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DESIGN AND PERFORMANCE EVALUATION OF SOME DIFFERENT FARM DRAINAGE TECHNIQUES

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ABSTRACT: In Egypt, the Nile Delta represents a large area of heavy clay soils with low permeability that might have a potential production. These soils are always threatened by a shallow saline groundwater. The main experiments were carried out to study the effect of drainage process and different drainage systems on productivity, physical and chemical properties of the soils of Earthen Delta. Three different drainage systems (unfilled mole drains, gravel filled mole drains and pipe drains) were designed and installed to select the suitable system for clay soil compared to without drainage (control). It could be concluded that the combined treatment of 4m spacing gravel field constructed mole with 40 cm depth (4F40) was the best treatment and should be recommended due to a relative high net profit comparing to other gravel filled mole treatments. On the other hand, the combined treatment of 4m spacing unfilled moles with 40 cm depth (4UF40) achieved the highest net profit comparing to the other drain treatments.

Key words: Drinage systems, pipe drains, gravel filled mole drains, net profit.

INTRODUCTION

An agricultural land is said to be waterlogged, when the soil pores in the crop root zone, get saturated with water. This is usually caused by a rise of the subsoil moisture due to periodical flooding, overflow by runoff, over irrigation, seepage artesian water and impede subsurface drainage. These conditions affect the growth and yield of crops and in course of time, turns the land to saline or alkaline and ultimately render it unfit for cultivation. Mole drainage (a subsurface system) is considered as an efficient, economic and successful drainage method and it improved the physical and hydrological properties of soil especially with wider spacing between tiles. On the other hand, drainage installation for leaching purposes will only be fully successful if they permit the uniform leaching of soluble salts from the hole soil profile.

Concerning soil physical properties, soil bulk density increased with depth either before or after executive tile drainage, but the values were relatively low after conducting tile drainage due to the wetting and drying cycles associated with swelling and shrinkage processes. El-Adl (2011) mentioned that decreasing distance between moles decreases bulk density (Db) values but increasing depth of moles decreases Db values. Also, data indicated that, Db values in all treatments were less than the control value.

Relating to soil chemical properties, Bahceci and Nacar (2014) stated that subsurface drainage is more effective in salt cleaning in the soil profile and salt cleaning process can begin immediately after providing suitable drainage. Jha and Krishi (2015) found that the effects of pipeless drainage on soil chemical properties were found to be very significant: pipeless drains with liming showed long-lasting improvement in soil pH and EC in the lower soil profile. Yaming *et al.* (2016) found that surface

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soil EC presented a fluctuating decline trend, the decline regularity of each treatment was similar. During 0~30 days after transplanting, EC changed not significantly and was slightly increased during 15~30 days. This was probably because that the tomato leaves grew slowly during this period, resulting in a relatively smaller leaf area index and a larger soil bared area, thus the soil evaporation and desalinization was strong. During 30~90 days after transplanting, surface soil EC reduced obviously and reached the lowest level at 90 days. Among the different treatments, the decline range of D2S1 was the greatest, reaching 50.87%. In general, in their experiment, the EC declined as the buried depth of drainage pipes increased or the space decreased.

The final product of any drainage process is the crop yield. If the drainage system is performing well it reflects on the yield increase. Therefore, it is important to focus on the relationship between drainage system and crop yield. El-Ashry (2008) indicated that almost all mole treatments exhibited differences on yield and yield components at the end of the two studied seasons comparing to the control (untreated soil). Jha and Krishi (2015) found that the effects of pipeless drainage on soil chemical properties were found to be very significant. Because of these improvements in the soil properties it was found that the soybean crop responded very well to pipeless drainage. There was about 46% increase in grain yield and 118% increase in the dry matter per plant. Yaming *et al.* (2016) reported that tomato yield generally increased with a larger depth and space of drains. The tomato yield of D2S3 (0.8 m depth combined with 10 m space) was the highest, which reached 128.33 ton/ha.

As to drain characteristics, Ritzema *et al.* (2007) reported that these deep drains have their drawbacks. Firstly, the deeper the drain, the higher the installation cost. Secondly, deep drains can only economically be installed by mechanical construction practices, ignoring the huge employment needs of the rural poor. Thirdly, deep drains lower the water table during the irrigation season. El-Ashry (2008) concluded that, although the total costs of moling for 60 cm mole depth recorded higher values than the other mole depth (30 cm), the net profit of this mole depth was in general higher than that of the other depth. Thus, it can be concluded that it is better economically to increase the mole depth up to 60 cm to increase the net profit.

Any possible application of mole drainage in soil reclamation will be dependent upon meeting minutes to 10 years or more depending upon soil type, soil conditions at moling, installation technique and equipment and the subsequent weather patterns. So in a situation where mole channels quickly collapse due to the instability of soil structure, their life can be increased considerably by filling them with fine gravel or course sand. Filling materials can be inserted into the moles through the hollow leg attached to a deep plough at proper depth.

Thereby the objectives of the present investigation are to:

1. Design and install three different drainage systems (unfilled mole drains, gravel filled mole drains and pipe drains) to select the suitable one for clay soil.
2. Optimize the main design parameters for mole drainage affecting the performance of installed drainage systems (depth and space).
3. Evaluate the three drainage systems from the economic point of view.

MATERIALS AND METHODS

The experimental studies were carried out at El-Hagarsa village, Kafrsakr District, Sharkia Governorate which located in the Eastern Delta. The increasing value of soil salinity is one of the main reasons of selecting the study area.

Four successive crop rotations were applied rice, 2013; wheat, 2013/2014; rice, 2014 and wheat, 2014/2015 under three different drainage systems. The initial of some soil properties for the experimental field is shown in Table 1.

Materials

Seeds

Rice seeds

Oryza Satoua, L. sakha 104 *cv* was sown on the 2^{nd} week of June.

Wheat seeds

Triticum aestivum L. Sakha 93 cv was sown on the 3^{rd} week of November.

Table 1. The initial properties of the experimental soil

Depth, (cm)	Soil fractions			Textural	EC (dS/m)	pH 1:2.5 (susp.)
	Clay (%)	Silt (%)	Sand (%)			
0-30	56.34	31.02	12.64	Clay soil	7.19	7.73
30-60	56.41	30.76	12.83	Clay soil	8.06	7.80

Machinery and equipment

The following machines were used in carrying out the present study:

Tractor

The tractor Fiat 55.1 kW (75 hp) was used as a power source to operate and draw the used equipment.

The manufactured mole plow

A locally manufactured mole plow was used to hole underground moles. The manufactured mole plow consists of a hopper with a volumetric capacity of 0.511m^3. A funnel was attached to mole plow under the hopper through a gate (usherette). The gravel was inserted into the moles using a devised funnel attached to the mole plow. Fig. 1 reveals the outlook of mole plow components.

Chisel plow

Locally made 9 tines chisel plow with working width 225cm and total mass 260kg was used for seedbed preparation.

Land leveler

Locally made land leveler with working width 305cm, hydraulic and total mass 370kg was used for soil leveling after tillage.

Planting machines

Seed drill Colorado, 20 rows and spacing of rows 13 cm.

Methods

Experimental layout

The experimental area was about 8 faddans. Equal fourteen soil profiles (50 × 48 m each) were dug to represent the different drainage conditions, *i.e.,* without drainage as a control (1 profile), subsurface or pipe drainage (1 profile) and mole drainage (12 profiles) as shown in Fig. 2.

Design of the Drains

Pipe drainage system

Pipe drainage system was installed by the Egyptian Public Authority for Drainage Project (EPADP). The drainage criteria were designed as a composed system, which means that the laterals are connected the collector pipes, which carry drainage water, to the open drains. Drain tubes (laterals) of 10cm diameter, perforated, polyethylene with synthetic materials were installed 1.25 m below soil surface on a grade of 0.1%, 200 m long and 40m spacing. The diameter of the slot was 4mm, the number of slots was 350 per m of pipe length and the total open area was approximately 4400 mm^2 per m of pipe length. On the other hand, plastic tubes were used as collectors with diameter of 20cm. On the collectors and every 4 laterals (160m spacing) there is one manhole for checking and maintaining the system.

Mole drainage

The mole drainage treatments are:

1. Mole spacing; 4, 8 and 12m.
2. Mole types; gravel filled (F) and unfilled (UF).
3. Mole depths; 40 and 60 cm.

The moles were constructed by mole plow and gravel was inserted into the filled moles by a devised hopper attached to the mole plow.

Seedbed preparation conditions

The plowing depth in general was about 20 cm, while the plowing speed was about 3.5 km/hr., for the first pass tillage and 5.5 km/hr., for the second. While leveling speed was in the range of 4.8 to 6.0 km/hr. Tillage operations were carried out at soil moisture content range of 13 to 15% at top 30cm depth.

No.	Part name	No.	Part name	No.	Part name
1	Hopper	3	Usherette	5	Share
2	Shank	4	Conduit	6	Frame

All dimensions in, m

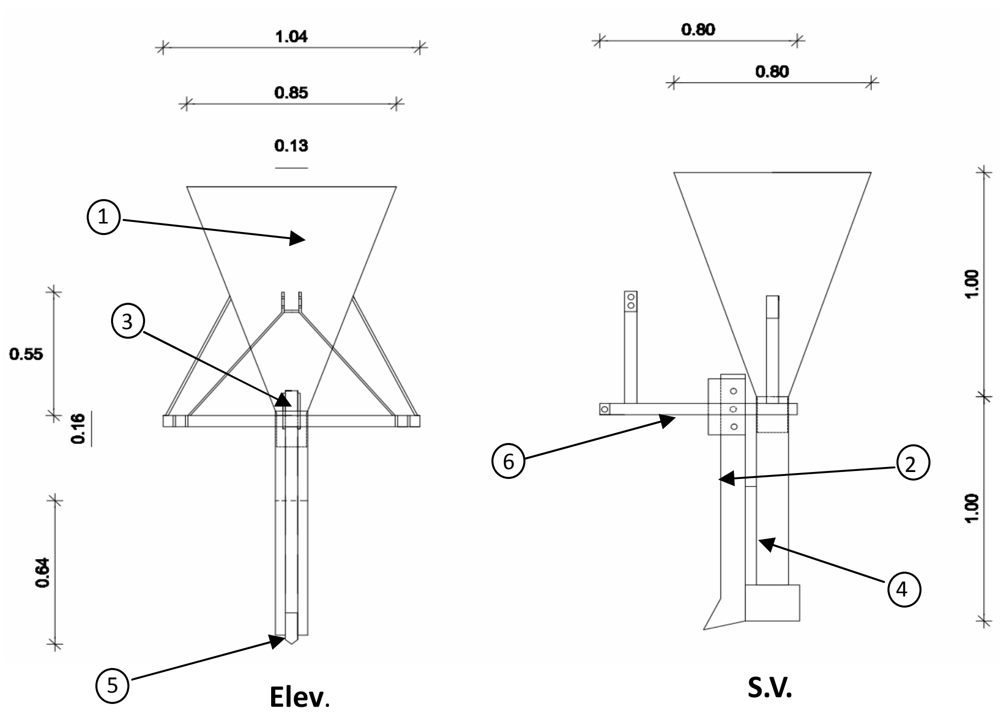


Fig. 1. Elevation and side view of the locally manufactured mole plough

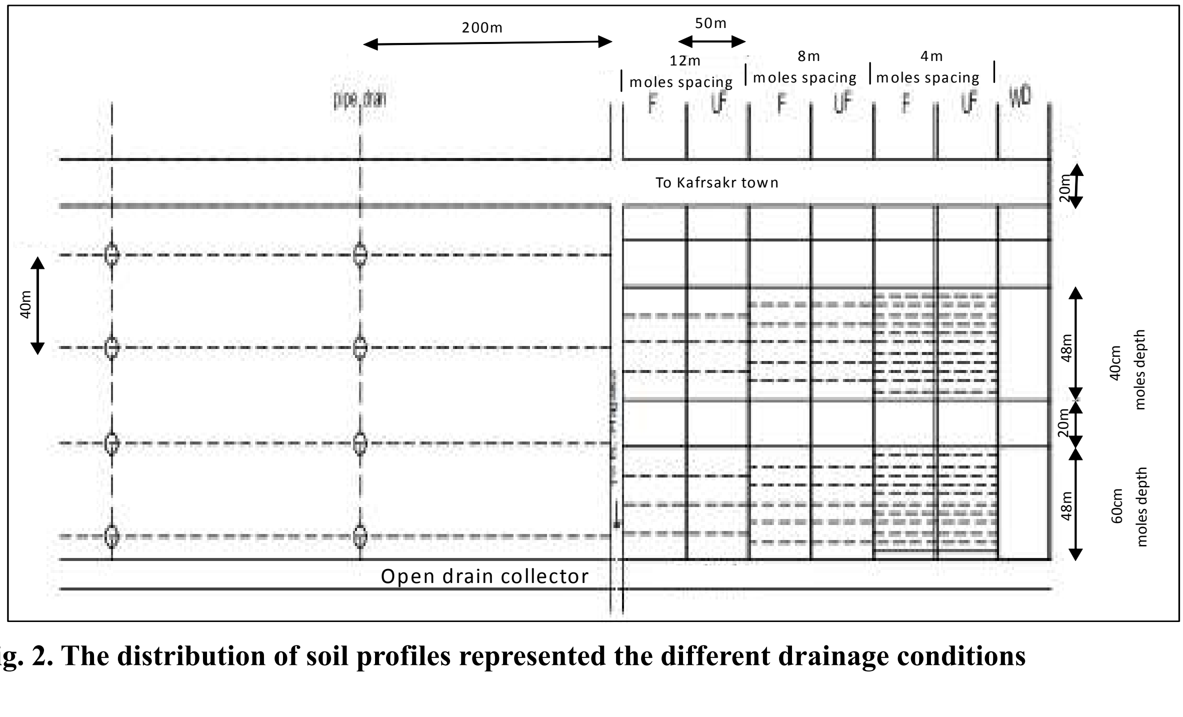


Fig. 2. The distribution of soil profiles represented the different drainage conditions

Planting conditions

Rice crop

The mechanical planting by seed drill requires about 60 kg/fad., of seeds. The planting depth was taken as constant as 2.5 to 3.0 cm. Planting speed was about 3.0 km/hr.

Wheat crop

The seeds were mechanically drilled at a rate of 50 kg/fad. The planting depth was taken as constant as 2.5 to 3.0 cm. Planting speed was about 3.0 km/hr.

Measurements

During execution the experiment, the following measurements were recorded.

Soil measurements

Soil mechanical analysis

Soil mechanical analysis was determined according to the hydrometer method.

Soil bulk density

Soil samples were taken quickly with cylindrical core (100 cm^3 volume) from depth levels of 0-20 and 20-40 cm. The bulk density after harvesting of each crop in each treatment was determined according to the use of paraffin black method, Black (1965).

Soil electrical conductivity

Soil electrical conductivity values (EC, dSm^{-1}) in soil paste extract were measured.

Crop measurements

Grain yield in Mg/fad., was adjusted to 15.5% moisture content. The yield relative to control was computed for each treatment [(Yield of treatment)/(Yield of control)×100].

Machine measurements

Power required

Fuel consumption was determined by measuring the volume of fuel required to refill the tank after operation time per each treatment using a graduated glass cylinder. The Power required (PR) was calculated according to the following formula (Embaby, 1985).

$$PR = (Fc \frac{1}{60 \times 60}) \rho_f \times LCV \times 427 \times \eta_{th} \times \eta_m \times \frac{1}{75} \times \frac{1}{1.36} \text{ (kW)}$$

Where:

Fc = Fuel consumption, l/hr.,

ρ_f = Density of the fuel (0.85 kg/l for diesel fuel);

LCV = Lower calorific value of fuel (10000 kcal/ kg for diesel fuel);

427 = Thermo-mechanical equivalent, kg.m/ kcal;

η_{th} = Thermal efficiency of engine (40% for diesel engine) and

η_m = Mechanical efficiency of engine (80% for diesel engine).

PR = 3.16 Fc

Energy requirements

Energy requirements was estimated according to fuel consumption for implement by the following equation:

$$E = PR/Fact$$

Where:

E = energy requirement, kW.hr./fad.

Cost determination

The cost of the mechanized process was based on the initial cost of machine, interest on capital, cost of fuel and oil consumed, cost of maintainance, and wage of operator according to the conventional method of estimating both fixed and variable cost.

The Total cost can be determined using the following formula:

$$\text{Total cost (LE/fad.)} = \frac{\text{Machine cost (LE/hr.)}}{\text{Effective field capacity (fad./hr.)}}$$

Net profit

The economical profit of crop yield was calculated by using the following formula (Younis *et al.,* 1991):

$$P = (Yt \times d) - Ct$$

Where:

P:net profit, LE/fad., Yt: total grain yield, Mg/ fad., d:yield price, LE/Mg, and Ct: total cost, LE/fad.

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following headings:

Soil bulk density

Soil bulk density is considered as one of the parameters which indicate the status of soil structure and consequently, soil water, air and heat regimes. Results in Fig. 3 show that, soil bulk density was increased with increasing soil depth for all tested profiles. This increase may be resulted from increasing soil compaction due to layers weight. The decreases of soil bulk density after four seasons from treatments installation are more pronounced compared to after one and two seasons.

Decreasing distance between moles decreases soil bulk density values but increasing depth of moles increases its values.

Soil Salinity

Results of soil salinity expressed as electric conductivity (Ec_e) in $ds.m^{-1}$ for two successive layers are shown in Fig. 4. In general, soil salinity for the studied area before starting the treatments was relatively high with an average 7.6 $ds.m^{-1}$.

The mole treatments in this study differed quietly in their effects on soil salinity with different crops. From the results, it could be concluded that 4m spacing was the best spacing since it led to the lowest value of EC_e. The effect of different spacing on the leaching of salts during the four seasons can be arranged in the following descending order: 4m> 8m> 12m> pipe drain. These results are somewhat consistent with Abou El-Soud *et al.* (1996). This trend may be due to double the numbers of moles per unit area with 4m spacing. Consequently, the mole spacing decrease enhanced the leaching of salts from soil and decreased EC_e values.

Considering the effect of mole depth, it could be observed that the 40cm depth was better than 60cm depth in all seasons since it gave lower values of EC_e.

Results could be attributed mainly to that mole forms many lines with big crack extend from soil surface to mole depth (40 or 60cm deep) and also numerous effective capillary cracks is formed. All these cracks together break the soil matrix and encourage downward of water as well as solute movement. The soil cracks life may be several months or years (Antar *et al.,* 2008).

Effect of drainage systems on crop yield

The crop yields of the rotation under study corresponding to different drainage treatments are illustrated in Fig. 5.

Effect of mole spacing

The data of the yield indicated that decreasing the mole spacing increased the crop yield in all growing seasons.

In other words, 4, 8 and 12 m mole spacing increased the yield by 42.5, 35.6 and 30.6%, respectively for rice grain in the first season, by 27.9, 24.2 and 22.3%, respectively of wheat grain in the second season, by 60.7, 58.5 and 49.6%, respectively for rice grain in the third season and by 40.4, 38.5 and 35.6%, respectively for wheat grain in the fourth season over that recorded with the control (without drainage).

This trend may be attributed to that the construction of moles, especially at closer spacing, improved the infiltration characteristic of the soil and consequently decreased its salinity content. These results are in harmony with those obtained by El-Sabry *et al.* (1992) and El-Abaseri *et al.* (1996).

Effect of mole types

The unfilled and gravel filled moles increased crop yield in all growing seasons. In all seasons unfilled mole was superior to the gravel filled mole in its effect on grain yield by 2.7, 2.6, 2.3 and 1.7% in 1^{st}, 2^{nd}, 3^{rd} and 4^{th} seasons, respectively. It is worthy to recognize that the unfilled mole becomes less effective on soil ability to transmit water due to partial collapse of its cross section. Meanwhile, the gravel as filling material protects the moles from collapsing, and consequently keeps them in a good manner for relatively long duration. These findings somewhat corresponded with that reported by El-Abaseri *et al.* (1996).

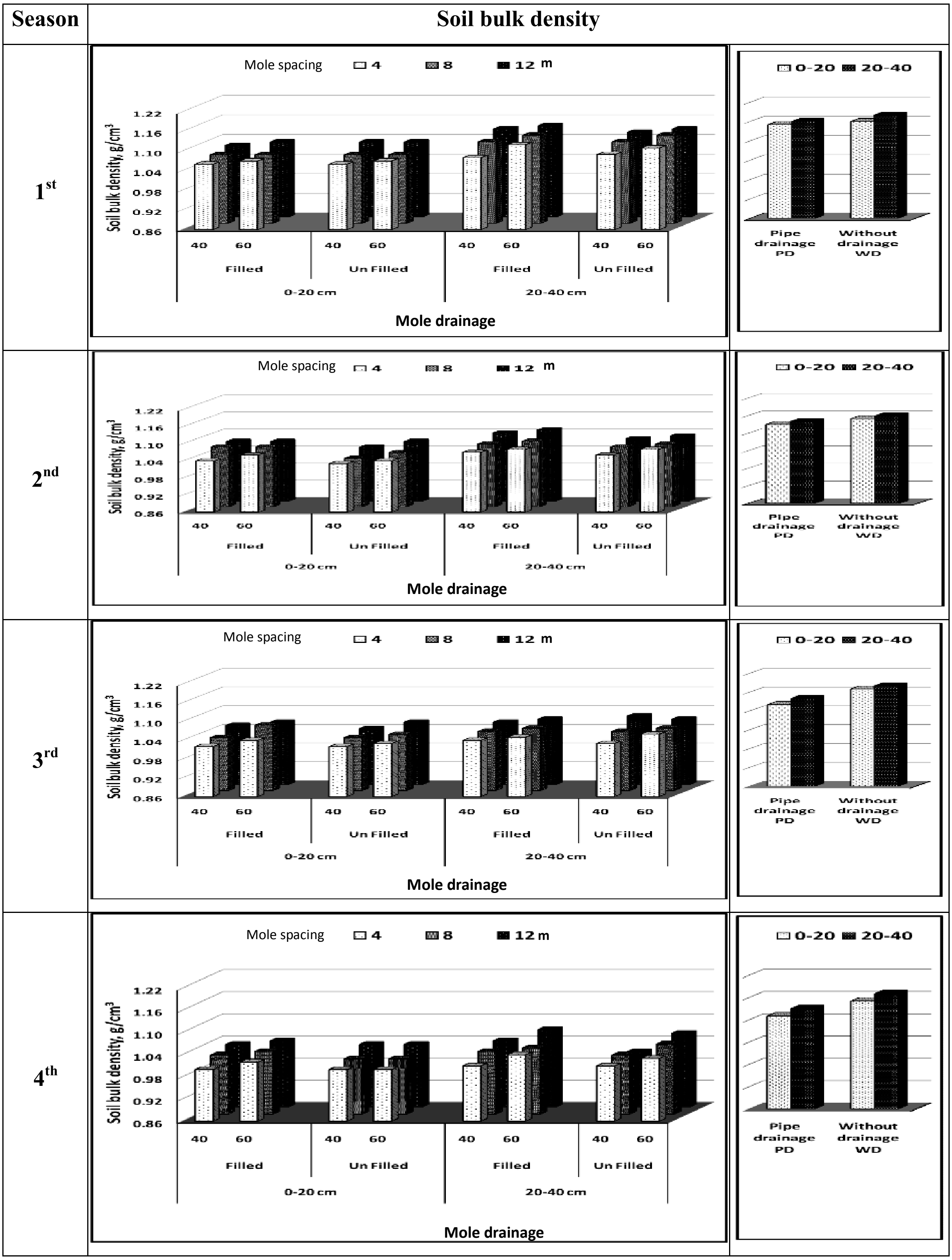


Fig. 3. Effect of different treatments on bulk density under different seasons

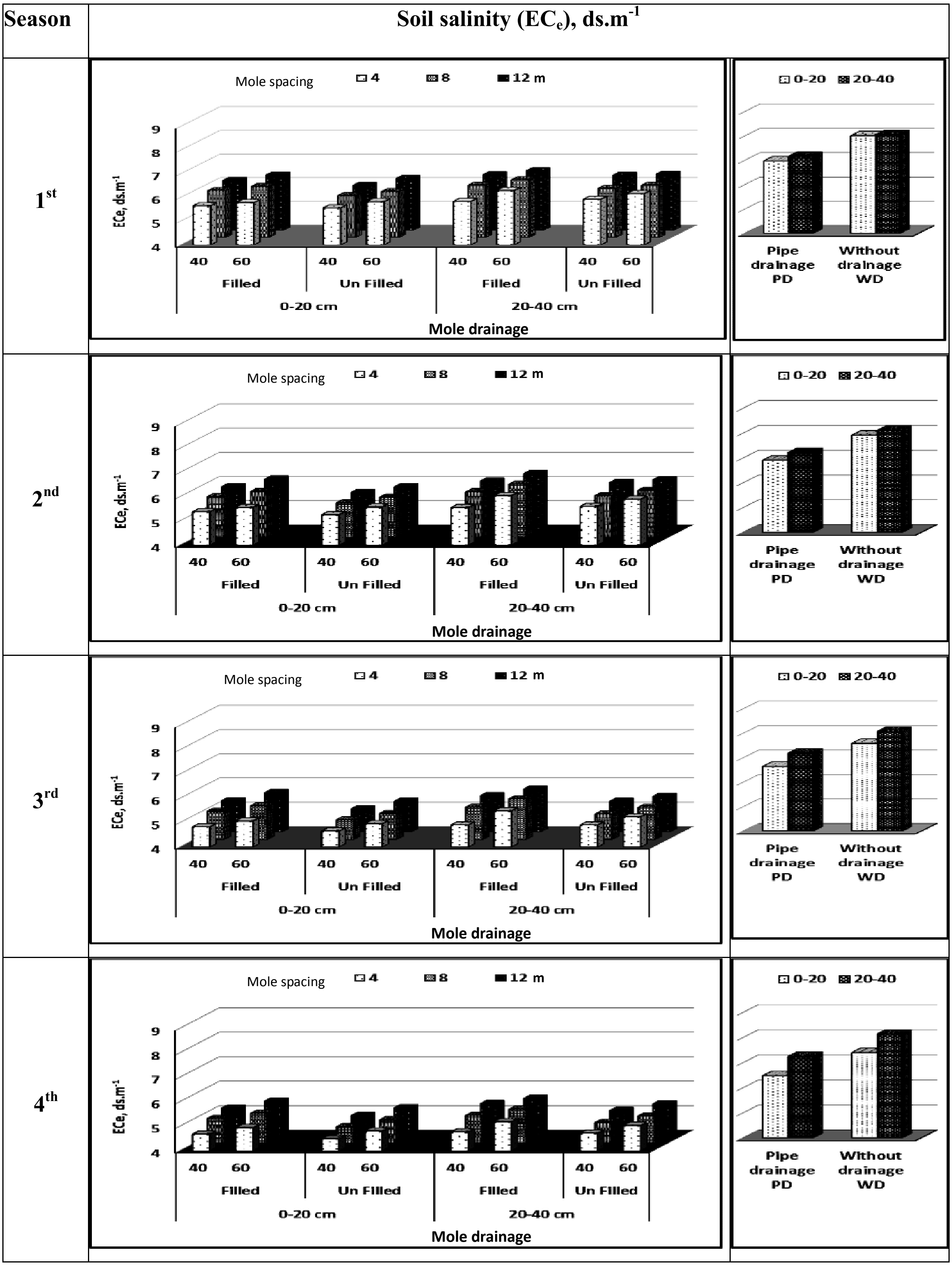


Fig. 4. Effect of different treatments on EC, ds.m^{-1} under different seasons

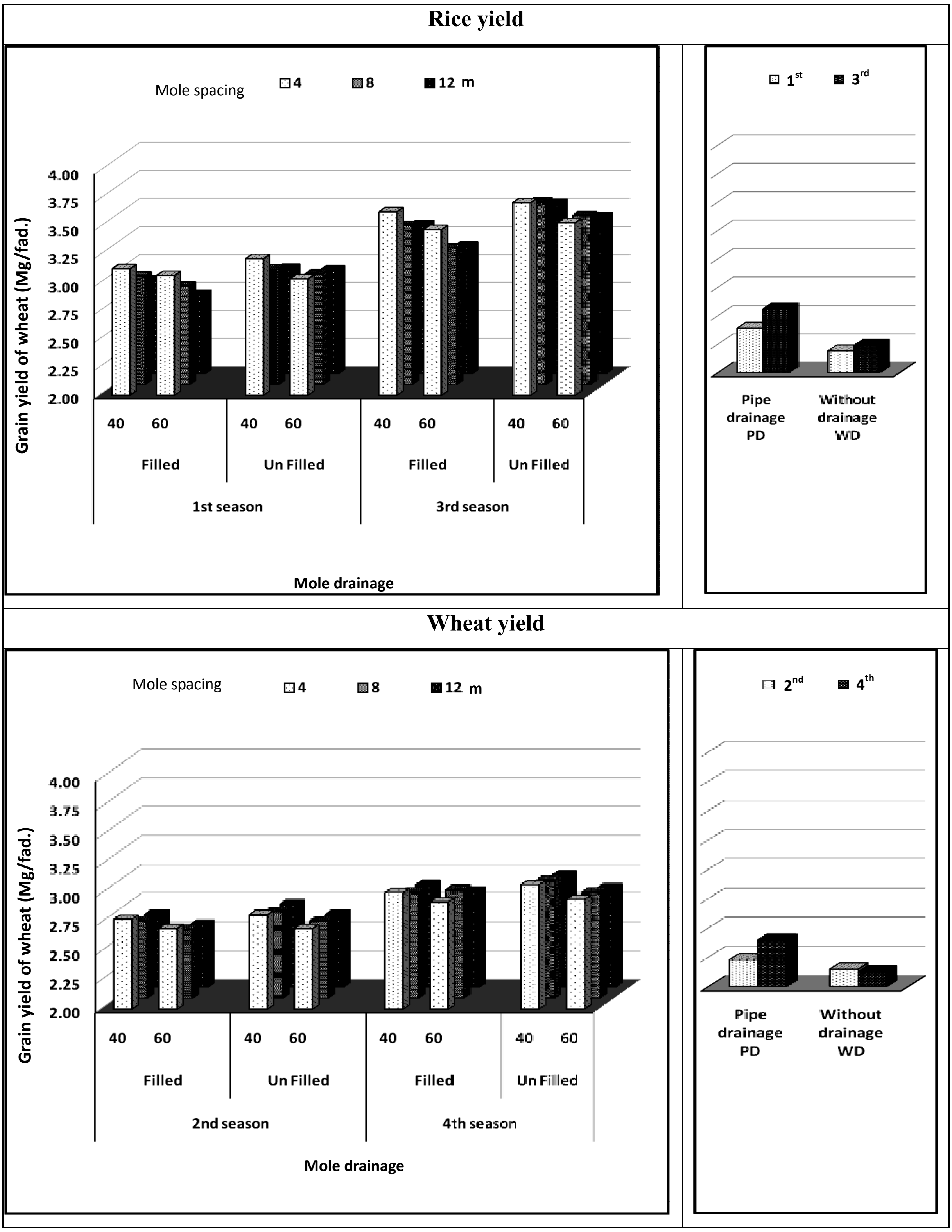


Fig. 5. The yield of different crops (Mg/fad.) as affected by different treatments

Effect of mole depth

With respect to the effect of mole depth, the mean values of the yield revealed that 40 cm moles depth were better than the 60 cm moles depth in all seasons. The mean yield obtained by the 40cm moles depth was greater than the 60cm moles depth by 0.08, 0.08, 0.16 and 0.07 Mg/fad., in 1st, 2nd, 3rd, and 4th seasons, respectively.

Effect of pipe drain

For pipe drain, rice and wheat grain yields are higher than that without drain in all seasons. Rice grain yield is higher under treatment of pipe drain by 9.1 and 14.2% in 1st and 3rd seasons, respectively than the control. In relation to wheat crop, the average grain yields under pipe drain are higher than without drain by 0.08 and 0.27 Mg/fad., in 2nd and 4th seasons, respectively.

Combined effect of different drain treatments

The results indicate clearly that rice and wheat grain yields are related to soil salinity content. The yields were increased when the EC_e decreased as affected by pipe drain or moling. It can be concluded that heavy clay salt affected soils could have good productivity with the execution of pipe drain or moling.

It could be observed that the highest yield of rice in the first and the third seasons (3.22 and 3.72 Mg/fad., respectively) were achieved by the combined treatment of 4m spacing unfilled moles with 40cm depth (4UF40). Also it (4UF40) produced the highest yield of wheat grains (2.82 and 3.08 Mg/fad., respectively) in the second and the fourth seasons, respectively and in all cases, the control gave the lowest yield.

Such findings may be attributed to the effect of pipe drain and moling on improving soil properties which affects water-air relationships in the root zone and increase the root penetration.

Effect of Different Treatments on Energy Requirements

Concerning the combined effect of different treatments on energy requirements, it could be observed that all treatments decreased energy requirements comparing to the control. As shown in Fig. 6, the best treatments were found from the combined treatment of 4m spacing unfilled moles with 40cm depth (4UF40) during the first, the second and the third seasons, respectively and the combined treatment of 4m spacing unfilled moles with 60cm depth (4UF60) during the fourth season, since they recorded the lowest values of energy requirement. While the control detected the highest values for all seasons.

Effect of Different Treatments on Total Cost

Results given in Fig. 7 indicate the total cost for different treatments used in rice and wheat production. It must be noted that the highest average values of operational cost were 2333.12 and 2003.92 LE/fad., from the treatment WD (without drain), while the lowest average costs were found from the treatments 4UF40 and 4UF60 which were 2326.71 and 1993.26 LE/fad., for rice and wheat production, respectively.

Effect of Different Treatments on Net Profit

The net profits as influenced by different drainage treatments are shown in Fig. 8. According to the economic evaluation, it could be concluded that the combined treatment of 4m spacing gravel constructed mole with 40cm depth (4F40) was the best treatment and should be recommended due to a relative height net profit comparing to other gravel filled mole treatment. On the other hand, the combined treatment of 4m spacing unfilled moles with 40cm depth (4UF40) achieved the highest net profit comparing to drain treatments.

It is worthy to mention herein that the unfilled moles seem to be more valuable than gravel filled ones, but by the time the contrary trend could be achieved because the duration of the unfilled moles may be 3-5 years (Spoor, 1993) but the filled moles may do better for a significant period of time. Therefore, after long term, the filled moles would be superior to unfilled ones.

Conclusion

The results obtained through four seasons in consecutive research phase, could be summarized as follows: (i) The bulk density values in all treatments were less than the

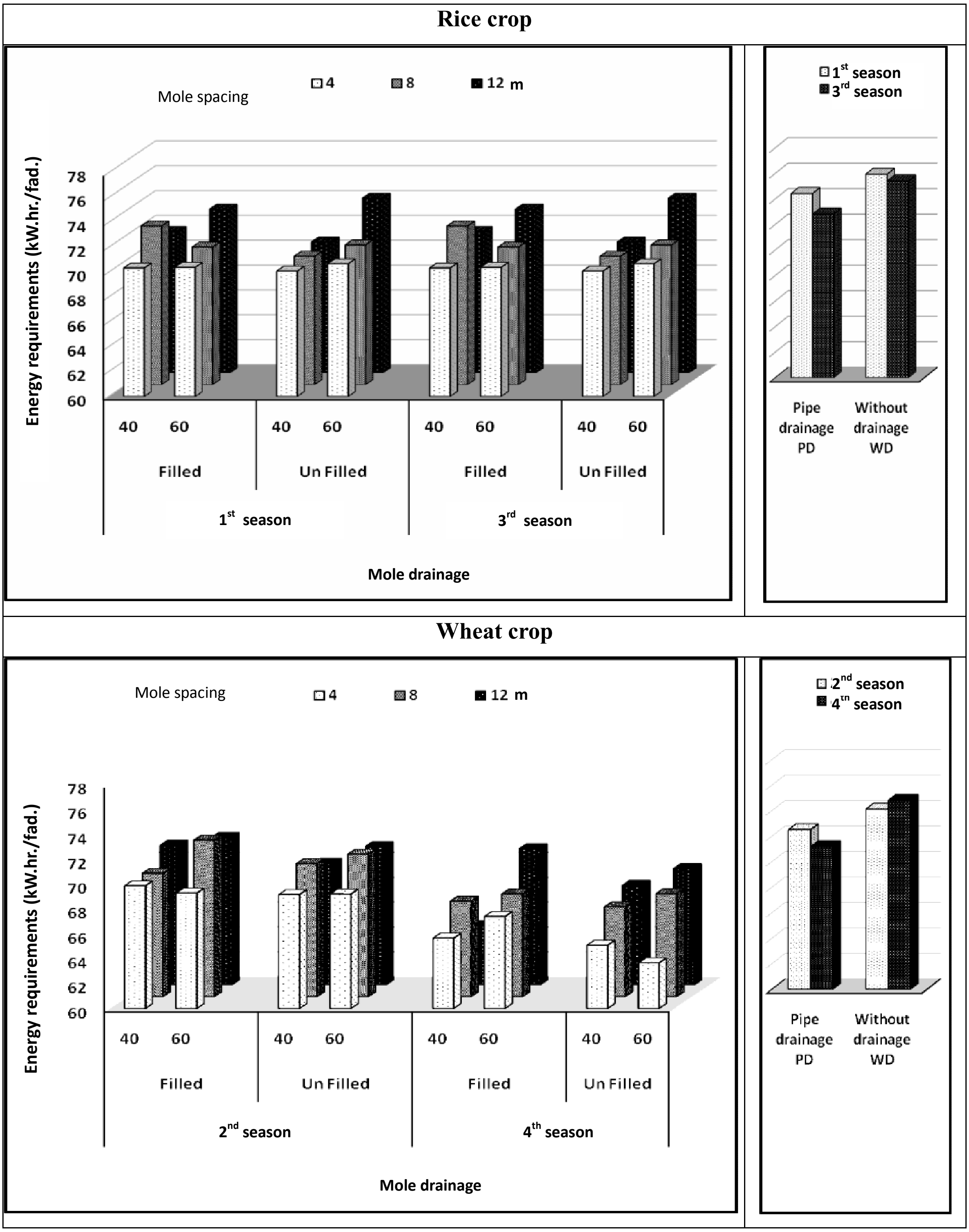
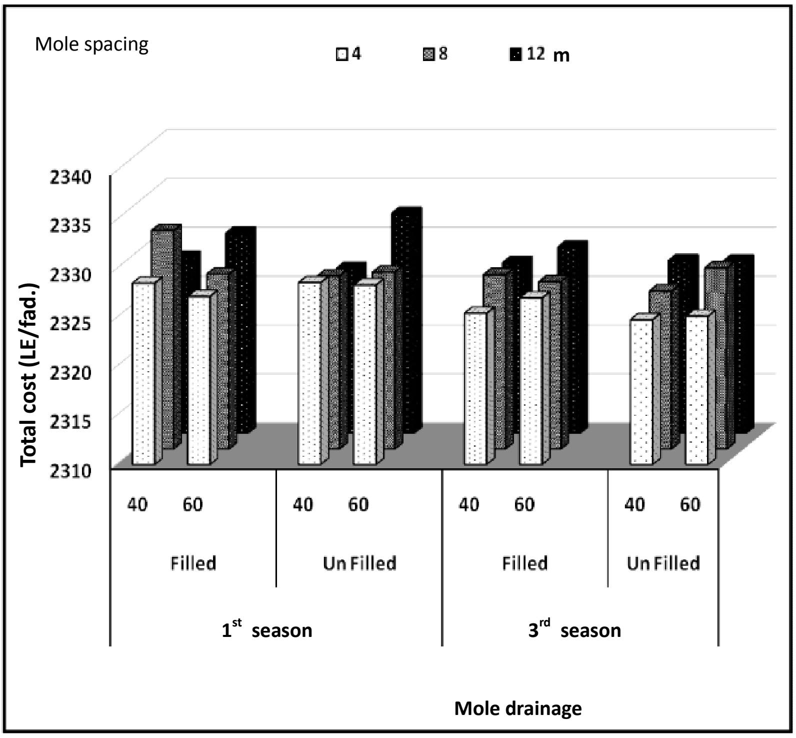
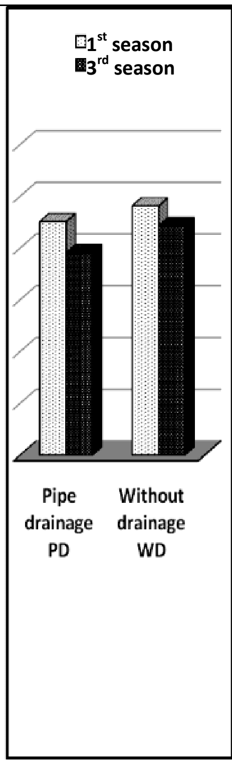


Fig. 6. Effect of different treatments on energy requirements (kW.hr./fad.) under different seasons

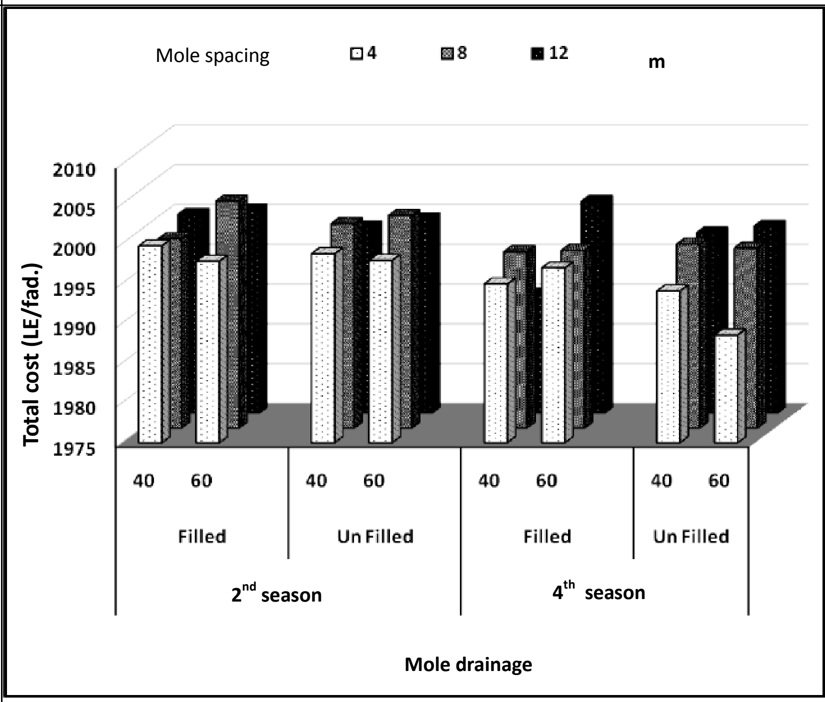
Crop	Total cost (LE/fad.)

Rice





Wheat



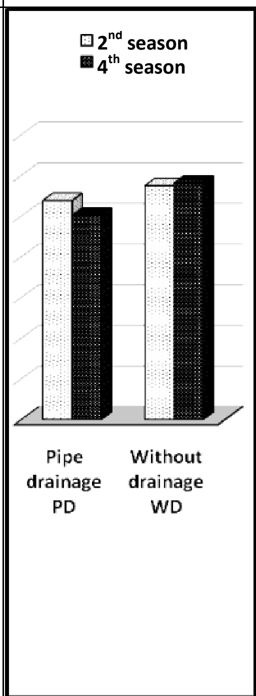
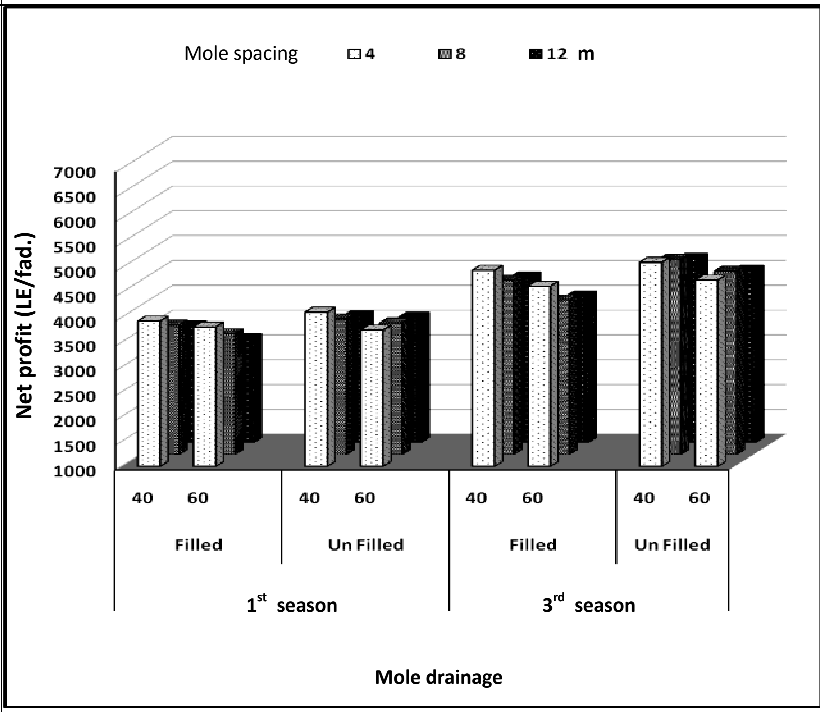
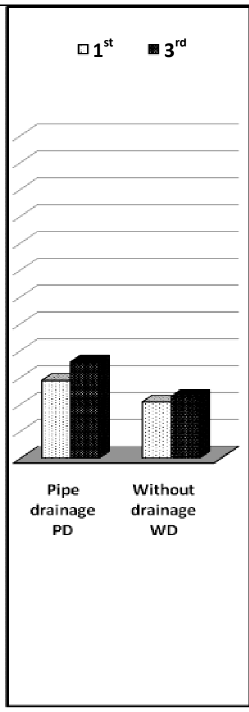


Fig. 7. Effect of different treatments on operational cost under different seasons

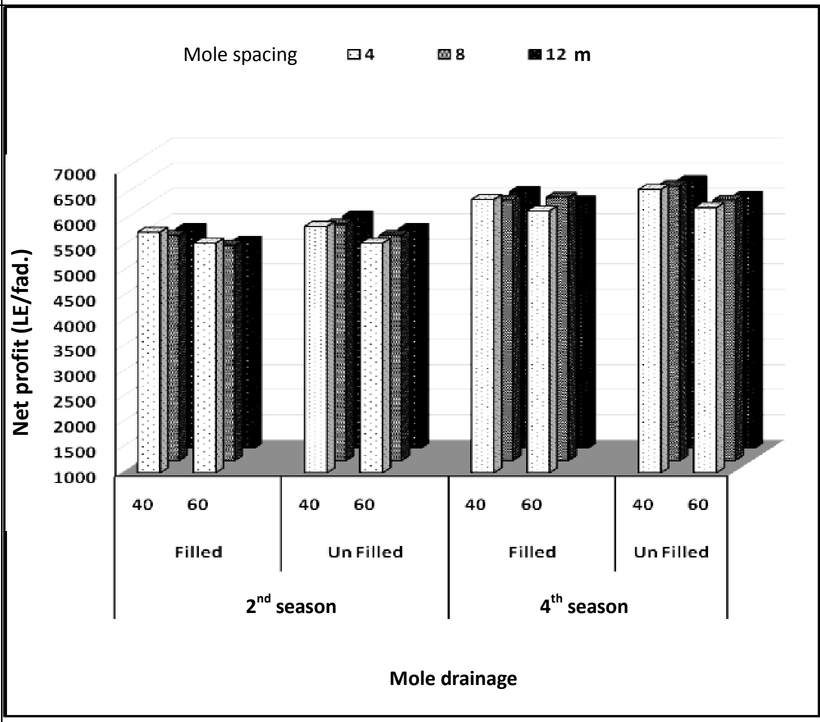
Crop	Net profit (LE/fad.)

Rice





Wheat



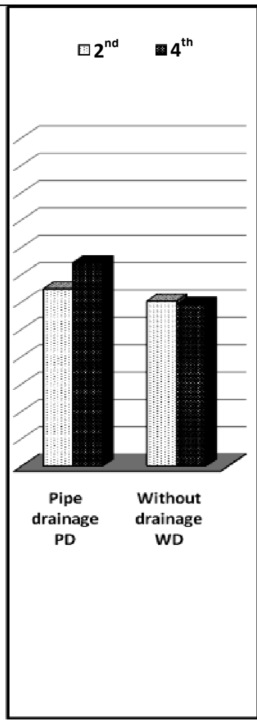


Fig. 8. Effect of different treatments on net profit under different seasons

control value during the four seasons. (ii) The mole treatments differed quietly in their effects on soil salinity with different crops. The effect of different spacing on the leaching of salts during the four seasons can be arranged in the following descending order: 4m> 8m> 12m> pipe drain. (iii) The highest yield of rice in the first and the third seasons (3.22 and 3.72 Mg/fad., respectively) were achieved by the combined treatment of 4m spacing unfilled moles with 40cm depth (4UF40). Also it (4UF40) produced the highest yield of wheat grains (2.82 and 3.08 Mg/fad., respectively) in the second and the fourth seasons, respectively and in all cases, the control gave the lowest yield. (iv) All treatments decreased the energy requirements comparing to control (without drainage); and moling seemed to be more effective on the decreasing than pipe drainage especially with closer mole spacing.

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تصميـــم وتقييـــم أداء بعـض الطــرق المختلفـــة للصـــرف الـــزراعـي

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يعتبر الصرف الزراعي من أهم العوامل المؤثرة على الإنتاج الزراعي في مصر، لذلك اتجه التفكير في هذا البحث إلى تصميم وتقييم أداء بعض الطرق المختلفة للصرف الزراعي بهدف الوصول إلي أفضل نظام صرف، أجريت تجربة في أرض طينية ثقيلة القوام متأثرة بالأملاح بقرية الهجارسة مركز كفر صقر بمحافظة الشرقية شرق دلتا النيل لتقييم أداء مصارف الأنفاق (المصارف الديدانية) المملوءة بالزلط وغير المملوءة علي أبعاد مختلفة (٤، ٨ ، ١٢ متر) وعمقين (٤٠ ، ٦٠سم) ومدى تأثيرها على بعض الخواص الطبيعية (الكثافة الظاهرية والمسامية) والكيميائية للتربة (ملوحة التربة وصوديتها) وكمية المحصول ومعدل استهلاك الوقود والطاقة المستهلكة والتكاليف بالمقارنة مع مصارف الأنابيب (تصميم وتنفيذ الهيئة العامة لمشروعات الصرف)، دلت النتائج المتحصل عليها على أن جميع أنظمة الصرف كانت فعالة في خفض الكثافة الظاهرية وبالتالي زيادة المسامية للأرض حتى عمق ٦٠سم من سطح التربة بالمقارنة بالمعاملة بدون صرف، انخفاض التوصيل الكهربي لمستخلص عجينة التربة المشبعة حتى عمق ٦٠سم نتيجة معاملات الصرف وبخاصة مصارف الأنفاق ويمكن ترتيب المعاملات من حيث كفاءتها في التخلص من الأملاح كالآتي: ٤م> ٨م> ١٢م> مصارف الأنابيب، أظهرت قيم نسبة إدمصاص الصوديوم للتربة اتجاهاً مشابهاً لقيم ملوحة التربة، إنتاجية الأرز والقمح تبعت درجة الملوحة حيث لوحظ زيادة الإنتاج مع نقص الملوحة، أعلى إنتاجية من محصول الأرز خلال الموسمين الأول والثالث (٣,٢٢ و٣,٧٢ طن/فدان) تم رصدها تحت مصارف الأنفاق غير المملوءة علي أبعاد ٤م وأعماق ٤٠سم، وهي المعاملة نفسها التي حققت أعلى إنتاجية في محصول القمح للموسمين الثاني والرابع (٢,٨٢ و٣,٠٨ طن/فدان)، يشير التحليل الاقتصادي إلي تفوق أنفاق الزلط على مسافات ٤م وأعماق ٤٠سم مقارنة بأنواع الأنفاق المملوءة الأخرى، ويبدو من النتائج تفوق مصارف الأنفاق غير المملوءة على مسافات ٤م وأعماق ٤٠سم حيث أعطت أكبر عائد اقتصادي، ولكن مع الوقت يمكن أن تتفوق أنفاق الزلط على الإنفاق غير المملوءة حيث أن النوع الأول يمكن أن يعمل بصورة جيدة لمدة أطول.

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