Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (1) January 2021

Assessment of Controlled Drainage System under the Egyptian Condition, Case Study: EL-Baradie Area

Emad M. Mahmoud[1,2], Mohamed M. Nour Eldeen[2], Peter Riad[2]

[1]Ministry of Water Resources and Irrigation, Cornish El Nile, Embaba, Giza, Egypt. emad_mm@hotmail.com;
[2]Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University

الملخص:

تعتبر شبكات الصرف الزراعي تحت السطحي (المغطي) أحد الأنظمة الشائعة الإستخدام في المناطق الجافة و التي تستخدم لخفض مناسيب المياه الأرضية وبالتالي تؤدي إلي زيادة الإنتاجية الزراعية والتحكم في تراكم الأملاح في منطقة جذور النباتات. وبالرغم من فوائد الصرف الزراعي التقليدي، إلا أنه يعد أحد أسباب تدني كفاءة الري بمصر حيث يتم تصريف المياه من قطاع التربة بشكل سريع و مستمر والذي يعرف بالصرف الجائر مما يؤدي إلي هبوط مستوي المياه الأرضية دون السماح للنبات بالإستفادة الكاملة من المياه و الأسمدة لأطول فترة ممكنة. ويهدف هذا البحث إلي تقييم أثر تطبيق كلا من الصرف القابل للتحكم علي كميات مياه الري ، ملوحة التربة و الإنتاجية الزراعية للوصول لأفضل الأنظمة لتحسين إدارة المياه علي مستوي الحقل. وتعتمد منهجية الدراسة علي مقارنة نظام الصرف التقليدي بنظام الصرف القابل للتحكم (المقيد) بإستخدام بيانات إدارة المياه للموسم الزراعي 2015 – 2016 بمنطقة البرادعي.

و قد أظهرت النتائج فاعلية الصرف المقيد في توفير مياه الري وخاصة خلال زراعة محصول الأرز وتوفير كميات الأسمدة الزراعية وتقليل تكلفة الوقود المستخدم في ري المحاصيل، فالتحكم في مجمعات الصرف الثانوية من خلال تقنية الصرف القابل للتحكم علي أعماق مختلفة عمل علي تقليل كميات المياه المستخدمة في الري بحوالي 25% و 16,7% لمحاصيل الأرز و الذرة علي التوالي مقارنة بنظام الصرف العادي. كما أن الحفاظ علي منسوب المياه الجوفية قريب من جذور النبات في المراحل الأولي من الزراعة يقلل من معدلات الصرف وبالتالي يقلل من الفقد في الأسمدة الزراعية مما يؤثر إيجابيا علي التكلفة والإنتاجية حيث زادت إنتاجية الذرة ما بين 10 و 13%، وزادت إنتاجية الأرز ما بين 15 و 19% . وقد أظهرت النتائج أيضا إرتفاع طفيف في ملوحة التربة خلال مرحلتي الإنبات و مرحلة منتصف الموسم الزراعي نتيجة الإحتفاظ بالمياه علي مناسيب أعلي في المراحل الأولي.

كلمات مفتاحية: الصرف المغطي، الصرف المقيد، إدارة الصرف، الإنتاجية المحصولية

Key word :

Abstract:

Subsurface drainage systems ensure aeration of plant root zone and eliminate waterlogging. This enhances soil properties, promotes crop growth, and reflects positively on the crop yield. Moreover, in arid areas, drainage critically provides leaching capability to control salinity build-up in the crop root zone and soil profile. Conventional subsurface drainage (free discharge) systems have no management to control drained water flow, and the systems are left to flow continuously by gravity. The drainage water flows continuously and quickly with

nutrients from the soil profile, thus reducing opportunities of plants to use water from the shallow water table.
Two summer season's field experimental study investigates the advantages of the controlled drainage technique to manage the water level. The study followed certain operational scenario to satisfy the crop water requirements through controlling water level by using (ON/OFF) gates at different depths against effective plant root zone.
The results showed that controlled drainage technique proved its effectiveness in saving irrigation water, especially with Rice cultivation, saving fertilizers, and reducing the cost of irrigation practices. The volumes of applied irrigation water in the study area reduced by 25 % and 16.7 %, for Rice, and Maize crops respectively compared to conventional drainage system. Maintaining the water table elevation close to the developing plants root zone for longer periods during different stages of the growing season reduced the drainage rates and nutrient losses, which leads to significant increase in crop productivity.
The productivity of maize crop increased by 10 and13 % and productivity of rice increased by 15 and 19% compared to the conventional drainage system. Significant reduction in the cost of agriculture filterers for Rice and Maize crops respectively has been observed.
A slight increase in soil salinity was observed during planting and mid-season stages when using controlled drainage technique.
Keywords: Subsurface drainage, Controlled drainage, Drainage management, Crop productivity.

1. Introduction

Egypt's major challenge is to close the rapidly growing gap between the limited water availability and the increasing water demand by various economic sectors. Rationalization of water use especially in the agricultural sector is considered an effective measure formulating future policies and strategies to face the expected water scarcity. Therefore greater emphasis is now being placed to improve the efficiency of using available water resources for crop production. The agricultural sector is the largest water consumer in Egypt. It consumes about 76% of surface water resources (NWRP 2017- 2037). A network of 48,000 km of irrigation and drainage canals serves around 3.7 million hectare of irrigated lands (MWRI, 2017). After construction of High Aswan Dam (HAD) and introduction of perennial irrigation, the government of Egypt adopted a strategy to provide all arable lands with artificial drainage systems. Drainage development in Egypt costs less than 1000 USD per Hectare. This is practically low considering the amount of works (The World Bank, 2015).

Drainage of agriculture lands is an instrument for production growth, a safeguard for sustainable investment in irrigation, and a tool for conservation of land resources (Ritzema et al., 2006). The design of subsurface drainage aims to find the best spacing between drains and the depth of drains, which would maintain the water table at a suitable depth for crop root development. The required depth depends on soil properties, irrigation practices, and crop types (effective root depth), (Abdel-Dayem, S & Ritzema H.P. 1990). Conventional (free) drainage system consists of lateral pipes, connected to collector pipes that outfall into open canals (surface drains). Free discharge system has no formal operation management; the system is left to flow continuously as shown in figure 1. Sometimes farmers try to reduce the amount of drained water by blocking subsurface drains during Rice cultivation period to keep water for longer period in the soil profile. This is an illegal action, untested, and jeopardizes the overall functioning of the system.

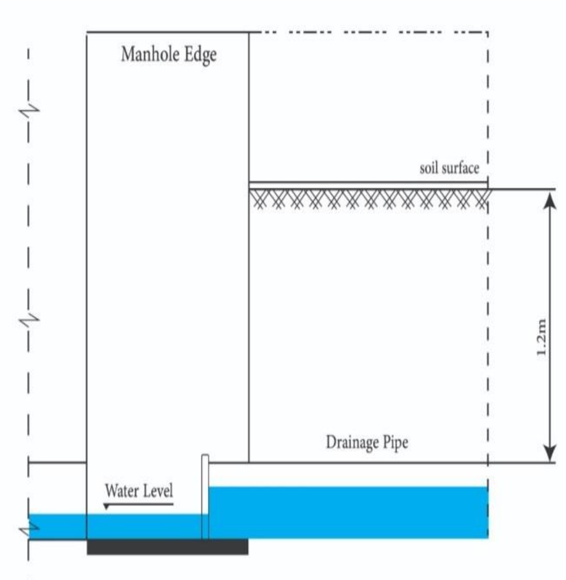

Figure (1) Vertical section in free drainage system

Currently, subsurface drainage makes irrigation less efficient where water is quickly removed (with nutrients) from the soil profile. Plants do not get enough time to use all water from the shallow water profile. Consequently more additional irrigation water is applied for leaching soil salinity. According to (Hvidt 1998), farmers are applying 50 % to 250 % more water than the required to leach salts away from the plant root zone (over irrigation).

To save irrigation water and reduce drainage volumes, irrigation and drainage systems are to be managed in an integrated form (Christen and Ayars, 2001). This will also reduce the cost of energy paid for lifting irrigation water from drainage canals to substitute the shortage of irrigation water, especially at the tail end of canals (reuse practices). Many researchers recommend modifying the current subsurface drainage design criteria in arid areas (drain depths and spacing) to preserve water quality, reduce discharged drainage volume and reduce the volume of irrigation water required (Ayars et al, 1997), (Christen and Skehan, 2001); (M. Wahba, 2008), and (Valipour, M. 2012).

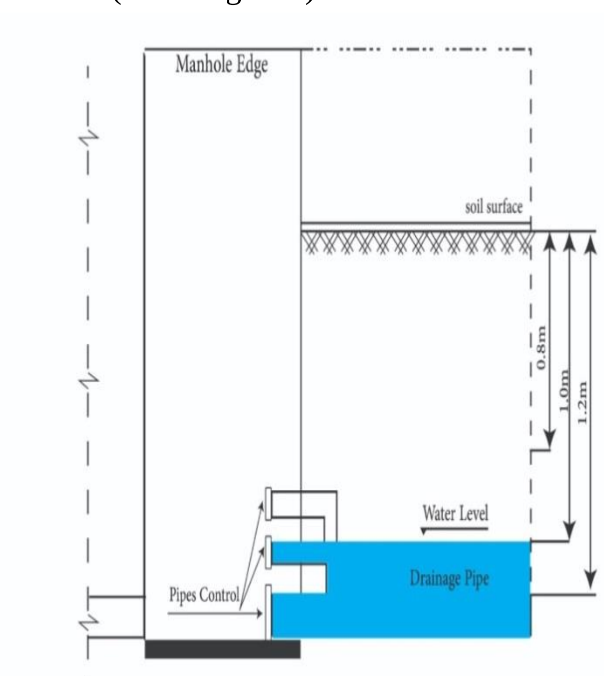

Figure (2) Vertical section in Controlled drainage system

Controlled Drainage (CD) is a system that physically restricts discharged water volumes through controlling the outlet of the drains (Gilliam et al., 1979; Evans et al., 1995; Skaggs et al., 2010; Frey et al., 2016) as shown in figure (2). It has the potential to improve water use efficiency, maintain crop yields in periods of water stress and ensures land drainage systems work to the maximum benefit of farmers (Abbott, C. L., et al. 2002). This technique enables efficient re-use and protection of drainage water from potential pollution if it reaches open drains, where it reduces nitrate and phosphate losses by 30% to 50% compared with conventional subsurface drainage, and reduces eutrophication and ecological damage downstream water bodies (Evans, R. O. et, al. 1995).

In arid and semi-arid regions, controlled drainage is considered the most promising solution to improve water management in agriculture and to reduce the environmental impacts of subsurface flow, (Ayars J.E., 2006). The technique is used to manage water level in the subsurface drainage outlet. It may reduce total outflow by (15 – 35) %, (Abbott, C. L., et al. 2002), when managed all year compared with free systems. In a comparative study, controlled drainage system was tested against conventional free drainage system (FD). The controlled drainage system significantly reduced drainage rates for wheat, barley, and maize by 33%, 45% and 44% respectively lower than FD systems (Jouni et al., 2018).

It is obvious that controlled drainage will protect drainage water quality against pollution, as water is stored into sub-surface collectors and sub-collectors. This is a major benefit that might not be equally observed in the literature quoting experiences of other countries.
Field experiments conducted for two years in Western Delta of Egypt to investigate the effects of controlled drainage on the quality of subsurface drainage outflows. It was reported that the controlled drainage reduced the total orthophosphate-phosphorus losses by 77% during summer season and by 30% during winter season compared to the conventional drainage (Wahba, M. et, al. 2001), (DRI, 2013).
The cost of controlled drainage system is approximately (15% - 20%) higher than those of the conventional system (EPADP, 2016).

The objectives of the study is to assess drainage management (controlled drainage) at field scale on saving irrigation water, increase water use efficiency, and crop yields.

2. Materials and methods

2.1 Study area

The study was conducted during the growing seasons of 2015 – 2016 within El-Mahmudiya District in El-Beheira Governorate. which is located between 30° 26′ 48″ to 30° 28′ 52″ East and 31° 6′ 35″ to 31° 5′ 6″ North. El-Beheira Governorate at the Northern West of Egypt, about 50 km south of Alexandria City as shown in figure 3.

EL-Baradie, is a relatively flat area. The area is characterized as semi-arid region. The mean temperate ranges between 15.0 and 30.5 °C in December and August respectively, with a long-term (2000–2015) average annual precipitation of 90 mm. The average humidity of the area is about 70%. The fields have clay to clay loam soils, with medium permeability and need subsurface drainage for economically viable crop production.

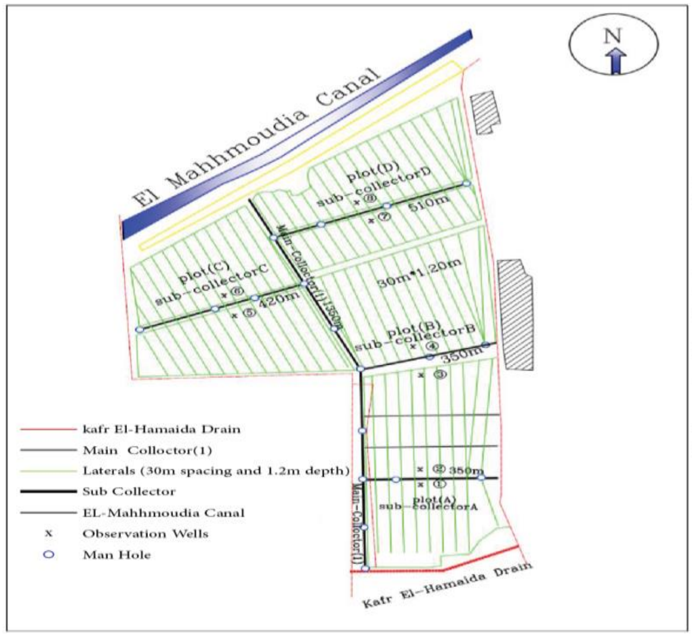

Figure 3 El-Baradi area – EL-Beheira governorate

Figure 4 shows the existing conventional subsurface drainage network in the area consists of parallel lateral pipes of 100 mm diameter at depth 1.2 m, and 30 m evenly spaced. These pipes are installed perpendicular to sub-collector drains. The sub-collector drains (pipe of 150 - 200mm diameter) are installed perpendicular to main collector, which discharges the excess drained water into Kafr El-Hamida.

The research was conducted in four plots. Sub-collectors C&D are operated as conventional drainage system at level 1.20 m and served plots C and D. Sub-collectors A&B are operated as controlled drainage system

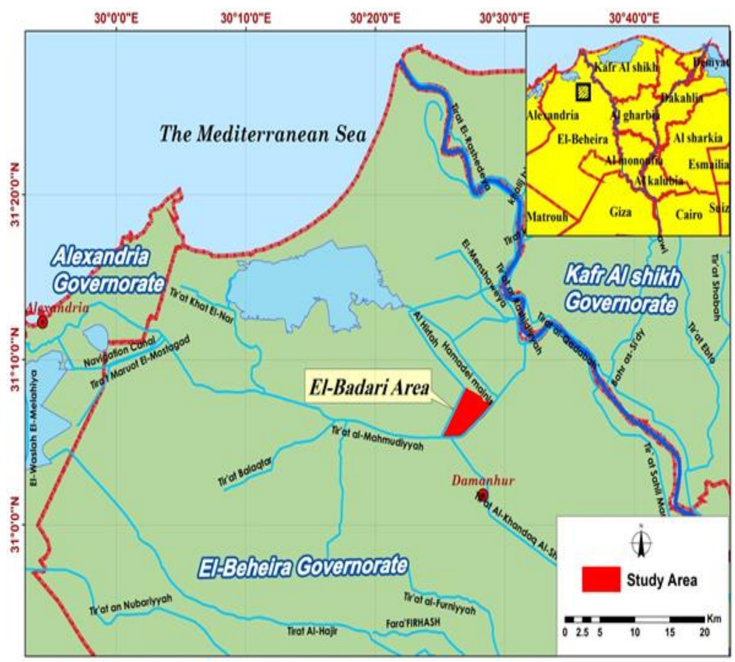

Figure 4 schematic diagram of subsurface drainage network (served 180 feddan) in El-Baradi area

and served plots A and B.
In this study, the conventional sub-surface system is modified to changeable controlled drainage system by adding a riser pipe with multi (On/Off) manual gates at depth 0.80 m, and 1.00 m from land surface connected to the sub-collector.

2.2 Study Procedures

The scope of work includes:

- Field measurements of water table, soil salinity, irrigation water salinity, and crop yield have been conducted during summer seasons of 2015, 2016.
- Water table depth measurements by 4 sets of observation wells, 5 cm diameter and 2.0 m deep. Each set consisted of 2 observation wells installed at the middle path between parallel two laterals in the subsurface drainage system as shown in figure (4).
- Collecting and analyzing soil samples for chemical and Physical analyses and to estimate the soil salinity.
- Analyzing the collected data

The crop pattern in the study area is presented in table – 1. The area is served by collector drain No. 1 and its 4 secondary subsurface drains (A, B, C, D).

Table 1: Crop distribution and observation wells of collector No. 1 (2016)

Sub-collector	**Total area (feddan)**	**Area of each crop for summer season 2016 (fed)**		
		Maize	**Rice**	**Observation well**
A	37	27.5	7.5	(1) - (2)
B	18	8	9.5	(3) - (4)
C	57	48	5.5	(7) - (8)
D	41	21	17.5	(5) - (6)

Rice, Maize, and vegetables are the dominate crops in the area. The diversity of the crops made operating scenario of the controlled drainage more difficult, as there are differences in irrigation water requirement for rice and maize crop. For Rice the objective is to keep the water table as close to the soil surface as possible. For Maize the water table must be kept below a level at which water-logging in the root zone would affect crop production. Based on previous conditions the study follows a certain operational procedures that satisfy the crop water requirements through controlling water level by using manual pipe plugs against effective plant root zone
At the planting stage the root of the plant is very small, and it is crucial to reserve water table slightly high, so the plugs at depths 1.00 and 1.20 m are closed, and the plug at depth 0.80 m is open figure 5-a. At the midseason stage, second plug at depth 1.00 m is open figure 5-b while the second and third are closed. Before the harvesting stage the root of plant is bigger enough to absorb water form deeper distances, so the third plug at depth 1.20 m is open (all plugs are opened) figure 5-c.

Table 2 operating roles of controlled drainage system

Irrigation gifts	Plug No. (1) at 80 cm	Plug No. (2) at 100 cm	Plug No. (3) at 120 cm
First	Opened	Opened	Opened
Second	Opened	Closed	Closed
Third	Opened	Closed	Closed
Fourth	Opened	Opened	Closed
Fifth	Opened	Opened	Closed
Sixth	Opened	Opened	Opened
Seventh	Opened	Opened	Opened
Eighth	Opened	Opened	Opened

Figure (5-a) First plug is open while the second and third closed (planting stage)

Figure (5-b) Second plug is open while the third closed (med-season)

Figure (5-c) all plugs are open (pre-harvesting)

2.3 Field Measurements

Field measurements are carried out during summer season 2015, 2016 including irrigation water volumes of applied irrigation water, water table depth, soil salinity and crop yield.

Water table depth measurements over the whole summer season were obtained by using set of two observation wells installed in each sub-collector.

Harvesting experiments were conducted for maize and rice crops to estimate crop yield and productivity. Soil salinity was measured at different depths along the summer season 2016 to follow up the variation in the salinity at the project's area.

Soil samples were taken at depths 50, 100 and 150 cm at the beginning of the season, at the germination stage, at the vegetative growth stage and during harvesting.

3. Results Analysis

3.1 Irrigation Water Volumes

Applied irrigation water volumes were calculated by utilizing data of pump operation, number of irrigation gifts per season, and irrigation period per feddan. These data had been interpreted to equivalent water depth in cubic meter per feddan.

Table 3 Average water duties per feddan, collector No. (1)

Indicator	Water quantity for Rice area		Water quantity for Maize area	
	Conventional drainage	Controlled drainage	Conventional drainage	Controlled drainage
No. of irrigation gifts per season	16	16	8	8
Irrigation period (hours)	4	3	4	3.75
Irrigation volume / gift (m^3)	360	270	360	337.5
Water volume m^3/feddan/season	5760	4320	3240	2700

Applied irrigation water for Rice crop in the conventional drainage system was calculated by 5760 m3/ season/feddan, it was estimated by multiplying the number of irrigation gifts per season, the duration of field pump operating and actual pump capacity equal 25 l/s. While applied irrigation water for Rice crop in controlled drainage is approximately 4320 m3/ season/Feddan, the number of irrigation gifts per season is 16, the duration of pumping irrigation water is 3 hours with pump capacity equal 25 l/s.

Applied irrigation water for Maize crop in the conventional drainage system was calculated by 3240 m^3/ season. While applied irrigation water in controlled drainage system is approximately 2700 m^3/season.

The previous measurements illustrate that the saving in water volumes equal 25, and 16.7 % in Rice and Maize crops respectively.

3.2 Water Table Depth

The performance of a drainage system is considered to be good, if the observed water table depth drawdown coped with the desired drawdown curve, according to the drainage design. The water table depth changes with time and depends on the irrigation regime. For this reason, all observations are related to the irrigation calendar and the water table depth is measured and plotted against different days after irrigation to illustrate water table drawdown.

Water table depth was measured through eight observation wells (OW) which cover Rice and Maize areas, during the whole growing summer season at different irrigation periods.

Figure 6 illustrates that, in the controlled drainage system the water table depth directly recedes to 40 - 50 cm below the soil surface after three or four days from the irrigation time. Over a period to the next irrigation 14 to 20 days, the water table gradually fall down to 80 – 120 cm below the soil surface.

Significant rise in water table during the (planting phase), while the first plug is opened, the second and third plugs are closed. Therefore water table is step high near the root zone at the early planting stage which eliminates crop water stress under water shortage condition.
Figure 7 illustrates that in the conventional drainage system, after three days from the irrigation time the water table depth records 40 – 50 cm below soil surface. Over period 14 – 20 days, the water table recedes to 120 – 150 cm along the season. This means that the water table is being drawn down to a depth greater than what is actually required to maintain crop growth production. This removes the applied irrigation water from the soil profile before it is used by the plant causing "over drainage" conditions.

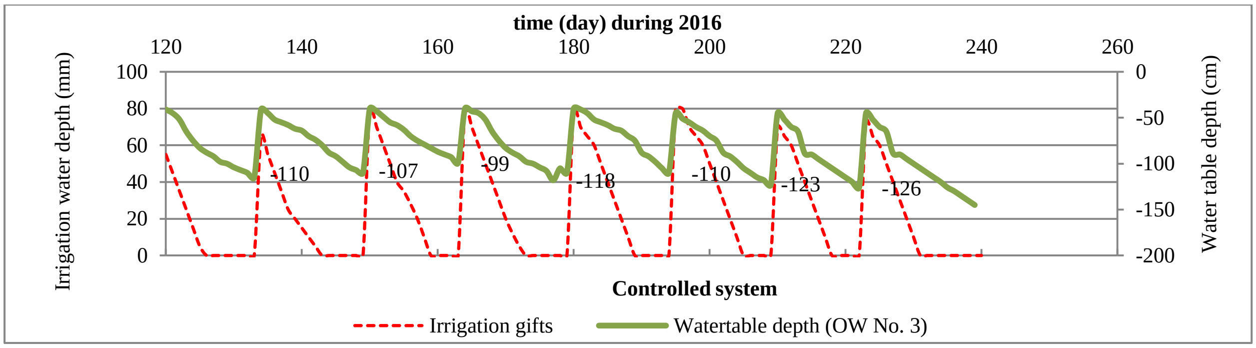

Figure (6) Water table depth in controlled drainage system for Maize crop

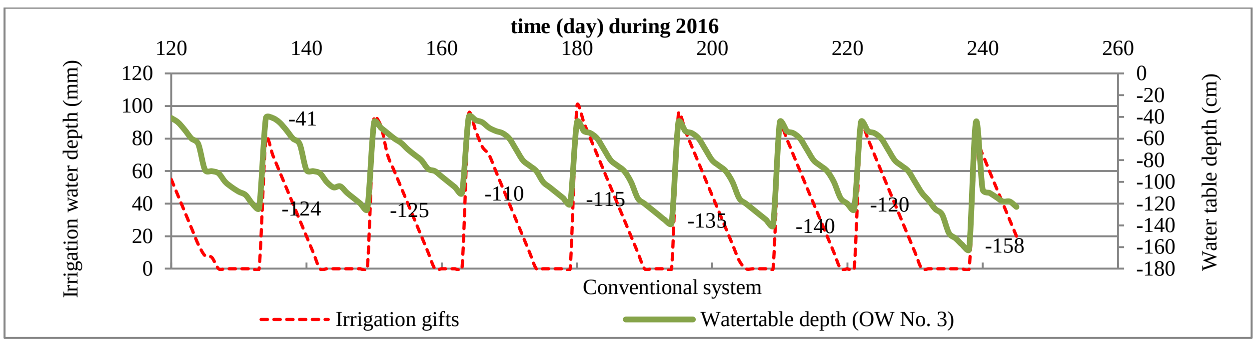

Figure (7) Water table depth in Conventional drainage system for Maize crop

3.3 Soil Salinity Measurements

Soil salinity is expressed in Electrical Conductivity (EC_e), and measured in units of (dS/m).
Soil salinity was measured at the locations of the observation wells during the following different stages: (1) Planting period, (2) mid-season and (3) prior to harvesting. Figures (8) shows the values of soil salinity through different stages, which are slightly increased in the planting and growing stages due to reserve water for longer time.
It was observed that keeping water table within the root zone for a longer time may be a reason for the redistribution of salts in soil profile which led to a slight increase in soil salinity during planting period, and mid-season stage.

It is remarkably noticed that not all the samples points show the same behavior regarding soil salinity. However, some general observations with certain exceptions could be concluded as follows:

1. Soil salinity measurements at 50 cm depth for all the locations at planting period ranged from 1 - 2 ds/m and mostly decreased around 1 ds/m for the final sampling taken prior to harvesting stage. This is because of the last irrigation practice that is considered as leaching process where all plugs are open according to the operating scenario.
2. At 100 cm depth, results were inconsistent. Some measurements of soil salinity were raised up while others presented the opposite trend; this may refer to changing in the salinity of irrigation water, where farmers may reuse drainage water for irrigation in case of shortage of irrigation water.
3. Samples of soil salinity at 150 cm depth show decreasing of salinity values which were taken as reference for the starting and ending of the growing season. Also, values of soil salinity for all locations were lower than those measured at 50 cm depth because the control level was lowered to 120 cm at the end of growing season. This resulting in more leaching and significant reduction in soil salinity.

Soil salinity was always lower at the end of the growing season than the beginning, although during the season there was some increase observed. Over the period of the growing season, soil salinity changed with depth. The results are indicating that higher increase were observed in the upper soil layers, especially in the 0-100 cm layer.

3.4 Crop Productivity

According to farmers' feedback in the study area, the average actual yield for rice crop is varying between the 3.5 and 4 ton per feddan. This corresponds with the national average potential rice yields (approximately 4 ton per feddan). The high rice yields are associated with high inputs of fertilizers.

For the determination of yields, sample areas of dimensions 1 X 1 m were randomly selected in Rice and Maize plots. It has been noticed that reducing drainage rates and nutrient losses resulted in significantly higher crop yields compared to the conventional drainage system. Also, it has been observed the increase in Maize productivity equals 10-13 %, and Rice productivity increased by 15-19 %.

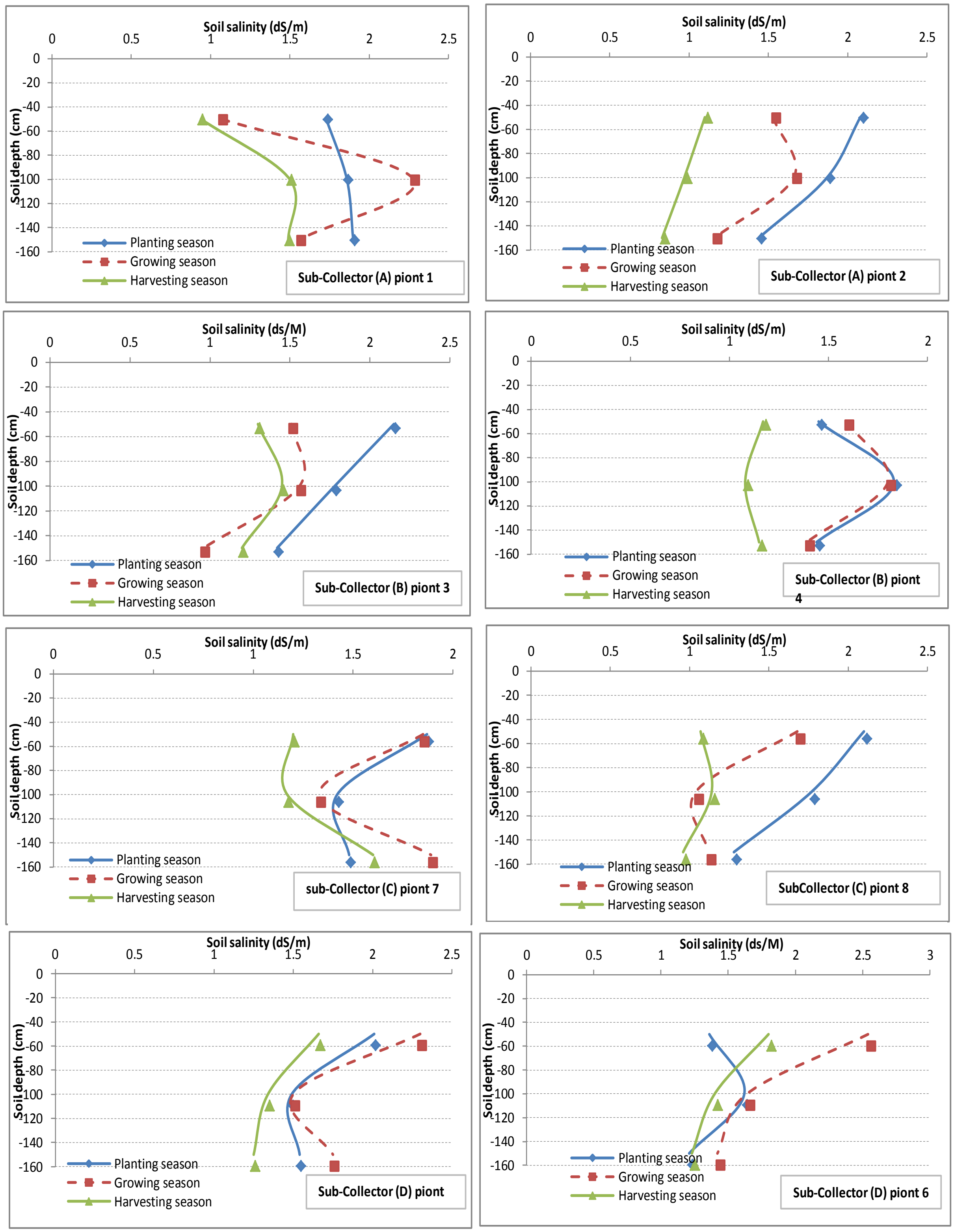

Figure (8) Soil salinity profile during the different cultivation stages

3.5 Costs and Benefits

The motivation of any change in agricultural practices requires direct incentives to farmers. In this case, they look for significant financial benefits to apply controlled drainage

Based on the questionnaire that was developed to compare the reduction in cost between controlled and conventional drainage system for fertilizers and water pumping costs the following information were used to calculate the benefits to farmers.

3.5.1 Cost of fuel:

Cost of 1 liter of diesel (fuel)	= L.E 5.5
Cost of 1 Kilogram oil	= L.E 35
Consumption of diesel	= 11 liter/4 hours for
Consumption of oil	= 4 kg/ 60 hours for
Capacity of pump	= 25 liter/s
Total pumping cost	= 17.45 L.E / hr = 0.90 USD/hr.

During rice cultivation season with controlled drainage system the irrigation period was reduced to 3 hr/feddan instead of 4hr/feddan with the conventional system.

For conventional drainage system, number of irrigation gifts per season= 16

Irrigation period per feddan= 4 hours

Consumption of fuel and oil = 16×4×17.45 = 1116.8 L.E

For controlled drainage system Number of irrigations per season: 16

Irrigation period per feddan= 3 hours

Consumption of fuel and oil = 16×3×17.45 = 837.6 L.E

Saving in Fuel Cost = 1116.8 – 837.6 = 279.2 L.E/season

Table 4 Benefits of controlled drainage

Indicator	Convention	Controlle	Convention	Controlle
	Maize		Rice	
Irrigation	4	3.75	4	3
Fertilizers	400	300	200	150
Water	**3240**	**2700**	**5760**	**4320**
% Saving of		**16.7%**		**25%**
Saving of		**139.6**		**279.2 EGP**
Saving of		**340 EGP**		**170 EGP**

*** 1 USD = 16 EGP**

*** 1 kg of fertilizers = 3.4 EGP**

4. Conclusions

Based on the results of the study, the following can be concluded:

- Controlling sub-collectors drain outlets managed to reduce the applied irrigation water quantities in the study area by 25% and 16.7% in rice and maize areas respectively.
- The reduction in irrigation water volume was observed due to reduction in irrigation cycles (increasing irrigation intervals) and by decreasing the applied irrigation water quantities (shorter irrigation pump operating time)
- The controlled drainage system leads to reduce the discharge of drainage water into the open drain and preserves drainage water from the pollutants resulting from agricultural practices.
- Water table is affected positively due to control of sub-collector outlets by keeping water close to the root zone for a longer period than in case of the free sub-collector outlets. It ranged between 0.40 to 1.00 m during the planting and mid-season stages while it decreased to below 1.20 m during the pre-harvesting stage.
- Soil salinity slightly increased in the planting and growing season as it ranged between 1-2 dS/m, while these values mostly decreased around 1-1.5 ds/m in the samples taken prior to harvesting stage. This is because the last irrigation practice is considered as leaching process where all plugs are open according to operating scenario.
- Under the same conditions, Rice production increased from 3150 kg/feddan in 2015 to 3622kg/feddan in 2016. Also, maize production increased from 3360 kg/feddan in 2015 to 3696 kg/feddan in 2016.
- Significant reduction in applied quantities of fertilizers was observed and the saving in cost equals 170 and 340 EGP for rice and maize respectively.
- The real motivation of controlled drainage to farmers includes savings in fuel due to reduction in irrigation period, and fertilizers cost.

5. Recommendations

It is recommended to consider the following

- Expansion in controlled drainage networks should be implemented especially for low saline soil areas.
- Applying controlled drainage is preferred for areas with soil salinity values less than 6 dS/m. For areas with high soil salinity values conventional sub surface drainage network is recommended because of its need for regular leaching.
- Reconsidering investment in controlled drainage can be rewarding in protecting quality of drainage water, enabling recycling of water, reducing pollution, and decreasing fertilizers use and fuel consumption.

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