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Impact of Using Desalinated Brackish Water on Chemical and Physical Characteristics of Heavy Saline Soil

تأثير إستخدام المياه المالحة المحلاة على الخصائص الفيزيائية والكيميائية للتربة المالحة الثقيلة

MSc. Program in Water and Environmental Science

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The findings, interpretations, and conclusions expressed in this study, don not necessary express the views of Birzeit University, the views of individual members of M.Sc. Committee or views of their respective employers

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List of Abbreviations

Acronym	Definition
SAR	Sodium Adsorption Ration
ESP	Exchangeable Sodium Percentage
DW	Desalinated water
$dS. m^{-1}$	Decisiemens per meter
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
MoA	Ministry of Agriculture
RO	Reverse Osmoses
ppm	Parts per Million
PWA	Palestinian Water Authority
TDS	Total Dissolved Salts
JV	Jordan Valley
WB	West Bank
EBA	Eastern Basin Aquifer
ECW	Water Electrical Conductivity
LRC	Land Research Centre
pH	Potential Hydrogen

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Abstract

The study area is located in Marj Na'aja in the northern part of Jordan valley where the area is facing deterioration of soil and water quality. The soil became salinized with bad physical and chemical properties as result of using low irrigation water quality for long time. Therefore, the Ministry of Agriculture (MoA) tried to find alternative irrigation resource by installing desalinated water plant to desalinize the brackish water to use for irrigation.

The objective of this research is to study the impact of using desalinated water (DW) on saline soil properties especially Sodium Adsorption Ratio (SAR), soil structure, moisture content and to define the suitable blending ratio for irrigation to avoid expected negative impact on the heavy soil.

To achieve the research objective, four types of water, based on TDS content were considered. Raw brackish water with TDS 4500 ppm (T4), desalinized water with 200 ppm (T1), blinding ratio between desalinated water and brackish water with 750 ppm (T2) and blending ratio with 1600 ppm (T3). The planted crop was tomato Izabella variety.

Soil sampling were conducted two times for four depths 0-15, 15-30, 30-45, and 45-60 cm, before crop season and after crop season to study Sodium Adsorption Ration (SAR).

Soil moisture content and EC were measured four times (after third irrigation, after one month of the planting date, after 2 months of planting date and after crop completion) for treatment 1 and treatment 4 at the four mentioned depths with 12 samples at each depth with 10 cm distance between sequent in the X-Y direction.

Soil structure was measured on site for all treatments before planting and after completion the growing season.

The results of the research showed increase of SAR values in T1 at all depths especially in depth one whereas SAR decreased in T2, T3, and T4. The lowest SAR was registered at T3. The study also showed that, the soil moisture content increased horizontally in T1 comparing with T4 while the soil moisture content increased vertically in T4 comparing with T1. The difference of water content between T1 and T4 refer to increase SAR and decease the salinity in T1 while in T4 SAR was decreased and salinity was increased.

Soil structure results showed visible changes in structure type and structure grade in T1 whereas in T2, T3, and T4 there were no visible changes appears in the soil structure.

ملخص الدراسة

تقع منطقة الدراسة في منطقة مرج نعجة شمالي غور الاردن وهي منطقة تعاني من تدهور مصادرها الطبيعية سواء كانت تربة او مصادر مياه حيث تعاني تربتها من تدهور في الخواص الكيميائية والفيزيائية وارتفاع نسبة الملوحة والصوديوم ناتج عن شح ونقص في مياه الري واستخدام مياه ذات نوعية سيئة وارتفاع في نسبة ملوحتها وزيادة تركيز الصوديوم فيها وذلك لفترات طويلة، مما ادى للبحث عن مصادر مياه بديلة لاستخدامها في الري. حيث قامت وزارة الزراعة بانشاء محطة لتحلية المياه واستخدامها في الزراعة.

يهدف هذا البحث الى دراسة تاثير استخدام المياه المحلاة على الخصائص المالحة الفيزيائية والكميائية للترب المالحة خاصة نسبة ادمصاص الصوديوم وبناء التربة والمحتوى الرطوبي للتربة بالاضافة لتحديد نسبة خلط المياه الافضل التي تضمن استمرارية التربة واستدامتها.

ولتحقيق هدف الدراسة تم استخدام اربع معاملات للمياه بحيث تحتوي كل معاملة على تراكيز مختلفة من الاملاح الذائبة ، 200 ، 750، 1600 و 4500 ملغ/ ليتر، للمعاملة الاولى T1 و T2 وT3 و T4 على التوالي.

اخذت عينات التربة قبل الزراعة وبعد الزراعة لدراسة تاثير نسبة ادمصاص الصوديوم SAR وذلك على اربعة اعماق 0-15 ، 15-30 ، 30 -45 و45-60 سم، ومن اجل دراسة المحتوى الرطوبي والملوحة للتربة ,اخذت عينات تربة لنفس الاعماق المذكورة و على مراحل مختلفة من الزراعة كانت العينة الاولي بعد الرية الثالثة والعينة الثانية كانت بعد شهر من تاريخ الزراعة والعينة الثالثة كانت بعد شهرين من تاريخ الزراعة اما العينة الرابعة فكانت عند انتهاء المحصول وبعد الرية الاخيرة علما بان دراسة المحتوى الرطوبي تم دراسته على المعالة الاولى T1 والمعاملة الرابعة T4.

اما دراسة بنية التربة فقد تم دراستها في موقع تنفيذ البحث على مرحلتين ، الاولى قبل الزراعة وتحضير الارض اما المرحلة الثانية كانت بعد الانتهاء من التجربة.

بينت نتيجة الدراسة ان استخدام المياه المحلاة لري الترب المالحة الثقيلة ادت الى ارتفاع نسبة ادمصاص الصوديوم SAR في جميع اعماق التربة المدروسة للمعاملة الاولى T1 بينما هناك انخفاض واضح في قيمة SAR في المعاملات الاخرى خاصة المعاملة الثالثة T3 حيث سجلت اقل نسبة SAR في جميع الاعماق, وبينت الدراسة ايضا ان المحتوى الرطوبي للتربة ازداد افقيا في المعاملة الاولى T1 مقارنة مع المعاملة الرابعة T4 وتبين ايضا ازدياد نسبة الرطوبة عاموديا في المعاملة الرابعة مقارنة مع المعاملة الاولى.ويعود السبب في ذلك الى ارتفاع نسبة SAR في المعاملة الاولى وانخفاضها في المعاملة الرابعة بالاضافة الى ارتفاع نسبة الملوحة في هذه المعاملة وانخفضها في المعاملة الاولى T1.

اما بنية التربة فقد بينت النتائج حدوث تغيير في نوعية بناء التربة في المعاملة الاولى تدهور الخواص الفيزيائية للتربة, بينما لم يحدث اي تغير ملموس على بنية التربة في المعاملات الاخرى بسبب ارتفاع تركيز الكالسيوم والمغنيسيوم في مياه الري.

Chapter one

Introduction

1.1 Background

The rapid global growth in population together with the change in behaviour and life standard, has resulted in growing stress on the natural resource. From one side the population growth is requiring an equivalent increase in food production to meet the human needs. On the other hand, the rapid development of the global economy, expansion of urban scale, and the increase of annual industrial and municipal water consumption, the imbalance between supply and demand of water resources is becoming a more and more serious problem around the world (Döll and Siebert, 2002).

Globally, agriculture is the main water consumer. Thus agriculture is the most affected sector by the water shortage. In many cases part of the agricultural water is reallocated for other sectors (Qadir *et al.,* 2007). This leads to increase the water supply to meet the growing demand. Unfortunately, the limited fresh water resources is not able to satisfy this demand growth. But at the same time the existence of marginal resources, and the development in technologies produced many solutions for the water quality, among these is the use of desalinated water in irrigation.

In Palestine, the problem of water shortage is coming mainly from the Israeli occupation, climate change and over pumping. However, the shortage of water supply is one of the most important problems facing the agricultural sector, and restricting the irrigated agriculture. In Palestine, the irrigated area produce almost 50% of the food production, even though it is very limited, where it is estimated to be around 11% of the agricultural area (MoA, 2014).

The Jericho district suffers from the phenomenon of saline upcoming. The Eastern Aquifer Basin (EAB), which is the main source of water supply for irrigation in the Jericho district, comprises a layer of salt water covered with lenses of fresh water.

Soil salinity and alkalinity are most widespread in the arid and semi-arid regions. In addition to water shortage in Palestine salinity and soil saline is dominated in the Jordan Valley and in some other scattered areas in the West Bank.

To overcome water shortage, Ministry of Agriculture installed recently a desalination unit on low water quality agriculture well in Marj Na'aja in order to cope with the shortage in irrigation water quantity and quality in terms of increasing salinity level and increasing the concentration of the sodium.

The impact of using desalinated water on soil properties still under investigation in the world despite of desalination water process is used since 50 years ago, the majority of the researches were conducted to study the economic visibility of using desalinated water as alternative of water resources over the world in different locations and conditions. In addition few researches focusing on impact of using desalinated water on soil fertility status on the sandy soils which is consider light soils to study the deficiency of nutrients on plants irrigated with desalinated water. The impact of using desalinated water for irrigation is not investigated before under the local conditions in Jordan rift valley with saline clay loam soils. Thus there is a highly need for assessing the required management practices for using it in irrigation. Moreover it is under investigating around the world. Studies showed that irrigating sodic soil or saline soil with high content of sodium, with fresh water, for example desalinized water, will lead to increase exchangeable sodium percentage (ESP) in the soil profile. Several authors reported that the impact is coming from both salinity of brackish water and very low Ec water like desalinated water (Carrow *et al.,* 2008). Consequently the primary physical processes associated with high sodium together are disrupted when too many large sodium ions come between them (Hopkins *et al*., 2007).

Dispersed soil causes clay particles to plug soil pores, resulting in reduced soil permeability. Accordingly, when soil is repeatedly irrigated and dried, it will solidify into almost cement-like soil with little or no structure, which will reduce infiltration rate, hydraulic conductivity, and creating surface crusting (Raine *et al*., 2003).

1.2 Study objective

1.2.1 Overall Objective

The overall objective of this research is to assess the impact of irrigating heavy saline soils with desalinated water and blended desalinated water with brackish water of different ratios on the soil physical and chemical properties that influence water spatial content.

1.2.2 Specific Objectives

The specific objectives of this research are to investigate the effect of irrigating heavy saline soil with desalinated water and blended water on:

- ✓Soil Sodium Adsorption Ratio (SAR) at different depths.
- ✓Soil structure.
- ✓Water movement in the saline soil profile.
- ✓ Determining the best mixing ratio to avoid deterioration of the soil properties.

1.3 Hypothesis

Irrigating heavy saline soil with desalinated water might hamper soil quality that could be accommodated by blending with brackish water of different ratios to increase the main cations especially calcium and magnesium in the irrigation water.

Chapter two

Literature Review

2.1 Introduction

Since it is estimated that irrigation is responsible for 87% of global water consumption (Döll and Siebert, 2002), the agricultural sector becomes the most affected by the water shortage. However in many cases part of the agricultural water is reallocated for other sectors (Qadir *et al.*, 7007). Brackish and saline water provide an effective way for mitigating water resource shortage problems in some areas (Rhoades, 1992; Liu and Fu, 2004). Moreover, Shunjun *et al*. (2012) reported that saline water plays a vital role in agricultural water use, mainly in many freshwater resource-poor countries and regions. In many areas, lack of fresh water resources has been a bottleneck problem and continues to restrict agricultural sustainable development. Ghermandi and Messalem (2009) reported that "improving the management of water demand by preventing waste and introducing efficient irrigation techniques is generally a cost-effective and sustainable way to cope with scarcity, but the implementation of such improvements is slow and may not be suitable to the sustainable development of areas suffering from chronic water scarcity. Therefore, water supplies are increasingly being augmented through the exploitation of non-conventional water sources such as water recycling, marginal-quality groundwater aquifers, desalination, and rainwater harvesting".

2.2 Water resources in Palestine

2.2.1 Water quantity

In Palestine the water resources are limited and all sectors are suffering from water shortage and a severe water scarcity for both natural and politically induced reasons (PWA, 2010). This water scarcity is affecting the agricultural sector which is considered as the main water consumer (more than 45% of the total consumption) among the different sectors (MoA, 2010). In the same time the discharge from ground water exceeds the expected recharge (negative water balance), mainly in the eastern aquifer. Not only but the arid climate (low rainfall with high intensity) make the situation worst. Hence it is a very important step to shift the irrigation methods toward using marginal and unconventional water resources, which include the use of brackish and desalinated water in irrigation to meet the growing demand and to expand horizontally the irrigated areas (MoA, 2014).

2.2.2 Water quality

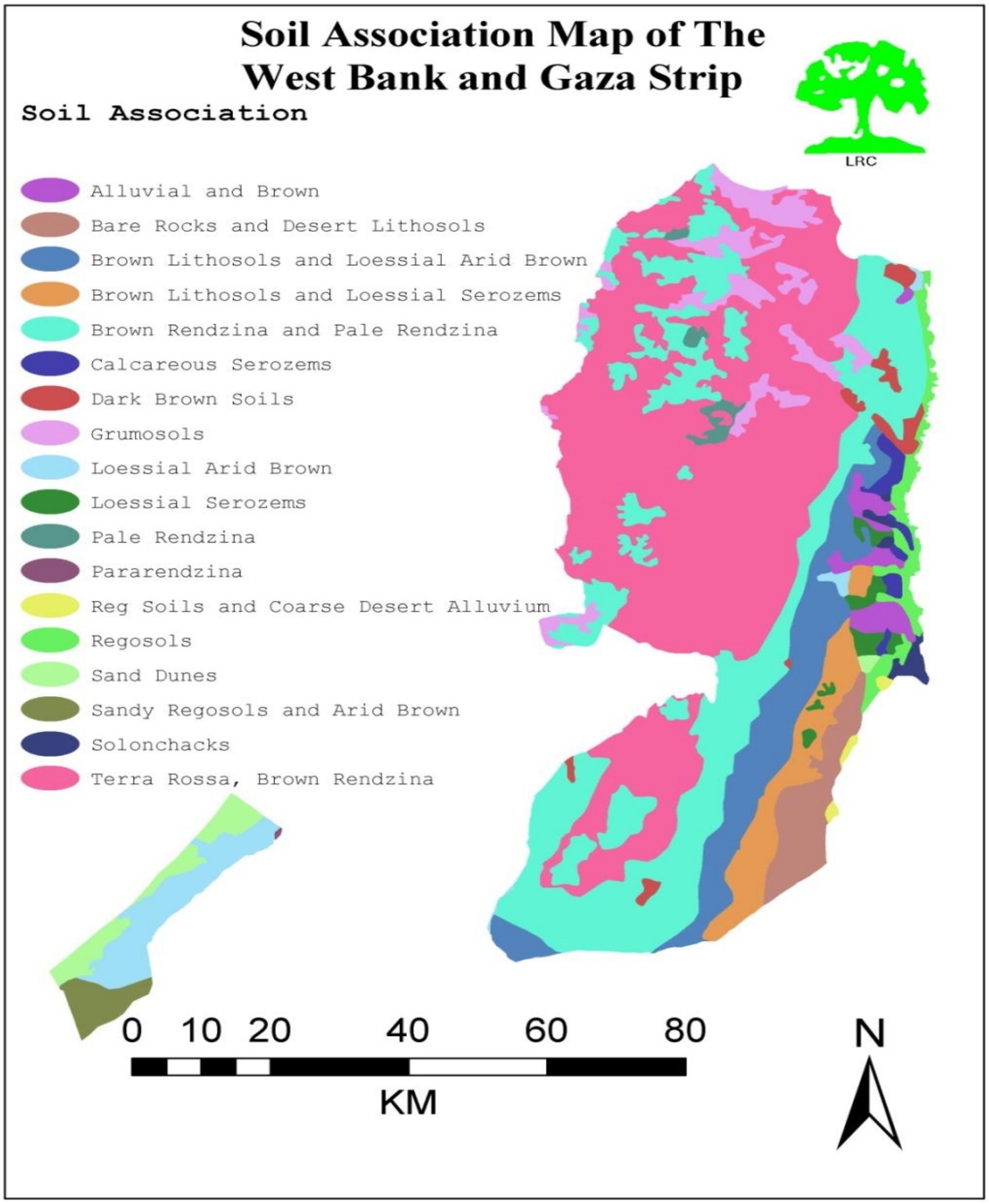
The Jericho district suffers from the phenomenon of saline upcoming (PWA, 2006). The Eastern Aquifer Basin (EAB), which is the main source of water supply for irrigation in the Jericho district, comprises a layer of salt water covered with lenses of fresh water. It appears that drought and heavy exploitation from Jericho wells are the main reasons for the saline upcoming problem in the Eastern Aquifer Basin (EAB).The water in Jericho district is classified as alkali water with high concentration of alkali elements and sulfates.

2.3 Soil of Palestine

2.3.1 Soil classification

West Bank is relatively small geographic area however the soils are remarkably divers in their properties as mentioned above soils grouped into 15 different soil associations, Figure (2.1) (Solonchalks, Calcareous Serozems, Dark Brown Soils, Pale Redndzinas, Brown Lithosols, and Loessial Serozems, Sandy Regosols and Arid Brown Soils, Alluvial and Brown Soils, Regosols, Terra Rossa, Brown Rendzina, Loessial Arid Brown Soils, Brown Lithosols and Loessial Arid Brown Soils, Grumusols, Bare Rock and Desert Lithosols, Brown Rendzinas and Pale Rendzinas (Dan *et al.,* 1976). This diversity is due to the variation in climatic, origin parent material and topographic features (LRC, 2000). Due to lacking data about soil resources in West bank we, still don't have enough information about the degradation processes that taking place in the different agricultural areas.

In Jordan valley where the research area is located the main soil type is lisan marls they are deposits of a former inland lake and consist of loose diluvial marls (Reifenberg, 1947). The lisan marl soils are generally of a rather light nature, their clay content varies from approximately 10-20%. High concentration of lime content is present which varies between 25-60% where there is possibility for irrigation, the lisan marls are covered with a very sparse growth of halophytic plants. According to the available soil classification the dominant soil associations in the Jericho and Jordan Valley areas are: Loessial Arid Brown Soil, Alluvial and Brown Soils, Regisoils and Coarse Desert Alluvium, Calcareous Serozems, and Solonchalks soils, (Reifenberg, 1947).



Figur*e* 2.1 Soil association map for Palestine (LRC, 2000).

2.3.2 Soil degradation

According to MoA strategy, soil degradation especially soil salinization considered as one of the major constraints facing arable lands and cultivation development in the West Bank (WB) (MoA, 2011). Proper management of natural resources is essential for sustainable agricultural development taking into consideration the growing pressure on the limited natural resources as a result of population increase and the need for soil conservation and protection of the natural vegetation and water resources. Soil salinity and alkalinity are most widespread in the arid and semi-arid regions. However, in the Palestinian areas saline soil is dominated in the Jordan Valley and in some other scattered areas in the West Bank. Soil salinity and increasing sodium concentration in the soil also considered serious problem in areas where groundwater of high salt content and sodium is used for irrigation (PWA, 2006).

2.4 Desalination

Desalination can be defined as remove the excess salt and other minerals from water in order to get fresh water suitable for drinking water, animal consumption and irrigation purposes, and if almost all of the salt is removed, for human consumption, sometimes producing table salt as a by-product. Ghermandi and Messalem (2009) stated, that “desalination is a water saving alternative to brackish water irrigation, but its diffusion as a viable method of water treatment has been limited by high costs and concern about the lack of plant nutrients in desalinated water”.

According to Ben-Gal and Yermiyahu (2009), water-scarce countries will have to rely more on the use of non-conventional water resources to partly alleviate water scarcity. Technological advances have made desalination an economically feasible solution for high-return agriculture, especially in arid regions where water cost may be excessive due to distance from, or depth to, the water supply, also they reported that "in arid-zone agriculture where available irrigation water is saline, desalination is becoming an attractive method for increasing yields and reducing negative environmental consequences". Although they admitted that improper management of nutrients could result in negative impact as, irrigation with desalinated water can be problematic if essential nutrients, including Ca^{2+}, Mg^{2+}, and S^{2-}, removed during reverse osmosis, are not reintroduced. On the other hand, Yermiyahu *et al.* (2009) confirmed that:" when farmers receive desalinized water, the lowered salinity is perceived as a bonus, because the salts (especially Na^{+} and Cl^{-}) damage soils, stunt plant growth, and harm the environment. Indeed, desalination do not only separate the undesirable salts from the water, but also removes ions that are essential to plant growth. Desalinized water typically replaces irrigation water that previously provided basic nutrients like calcium (Ca^{2+}), magnesium (Mg^{2+}), and sulfate (SO_4^{2-}) at levels sufficient to preclude additional fertilization of these elements. Also they mentioned, to meet agricultural needs, missing nutrients might be added to desalinized water in the form of fertilizers".

At the same time in the desalination process the removal of calcium and magnesium is much higher than sodium, thus SAR in the desalinated water is high. Lahav *et al.*

(2010) reported that “the typical Na^+ concentration addition to water (between, 100 and, 165 mg/ L) is much higher than the combined addition of Ca^{2+} and Mg^{2+} (between 0 and several mg/L). Since desalinated water is typically supplied with low Ca^{2+} and Mg^{2+} concentrations (35 and 0 mg/L respectively). The treated water is characterized by very low Mg^{2+} concentrations, low salinity and very high SAR values, typically > 6 and up to 10. SAR values can be lowered by adding either Ca^{2+} or Mg^{+2} to desalinated water. Adding Mg^{2+} is preferable from both health (minimizing cardiovascular disease hazards) and agriculture (inexpensive Mg^{2+} fertilization) aspects. The low cost of Mg^{2+} addition at the post-treatment stage of desalination plants corroborates the request for Mg^{2+} addition in regions where treated water from desalinated water origin is planned to be reused for irrigation”, obviously the minerals low content can be augmented by blinding with raw brackish water (Yermiyahu 2009).

Ghermandi and Messalem (2009) summarized the reasons of not using desalinated water in agriculture into two main reasons, where the mentioned “that the range of design solutions were investigated in the literature, including solar stills, solar green houses, enhanced solar green houses, and hybrid pressure-driven/distillation systems. None of these design solutions, however, achieved commercialization. Two main issues have prevented desalination from achieving wide application in agriculture. First, irrigation with desalinated water is limited by its high costs relative to other sources of water. The high energy requirements of conventional technologies account for 40–45% of the total costs of desalination. Second, water desalinated with reverse osmosis (RO) and distillation technologies lacks ions such as calcium, magnesium, and sulphate that are essential to plant growth. The absence of such nutrients may adversely affect agricultural productivity and make additional fertilization necessary". Another aspect of using the desalinated water is the impact of the desalination process on the environment, including the brine disposal. Beltrán and Martínez, (2006) found that "water desalination has positive impacts on the environment, such as increasing water availability and recycling poor-quality water".

"The potential negative impacts are mainly attributed to the concentrate and chemical discharges, which may impair coastal water quality and affect marine life, and air pollutant emissions attributed to the energy demand of the processes" (Dawoud and Al Mulla, 2012).

2.4.1 Desalination advantages

According to Zarzo *et al.* (2012), "the main benefits of using desalinated water for agriculture are:

- Non-conventional and additional water resource.
- In the case of seawater, inexhaustible resource not depending on the weather.
- Increase in productivity and quality of agriculture products.
- Less water consumption and recovery of salty soils.

2.4.2 Desalination disadvantages.

Using desalinated water for irrigation has following disadvantages.

• “Higher water costs (depending on the source) not economically sustainable by some products or in certain areas (inland).

• Water has to be ionically balanced (SAR (sodium adsorption rate) and other indexes).

• High quality requirements from the point of view of some toxics (such as boron).

• Possible exhaustion of aquifers in the case of ground water desalination.

• In the case of brackish water, the additional problem of brine management and discharge without an economically feasible solution inland”.

2.5 Salinity and sodicity

Saline soil can be defined as, soil containing sufficient soluble salt to adversely affect the growth of most crop plants with a lower limit of electrical conductivity of the saturated extract (ECe) being 4 (dS/m), whereas sodic soil is defined as *soil* containing sufficient exchangeable sodium (Na) to adversely affect crop production and soil structure under most conditions of soil and plant type. The sodium adsorption ratio of the saturation extract (SAR) is at least 13.

The impact of using desalinated water in irrigation is going to be mainly on the soil. Several authors reported that the impact is coming from both salinity of brackish water and very low Ec water like desalinated water (Carrow *et al.,* 2008). However, irrigation-induced sodicity in soils exhibits structural problems created by certain physical processes (slaking, swelling, and dispersion of clays) and specific conditions (surface crusting and hard setting) (Shainberg and Letey, 1984; Sumner, 1993; Qadir and Schubert, 2002). Such problems affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff, erosion, and tillage and sowing operations (Murtaza *et al.,* 2005). In addition, imbalances and induced deficiencies in plant available nutrients in salt-affected soils may affect plant growth adversely. Also they stated that: "High amount of soluble salts in irrigation water or in saline sodic soil do not have adverse impacts on soil structure and hydraulic properties", based on sodium concentration in the soil (Qadir *et al.*, 2007). "Rather, saline conditions may have favourable effects on saline soil structure development and stability. The adverse effects of salinity on crop growth stem from two aspects: increasing the osmotic pressure and thereby making the water in the soil less available for the plants and specific effects of some elements or ions present in excess concentrations".

Moreover, Raine *et al.* (2003) reported that "soils with high Exchangeable Sodium percentage (ESP) levels and low electrolyte concentrations are unstable and exhibit a range of properties including weak aggregate stability, spontaneous dispersion, surfaces which seal and crust, the formation of hard setting layers and low hydraulic conductivities".

Izlet *et al*. (2010) found that the integration of salinity – Sodicity effect on physical and hydraulic properties of soil are very complicated process that can be influenced by many factors. The main factors that control soil sodasity is soil type (Felhlenler *et al.*, 1974*;* Quik and Shcofield, 1955), clay type (Goldberget *et al.*, 1991) and content, pH of soil solution (Souraze *et al.*, 1984*;* Sumner, 1993), the manner of application irrigation water, the initial water content of the soil (Dehayer and Gordon 2005). Therefore, the soil structure degradation due to rising sodasity is unique for a given soil new condition (Evanglue and Maccdonald, 1991).

2.6 Soil physical properties

Warrence *et al.* (2002) mentioned that sodium has the opposite effect of salinity on soils. The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling. Also he mentioned that “the forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting”.

Seelig (2000) mentioned that the forces that bind clay particles together to create soil aggregates are greatly weakened when soil with high sodium content and are watered. In this condition clay particles are easily degraded from larger aggregates to small or dispersed Figure (2.2).

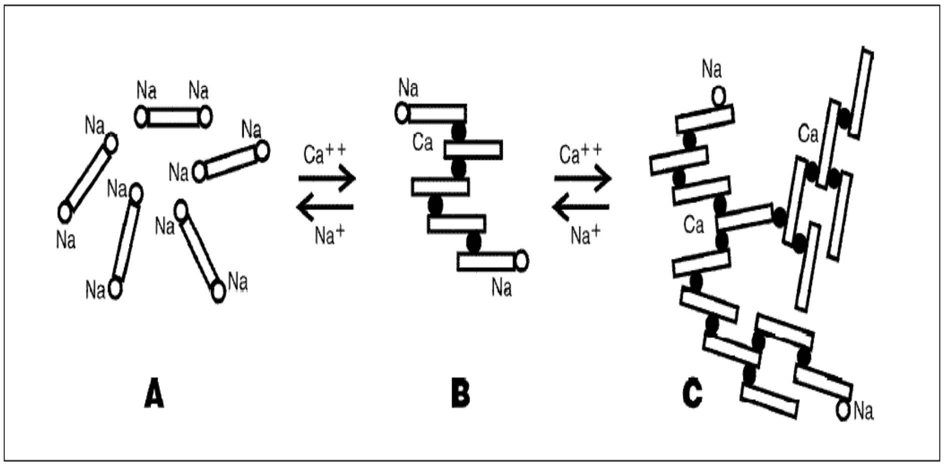


Figure 2.2: "The exchange complex has greater than 15 % of (Na) the clay is dispersed (A) resulting soil structure, when Ca replaces enough sodium the clay is flocculated (B), stable soil aggregate are formed that create good soil structure (C)" (Seelig, 2000)

Hopkins *et al*. (2007) showed that using irrigation water with salinity concentration below 0.2 dS/m may cause problems for soil and plant. Very low EC water like desalinated water dilutes and/or leaches calcium and makes soil aggregates very weak and causing water infiltration problems and to overcome these problems water is treated by adding excess calcium into the water to reduce SAR and to increase water EC.

The impact of SAR and EC on soil structure potential effects of irrigation water on soil structure can be summarized in Table (2.1).

Table 2.1: Effect of water quality on soil structure (Oosterbaan, 2003)

Water quality test	**Effect of chemical property on soil structure**
Relative concentrations of calcium, magnesium, and sodium (sodium adsorption ratio or SAR)	The higher the SAR, the greater the risk of damaging soil structure.
Dissolved salt (electrical conductivity or EC)	Increased salt concentration (higher EC) in water helps maintain soil structure. (Note, however, that a higher EC increases the salt hazard)

Oosterbaan (2003) found that sodic soils with SAR > 13 or ESP > 15 in non-saline conditions, irrigating with non-saline water, occupy a larger volume than otherwise, because the Na^+ ions are mobile and have smaller electric charges than Ca^{++} ions, hence they are adsorbed less coherently to the surface of the clay particle and they leave farther away. This process is called sodicity and results in breakdown soil aggregates and soil structure causing reducing of soil infiltration capacity and vertical water movement, surface-water-logging or runoff is increased. They also found the alkalinity problem in the soil is worse in less salinity condition while under saline conditions, the many ions in the soil solution counteract the swelling of the soil. Hanson *et al*. (1999) showed that the effects of elevated sodium adsorption ratios increase as the salinity of the water decreases, as shown in Figure 2.2.

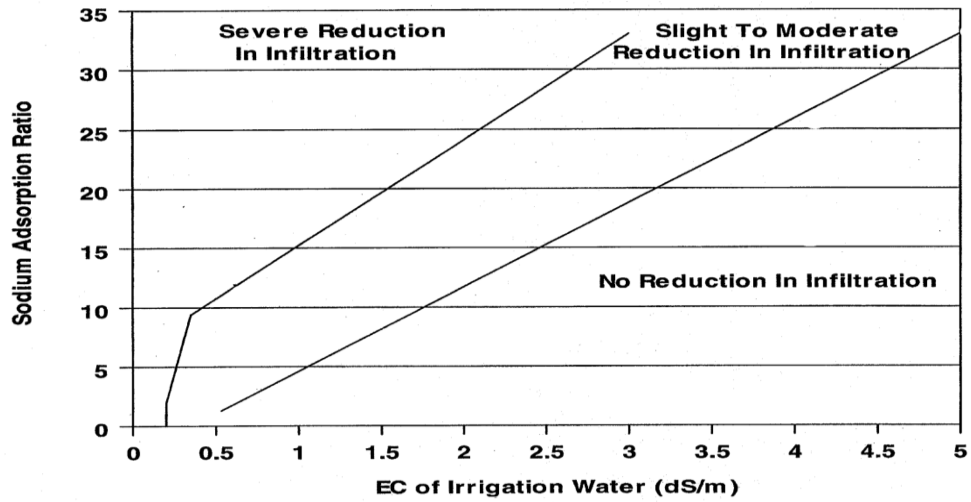


Figure 2.3: Relationship between EC and SAR and the effect on infiltration of water into the soil (Hanson *et al.*, 1999).

Deiricks (2007) clarified that high values of ESP or SAR are usually indication for poor physical soil conditions and high pH. Dispersion problems may appear at greater ESP or SAR. Also, Deiricks (2007) mentioned that salt affected soils with excess amount of exchangeable sodium SAR more than 13 may have good structure and will not disperse when the salt concentration of the soil solution is high. When the salt concentration in the soil solution decrease due to irrigation, soils may become more susceptible to dispersion, thus soil amendment like calcium may then require replacing sodium.

Tajik *et al.* (2003) stated that understanding the process of soil structure degradation and aggregate soil particles under saline and sodic conditions in arid and semi-arid regions could improve crop management. Bybordi (1993) found that the dispersion of soil particles and slaking of soil aggregates resulting in soil hardening of soil surfaces, and lead to negative effects on soil aeration and water movement, and also intensify soil erosion.

Shainberg *et al.* (1981) demonstrated that clay dispersion and hydraulic conductivity reductions can occur at an ESP as low as 1-2 when distilled water is used.

The Ca^{2+} amendments in the irrigation water would increase ECW while reducing SAR, which can improve water infiltration.

Calcium as amendments when applied into the irrigation water are most effective when the irrigation water SAR is high and/or the salinity is low to moderate (ECW<1.0 ds/m Carrow *et al.* (2008).

The American Water Quality Planning Bureau (2011), reported that the increase of SAR in the soil or in the irrigation water will impair soil aggregate and soil structure. Thus, the permeability of the soil leading to a lack of soil moisture especially when the EC of the soil water or applied irrigation water is insufficient or low EC water to combat the negative effects of adsorbed sodium on soil structure.

Chapter three

Material and methods

3.1 Study location

The research was conducted in Marj Na'aja village which is located to the Northern part of the Jordan Valley (32° 10′ 56.74 N, 35° 10′ 28.33 E) and about 40 km north to Jericho, and lays 270 m below sea level as shown in Figure (3.1).

According to the soil analysis and land observation the soil is classified as saline soil with high content of sodium as a result of using low quality water with high TDS reaches 4500 ppm.

The cropping pattern in the study region is mainly vegetables and some date palm and field crops. The total cultivated lands equal 111.3 hectare in which 93% of it is cultivated by vegetables. Despite that the agriculture is the main economic activity in the study region, it faces many constrains like, low land quality, water salinity, the low productivity of the crops, low fruit quality. These constrains affect negatively the marketing and economical value of cultivated vegetable crops (mainly tomato and cucumber), and to overcome these constrains, some wealthy farmers had shifted from growing vegetables to another soil and water salinity resistance crops such as date palm trees (MoA, 2010).

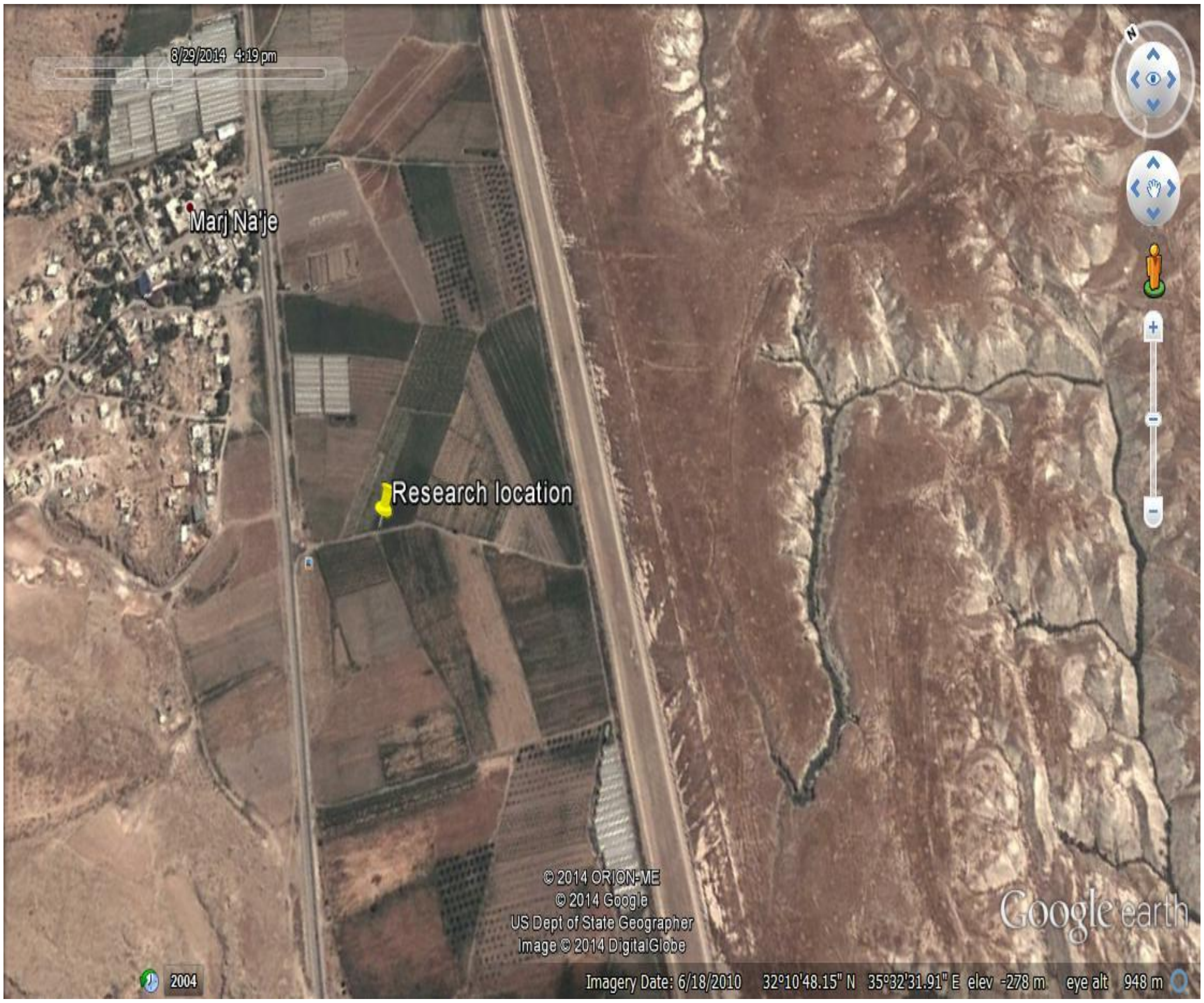


Figure 3.1: Research location in Marj Na'aja – Jericho (Source: Google earth 20/11/2014)

3.2 Methodology

The applied research was carried out at one of the effected lands of saline farms in Marj Na'aja village, where the desalination unit provided by MoA is located. Four types of water, based on TDS content were considered, namely:

-T1 Desalinized water with TDS of 200 ppm.

-T2 blended water with a final TDS of 750 ppm.

-T3 blended water with a final TDS of 1600 ppm.

-T4 Raw brackish water with TDS of 4500 ppm.

In the experiment, plant tomato Izabella variety was used to introduce the root effect on the investigated depths and to grow long planting period as irrigation extend to 7 months. Plant spacing 80 cm, drip irrigation system was used with emitter spacing of 80 cm and raw spacing of 1.2 m. The emitter discharge is 4 L/h. The irrigation system is not supplied with fertilizer injector to avoid any addition of salts that may affect the results.

Soil sampling were conducted two times at four depths of 0-15, 15-30, 30-45, and 45-60 cm, before the crop season and after the crop season to measure the soil chemical properties pH, EC, soluble cations (Ca^{2+}, K^{+}, Na^{+}, Mg^{2+}), Cl^{-} and to calculate SAR.

Soil moisture content and EC were measured four times (after third irrigation, after one month of the planting date, after 2 months of planting date and after crop completion) for treatment 1 and treatment 4 at the four mentioned depths with 12 samples at each depth with 10 cm distance between sequent in the X-Y direction.

Additional soil physical properties, like soil texture and soil structure, were determined to understand the water and salt movement and proper soil and irrigation management.

Irrigation was applied with three days interval. The quantity of applied water ((31 cubic meter) (see annex1)) was calculated for the actual crop water requirements according to FAO Penman – Montieth equation using CROPWAT software, utilizing the local climatic data with total amount of irrigation water. The leaching requirements were not considered to examine the changes in soil moisture content and not to affect the results.

Irrigation water quality was analysed for pH, EC, soluble cations (Ca^{2+}, K^{+}, Na^{+}, and Mg^{2+}), and Cl^{-}, four times during the crop growing period from the initial irrigation time to crop completion with 45 days intervals.

3.3 Experiment layout

The allocated experiment layout was covered with a green houses, 10 meter length and 7.35 meter width. The lot was divided into four trains. Each line contained 3 rows of plants with 7 plants for each line. The space between rows and between plants was 80 cm to avoid overlapping of irrigation water from emitters to the plants. The experiment layout is shown in Figure 3.2.

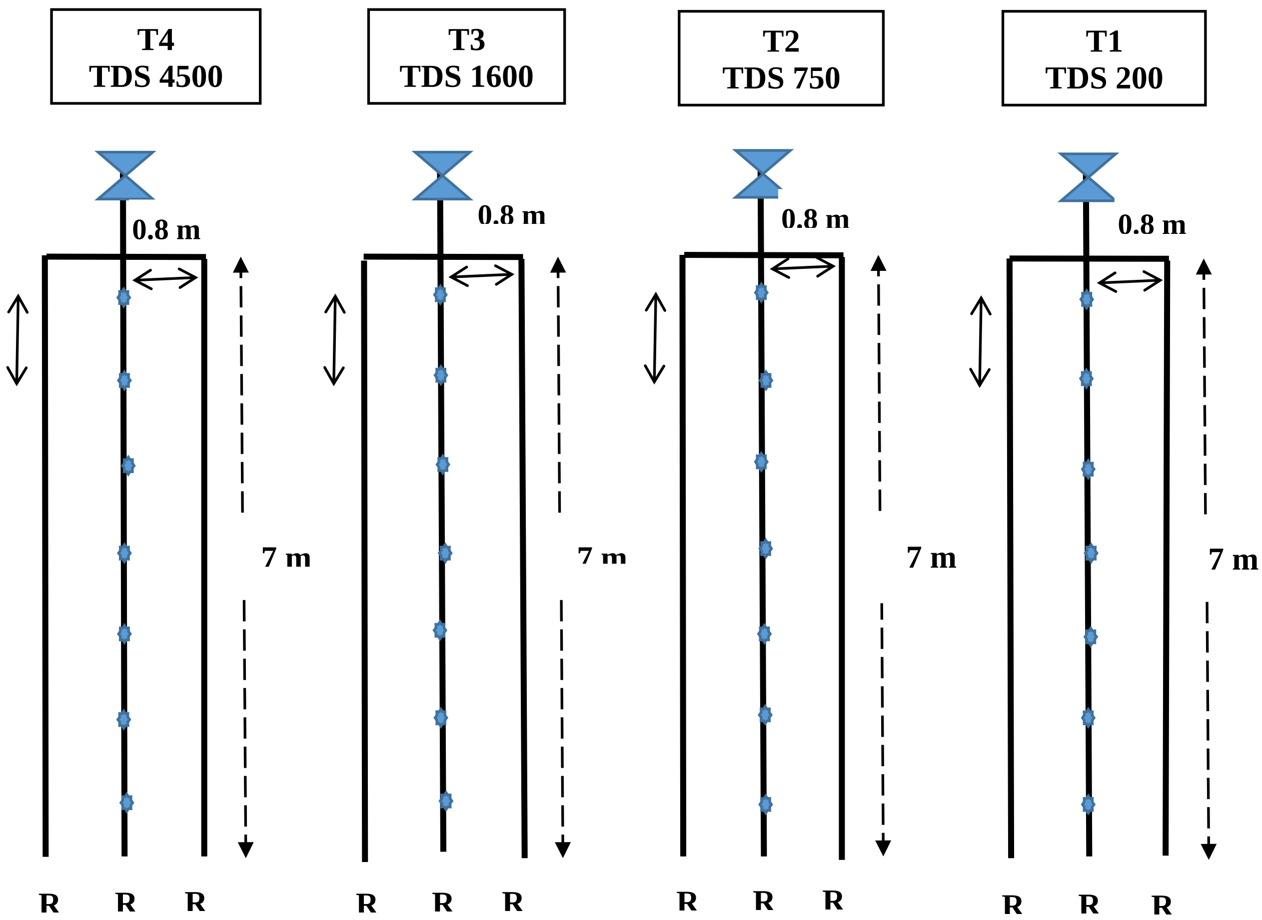


Figure 3.2: Experiment layout

3.4 Soil sampling

3.4.1 Determination chemical properties

Soil sampling were conducted two times at four depths of 0-15, 15-30, 30-45, and 45-60 cm, before the crop season and after the crop season to measure the soil chemical properties pH, EC, soluble cations (Ca^{2+}, K^{+}, Na^{+}, Mg^{2+}), and Cl^{-} and to calculate SAR.

Soil samples were taken at four directions for at the four depths with total 16 soil samples for each treatment as shown in Table (3.1).

Table 3.1: Soil samples for chemical properties

Sampling time	Soil depth	Soil sample /each depth	No of treatments	Total soil samples
Before planting	4	1	4	16
At the end of crop season	4	4	4	64
Total				80

3.4.2 Determination of moisture content and electrical conductivity

Soil moisture content and EC were measured four times beside the blank (after third irrigation, after one month of the planting date, after 2 months of planting date and after crop completion) the measured were conducted for treatment 1 and treatment 4 at the four mentioned depths with X-Y direction with 3 locations 10 cm distance between sequent at each direction. The total soil samples for each treatment are 48 samples as shown in Table (3.2).

Table 3.2: Soil sampling for EC and soil moisture content

Sampling time	Soil depth	Soil sample /each depth	No of treatments	Total soil samples
Before planting	4	1	4	16
After third irrigation	4	12	2	96
After 1 month of planting	4	12	2	96
After 2 month of planting	4	12	2	96
At the end of the crop season	4	12	2	96
Total				**400**

3.4.3 Determination of soil texture

Soil texture was measured for all treatments and all investigated depths to realize the mechanism of salt and water movement within soil profile and to conduct proper soil management, and irrigation requirements, the total soil samples for each treatment is 16 sample as shown in Table (3.3).

Table 3.3: Results of soil texture analysis for all treatments

Treatment	Sample no	Soil depth (cm)	Soil texture (%)			Texture class
			Sand	Silt	Clay	
T1	1	0-15	35.4	42.1	22.5	loamy
	2	15-30	34.4	31.5	34.1	Clay loam
	3	30-45	25.6	39.9	34.5	Clay loam
	4	45-60	29.1	36.7	34.2	Clay loam
T2	1	0-15	35.9	41.7	22.1	loamy
	2	15-30	35.2	32.3	32.5	Clay loam
	3	30-45	26.1	39.2	34.7	Clay loam
	4	45-60	28.3	37.1	34.6	Clay loam
T3	1	0-15	35.9	41.7	22.1	loamy
	2	15-30	35.2	32.3	32.5	Clay loam
	3	30-45	26.1	39.2	34.7	Clay loam
	4	45-60	28.3	37.1	34.6	Clay loam
T4	1	0-15	34.1	40.9	25	loamy
	2	15-30	33.9	32.2	33.9	Clay loam
	3	30-45	25.1	39.2	35.7	Clay loam
	4	45-60	29.5	35.8	34.7	Clay loam

3.5 Water analysis

Water analysis was conducted 4 times during the cropping season for the four irrigation water treatments. The studied water parameters and the results are shown in the Table (3.4).

Table 3.4: Quality of desalinated water (T1), blended water (T2 and T3) and raw saline water (T4) used for irrigation

Chemical Parameter	Unit	Desalinized water with TDS 200 ppm (T1)	Blending water with TDS 750 ppm (T2)	Blending water with TDS 1600 ppm (T3)	Raw saline water with TDS 5400 ppm (T4)
pH	--	7.2	7.2	7.4	7.5
EC	dS\m	0.3	1.2	2.6	7.2
P	ppm	1.0	2.7	3.3	4.2
K^+	ppm	24.1	129.3	149.7	337.3
Ca^{2+}	ppm	4.4	47.2	65.7	125.1
Mg^{2+}	ppm	1.6	52.3	61.4	98.1
Na	ppm	69.3	303.8	436.0	891.5
Cl	ppm	53.9	434.0	589.3	1929.5
Total (N)	ppm	12.3	16.3	19.5	28.5
SAR	**--**	16.43	3.78	4.43	5.34

3.6 Statistical analysis

The results were statistically tested using SPSS software 20. The soil data were analysed by analysis of variance (ANOVA) to study the effect of water quality on sodium adsorption ratio (SAR) and moisture content. All values were evaluated at a 95.0 % confident level with Scheffe analysis.

3.7 Soil analysis

The soil and water samples were analysed following ICARDA procedure for soil and water samples analysis (ICRDA, 2013). The USDA soil triangle was used to define the soil texture classes as described in ICARDA (2013).

3.8 Moisture content

The moisture content was measured using infrared Moisture Analyser MA100C-000115V1 (Sartorius AG, Germany). The MA100 infrared moisture analyser combines the highest possible accuracy of an analytical balance and practical application software for auto calculations.

3.9 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) was calculated by determined the concentrations of dissolved calcium, magnesium and sodium in the water extracted from the soil flowing ICARDA procedure for soil and water samples analysis (ICRDA, 2013).

The formula for calculating the Sodium Adsorption Ratio is:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

3.10 Soil structure

According to the FAO, (2006) Soil structure can be defined as "arrangement of soil particles into separated soil units or small aggregates, separated from each other by pores or voids. These aggregate are characterised primarily on basis of its dominant shape" spheroidal (granular, crumb), platy, prism (columnar- top of the prisms are rounded and prismatic- top of the prisms are level) and blocky (angular blocky and sub angular blocky). Besides the structure type, also grade and size of aggregates are recorded".

According to FAO, (2006), "when a soil horizon contains aggregates of more than one grade, size or type, the different kinds of aggregates should be described separately and their relationship indicated".

Chapter 4

Results and discussion

4.1 Sodium Adsorption Ratio (SAR)

4.1.1 Comparison between treatments

The results of soil content of sodium in relative to calcium and magnesium expressed as SAR are presented in Table (4.1) for all treatments and depths.

Table 4.1: Soil SAR values for all treatments and depths

Soil depth	blank		T1		T2		T3		T4	
D1: 15 cm	8.17	b*	10.21	a*	7.62	c*	6.04	e*	6.74	d*
D2: 30 cm	7.40	b	8.33	a	6.26	e	6.58	d	7.12	c
D3: 45 cm	6.66	c	8.78	a	6.92	c	6.80	c	7.35	b
D4: 60 cm	6.10	d	8.58	a	7.18	bc	7.08	c	7.54	b

*Letters represent statistical groups (a, b, c, d, e) a= the highest value, e= is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The results in table (4.1) indicate that soil SAR was increased significantly when using desalinated water for irrigation. SAR values increased from 8.17 for the soil before planting to reach 10.21 at the surface layer (15 cm) after completion. While at the same time, the SAR values decreased significantly when irrigation water is blended with saline water. The T2 (750 ppm), T3 (1600 ppm) and T4 (4500 ppm) were respectively 7.62, 6.04 and 6.74 for T2, T3 and T4 as shown in Figure (4.1).

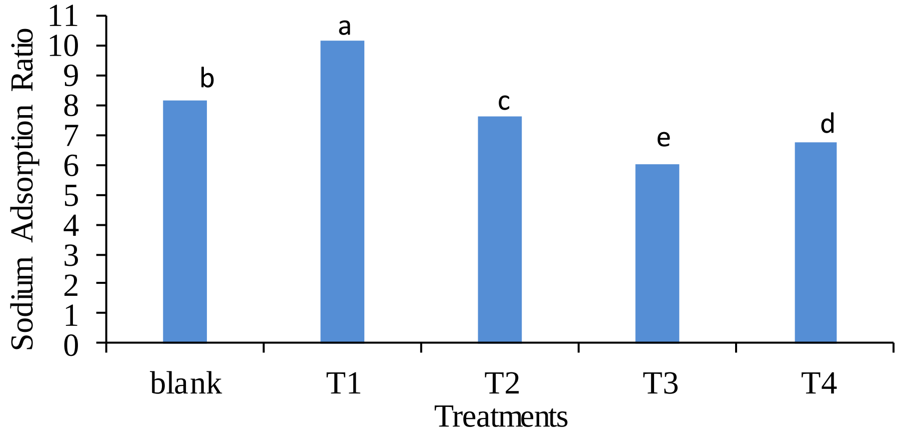


Figure 4.1: SAR at D1 (15 cm) for all treatments comparing with Blank

At the second depth (30 cm) the calculated values of SAR increased significantly from 7.40 (soil before planting and irrigation) to 8.33 in the desalinated water. While SAR decreased significantly from 7.40 at blank to 6.26, 6.58 and 7.12 for T2 with TDS 750 ppm,T3 with TDS 1600 ppm and T4 with TDS 4500 ppm respectively as shown in Figure (4.2).

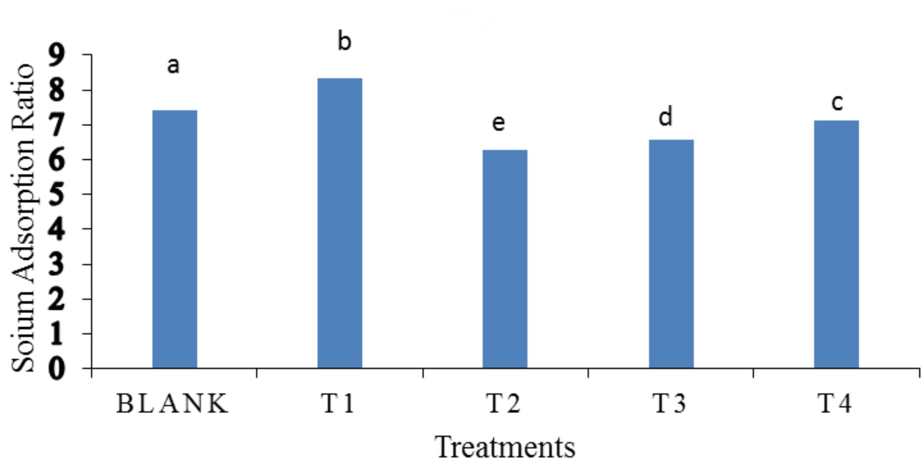


Figure 4.2: SAR at D2 (30 cm) for all treatments comparing with Blank

In the underlying layer D3 (45 cm) SAR increased significantly from 6.66 for blank (soil before planting and irrigation) to 8.78 at T1 with TDS 200 ppm and to 7.35 at

T4 with TDS 4500 ppm. While SAR showed that no significant difference between the blank and T2 with TDS 750 ppm, and T3 with TDS 1600 ppm as shown in Figure (4.3).

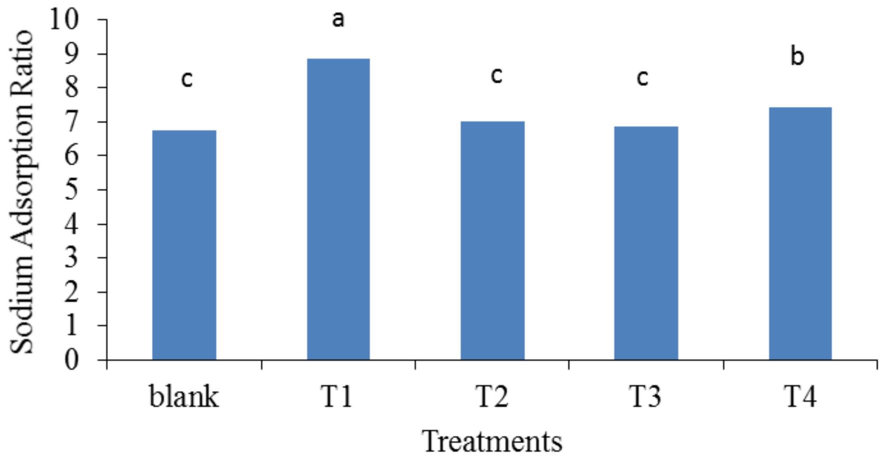


Figure 4.3: SAR at D3 (45 cm) for all treatments comparing with Blank

In the bottom layer of the soil D4 (60 cm), SAR increased significantly from 6.10 for blank (soil before planting and irrigation) to 8.58 at T1 with TDS 200 ppm and to 7.18 at T2 with TDS 750 ppm, to 7.08 at T3 with TDS 1600 ppm and to 7.54 at T4 with TDS 4500 ppm as shown in Figure (4.4).

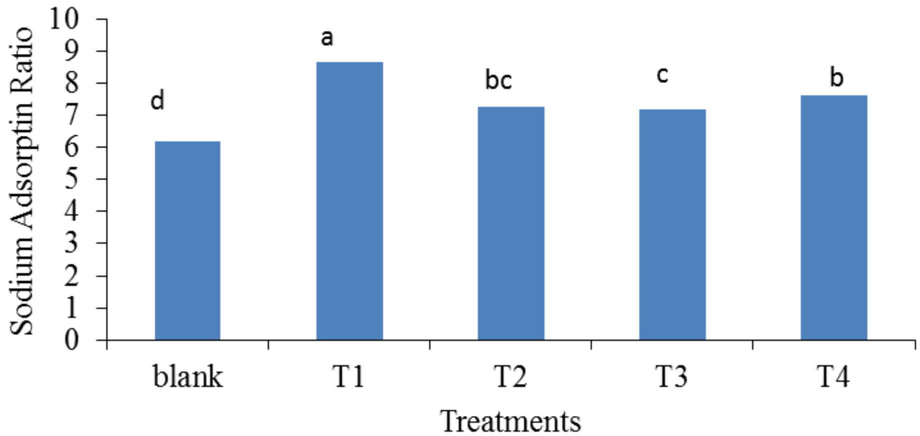


Figure 4.4: SAR at D4 (60 cm) for all treatments comparing with Blank

The results of the soil SAR in the different treatments as shown in (Table 4.1), reflect the effect of desalination on the soil sodicity. These results show that the desalinated water which is poor with salts (TDS = 200 ppm) will produce high SAR in the soil, since the rejection rate of calcium and magnesium is higher than that of sodium (Lahav *et al*., 2010).

As described in site location (blank) the soil is rich with sodium content, thus the result of the interaction between desalinated irrigation water and soil sodicity resulted in a significant increase in soil SAR (10.21) as shown in Figure (4.5).

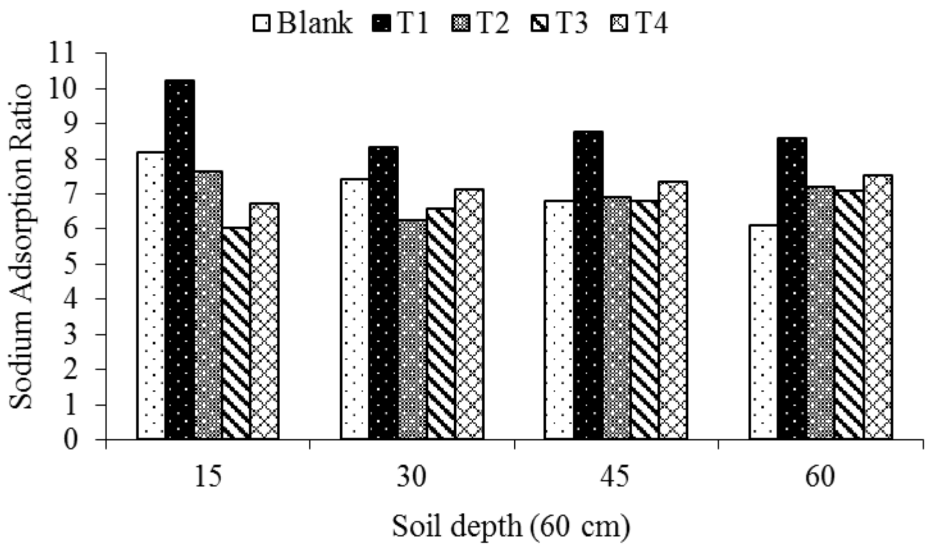


Figure 4.5: Soil SAR at all treatments with depths

With adding salts through blending, the soil SAR values decreased. However, in T2 the concentration of calcium and magnesium decreased the SAR values from 8.17 in the blank (non-irrigated soil) to 7.62 at T2 (750 PPM). This is also true for T3 (1600 ppm), where the SAR values is lower (6.04) than T2 (1600 ppm) and the original soil status. On the contrary in the non-blended brackish water T4 (4500), the sodium content is high. Thus the effect in reducing SAR values (6.74) at T4 (4500 ppm) is less than expected, and the resulted SAR is related to the water content.

The effect of blending disappeared with depth, where, in the second layer (30 cm), the resulted SAR of non-irrigated soil is less than the upper layer (15 cm). This could be related to the water movement and capillary rise, which increased sodium in the upper layers, this stated by (Sheppard and Dzik, 1987), as thy said, irrigating surface soil with clean water could increase contaminants of surface soil because of capillary rise.

When we used blended water, and due to the SAR effect on soil structure, the movement of water is less. This appeared in the significant changes between T2 and T3, where, SAR of T3 (1600 ppm) is higher than T2 (750 ppm). The main effect of SAR on soil resulted in the effect on structure in hindering downward water movement. As the results show, the significant differences between T2 (750 ppm) and T3 (1600 ppm) disappeared in the deeper layers. However the brackish water has a higher SAR results due to its content of sodium in these depths. This content of sodium raised the soil SAR in T4 to exceed that of non-irrigated soil.

The results show that the desalinated water T1 (200 ppm) significantly increased the SAR values. This is expected since the desalinated water is low in soluble salts, and thus, it will dissolve the existing salts in the soil, in addition to its content of sodium, calcium, and magnesium. The solubility of sodium is higher than calcium and magnesium (Oosterbaan, 2003) when he stated that, Na^{+} ions are mobile and have smaller electric charges than Ca^{++} ions, hence they are adsorbed less coherently to the surface of the clay particle and they leave farther away, therefore, SAR is expected to increase. This is confirmed by the reduction in SAR as water is blended, the saline water contain calcium and magnesium that balanced the sodium, and as salinity increases the SAR values for the same depth decreased (7.62, 6.04 in T2 (750 ppm) and T3 (1600 ppm) compared to 10.21 in T1 200 ppm) in the surface layer (15 cm). However as we irrigate with brackish water, the SAR is related to the original content of sodium Na^{+} and calcium $Ca^{2+}$and magnesium Mg^{2+}, which explain the increase of

SAR value (6.74) at T4 (4500 ppm) than that of SAR value (6.04) at T3 (1600 ppm) as shown in Figure (4.6).

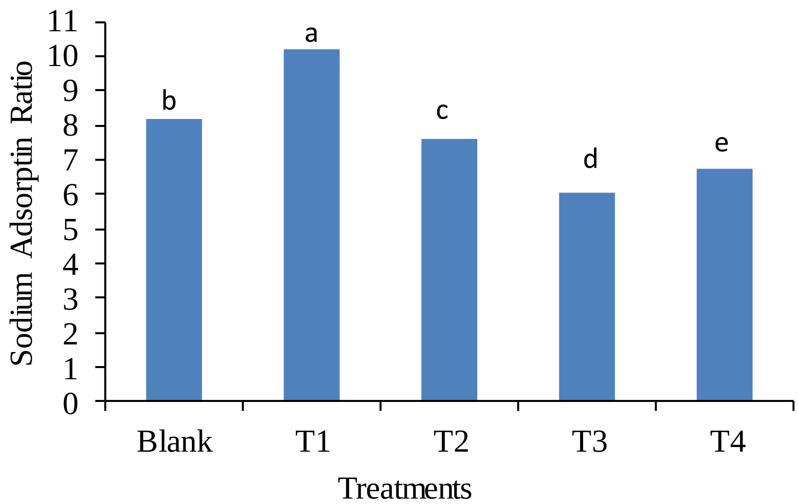


Figure 4.6: SAR of different treatments at the surface layer D1 (15cm)

At this depth, the differences between treatments are significant, and reflect the direct interaction between the irrigation water salinity and sodicity with this soil (see Fig 4.6).

In the desalinated water, as the sodium concentration is high in relative to calcium and magnesium, the SAR would increase. This is correct since the rejection rate of calcium and magnesium is higher in the RO membrane. The resulted SAR, the irrigation water after the desalination process is 16. This agrees with findings presented by Lahav *et al.* (2010) who stated that, in desalination process, the removal of calcium and magnesium is much higher than sodium, thus SAR in the desalinated water is high. This leads to significant increase in soil sodicity at all depths comparing to the original soil sodicity before irrigation (blank). When brackish water was blended with the desalinated water T2 (SAR = 3.78), the resulting SAR is low, and in result the soil SAR significantly decreased Figure (4.7).

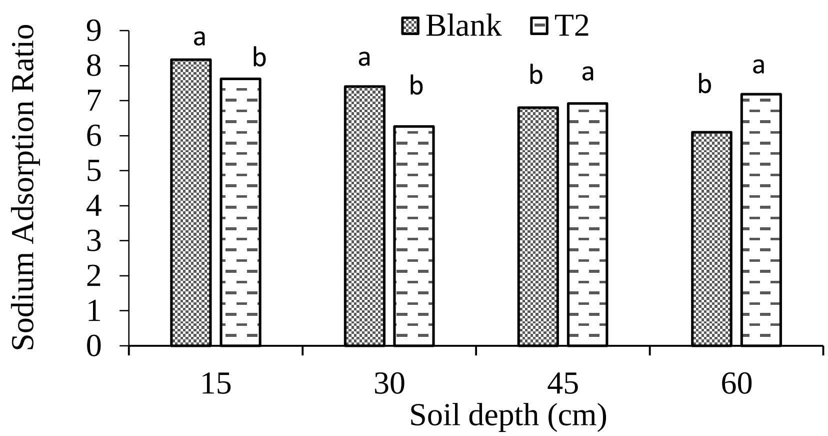


Figure 4.7: A comparison between SAR results in non-irrigated soil with T2 (750 ppm)

4.1.2 Comparison between depths

The results of the soil SAR at the four investigated depths are presented in Table (4.2). These results show a general reduction in SAR results with depth.

Table 4.2: Soil SAR values for all treatments and depths

Soil Depth	blank		T1		T2		T3		T4	
D1: 15 cm	8.17	a*	10.21	a*	7.62	a	6.04	d*	6.74 c*	
D2: 30 cm	7.4	b	8.33	c	6.26	d	6.58	c	7.12	b
D3: 45 cm	6.66	c	8.78	b	6.92	c	6.8	b	7.35	a
D4: 60 cm	6.1	d	8.58	bc	7.18	b	7.08	a	7.54	a

*Letters represent statistical groups (a, b, c, d) a= the highest value, d= is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The SAR values at the blank soil (soils before irrigation) were found significantly lowers with increasing the depth table (4.2). The maximum value of 8.17 was found at the first layer (15 cm), and then started to decrease to 7.40, and to 6.66, to 6.10 for D1 (15 cm) to D2 (30 cm) to D3 (45 cm) and to D4 (60 cm) respectively as shown in Figure (4.8).

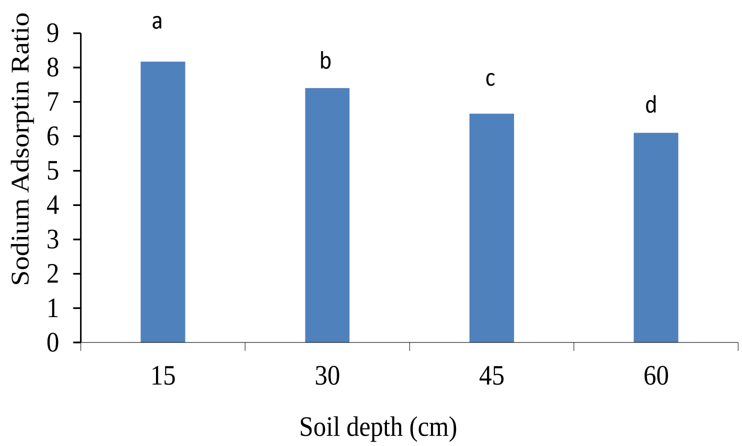


Figure 4.8: SAR values of the blank soil at all depths

At T1 (200 ppm) SAR values were significantly decreased from 10.21 in the surface layer (15 cm), to 8.33 in the second depth (30 cm). In the third depth (D3) SAR increased to be 8.78, is still lower than the surface layer. However, in the bottom layer D4 (60 cm) SAR decreased significantly in comparison to D3 (45 cm) to reach 8.58. Even though this value is not significantly higher than that of D2 (30 cm), but it is lower than the surface layer as shown in Figure (4.9).

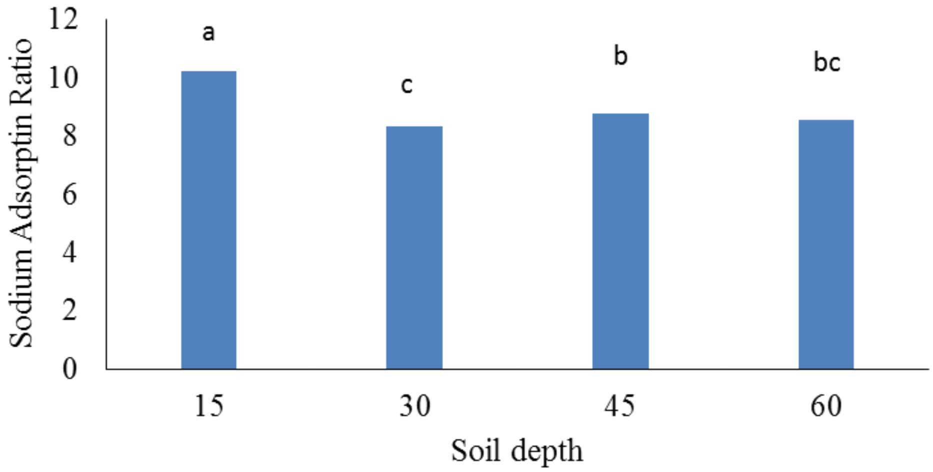


Figure 4.9: Soil SAR for all depths in T1 (200 ppm)

At T2 (750 ppm) the same pattern of T1 (200 pm) is found. SAR values were significantly decreased from 7.62 (15 cm) to 6.26 (30 cm), while there is a significant increase at (45 cm) 6.92 and 7.18 at (60 cm) as shown in Figure (4.10).

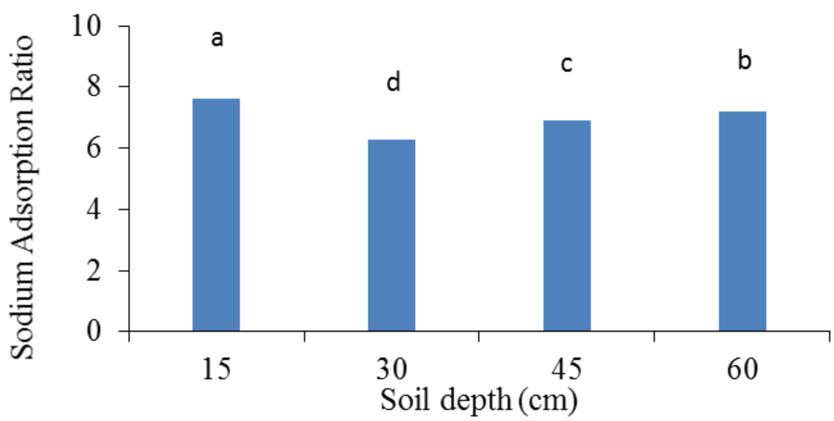


Figure 4.10: Soil SAR for all depths in T2 (750 ppm)

At T3 (1600 ppm) a continuous increase in the calculated SAR values was found. SAR values increased significantly with depth, where, the maximum SAR values are found for D4 (7.08) and the minimum for D1 (6.04), as shown in Figure (4.11).

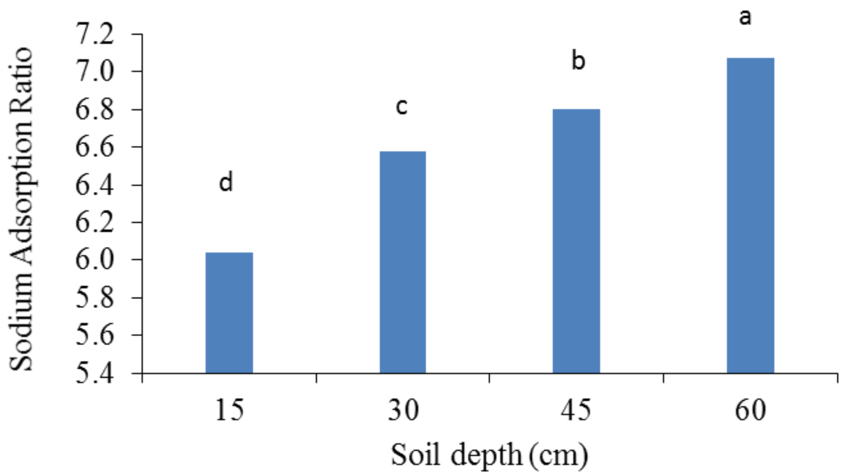


Figure 4.11: Soil SAR for all depths in T3 (1600 ppm)

Also for T4 (4500 ppm), SAR values where significantly increased from 6.74 to 7.12 to 7.35 and to 7.54, D1 (15 cm) to D2 (30 cm), D3 (45cm) and D4 (60 cm) respectively as shown in Figure (4.12).

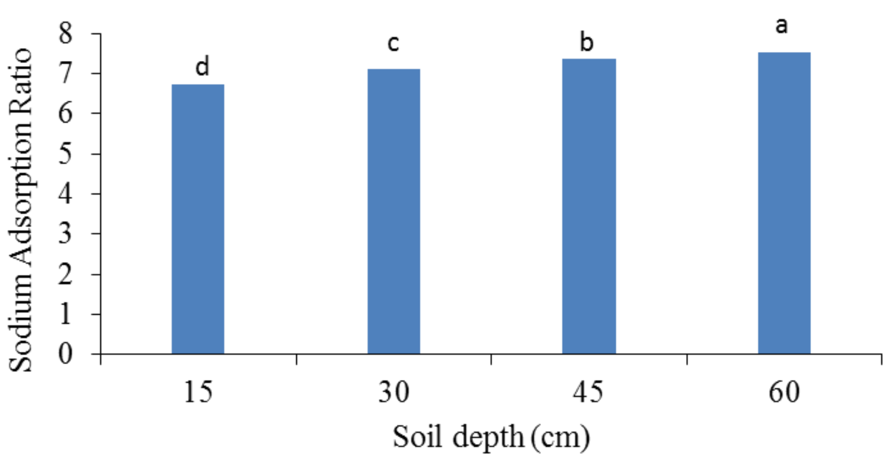


Figure 4.12: Soil SAR for all depths in T4 (4500 ppm)

This significant reduction is clear in the first two layers of the soil D1(15 cm) and D2 30 (cm), however since the SAR of the irrigation water relatively reduce SAR of the soil, but in the same time it didn’t reduced it to remove the negative impact of sodium on soil.

This resulted in significant differences in SAR between different treatments with depths. The infiltration rate from the upper layers into D3 (45 cm) and D4 (60 cm) in the deeper layers is affected by increased SAR in D1 (15 cm) and D2 (30 cm).

Another reason is that sodium is more mobile than calcium, and it is lower adhesive to soil particles, which mean that water moving into the lower depths, will transfer sodium and increase SAR as a result. This totally agrees with the explanations of Oosterbaan, (2003) who reported that sodium is mobile elements compared with calcium and magnesium.

At D2 (30 cm), the significant differences in regard to D1 (15 cm), still exist, with a change in the order between depths in the different treatments. This is explained when vertical movement of water is considered. However the irrigation quantity affects the rate of change as seen in the Table (4.1) and (4.2).

As irrigation water salinity increase (T3 (1600 ppm), T4 (4500 ppm), a reduction in SAR values is expected as shown in Figures (4.13) and (4.14).

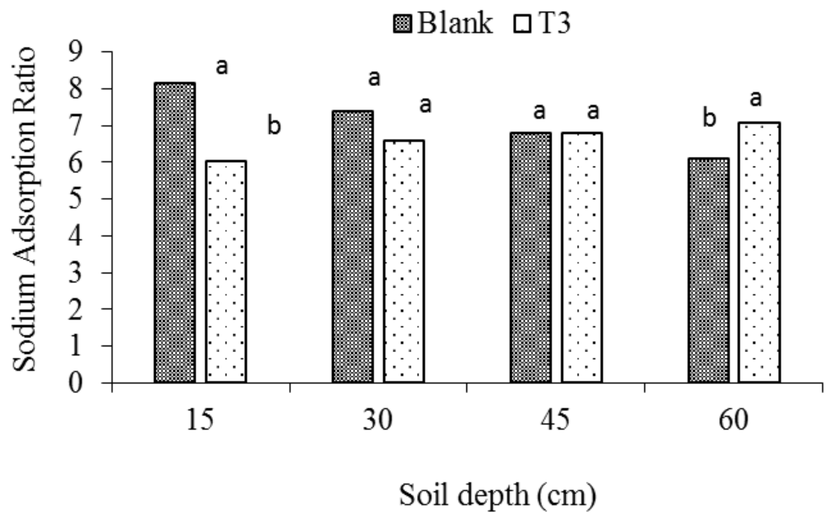


Figure 4.13: Increasing SAR with depth in T 3 (1600 ppm)

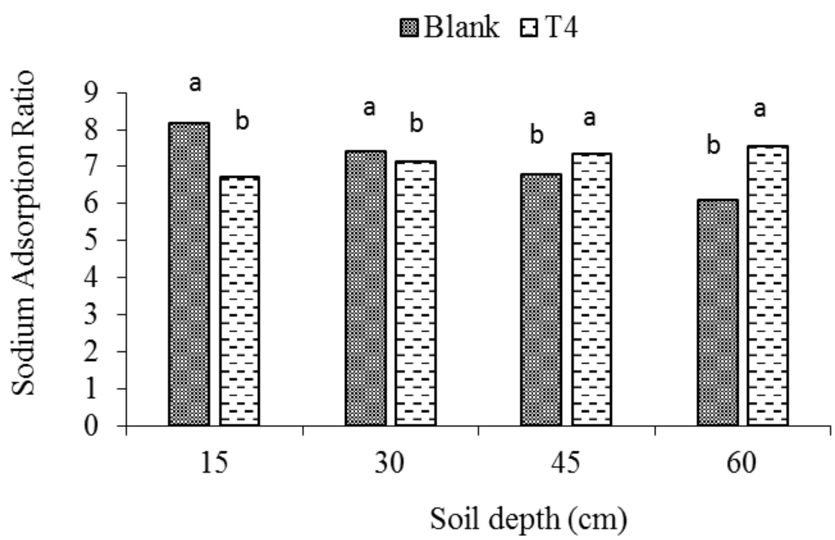


Figure 4.14: Increasing SAR with depth in T 4 (4500 ppm)

The results presented in Figures (4.13 and 4.14) clearly show that SAR is increasing with depth starting from the first layer. This is expected, due to the movement of water and salts. Again the sodium movement is higher than calcium or magnesium; this will lead to an increase in SAR values with depth. This explanation is supported by the blank results (non-irrigated soil) where, the capillary raise moved sodium upward and resulted in increasing SAR in the surface layer.

However the quality of irrigation water explains the changes of SAR results in the different treatments with depth. In T4 (4500 ppm), the original SAR values are high (5.34) compared to (4.43) in T3 (1600 ppm). Therefore, the sodium content is higher than in T3, and the effect on soil sodicity is larger. As a result the soil physical properties (mainly infiltration and hydraulic conductivity) are affected, and the water is not moving freely downward due to the impact on soil porosity. In such soils the movement of sodium has a higher mobility than calcium and magnesium, which explain the increasing of SAR with depth in T3 (1600 ppm) and T4 (4500 ppm). The findings of (Oosterbaan, 2003) support this understanding when he stated that the Na^{+} ions are mobile and have smaller electric charges than Ca^{2+} ions,

4.2 Moisture content

4.2.1 Stage one (after the third irrigation)

The results show that the moisture content decline in both directions (the depth and the space from emitters), as Table (4.3) shows.

Table 4.3 Soil moisture content in T1 (200 ppm) at all soil depths for all horizontal distances after third irrigation / Stage 1

Soil depth	Horizontal distance from the emitter (cm)								
	10			20			30		
D1: 15 cm	A+	a*	30.14	A+	b*	25.69	A+	b*	24.48
D2: 30 cm	B	a	25.53	B	b	22.80	B	b	21.52
D3: 45 cm	C	a	21.91	C	b	20.12	C	b	19.01
D4: 60 cm	D	a	18.83	C	ab	17.88	D	b	16.39

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Small Letters represent statistical groups (a, b, c, d) a = the highest value, d = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The maximum value of moisture content (ϴ = 30.14%) was achieved at 10 cm from the emitters with 15 cm depth. While the minimum value was (ϴ =16.39%) at (60 cm) depth and (30 cm) space from emitters. The moisture content significantly differs with depth (α=0.05), while there is significant differences between horizontal distance 1 (10 cm) and the other spaces (and no significant differences between horizontal distance 2 and 3). The same pattern resulted when the saline water was used for irrigation as shown in Table (4.4).

Table 4.4: Percent of soil moisture content in T4 (4500 ppm) at all soil depths for all horizontal distances after third irrigation / Stage 1

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1: 15 cm	A*	a*	29.97	A*	b*	26.19	A*	b*	25.56
D2: 30 cm	B	a	26.47	B	b	23.91	B	b	23.47
D3: 45 cm	C	a	23.05	C	b	21.29	C	b	20.52
D4: 60 cm	D	a	19.51	D	a	18.80	D	b	17.40

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, d = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

Table (4.4) shows that the maximum value of the moisture was (ϴ =29.97%) at 10 cm horizontal space and 15 cm depth, while the minimum value was (ϴ =17.40%).With a significant differences among the depths while there is significant differences between horizontal space 1 (10 cm) and the other horizontal spaces (and no significant differences between horizontal space 2 and 3). The Figures (4.15) show the moisture content of each treatment separately.

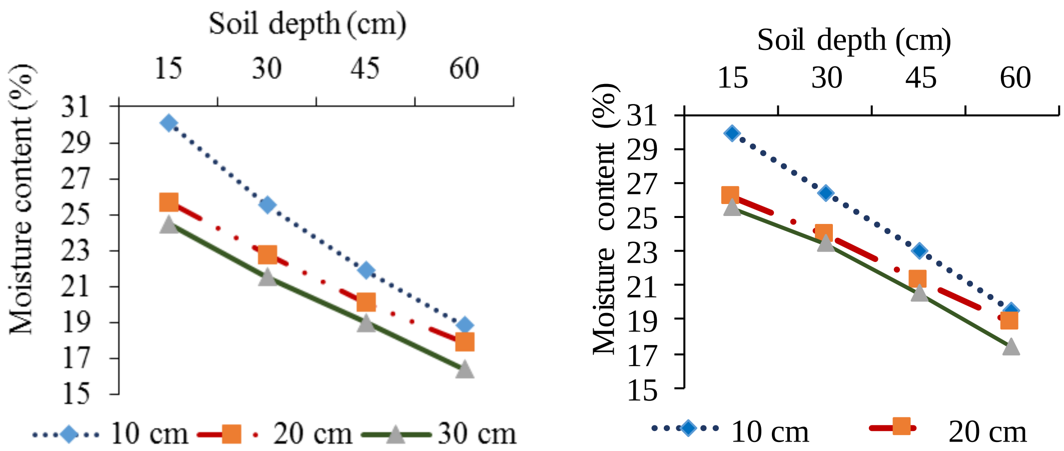


Figure 4.15: Soil moisture content for T1 (200 ppm) and T4 (4500 ppm) / stage one

In this stage, sampling started after the third irrigation event. This indicates that the moisture content started to increase from the original status before irrigation, however the moisture content for both treatments one and four, in this stage are very close to each other's as the results show. This is related to the original hydraulic conductivity of the soil, since sodium effect is not appearing in the first stage and the soil content of calcium ions is high. These results agrees with the results found by (Burt and Isbell, 2005) as they stated that After the first leaching, the distance between soil moisture content contours remains very similar; the levels of different soil moistures move down in the soil profile uniformly.

The results show a general reduction in soil moisture content as moving far from the emitters in both treatments (T1 and T4). At 60 cm depth, the moisture was significantly lower from the above depths. This is resulting from the fact that water is moving in both directions vertical and horizontal, but the quantity of applied water was not enough to make a significant difference within the horizontal space of 10 cm. Thus in the fourth depth (60 cm) the difference is decreasing slowly in both treatments. Moreover in treatment 4 as the salinity content is higher this reduced the sodium effect as shown in Figure (4.16).

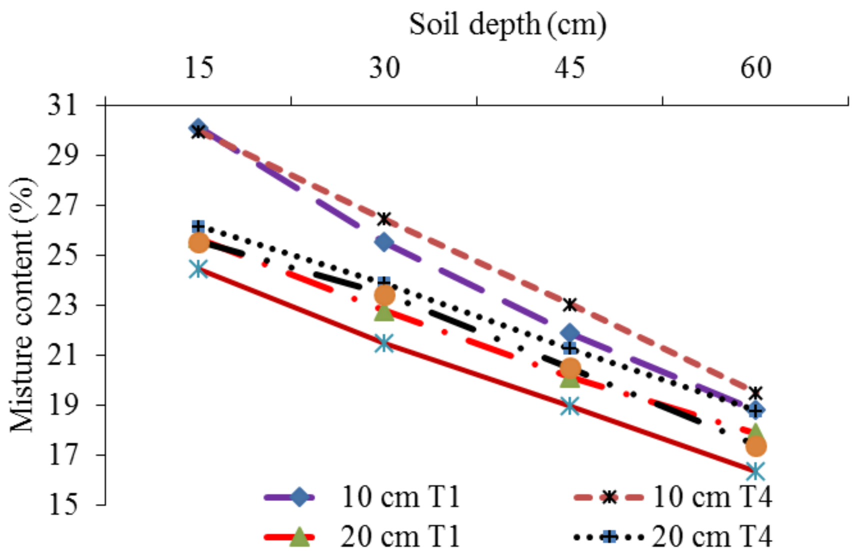


Figure 4.16: Soil moisture content for the T1 (200 ppm) and T4 (4500) ppm at the different depths

It is clear from the Figure (4.15) that the moisture content starts to decrease by increasing the horizontal space from the emitter, but in the same time the difference between the moisture content of T1 (200 ppm) and T4 (4500 ppm) start to increase for the same space. In the results the moisture content of T4 (4500 ppm) is higher than that of desalinated water. This could be explained by the content of calcium and magnesium in saline water, which reduced the effect of sodium on soil physical properties. These results are confirmed by Warrence *et al.* (2002) who stated that calcium and other divalent cations reduces the harmful effect of Na^+ ions.

In the desalinated water the cations concentration is low, thus SAR is highly affecting water vertical movement in soil through effect on physical properties, these results agrees with (Yermiyahu *et al.*, 2009).

Since the soil is not fully saturated with water in the first stage (after third irrigation). The lateral movement is slower than the vertical movement, this is confirmed by the results, where, it shows a significant differences between soil moisture content of 10 cm space (30.14%) at 15 cm depth, with that of 20 and 30 cm space (25.69% and 24.48%, consequently).

In T4 (4500 ppm), it is more clear in all depths, that there is a significant differences in moisture content, this prove the fact that water quantity was not high enough to reach the lowest depth, and it was kept in the layers above .This agrees with Raine *et al.* (2003) and Murtaza *et al.* (2005), who discussed the effect of salinity and sodicity on soil hydraulic conductivity.

4.2.2 Stage two (after one month of planting date)

The same pattern were found, where, the moisture content decreased with depth and distance from the emitter despite, the treatment, Table (4.5) and Figure (4.17) show the results of stage two for the treatments.

Table 4.5: Soil moisture content at T1 (200 ppm) at all soil depths for all horizontal distances after one month of planting / Stage2

Soil depth	Horizontal distance from the emitter (cm)								
			10			10			30
D1: 15 cm	A+	a*	32.08	A	b	29.88	A	c	27.33
D2: 30 cm	B	a	28.58	B	b	26.11	B	b	24.73
D3: 45 cm	C	a	23.99	C	ab	22.96	C	b	21.78
D4: 60 cm	D	a	21.19	D	ab	20.48	D	b	19.36

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*.Letters represent statistical groups (a, b, c, d) a = the highest value, e = is the lowest
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

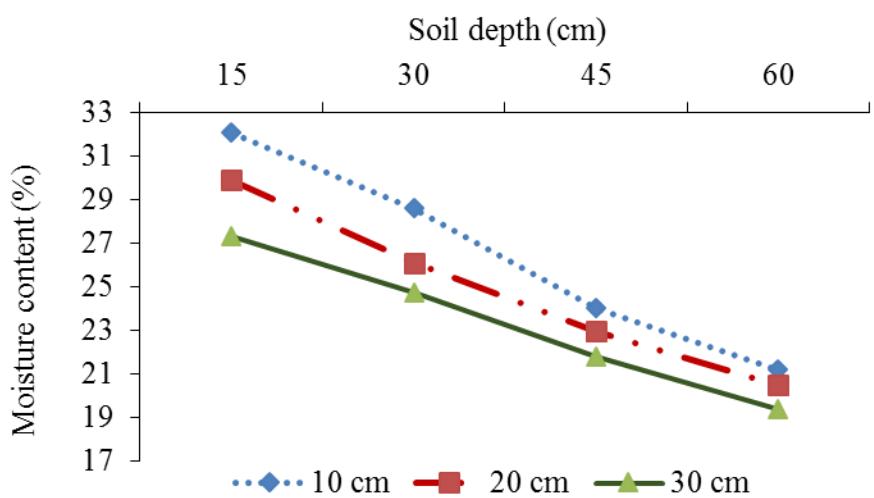


Figure 4.17: Soil moisture content at T1 (200 ppm) after one month of planting / stage 2

As shown in Figure (4.16), the maximum value of the moisture content was found near the emitter at 10 cm horizontal space and 15 cm depth (ϴ =32.08%), while the minimum is (ϴ =19.36%) at 30 cm horizontal space and 60 cm depth. It worth to mention that at 45cm and 60 cm, the moisture content at 20 cm is not significantly different from that at 10 cm nor at that at 30 cm, while moisture content has significant differences at 30 cm from that at 10 cm.

This is gained in treatment four too as shown in Table (4.6) and Figure (4.18), where the moisture content value decreased from (ϴ =31.82%) at 10 cm from emitters and 15 cm depth to reach (ϴ =20.85%) at 60 cm depth and 30 cm from the emitters.

Table 4.6: Soil moisture content at T4 (4500 ppm) for all soil depths and all horizontal distances after one month of planting / Stage 2

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1:15 cm	A*	a*	31.82	A*	b*	28.43	A*	b*	27.59
D2: 30 cm	B	a	29.38	A	b	26.74	B	b	25.95
D3:45 cm	C	a	25.55	B	ab	24.41	C	b	23.02
D4: 60 cm	C	a	23.55	C	ab	22.01	D	b	20.85

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, e = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The moisture content is significantly different with depths, while in the first two depths it was significantly different with space from emitters. Again in 45 & 60 cm depths, the moisture content of 20 cm horizontal space is not significantly different from that of 10 cm or 30 cm, while the moisture content at 30 cm space has significant differences from that of 10 cm space.

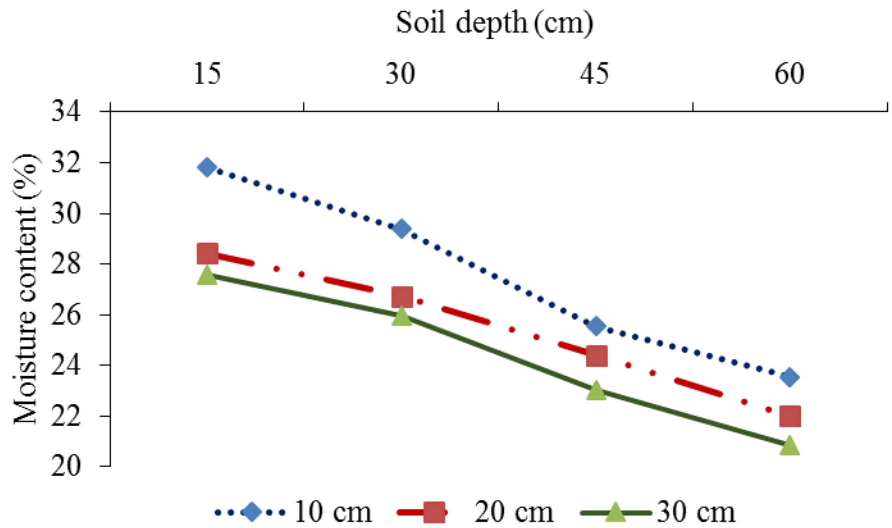


Figure 4.18: Soil moisture content at T4 (4500 ppm) after one month of planting / stage 2

The results show an increase in the soil moisture content; this is coming from the water added through irrigation. In the first depth (15 cm) the significant differences appear between the three spaces, while this significant differences is not existing in the other depths between horizontal space two and three (20 and 30 cm). This is not valid for treatment 4, where there are no significant differences between 20 cm and 30 cm at any depth, moreover there is no significant differences between 10 and 20 cm at the third depth (45 cm) and the fourth depth (60 cm) as shown in Figure (4.19). This is expected since the saline water has counteract the sodium effect and maintain the soil properties from being destroyed. Therefore, water moved vertically in this soil.

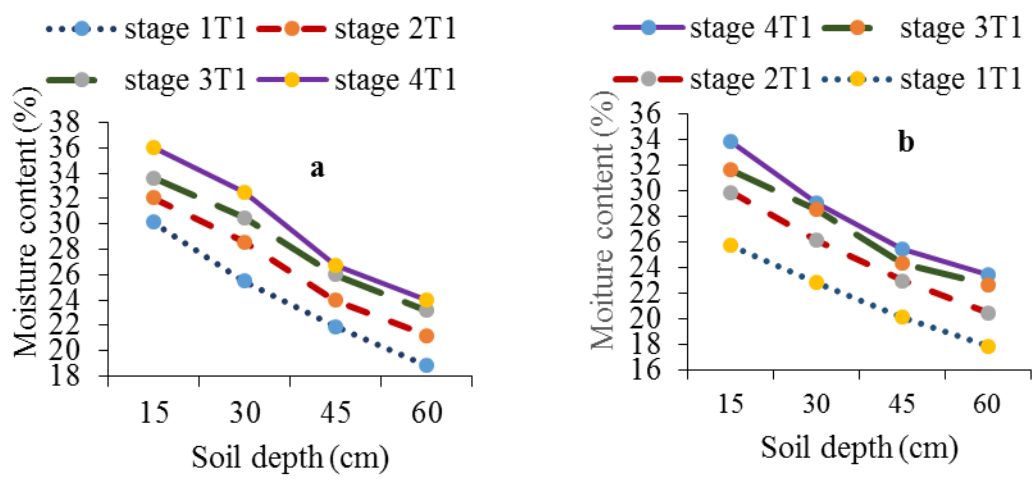


Figure 4.19: Soil moisture content for T1 (200 ppm) at the different stages and depths for a: 10 cm horizontal space; b: 20 cm horizontal space

The results show that during the different stages in treatment one (desalinated water) even though the moisture content is increasing as a result of irrigation, but the vertical movement of water is reduced compared to the lateral movement, due to the effect of sodium on physical properties. This is confirmed by the disappearing of the significant differences between the different spaces for the same depth, this understanding is confirmed by the results of Hanson *et al.*(1999) and (Oosterbaan (2003) when they stated that, breakdown soil aggregates and soil structure causing reducing of soil infiltration capacity and vertical water movement, surface-water-logging or runoff is increased.

As the saline water is used in treatment 4, the salt content kept the balance in cations in the soil. This balance has reduced the effect of increasing SAR, and as a result maintains the soil physical properties (porosity in particular). And the soil hydraulic conductivity didn’t affect. This is shown in Figure (4. 20).

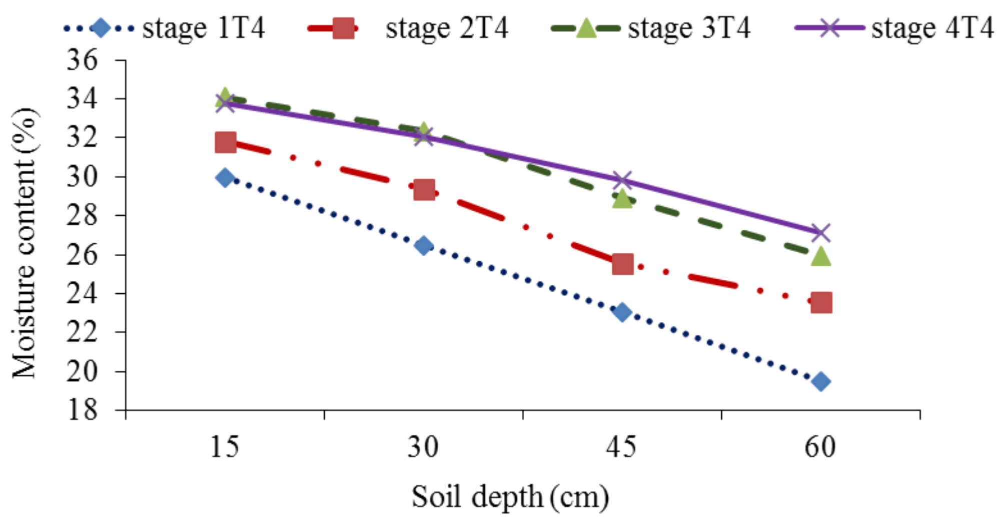


Figure 4.20: Soil moisture content at T4 (4500 ppm) for the different stages and different depths

As the results show that, the differences in moisture content at the different depths is decreasing with the stages due to the addition of water through irrigation, but still, the differences among the stages in the moisture content is decreasing. This is due to the effect of salinity on soil aggregates, where the sodium effect is lower. In the same time as salinity reduced the effect of sodicity on soil, the moisture content at the same depth and stage is higher in treatment four (saline water) than that of treatment one (desalinated water). These results are in parallel with the findings of (Shainberg and Letey, 1984; Sumner, 1993; Qadir and Schubert, 2002) as they reported that, irrigation-induced sodicity in soils exhibits structural problems created by certain physical processes (slaking, swelling, and dispersion of clays) and specific conditions (surface crusting and hard setting).

4.2.3 Stage three (after two months of planting date)

The results show a general increase in the soil moisture content for the depths and spaces as Table (4.7) shows. The maximum moisture content however decreased from (ϴ =33.64%) at 10 cm horizontal space and 15 cm depth to reach (ϴ =21.12%) at 60 cm depth and 30 cm horizontal space from the emitter.

Table 4.7: Soil moisture content at T1 (200 ppm) for all soil depths and all horizontal distances after two month of planting / Stage3

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1: 15 cm	A+	a*	33.64	A	ab*	31.63	A	b*	29.33
D2: 30 cm	B	a	30.51	B	ab	28.52	B	b	26.97
D3: 45 m	C	a	25.99	C	b	24.33	C	c	23.27
D4: 60 cm	D	a	23.16	C	a	22.65	D	b	21.12

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, e = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The results in Figure (4.21) show that the soil moisture content vary with significant differences with the depth, while the lateral moisture content differences are not significant 60 cm for 10 and 20 cm horizontal space.

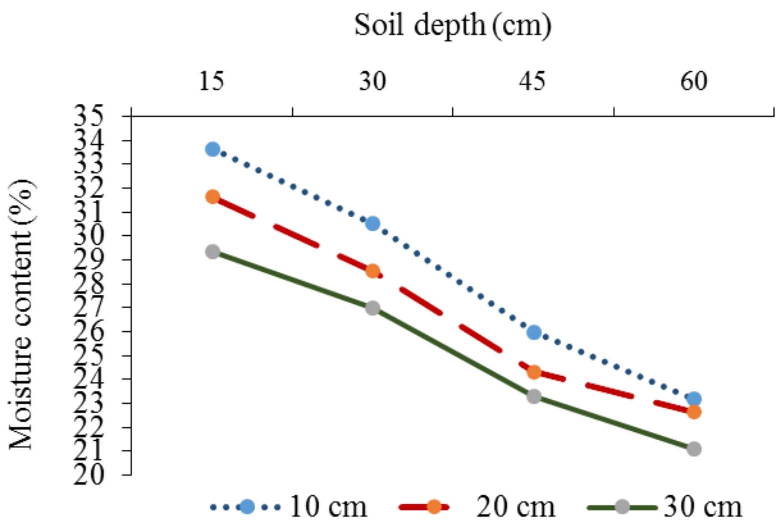


Figure 4.21: Soil moisture content for T1 (200 ppm) after two months of planting / stage 3

Almost the same trend was found for T 4 (4500 ppm) as the results are presented in Table (4.8). It is clear that the maximum soil moisture content result in the closest position to the emitter (10 cm horizontal space and 15 cm depth; ϴ =33.64%), while the minimum value was (ϴ =21.12%) at 30 cm space and 60 cm depth.

This is confirmed by the soil moisture content of T 4, where the results show similar trend but with a higher values of moisture content Table (4.8). The maximum value of soil moisture content for treatment 4 was (ϴ =34.10%) at 10 cm space and 15 cm depth, while the minimum value is (ϴ =22.53%) at 30 cm space and 60 cm depth.

Table 4.8: Soil moisture content at T4 (4500) for all soil depths and all horizontal distances after two months of planting / Stage 3

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1: 15 cm	A+	a*	34.10	A	b	32.86	A	c	28.33
D2: 30 cm	B	a	32.33	A	a	31.27	A	b	27.14
D3: 45 cm	C	a	28.91	B	a	26.96	B	b	24.94
D4: 60 cm	D	a	25.96	C	b	24.88	C	c	22.53

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, e = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

The results presented in Table 4.8 show that the variations are not regularly significant with depth as in the previous stages or as in T 1 (200 ppm). The significant differences are found for the first horizontal space (10 cm) while for the other horizontal spaces (20, 30 cm) we found no significant differences for the first two depths. In the same time the horizontal space from the emitter have only significant differences in the first depth (15 cm) as shown in Figure (4.22).

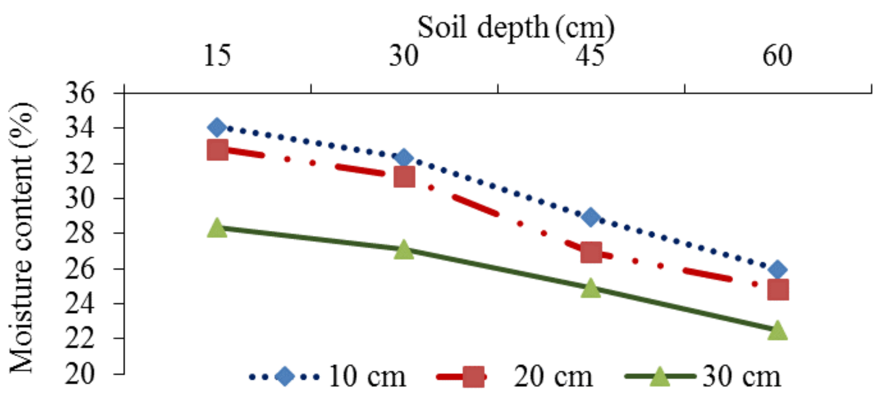


Figure 4.22: Soil moisture content at T4 (4500 ppm) after two months of planting / stage 3

4.2.4 Stage four (after season completion)

The results of soil moisture content continue to increase as shown in Table (4.9), where, the maximum value of the moisture content (ϴ =35.99%) is achieved at 10 cm horizontal space and 15 cm depth, compared to the previous stages. However the minimum value achieved in this stage is (ϴ =22.03%), which is higher than the minimum values for treatment 1 in the other stages.

Table 4.9: Soil moisture content at T1 (200 ppm) for all soil depths and all horizontal distances after crop completion / Stage 4

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1: 15 cm	A+	a*	35.99	A	b	33.87	A	c	31.67
D2: 30 cm	B	a	32.54	B	b	29.06	B	b	29.18
D3: 45 cm	C	a	26.70	C	a	25.40	C	a	24.78
D4: 60 cm	C	a	24.01	C	ab	23.46	D	b	22.03

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, e= is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

In the Table 4.10 there are significant variation between results for both directions spaces and depths, also the results of treatment 4 continue to increase in regard to the stages, in addition the table shows the maximum value of the moisture content (ϴ = 33.81%), is higher than the other stages for 10 cm horizontal space and 15 cm depth, with a minimum of (ϴ =24.42%).

Table 4.10: Moisture content at T4 (4500 ppm) for all soil depths and all horizontal distances after crop completion / Stage 4

Soil depth	Horizontal distance from the emitter (cm)								
			10			20			30
D1: 15 cm	A+	a	33.81	A	a	33.49	A	b	30.14
D2: 30 cm	B	a	32.08	B	ab	31.49	AB	b	29.07
D3: 45 cm	C	a	29.85	C	a	28.35	BC	b	26.26
D4: 60 cm	D	a	27.15	D	a	25.83	C	b	24.42

+Capital Letters represent statistical groups (A, B, C, D) A = the highest value, D = is the lowest.
*Letters represent statistical groups (a, b, c, d) a = the highest value, e = is the lowest.
Values followed by the same alphabetical letter in each column do not differ significantly from each other using LSD.

In this stage for treatment 4, the significant differences are clearer between the depths and the differences start to disappear with increasing both depth and horizontal distance from emitters.

In these stages (three and four), the soil moisture content in both treatments increased as shown in the results. However, in treatment one the differences in moisture content between depths continue to be significant, while it start to reduce between spaces (lateral movement). It is clear that with time as irrigation continue, the soil infiltration rate is decreasing due to the imbalance between different cations, and this affected the soil physical properties. In result, the horizontal movement increases versus the vertical movement.

In T4 (4500 ppm), the differences in soil moisture content are significant at the near horizontal space (10 cm space). This difference in moisture is not significant in the first two depths. This results is explained by the effect of salinity which maintained the infiltration rate, thus the differences have been reduced in the first two layers. Taking into consideration that the quantity of water is not enough to move downward, the differences in soil moisture content still to exist between these two surface layers and the deeper layers (45 and 60 cm).

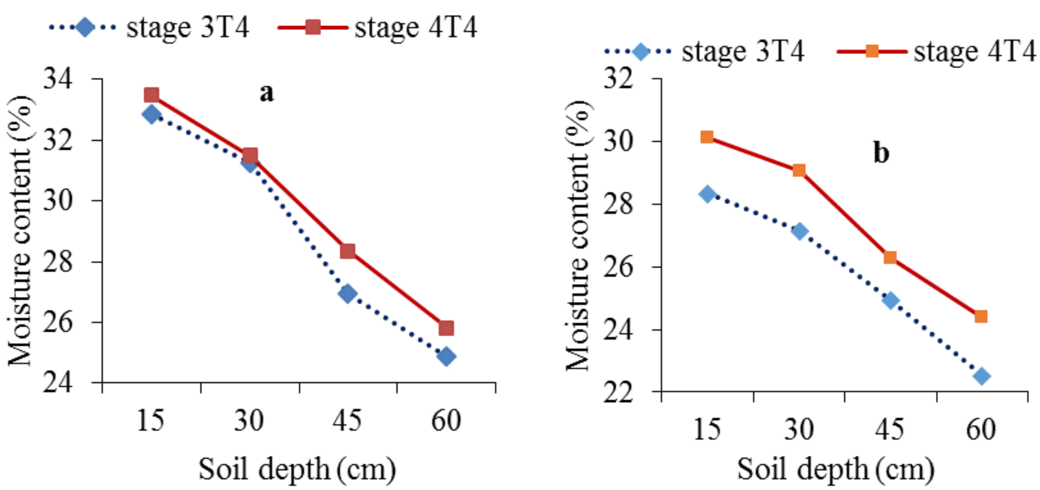


Figure 4.23: Soil moisture content of T4 (4500 ppm) at different stages with depths for a: 20 cm horizontal space; b: 30 cm space

As shown in Figure (4.23), the differences of soil moisture content for 20 cm horizontal space and 30 cm horizontal space are not significant for the first two layers, in the stage three and four. This is understood when compared to the desalinated water, where we found significant differences in the vertical axis, while the differences started to reduce in the lateral axis. Murtaza *et al.* (2005) explained this when he discussed the effect of salinity in reducing the SAR effect on soil In saline irrigation, the water is moving vertically faster to that in desalinated water, due to the antagonistic effect between sodicity and salinity; however salinity reduced the effect of increasing in SAR on hydraulic conductivity.

4.3 Soil structure

A field assessment of soil structure was conducted in the site of the experiment in different stages for the surface layer (0 – 15 cm); before planting and after the completion. The soil structure was studied in the end of August 2013 and after completion the soil structure was studied again at the end of June 2014 for the same treatments T1, T2, T3 and T4. The results show that there are no structure difference between all treatments before planting and after completion in the structure parameters Type, Size and Grade except in (T1) as structure type became granular and crumb with moderate grade. The full results are presented in Table (4.11).

Table 4.11: Soil structure assessed in site for all treatments in stage 1 (before planting) and stage 2 (at season completion)

Stage	Treatment	Structure		
		Type	Size	Grade
Before irrigation	T1	Granular and sub angular	Medium	moderate to strong
	T2	Granular and sub angular	Medium	moderate to strong
	T3	Granular and sub angular	Medium	moderate to strong
	T4	Granular and sub angular	Medium	moderate to strong
After irrigation	T1	Granular and crumb	Medium	moderate
	T2	Granular and sub angular	Medium	moderate to strong
	T3	Granular and sub angular	Medium	moderate to strong
	T4	Granular and sub angular	Medium	moderate to strong

The structure type in T1 before planting was Granular and sub angular with medium size and the structure grade was moderate to strong, while after season completion structure type was classified as granular and crump with medium size and moderate Grade as shown in Table (4.11).

According to FAO (1985), soil structure is defined as arrangement of the soil constituent or particles (sand, silt and clay) to the small groups call soil aggregates, the small aggregates can form larger aggregate separated by pores and cracks.

There are many factors that affect the structure, among these: climate, Organic matter, Tillage, plant and roots, organisms, witting and drying, inorganic cements, soil texture and finally exchangeable cations especially calcium, Magnesium and Sodium (introduction to soil science).

In the experiment, no significant changes in the soil structure were noticed in T2, T3, and T4 after irrigation completion in comparison to the status before planting. However in T1, there is significance variation seen in the soil structure after the growing completion. Since all treatments are subjecte3d to the same environmental conditions, the effect on structure in T1 is related to the irrigation water quality, namely the sodium content. As the irrigation with desalinated water started, the SAR in the soil increased due to the addition of high water (16), this lead to a negatively noticed change in the soil structure, which agrees with Warrence *et al.* (2002), who stated that increasing sodium in soil solution relatively to the calcium and magnesium resulted to degrade the soil aggregates to smaller aggregates and causes to destroy soil structure if SAR increased highly above 15. In addition this agrees with (Tajik *et al.*, 2003; Oster, 2002)**.**

In the view of contradicted effect of sodicity and salinity on structure we can understand the absence of structure changes with the irrigation blended water or raw brackish water.

In the other treatments (T2, T3, T4) the water content of calcium and magnesium has reduced the dispersion of soil clay particles, thus the structure didn't affect. This is confirmed by the SAR results.

In treatments T2, T3, and T4, saline water with different salinity levels and deferent levels of calcium, magnesium and other elements were added through irrigation, increased salinity and increased concentration of calcium and magnesium, this led to maintain soil structure without notice variation this result was agreed by Carrow *et al*. (1998). Sodium concentration in the soil solution control degree of soil structure degradation, high sodium concentration relative to calcium and magnesium reflect high structure degradation and soil particles dispersion because sodium conceder dispersion element comparing with other elements especially calcium and magnesium because sodium has large hydrous diameter and the forces hold clay particles (sand, silt, slay) together are greatly weakened if the soil have sodium, and water come into contact, this was approved by Seelig,(2000) as he mentioned that the forces that bind clay particles together to create soil aggregates are greatly weakened when soil with high sodium content, and clay particles are easily degraded from larger aggregates.

Chapter five

Conclusions and recommendations

5.1 Conclusions

1. Irrigating heavy saline soils with desalinated water increases the Sodium Adsorption Ratio (SAR).SAR was clearly increased especially in first 15 cm even worse than brackish water, SAR value was increased from 8.17 to 10.21 in the surface soil layer (15 cm) whereas SAR was slightly decreased in the in T2 (750 ppm), T3 (1600 ppm) which was irrigated with blinding ratio and T4 which was irrigated with raw brackish water with TDS 4500 ppm comparing with blank.

2. Irrigating heavy saline soils with desalinated water negatively affected the soil structure in the surface layer (15 cm), even worse than brackish water, as soil structure was changed from granular and sub angular with medium size and moderate to strong grad, when irrigated with saline soil, to granular and crump with medium size and moderate grade.

3. Irrigating heavy saline soils with desalinated water increases water movement horizontally and decreases water movement vertically as compared with brackish water. The value of moisture content reduced for the first horizontal 10 cm from (Θ = 35.99 %) for T1 (200 ppm) at D1 (15 cm) to (Θ = 24.01 %) at D4 (60 cm) for stage 4 (after crop completion), whereas at T4 (4500 ppm), the value of the moisture content reduced from (Θ = 33.81 %) at D1 (15 cm) to (Θ = 27.15 %) at D4 (60 cm) for the same stage. On the other hand, the value of the moisture content reduced from (Θ =

35.99 %) for T1 (200) ppm for horizontal space 10 of the emitters to (ϴ = 31.67 %) for horizontal distance 30 cm at D1 (15 cm). Whereas the value of the moisture content at T4 (4500) ppm reduced from (ϴ = 33.81 %) for horizontal distance 10 cm at D1 (15 cm) to (ϴ = 30.14 %) for the horizontal distance 30 cm at D1 (15 cm) for stage 4 (after crop completion.

4. The optimum blinding ration found to achieve the avoiding of soil degradation properties as a result of using desalinated water on heavy saline soil properties is that with total dissolved salts of the irrigation water 1600 ppm.

5.2 Recommendations

1. Continuous and comprehensive researches should be continued in the same conditions to overcome any expected negative results on soil properties and plant nutrition.

2. Calcium and Magnesium sources should be added or injected with irrigation system or direct to the soil.

3. Improving soil physical properties and soil management practises to increase leaching process of the sodium and salinity out of the root zoon.

4. Direct supervision form the soil and irrigation experts to follow the farmers whom using desalinated water for irrigation in their farms.

5. Blinding desalinated with brackish water to increase mainly calcium and magnesium content considered as is low cost strategy.

6.Annexes

6.1 Irrigation water requirement

Irrigation date	Irrigation quantity (liter)	Irrigation date	Irrigation quantity (liter)	Irrigation date	Irrigation quantity (liter)
02-Oct	402	22-Dec	228	12-Mar	777
05-Oct	302	25-Dec	60	15-Mar	809
08-Oct	286	28-Dec	181	18-Mar	837
11-Oct	270	31-Dec	63	21-Mar	866
14-Oct	242	03-Jan	76	24-Mar	893
17-Oct	197	06-Jan	284	27-Mar	919
20-Oct	236	09-Jan	74	30-Mar	945
23-Oct	242	12-Jan	302	02-Apr	969
26-Oct	181	15-Jan	79	05-Apr	990
29-Oct	152	18-Jan	244	08-Apr	1011
01-Nov	150	21-Jan	102	11-Apr	1032
04-Nov	239	24-Jan	189	14-Apr	1047
07-Nov	236	27-Jan	236	17-Apr	1063
10-Nov	176	30-Jan	391	20-Apr	1037
13-Nov	221	02-Feb	102	23-Apr	1005
16-Nov	231	05-Feb	417	26-Apr	958
19-Nov	231	08-Feb	423	29-Apr	929
22-Nov	226	11-Feb	473	02-May	866
25-Nov	218	14-Feb	501		
28-Nov	113	17-Feb	530		
01-Dec	207	20-Feb	562		
04-Dec	152	23-Feb	591		
07-Dec	53	26-Feb	622		
10-Dec	105	29-Feb	654		
13-Dec	53	03-Mar	685		
16-Dec	221	06-Mar	717		
19-Dec	55	09-Mar	748		

6.2 Results of soil analysis

Table 6.2.1: Soil EC (dS/m) concentration in all stages for all depths in T1

	Stage 1 T1	Stage 2 T1	Stage 3 T1	Stage 4 T1
Depth 1 & Space 1	3.20	2.54	1.60	0.79
Depth 2 & Space 1	3.37	2.76	2.18	1.11
Depth 3 & Space 1	4.00	3.07	2.18	1.48
Depth 4 & Space 1	4.45	3.61	2.61	1.99
Depth 1 & Space 2	3.56	3.13	1.98	1.23
Depth 2 & Space 2	4.13	3.37	2.46	1.41
Depth 3 & Space 2	4.36	3.61	2.49	1.87
Depth 4 & Space 2	4.95	3.98	3.12	2.59
Depth 1 & Space 3	4.24	3.43	2.35	1.35
Depth 2 & Space 3	4.55	3.64	2.64	1.75
Depth 3 & Space 3	4.75	3.95	3.18	2.23
Depth 4 & Space 3	5.25	4.39	3.54	2.65

Table 6.2.2: Soil EC (dS/m) concentration in all stages for all depths in T4

	Stage 1T4	Stage 2T4	Stage 3T4	Stage 4T4
Depth 1 & Space 1	6.53	5.54	3.96	2.32
Depth 2 & Space 1	7.12	5.19	4.18	2.70
Depth 3 & Space 1	7.43	5.44	4.33	3.21
Depth 4 & Space 1	8.09	6.29	4.81	3.83
Depth 1 & Space 2	7.06	6.10	4.37	2.54
Depth 2 & Space 2	7.32	5.00	4.61	2.88
Depth 3 & Space 2	7.49	5.72	4.77	3.48
Depth 4 & Space 2	8.30	6.46	5.25	4.23
Depth 1 & Space 3	7.47	6.37	4.55	2.83
Depth 2 & Space 3	7.66	5.87	4.92	3.51
Depth 3 & Space 3	8.00	5.90	5.28	4.15
Depth 4 & Space 3	8.56	6.45	5.64	4.59

Table 6.2.3: Mean values of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in the investigated soil For T1

	Soil depth (cm)	Ca^{2+} meq/l	Mg^{2+} meq/l	Na^{+} meq/l	K^{+} ppm
Treatment 1 Before planting	0 - 15	33.00	47.00	52.17	120.65
	15 - 30	20.8	41.00	41.43	112.4
	30 - 45	17.6	35.34	35.30	90.6
	45 - 60	15.8	31.22	30.43	75.36
Treatment 1 At completion	0 - 15	6.635	15.50	33.97	59.07
	15 - 30	5.32	12.07	24.56	69.09
	30 - 45	4.65	7.115	21.29	77.54
	45 - 60	4.61	9.385	22.69	95.47

Table 6.2.4: Mean values of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in the investigated soil For T2

	Soil depth (cm)	Ca^{2+} meq/l	Mg^{2+} meq/l	Na^{+} meq/l	K^{+} ppm
Treatment 2 Before planting	0 - 15	33.7	47.32	51.21	125.00
	15 - 30	22.5	42.32	42.49	120.00
	30 - 45	18.2	34.47	34.91	91.00
	45 - 60	17.22	32.39	31.31	77.00
Treatment 2 At completion	0 - 15	13.56	21.48	31.91	74.50
	15 - 30	12.64	22.34	26.18	81.00
	30 - 45	13.56	18.53	27.73	87.00
	45 - 60	15.05	25.72	32.42	96.00

Table 6.2.5: Mean values of Ca^{2+}, Mg^{2+}, Na, and K in the investigated soil For T3

	Soil depth (cm)	Ca^{2+} meq/l	Mg^{2+} meq/l	Na^{+} meq/l	K^{+} ppm
Treatment 3 Before planting	0 - 15	33.0	46.8	51.6	123.0
	15 - 30	21.7	41.9	41.6	127.0
	30 - 45	17.9	35.1	34.1	86.0
	45 - 60	16.8	32.1	30.8	79.0
Treatment 3 At completion	0 - 15	18.3	32.8	30.5	89.0
	15 - 30	16.4	28.3	31.1	90.8
	30 - 45	15.8	23.9	30.3	82.3
	45 - 60	15.7	24.0	31.6	90.5

Table 6.2.6: Mean values of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in the investigated soil For T4

	Soil depth (cm)	Ca^{2+} meq/l	Mg^{2+} meq/l	Na^{+} meq/l	K^{+} ppm
Treatment 4 Before planting	0 - 15	32.12	47.8	51.94	116
	15 - 30	22.52	42.5	41.75	119
	30 - 45	18.2	29.87	31.23	95
	45 - 60	21.1	33.18	29.25	69
Treatment 4 At completion	0 - 15	21.40	33.70	35.37	89.25
	15 - 30	17.70	27.50	33.88	93.5
	30 - 45	20.70	31.50	37.60	94.75
	45 - 60	30.00	41.20	45.00	83.25

6.3 SAR statistics

6.3.1 Homogeneous Subsets for SAR in soil depth 1

Value

Treatment	N	Subset for alpha = 0.05				
		1	2	3	4	5
3	4	6.039490				
4	4		6.737447			
2	4			7.622647		
0	4				8.171762	
1	4					10.213216
Sig.		1.000	1.000	1.000	1.000	1.000

6.3.2 Homogeneous Subsets for SAR in soil depth 2

Value

Treatment	N	Subset for alpha = 0.05				
		1	2	3	4	5
2	4	6.261756				
3	4		6.580108			
4	4			7.120465		
0	4				7.401639	
1	4					8.330073
Sig.		1.000	1.000	1.000	1.000	1.000

6.3.3 Homogeneous Subsets for SAR in soil depth 3

Value

Treatment	N	Subset for alpha = 0.05		
		1	2	3
0	4	6.664883		
3	4	6.800250		
2	4	6.923164		
4	4		7.352911	
1	4			8.781461
Sig.		.233	1.000	1.000

6.3.4 Homogeneous Subsets for SAR in soil depth 4

Value

Treatment	N	Subset for alpha = 0.05			
		1	2	3	4
0	4	6.102376			
3	4		7.076423		
2	4		7.180146	7.180146	
4	4			7.537950	
1	4				8.576186
Sig.		1.000	.933	.094	1.000

6.3.5 Homogeneous Subsets for SAR in the blank treatment

Value

Soil Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	6.102376			
3	4		6.664883		
2	4			7.401639	
1	4				8.171762
Sig.		1.000	1.000	1.000	1.000

6.3.5 Homogeneous Subsets for SAR in the treatment 1

Value

Soil Depth	N	Subset for alpha = 0.05		
		1	2	3
2	4	8.330073		
4	4	8.576186	8.576186	
3	4		8.781461	
1	4			10.213216
Sig.		.095	.191	1.000

6.3.6 Homogeneous Subsets for SAR in the treatment 2

Value

Soil Depth	N	Subset for alpha = 0.05			
		1	2	3	4
2	4	6.261756			
3	4		6.923164		
4	4			7.180146	
1	4				7.622647
Sig.		1.000	1.000	1.000	1.000

6.3.7 Homogeneous Subsets for SAR in the treatment 3

Value

Soil Depth	N	Subset for alpha = 0.05				
		1	2	3	4	
1	4	6.039490				
2	4		6.580108			
3	4			6.800250		
4	4				7.076423	
Sig.		1.000	1.000	1.000	1.000	

6.3.8 Homogeneous Subsets for SAR in the treatment 4

Value

Soil Depth	N	Subset for alpha = 0.05		
		1	2	3
1	4	6.737447		
2	4		7.120465	
3	4			7.352911
4	4			7.537950
Sig.		1.000	1.000	.058

6.4: Moisture content Statistics

6.4.1 Moisture content for T1 at stage1 and distance1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	18.827500			
3	4		21.905000		
2	4			25.530000	
1	4				30.137500
Sig.		1.000	1.000	1.000	1.000

6.4.2 Moisture content for T1 at stag1 dstance2

M.C

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	17.882500		
3	4	20.120000		
2	4		22.797500	
1	4			25.692500
Sig.		.070	1.000	1.000

6.4.3 Moisture content for T1 at stag1 dstance3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	16.390000			
3	4		19.007500		
2	4			21.520000	
1	4				24.477500
Sig.		1.000	1.000	1.000	1.000

6.4.4 Moisture content for T1 at stag2 dstance1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	21.190000			
3	4		23.990000		
2	4			28.582500	
1	4				32.075000
Sig.		1.000	1.000	1.000	1.000

6.4.5 Moisture content for T1 at stag2 dstance2

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	20.482500			
3	4		22.957500		
2	4			26.105000	
1	4				29.880000
Sig.		1.000	1.000	1.000	1.000

6.4.6 Moisture content for T1 at stag2 dstance3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	19.362500			
3	4		21.775000		
2	4			24.727500	
1	4				27.325000
Sig.		1.000	1.000	1.000	1.000

6.4.7 Moisture content for T1 at stag 3 distance1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	23.162500			
3	4		25.990000		
2	4			30.507500	
1	4				33.642500
Sig.		1.000	1.000	1.000	1.000

6.4.8 Moisture content for T1 at stage 3 distance 2

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	22.645000		
3	4	24.325000		
2	4		28.520000	
1	4			31.630000
Sig.		.164	1.000	1.000

6.4.9 Moisture content for T1 at stage 3 distance 3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	21.115000			
3	4		23.270000		
2	4			26.970000	
1	4				29.325000
Sig.		1.000	1.000	1.000	1.000

6.4.10 Moisture content for T1 at stage 4 distance 1

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	24.005000		
3	4	26.697500		
2	4		32.540000	
1	4			35.990000
Sig.		.053	1.000	1.000

6.4.11 Moisture content for T1 at stage 4 distance 2

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	23.457500		
3	4	25.397500		
2	4		29.060000	
1	4			33.870000
Sig.		.118	1.000	1.000

6.4.12 Moisture content for T1 at stage 4 distance 3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	22.030000			
3	4		24.782500		
2	4			29.182500	
1	4				31.670000
Sig.		1.000	1.000	1.000	1.000

6.4.13 Moisture content for T4 at Stage 1 distance 1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	19.507500			
3	4		23.050000		
2	4			26.470000	
1	4				29.972500
Sig.		1.000	1.000	1.000	1.000

6.4.14 Moisture content for T4 at Stage 1 distance 2

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	18.797500			
3	4		21.292500		
2	4			23.910000	
1	4				26.190000
Sig.		1.000	1.000	1.000	1.000

6.4.15 Moisture content for T4 at Stage 1 distance 3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	17.402500			
3	4		20.520000		
2	4			23.472500	
1	4				25.555000
Sig.		1.000	1.000	1.000	1.000

6.4.16 Moisture content for T4 at Stage 2 distance 1

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	23.547500		
3	4	25.552500		
2	4		29.382500	
1	4			31.817500
Sig.		.075	1.000	1.000

6.4.17 Moisture content for T4 at Stage 2 distance 2

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	22.012500		
3	4		24.407500	
2	4			26.740000
1	4			28.427500
Sig.		1.000	1.000	.055

6.4.18 Moisture content for T4 at Stage 2 distance 3

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	20.850000			
3	4		23.017500		
2	4			25.952500	
1	4				27.587500
Sig.		1.000	1.000	1.000	1.000

6.4.19 Moisture content for T4 at Stage 3 distance 1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	25.955000			
3	4		28.910000		
2	4			32.330000	
1	4				34.102500
Sig.		1.000	1.000	1.000	1.000

6.4.20 Moisture content for T4 at Stage 3 distance 2

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	24.875000		
3	4		26.955000	
2	4			31.265000
1	4			32.855000
Sig.		1.000	1.000	.059

6.4.21 Moisture content for T4 at Stage 3 distance 3

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	22.525000		
3	4		24.935000	
2	4			27.140000
1	4			28.330000
Sig.		1.000	1.000	.136

6.4.22 Moisture content for T4 at Stage 4 distance 1

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	27.150000			
3	4		29.845000		
2	4			32.080000	
1	4				33.807500
Sig.		1.000	1.000	1.000	1.000

6.4.23 Moisture content for T4 at Stage 4 distance 2

Depth	N	Subset for alpha = 0.05			
		1	2	3	4
4	4	25.825000			
3	4		28.350000		
2	4			31.490000	
1	4				33.485000
Sig.		1.000	1.000	1.000	1.000

6.4.24 Moisture content for T4 at Stage 4 distance 3

Depth	N	Subset for alpha = 0.05		
		1	2	3
4	4	24.415000		
3	4	26.262500	26.262500	
2	4		29.070000	29.070000
1	4			30.140000
Sig.		.285	.059	.705

6.4.25 Moisture content for T1 at Stage 1 Depth 1

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	24.477500	
2	4	25.692500	
1	4		30.137500
Sig.		.250	1.000

6.4.26 Moisture content for T1 at Stage 1 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	21.520000	
2	4	22.797500	
1	4		25.530000
Sig.		.090	1.000

6.4.27 Moisture content for T1 at Stage 1 Depth 3

M.C

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	19.007500	
2	4	20.120000	
1	4		21.905000
Sig.		.235	1.000

6.4.28 Moisture content for T1 at Stage 1 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	16.390000	
2	4	17.882500	17.882500
1	4		18.827500
Sig.		.087	.319

6.4.29 Moisture content for T1 at Stage 2 Depth 1

Distance	N	Subset for alpha = 0.05		
		1	2	3
3	4	27.325000		
2	4		29.880000	
1	4			32.075000
Sig.		1.000	1.000	1.000

6.4.30 Moisture content for T1 at Stage 2 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	24.727500	
2	4	26.105000	
1	4		28.582500
Sig.		.063	1.000

6.4.31 Moisture content for T1 at Stage 2 Depth 3

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	21.775000	
2	4	22.957500	22.957500
1	4		23.990000
Sig.		.102	.159

6.4.32 Moisture content for T1 at Stage 2 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	19.362500	
2	4	20.482500	20.482500
1	4		21.190000
Sig.		.122	.382

6.4.33 Moisture content for T1 at Stage 3 Depth 1

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	29.325000	
2	4	31.630000	31.630000
1	4		33.642500
Sig.		.066	.110

6.4.34 Moisture content for T1 at Stage 3 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	26.970000	
2	4	28.520000	28.520000
1	4		30.507500
Sig.		.225	.106

6.4.35 Moisture content for T1 at Stage 3 Depth 3

Distance	N	Subset for alpha = 0.05		
		1	2	3
3	4	23.270000		
2	4		24.325000	
1	4			25.990000
Sig.		1.000	1.000	1.000

6.4.36 Moisture content for T1 at Stage 3 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	21.115000	
2	4		22.645000
1	4		23.162500
Sig.		1.000	.569

6.4.37 Moisture content for T1 at Stage 4 Depth 1

Distance	N	Subset for alpha = 0.05		
		1	2	3
3	4	31.670000		
2	4		33.870000	
1	4			35.990000
Sig.		1.000	1.000	1.000

6.4.38 Moisture content for T1 at Stage 4 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
2	4	29.060000	
3	4	29.182500	
1	4		32.540000
Sig.		.988	1.000

6.4.39 Moisture content for T1 at Stage 4 Depth 3

Distance	N	Subset for alpha = 0.05
		1
3	4	24.782500
2	4	25.397500
1	4	26.697500
Sig.		.090

6.4.40 Moisture content for T1 at Stage 4 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	22.030000	
2	4	23.457500	23.457500
1	4		24.005000
Sig.		.128	.692

6.4.41 Moisture content for T4 at Stage 1 Depth 1

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	25.555000	
2	4	26.190000	
1	4		29.972500
Sig.		.457	1.000

6.4.42 Moisture content for T4 at Stage 1 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	23.472500	
2	4	23.910000	
1	4		26.470000
Sig.		.355	1.000

6.4.43 Moisture content for T4 at Stage 1 Depth 3

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	20.520000	
2	4	21.292500	
1	4		23.050000
Sig.		.106	1.000

6.4.44 Moisture content for T4 at Stage 1 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	17.402500	
2	4		18.797500
1	4		19.507500
Sig.		1.000	.337

6.4.45 Moisture content for T4 at Stage 2 Depth 1

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	27.587500	
2	4	28.427500	
1	4		31.817500
Sig.		.144	1.000

6.4.46 Moisture content for T4 at Stage 2 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	25.952500	
2	4	26.740000	
1	4		29.382500
Sig.		.240	1.000

6.4.47 Moisture content for T4 at Stage 2 Depth 3

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	23.017500	
2	4	24.407500	24.407500
1	4		25.552500
Sig.		.106	.195

6.4.48 Moisture content for T4 at Stage 2 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	20.850000	
2	4	22.012500	22.012500
1	4		23.547500
Sig.		.269	.124

6.4.49 Moisture content for T4 at Stage 3 Depth 1

Distance	N	Subset for alpha = 0.05		
		1	2	3
3	4	28.330000		
2	4		32.855000	
1	4			34.102500
Sig.		1.000	1.000	1.000

6.4.50 Moisture content for T4 at Stage 3 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	27.140000	
2	4		31.265000
1	4		32.330000
Sig.		1.000	.171

6.4.51 Moisture content for T4 at Stage 3 Depth 3

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	24.935000	
2	4		26.955000
1	4		28.910000
Sig.		1.000	.055

6.4.52 Moisture content for T4 at Stage 3 Depth 4

Distance	N	Subset for alpha = 0.05		
		1	2	3
3	4	22.525000		
2	4		24.875000	
1	4			25.955000
Sig.		1.000	1.000	1.000

6.4.53 Moisture content for T4 at Stage 4 Depth 1

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	30.140000	
2	4		33.485000
1	4		33.807500
Sig.		1.000	.839

6.4.54 Moisture content for T4 at Stage 4 Depth 2

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	29.070000	
2	4	31.490000	31.490000
1	4		32.080000
Sig.		.075	.816

6.4.55 Moisture content for T4 at Stage 4 Depth 3

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	26.262500	
2	4		28.350000
1	4		29.845000
Sig.		1.000	.142

6.4.56 Moisture content for T4 at Stage 4 Depth 4

Distance	N	Subset for alpha = 0.05	
		1	2
3	4	24.415000	
2	4		25.825000
1	4		27.150000
Sig.		1.000	.065

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