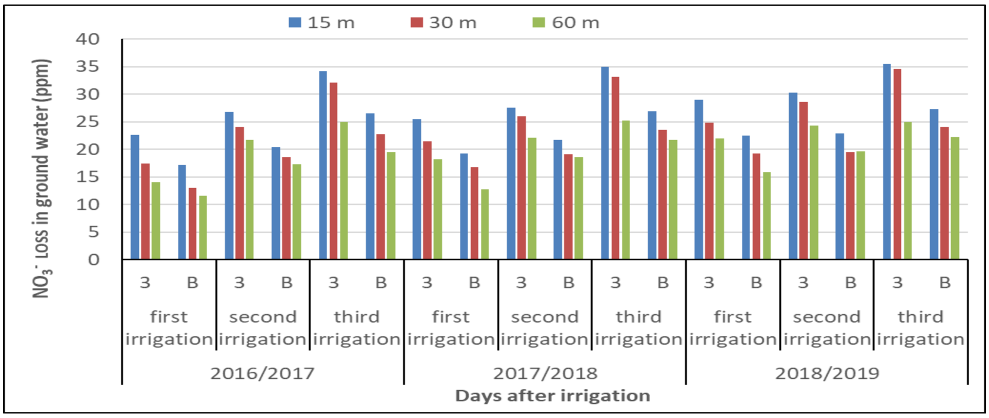

Fig. 9. NO_3^- loss in ground water (ppm) for the three studied seasons as affected by tile drainage spacings.

Yield component:

The data demonstrated in Table 3 indicated that tile drainage spacings had a highly significant effect on the components of the crop, volume root and fresh and dry roots in both seasons. It is also pointed out that the 15 m tile drainage treatment (narrow) gave the highest values of all the studied parameters during the three studied growing seasons compared to the tile drainage distance treatment 30 and 60 m.

Table 3. some plant characteristics as affected by tile drainage spacings for three seasons.

Drain spacing (m)	plant height (cm)	spike length (cm)	weight of 1000 grain (g)	root volume (cm^3)	Weight of fresh root (g $plant^{-1}$)	Weight of dry root (g $plant^{-1}$)
			First season			
15	101.55	11.33	52.823	3.9	2.320	0.843
30	96.50	10.13	49.615	3	1.155	0.448
60	87.38	8.68	45.033	2	0.690	0.160
F-Test	***	***	***	***	***	***
LSD 5%	0.278	0.305	0.141	0.216	0.121	0.053
			Second season			
15	102.35	12.13	53.6	4.15	2.39	0.978
30	97.28	10.93	50.6	3.48	1.275	0.543
60	88.08	9.1	45.878	2.05	0.76	0.21
F-Test	***	***	***	***	***	***
LSD 5%	0.657	0.173	0.270	0.345	0.033	0.023
			Third season			
15	103.88	12.55	54.075	4.58	2.53	1.45
30	98.38	11.53	51.525	3.9	1.373	0.638
60	88.5	9.98	46.45	2.1	0.85	0.315
F-Test	***	***	***	***	***	***
LSD 5%	0.489	0.290	0.232	0.214	0.035	0.104

This augment may occur as a result of the drain spacing 15 m obtains a good drainage, which leads to raise in the activity of microorganisms in the soil, the availability of nutrients to the plant roots, and the large volume and extension of the roots, which leads to maximum absorption of nutrients, and in general, improving the physical and chemical properties of the soil. These data agree with that found by (Abd El-Khalek, 2000; Moukhtar *et al.*, 2004; Antar, 2007 and Khafagy and Salama, 2018).

Yield and nitrogen uptake:

The results in Table 4 elucidated that the straw and grain yield of wheat during the study period was highest under a drainage spacing of 15 m compared to a spacings of 30 and 60 m. These results can be ascribed to the influence of narrow drainage distance on improving soil properties, which affects the relation between water and air in the root domain and root breakthrough, which dues to raised water intake and nutrients uptake. Similar results were got by (Abd El-Khalek, 2000; Moukhtar *et al.*, 2004; Antar, 2007 and Khafagy and Salama, 2018).

Table 4. Yield and N-uptake as affected by tile drainage spacings for the three studied seasons.

Drain spacing (m)	grain yield (ton fed^{-1})	Straw yield (ton fed^{-1})	N-uptake in grain (kg fed^{-1})	N-uptake in straw (kg fed^{-1})
		First season		
15	2.758	4.260	45.773	13.419
30	2.543	3.933	39.215	11.012
60	2.085	3.380	29.619	8.113
F-Test	***	***	***	***
LSD 5%	0.078	0.047	1.538	0.569
		Second season		
15	2.81	4.549	48.827	14.784
30	2.615	4.283	42.889	12.741
60	2.223	3.465	32.953	9.008
F-Test	***	***	***	***
LSD 5%	0.033	0.049	1.123	0.372
		Third season		
15	2.873	4.88	54.217	17.448
30	2.675	4.683	47.883	14.749
60	2.295	3.575	37.468	9.741
F-Test	***	***	***	***
LSD 5%	0.032	0.088	0.724	0.648

Regarding the uptake of nitrogen by grains and straw in wheat plants, the results existent in Table (4) indicated that absorption of nitrogen (kg fed^{-1}) from grains and straw increased significantly with reducing drainage distances. The increase in nitrogen uptake in wheat plants can be ascribed to the influence of 15 m drainage spacing which maintains good drainage. Under these conditions enough available nutrients will be transferred to the plant. Not only does nitrogen uptake increase but also other nutrients increase their concentration at each stage of growth. Similar results were reported by (Abd El-Khalek, 2000 and Antar, 2007).

Nitrogen application efficiency (NAE):

Nitrogen application efficiency (NAF) reverberate the capability of plants to benefit from soil fertilization. Soil fertilization comprises of Synthetic adding as well as basic content of a particular element before planting. As implied in Table 5, the 15 m drainage spacing had the highest NAF compared to the 30 and 60 m drainage spacing for three seasons. This is ascribed to the influence of the narrow drainage distance (15 m) on adaptation the air-water relations in the root domain and its impact on the transport of nutrients to the plant root. While, lands with wider drainage distances (60 m), raised soil moisture content and groundwater level, recurrence of anaerobic conditions in the root domain, and elevated denitrification. Analogous results were procured with Antar (2007).

Table 5. Nitrogen application efficiency as affected by tile drainage spacings for the three studied seasons.

Drainage spacing (m)	N-available before agriculture (ppm)	Applied (kg fed^{-1})	Nitrogen application efficiency (%)					
			Total N-uptake(Kg fed^{-1})			Efficiency (%)		
			1st	2nd	3th	1st	2nd	3th
15	31	106	59.19	63.61	71.67	56	60	68
30	33	108	50.23	55.63	62.63	47	52	58
60	37	112	37.73	41.96	47.21	34	37	42

CONCLUSION

Based on the results obtained from the present study, it can be concluded that the narrow spacing between tiles had a positive effect on lowering the groundwater level and its salinity, reducing salinity and alkalinity, improving the physical and chemical properties of salt effect soils, in addition to augmenting the production and N- application efficiency to the wheat crop, but it enlarged the NO_3^- losses by leaching. However, However, it is worth noting that treating wider drainage distance (30 m) gave satisfactory results in reducing groundwater and its salinity and lowering sodicity and salinity soil with improving the physicochemical properties of soil. It also lowering tile drain costs. Also, treating tile drainage spacing encouraged favorable conditions via reducing soil salinity and sodicity and making appropriate soil moisture content which plays a great role in ameliorating soil moisture and aeration condition in the root domain as for nitrate loss, it can be reduced by dividing the nitrogen fertilizer addition into three doses according to crop need.

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تأثير المسافات بين حقليات الصرف تحت السطحي على فقد النترات وبعض خصائص التربة الطينية الثقيلة وإنتاجية محصول القمح في مصر

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الملخص

أجريت هذه الدراسة في حقل تجريبي لتربة طينية ثقيلة بمحطة البحوث الزراعية بالسرو- مركز البحوث الزراعية - محافظة دمياط بشمال شرق الدلتا بمصر خلال ثلاثة مواسم شتوية من عام ٢٠١٦ إلى عام ٢٠١٩ لدراسة تأثير نظام الصرف تحت السطحي على بعض خواص التربة وإنتاجية القمح وفقد النترات. أجريت التجربة بتصميم القطاعات الكاملة العشوائية بثلاث مكررات. تم تقسيم خطوط الصرف تحت السطحي إلى ثلاث مسافات ١٥ م و٣٠ م و٦٠ م بين المصارف الحقلية، مفصولة بمنطقة عازلة ومنفذة على عمق ١,٥ م وميل ٠,١٪. وأظهرت النتائج أن تقليل مسافات الصرف إلى ١٥ متراً أدى إلى خفض منسوب الماء الأرضي وملوحته وتحسين بعض خواص التربة الفيزيائية والكيميائية. أما بالنسبة لزيادة المحصول ومكوناته، وكذلك امتصاص النبات للنيتروجين وكفاءة تطبيق النيتروجين (NAE) لنباتات القمح فقد تحققت مع مسافات الصرف الضيقة مقارنة بالمسافات الأوسع. أما فيما يتعلق بمحتوى النيتروجين الصالح في التربة وفقد النترات بالغسيل إلى الماء الأرضي، فقد انخفض مع تقليل مسافات الصرف تحت السطحي، لذلك يوصي بتقسيم معدل السماد النيتروجين المضاف إلى ثلاث جرعات لتقليل فقد النترات بالغسيل. وأخيراً، فإن تضييق المسافات بين خطوط الصرف التحت السطحي يؤدي إلى تحسين بعض الخواص الفيزيائية والكيميائية للتربة الطينية الثقيلة المتأثرة بالأملاح، وخفض منسوب الماء الأرضي وملوحته، وزيادة الإنتاجية وكفاءة استخدام النيتروجين لمحصول القمح.