



The role of Controlled and Mole Drainage in Relation to Water Saving, Salt Accumulation on Sugar Beet Yield and Quality in North Nile Delta, Egypt

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This work was carried out in collaboration among all authors. Author KMEG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AES and IAN managed the analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2021/v33i130407

Editor(s):

(1) Dr. Hon H. Ho, State University of New York, USA.

Reviewers:

(1) Umberto Antonio Sesso Filho, State University of Londrina, Brazil.

(2) Francisco Navarro, University of Granada, Spain.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/66432>

Original Research Article

Received 02 January 2021

Accepted 06 March 2021

Published 17 March 2021

ABSTRACT

Two field experiments were conducted at Sidi Salem region, Kafr El-Sheikh Governorate, Egypt, during two winter seasons 2018/2019 and 2019/2020 to study the impact of controlled drainage at 0.5, 0.75, 1.25 m and mole drain spacing 2 m on soil salinity, water-saving and sugar beet productivity. Results obtained that using controlled drainage saved irrigation water 24.56 and 11.35% in 1st season and 23.73 and 15.08% in 2nd season for 50, 75 cm depth of water table respectively, compared to 125 cm depth of water table. Application of mole drains seems to be more effective in decreasing soil salinity and sodicity especially, in the topsoil (0-60 cm) and narrow spacing between the plowed lines (2 m). Data showed that the water table level at 0.5 and 0.75 m treatments rose more rapidly and remained higher for longer time than the uncontrolled drainage treatment, the average water table depth was above specified depths between irrigation intervals from 3-7 days depending on the depth. There was a marked variation between the treatments that controlled drainage increased the yield at 0.50 m water table depth by 39 and 30% for both seasons, respectively. It can be concluded that the treatment of controlled drainage may give more

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profit than the uncontrolled one. At the same time, the contents of K^+ , Na^+ , alpha- amino N and alkalinity in root beet were insignificantly affected by controlled subsurface drainage in both seasons.

Keywords: Controlled drainage; mole drainage; water table; salinity; sodicity.

1. INTRODUCTION

Soil salinity and sodicity are one of the main agricultural problems limiting plant, growth and development in the world especially in arid and semiarid regions [1]. In Egypt, the Northern part of the Nile Delta represents a large area of heavy clay soils with shallow drainage which are low permeability that might have low productivity. Drainage plays a vital role in low permeable clay soils in order to prevent soil degradation. A secondary drainage treatment of moling seeks to be an inexpensive "drain" at close spacing, intercepted by permanent laterals at wider spacing. Moling is the best suited to clay soils with a minimum clay content of about 30%. Mole drainage, on the suitable soil type and done properly can reduce waterlogging problems. Mole drainage is widely used on heavy soils to improve the productivity of pastures and crops [2]. Improved salt-affected soils and crop growth following subsurface drainage and mole drains are generally considered to be the result of the physical shattering of the hardpan, which allows increasing water penetration into the subsoil. The ultimate objective of water-table management is to maintain it at the desired depth to ensure adequate root-zone aeration [3,4]. In controlled drainage, drains are shallower than in FD, thus the water-table is raised to a shallower depth. A shallower placement of drain might minimize deep percolation and increases the upward flow by capillarity, substituting the decreased soil water content of the surface layer due to evapotranspiration [5,6]. Hence, the shallower drain might increase water availability for crops during dry periods, thereby reducing drought or water deficit stresses [7]. In a review article conducted by Skaggs et al. [8] a reduction of 16 to 85% in drain outflows was reported. The reductions in the drained water volumes corresponded to an increase in evapotranspiration and plant water uptake [9,6] depending on drainage system design, climate, soil, and site conditions. Owing of the conservation in water and nutrients which become readily available for crops, an increase in crop yields ranging from 10 to 64% was observed [10,7,9,11]. However, the effect of drain depth on crop yield showed conflicting

results [8]. In the Nile delta clay soil, northern Egypt, most of the cultivated lands have a shallow water-table, creating waterlogging and salinization problems that lead to yield losses and land degradation. Therefore, extensive subsurface drainage schemes have been implemented and presently most of the area is served by subsurface drainage at 120 cm. The success in preventing waterlogging and salinization was clearly evident by the high productivity and maintained soil quality [12]. However, surface irrigation is the main irrigation system in the Nile Delta, due to land defragmentation.

The aim of this work was to study the effect of controlled drainage on sugar beet productivity for computing controlled drainage and using mole drain to reduce salinity under controlled drainage, as well as find out the proper depth of water table to decrease drain outflow and the most suitable depth of water table.

2. MATERIALS AND METHODS

A Field experiment was conducted in the two successive winter seasons 2018/2019 and 2019/2020, at Sidi Salem region, Kafr El-Sheikh Governorate, Egypt ($31^{\circ}07' N$ and $30^{\circ}57' E$ at an elevation of about 3 m above mean sea level). The study area is characterized by semi-arid Mediterranean climatic conditions. Some physical and chemical characteristics of the experimental site are given in Table 1. The area served by a tile drainage system, which was adapted to carry out the current study Fig. 1. It is divided into three treatments each one drained by three laterals connected to the riser through a manhole and the drain spacing is 20 m. three drainage treatments were adopted in this study i.e.:

- Controlled drainage: (1) water table depth is 50cm below the soil surface.
- Controlled drainage: (2) water table depth is 75 cm below the soil surface.
- Conventional drainage: (3) drain depth is 125 cm below the soil surface.

Construction of controlled drainage system:
Controlled drainage' a device to fix the level of

groundwater to delimit depths in the different treatments.

2.1 Installation of Observation Wells

Wells were installed to observe the fluctuation of water table and collecting groundwater samples for chemical analysis. The observation wells were installed using polyethylene tubes with a 5 cm diameter and 2 m length. Tubes were perforated at the lower end and covered with permeable materials and a screen to allow easy movement of groundwater to the tubes and to avoid clogging by clay and fine particles. The tubes were put in the prepared auger holes to a depth of 170 cm and the residual 30 cm in length of the tube was left above soil surface. The fluctuation of water table in observation wells was regularly registered using a sounder device [13].

2.2 Measurements of Irrigation and Drainage Water Discharge

Drain discharge rates were measured by using a bucket and stopwatch and were observed two times every day when drain flow occurred, by measuring the amount of water running from the tile line during a short interval and converting water flow to m³ha⁻¹. The average daily discharge rates were used in this study.

Applied water. Amount of irrigation water was measured by using a rectangular sharp crested weir. The discharge was calculated using the following equation as described by, as follows

$$Q = CL(H)^{1.5}$$

Where: Q = Discharge (m³s⁻¹), L = Length of the crest (m), H = Head above the weir (m), C = Empirical coefficient determined from discharge measurement [14].

2.3 Agricultural Practices for Sugar Beet Crop

The sugar beet variety Karm was sown on the 5th of November and the harvesting date was on 15 May 1st and 25 May in 2nd seasons. Nitrogen, phosphorus, and potassium fertilizers were added according to the recommended doses of North Delta area.

2.4 Soil Samples

Soil samples were collected from soil surface down to the water table depth each 30 cm

intervals and were analyzed according to recommended methods as shown in Table 1.

2.5.1 Yield and its components

Root length (cm), Root diameter (cm), Root and top fresh weights (kg/plant). Root and top yields ton/fed.

2.5.2 Quality parameters

Quality parameters were determined in Delta sugar company limited laboratories at El-Hamaul, Kafr El-shaiekh Governorate according to the methods of Mc Ginnus [15].

*Gross sugar %: Juice sugar content of each treatment was determined by means of an automatic sugar polarimetric according to Mc Ginnus [15].

*Extractable white sugar%: Corrected sugar content (white sugar) of beets was calculated by linking the beet non-sugar, K, Na and α amino N (expressed as mill equivalent /100g of beet) according to Harvey and Dutton [16] as follow:

$$ZB = pol - [0.343 (K + Na) + 0.094 \alpha\text{-amino N} + 0.29]$$

Where:

ZB = corrected sugar content (%per beet) or extractable white sugar

Pol= gross sugar %

Am N = α amino Nitrogen determined by the "blue number method"

Purity percentage (QZ %): QZ= (ZB/Pol) x100

*Soluble non sugar content (Impurities): The soluble non sugar (potassium, sodium and α amino Nitrogen (meq/100g of beet) in roots were determined by means of an automatic sugar polarimetric.

*Gross sugar yield (t/fed) = root yield (t/fed)

X gross sugar %

*White sugar yield (t/fed) = root yield (t/fed) X white sugar %

*Losses sugar yield (t/fed) = root yield (t/fed) X loss sugar %

*Losses sugar percentage (%) = gross sugar % - white sugar %

2.6 Statistical Analysis

All obtained data were statistically analyzed

according to the technique of analysis of variance (ANOVA) for complete block design in three replicates in the two growing seasons as published by Gomez and Gomez (1984) using (MSTAT-c) computer software package. The least significant difference (LSD) was used to test the differences between treatment means at 5% level of probability as described by Snedecor and Cochran [17].

3. RESULTS AND DISCUSSION

Results showed that the lowest amount of water applied values 2662.8 and 2591.4 m³fed⁻¹ were recorded in both seasons respectively, at 50 cm depth of water table. Whereas the highest one was 3529.5 m³fed⁻¹ in 1st season and 3397.8 m³ fed⁻¹ in 2nd season, which was observed at uncontrolled drainage treatment. Data showed that using controlled drainage saved 24.56 and 11.35% in 1st season and 23.73 and 15.08% in 2nd season for 50, 75 cm depth of water table, respectively compared to 125 cm depth of water table. This is mainly related to soil water conditions under controlled drainage, where the irrigation water was replenished to maintain the water through soil, where uncontrolled drainage caused more drain outflow [18]. These results are similar to that found by [19] who stated that the amounts of irrigation water increased with lowering the water table depth. The managing of water table position will provide the opportunity to increase in situ crop water use, which should result in improved irrigation efficiency and reduced drainage outflow [20]. The rainfall shared in water applied with 7.5 cm in 2018 and 8.45 cm in the first season.

3.1 Fluctuation of Water Table Depth During the Growing Seasons of Sugar Beet as Affected by Controlled Drainage

The depth of water table reached the lowest value immediately before irrigation, while the highest water table reached at 2 days after irrigation, seasonal averages of water table depth were 42 and 127 cm for the highest and the lowest water table depths at controlled drainage treatments, respectively in the 1st season. While the corresponding values in the 2nd season were 45.5 and 130 cm). It can be obtained that, the absolute values of both shallow and deep depth of water table increased directly with an increasing percentage of soil moisture and as much as raising the outlet or closing the valves at predetermined depths. This

result was in the same trend as those reported by. [3] It's worth mentioning that, the water table level at 50 and 75 cm treatments rose more rapidly and remained higher for a longer time than the uncontrolled drainage treatment. The time that the average water table depth was above specified depths between irrigation intervals from 3-7 days depending on the depth. The controlled drainage at 50 and 75 cm treatments had a higher proportion of time that the water table depth was above 80 cm allowing potential beneficial use of the controlled drainage. The control valves installed on the drainage lateral were effective in maintaining a higher water table in the controlled drainage treatments, which had a significant effect on the drainage volumes and salt loads. In general, the fluctuation of the water table regime for sugar beet could be summarized under this work as follows: Irrigation regime and controlled drainage was a main effect on the regime of the water table. The uncontrolled drainage at 125 cm depth was the deepest water table and vice versa.

3.2 Soil Salinity and Sodicity

Data of soil salinity as affected by controlled subsurface drainage under sugar beet crop during the two growing seasons are shown in Fig. 2. The mean value of soil salinity before conducting the experiment was 5.3 dS/m. It is obvious from the data that the shallow water table depth leads to salt accumulation. While the deepest ones resulted in leaching salts from the surface layers of a soil profile. The same trend was shown in the 2020 season. While the increases of salinity in soil did not reduce the measured sugar beet yield, it's apparent that sustainability issues will need to be carefully considered when implementing controlled drainage. Similar results were obtained by Hornbukle [21]. These data are in agreement with that by Kandil et al. [22] they stated that the shallower of ground water, the easier upward movement by capillarity rise where it can be evaporated under the prevailing hot and dry conditions, leaving its load of soluble salts at the surface. The accumulating salts can be redistributed by irrigation water and water table management through the whole profile. The application of mole drains seems to be more effective in decreasing soil salinity and sodicity. The salinity and sodicity of the soil increased markedly with the increase of water table. The decreases of soil salinity and sodicity in the topsoil up to 60 cm, after the second season of treatment installation, are more pronounced

compared to that after one season. These results might be explained by the effect of mole drains on water table recession, which occurred only through mole depth and thus contributed to an active salt transfer during the falling of the water table. It could be concluded that in heavy textured soils, the ponding conditions under open drains, realizes desalinization of the surface soil layers and parts of the subsurface layers. Whereas, mole drains are effective in removing salts from the upper layers only. Salt leaching from deeper layers depends on the efficiency of a drainage system. Similar results were obtained by Moukhtar et al. [23].

The reduction of soil salinity in the topsoil up to 60 cm, were 4.5, 4.3 at 75 cm of water table and 4.1 and 3.85 at 125 cm for 1st and 2nd seasons respectively. These results could be attributed mainly to that subsoil forms many lines with big crack extent from the soil surface to subsoil depth (60 cm deep) and numerous effective capillary cracks are formed. All these cracks together break the soil matrix and encourage downward of water as well as solute movement. The soil crack's life may be several months or years Moukhtar et al. [24] who reported that, moling or subsoiling enhances the downward movement of irrigation water carrying off excess salts from surface layers. After wards, regular subsequent irrigations will gradually reduce the salt content in groundwater at least when it is close to the soil surface.

3.3 Drain Discharge During the Growing Season of Sugar Beet as Affected by Controlled Drainage

Water table management systems may be designed to control drainage volumes, peak flow rates or chemical losses from agricultural fields, or catchments. Hydrologic impacts will depend

on the degree and method of drainage improvement. Design of the drainage system, particularly with regard to drain spacing and intensity of surface drainage, can have a large influence upon the proportion of outflow that occurs via surface runoff which is fast and that which moves more slowly via subsurface flow, Evans et al. [25].

Data in Table 2 indicated that the mean values of drains discharge as affected by controlled drainage treatments under sugar beet in both seasons. The highest rates of drain discharge were found for planting irrigation as compared to other irrigations.

Concerning the treatments of 50 and 75 cm, the drain discharge was started during irrigation and increase until it reaches a high value after few hours of irrigation then decreased with time for all irrigation cycles. Ibrahim [26], Antar [27], Ramadan et al. [28] found that in clay soil most of the discharge water is from preferential flow or from water movement through soil cracks and macropores.

It was found that the controlled drainage achieved substantially less drainage than free drainage. The controlled drains only flowed between 24-48 hours for the first treatment 50 cm depth of water table, while the discharge from the free drainage treatment occurred for over 192 hours. The different flow volumes had a large effect on the salt loads, the free drainage removed more substantially salts than the controlled drainage treatments. After each season the control valves removed from the controlled drainage laterals to allow the drains to flow freely and some salts were leached. This provided the opportunity to compare the performance of those laterals with and without pipe.

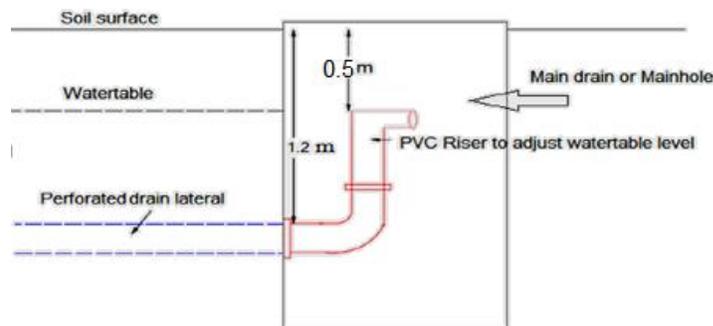


Fig. 1. Illustrate of the control valve

Table 1. Some physical and chemical properties of the experimental site

Parameter	Value
1-Physical properties	
Particle size distribution	
Clay	50.03
Silt	33.27
Sand	16.70
Texture class	Clayey
Bulk density gm/cm ³	1.20
2- Chemical properties	
EC dSm ⁻¹	5.27
pH	8.01
Soluble cations meq/l	
Na ⁺	27.30
K ⁺	0.85
Ca ⁺⁺	18.20
Mg ⁺⁺	15.13
Soluble anions meq/l	
CO ₃ ⁻	0.00
HCO ₃ ⁻	6.35
SO ₄ ⁻	29.78
Cl ⁻	25.35

Table 2. Seasonal values of applied water and water saving during two seasons

Treatments	IW	R	Wa	Wa m ³ /fed	water saving	%
First season						
50	55.9	7.5	63.4	2662.8	866.7	24.56
75	67.0	7.5	74.5	3129	400.5	11.35
125	76.5	7.5	84.0	3529.5	-	-
Second season						
50	53.25	8.45	61.7	2591.4	806.4	23.73
75	60.25	8.45	68.7	2885.4	512.4	15.08
125	72.45	8.45	80.9	3397.8	-	-

IW=Irrigation Water, R= Rainfall, Wa= Applied Water

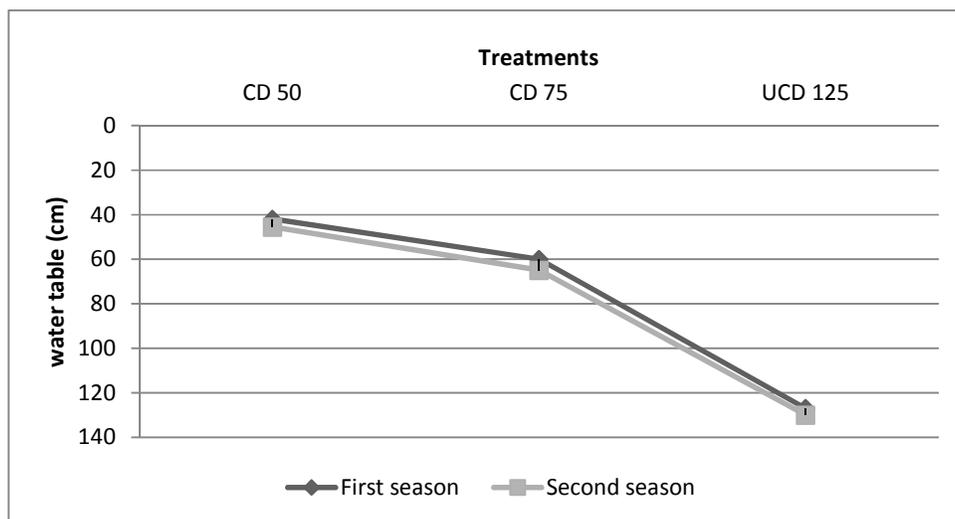


Fig. 2. Seasonal average of watertable under different treatments

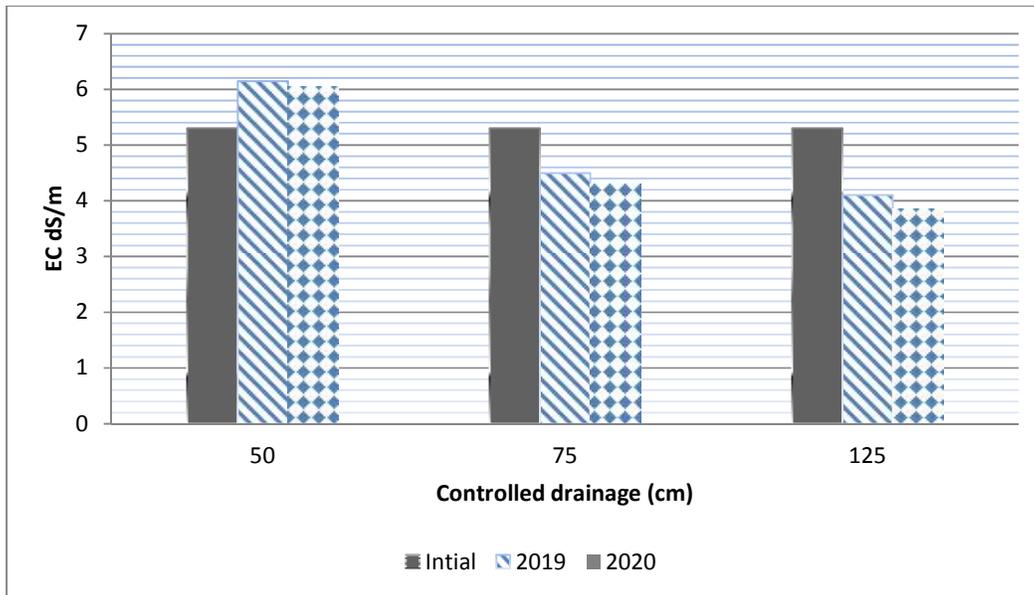


Fig. 3. The mean values of the soil salinity

- Effect of controlled drainage on yield, yield components and
- quality of sugar beet crop during the two successive seasons.

3.4 Root Length and Diameter (cm)

Data in Table 4 indicated that the controlled subsurface drainage had a significantly reduced effect on root length and an increase in root diameter in both seasons. The highest value of root length 26.43 and 24.45 cm were obtained in the 1st and 2nd seasons respectively, while at 125 cm the depth of water table and had the lowest values of root length 21.92 and 18.84 cm in the first and second one at 0.5 cm depth of water table treatment.

Regarding top yield, data showed that the maximum top yield (8.837 and 9.381 ton/fed) was observed at 50 cm water table depth in both seasons, respectively. Whereas, the minimum top yield (6.224 and 5.923 ton/fed) were recorded at uncontrolled drainage (125 cm water table depth) in the 2019 and 2020 seasons, respectively. The obtained results that lowering the groundwater table depth had a pronounced effect in decreasing both root and top yields in both growing seasons. Similar results were reported by Antar et al. [29]. This reduction, however, was more pronounced at 1.25 m depth probably due to less availability of water for crop use. There was a marked variation

between the treatments; that controlled drainage increased the yield at 0.4 m water table depth by 24.4 and 30% for the 2019 and 2020 seasons, respectively. From the abovementioned discussion, it can be concluded that the treatment of controlled drainage may give more profit than the uncontrolled one. There was a marked difference between the treatments, the highest values of root diameter were recorded at 50 cm depth of water table, while the lowest values when the uncontrolled drainage at 125 cm depth of water table treatment in both seasons. Results may refer to that the deepest water table enhanced deep rooting and the shallowest water table increased diameter roots. Such results are in harmony by El-Zayat [30].

3.5 Effect of Controlled Subsurface Drainage on Quality Parameters of Sugar Beet: Sugar Content

Results obtained in Table 5 indicated the sucrose % and sugar yield/ fed as affected by controlled drainage in both seasons. The highest values of sucrose % were recorded at uncontrolled drainage compared to the lowest values at 50 cm depth of water table. This result may point to that mole drains application caused a significant increase in root, top and sugar yields/fed compared to check treatment where, these yields were increased when the EC decreases as affected by mole drains. this result

may be due to that heavy clay salt affected soils could have good productivity. whilst, there were no obvious differences between top yield in the first seasons only. at same time, a significant difference was found between values of sucrose % and root yield/fed in both seasons.

As for, sugar yield /fed, it was found that the maximum yield were 2888 and 2631 kg/fed were achieved at 50 cm water table depth in the 1st

and 2nd seasons, respectively, while the minimum sugar yield were 2170 and 2238 kg/fed at uncontrolled drainage in both seasons, respectively. This result in agreement with Dunham [31].

It was noticed in the same Table that controlled drainage at a depth of 50 cm depth caused a significant increase in sugar yield in 1st season in spite of its lowest sucrose %.

Table 3. The mean values of drain discharge during the growing season of sugar beet

Year	Time after IRR Hour	Drain discharge mm hour ⁻¹ in 2013 and 2014		
		Controlled drainage treatments		
		T 50	T 75	T 125
2019	24 H	1.3	3.2	4.25
	48 H	2.4	2.55	3.20
	72 H		1.5	2.75
	96 H		0.55	1.75
	120 H			1.25
	144 H			0.85
	168 H			0.80
	192 H			0.50
	24 H	3.15	3.9	5.45
	48 H	1.25	2.5	3.75
2020	72 H		2	3
	96 H			2.5
	120 H			2.1
	144 H			1.25
	168 H			1.0
	192 H			0.95

Table 4. The mean values of root yields and its components as affected by controlled drainage during the two successive seasons

Treatments	Root yield /fed (ton)	Top yield /fed (ton)	Root length (cm)	Root diameter (cm)
2018/2019 season				
50	23.364 a	8.837 a	21.92 e	12.51 a
75	17.31 c	7.775 c	24.17 c	10.82 c
125	14.23 e	6.224 e	26.43 a	9.62 e
LSD 0.05%	0.503	0.354	0.293	0.253
2019/2020 season				
50	20.821 a	9.381 a	18.84 e	12.25 a
75	18.230 c	7.477 c	21.40 c	10.63 c
125	14.639 e	5.923 e	24.45 a	8.76 e
LSD 0.05%	0.451	0.344	0.289	0.223

Table 5. Sugar qualities of sugar beet crop as affected by controlled drainage in both seasons

Treatments	Sucrose %	Sugar yield kg/fed	Nameq / 100g beet	Kmeq/100g Beet	α-Amino Nmeq / 100g beet	Alkalinity %	White sugar %
2018/2019 season							
50	16.34 e	2888 a*	5.29 a	7.78 a	5.89 a	2.24 a	2.57
75	17.74 c	2485 c	4.84 b	7.25 b	5.33 b	2.08 a	2.19
125	18.79 a	2170 e	4.13 c	6.55 c	4.76 c	2.26 a	2.05
F test	*	*	NS	NS	NS	NS	NS
2019/2020 season							
50	17.42 e	2631.5 a	5.95 a	8.15 a	5.80 a	2.32 a	2.45
75	18.15 c	2359.5 c	4.75 b	7.85 b	5.71 b	2.19 b	2.37
125	19.80 a	2238 e	4.29 c	7.45 c	5.24 c	2.22 c	2.19
F test	*	*	NS	NS	NS	NS	NS

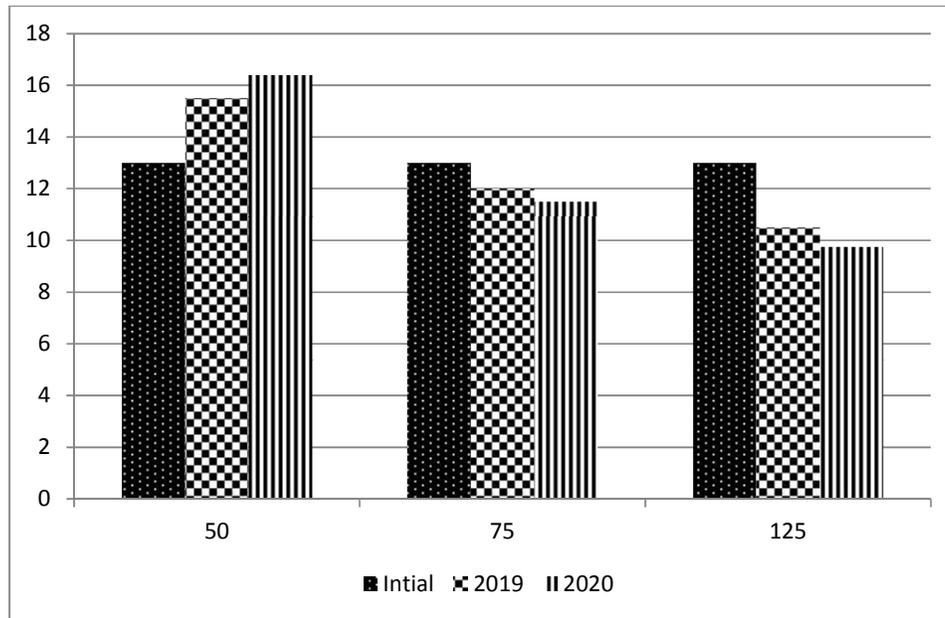


Fig. 4. The values of soil sodicity SAR

3.6 Potassium, Sodium, Alpha-Amino N Contents and Alkalinity

Data in Table 5 manifested that K^+ , Na^+ , α -amino N contents and alkalinity were insignificantly affected by controlled subsurface drainage in both seasons. Meanwhile, the shallowest water table increased impurities contents (K, Na, α -amino N) and Alkalinity in both seasons. the lowest values of potassium (6.55 and 7.45 meq/100g) were recorded at uncontrolled drainage in 1st and 2nd seasons, respectively. The same trend was detected for Na, α -amino N contents and Alkalinity in both seasons. These results may be due to high soil moisture content at 50 cm than uncontrolled drainage. Such results were in harmony with those of Gharib and EL-Henawy [32].

4. CONCLUSIONS

Mole good way in clay soils to reserve the root zone from salinity under controlled drainage which will need to be carefully monitored and managed. As well, using controlled and mole drains can improve water relations and increase sugar beet yield and quality. Conjunctive use of irrigation and shallow groundwater could be, with proper management, a viable option to increase framers income and resilience to irrigation water supply shortages. Controlled drainage in this study saved on average 24.56 % and 23.73 %

for the sugar beet water requirements in both seasons. Controlled and mole drains increased yield by 39 and 30 % at shallow groundwater table depth compared to the free drainage in 2018 and 2019 seasons and can provide more profit to the farmer

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