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Evaluation of the growth of date palm seedlings irrigated with saline water in Sultanat of Oman

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Salim bin Abdullah bin Rashid Al-Rasbi

LIST OF ABBREVIATIONS

Abbreviation	Meaning	Abbreviation	Meaning
%	Percent	RGR	Relative growth rate
C	Carbon	SO_4^-	Sulphate ions
Ca^{2+}	Calcium	SAR	Sodium Adsorption Ratio
Cm	Centimeters	MPa	Mega pascal
$dS\ m^{-1}$	Deci Siemens per meter	NFR	Nitrogen fixation rate
EC	Electrical conductivity	mM	Milli mole
EC_e	Electrical conductivity of saturation extract	P	Phosphorus
EC_{iw}	Electrical conductivity of irrigation water	$mmol_c\ L^{-1}$	Milli mole charge per liter
$mg\ Kg^{-1}$	Milligram per Kilogram	DM	Dry Matter
Ha	Hectare	Cl	Chloride
K	Potassium	N	Nitrogen
Kg	Kilogram	SNB	Symbiotic Nitrogen Fixing Bacteria
M/m	Meter	m^2	Meter square
ha^{-1}	Per hectare	Kg^{-1}	Per kilogram
$t.ha^{-1}$	Ton per hectare	C^o	Centigrade
USDA	United State Department of Agriculture	UAE	United Arab Emirates
Wt.	Weight	L	Litre
Yr.	Year	Mm	Millimeter
pH	Negative logarithm of hydrogen ion activity	Ml	Milliliter
Ppm	Parts per million	OM	Organic matter
RCBD	Randomized complete block design	Km	Kilometer
SO_4^{2-}	Sulphates	FAO	Food and Agricultural Organization
MCM.	Million cubic meters	AOAC	Association of Official Analytical Chemists.
OR	Omani Rial	>	Greater than
BC	Before Christ	:	Ratio
LF	Leaching Fraction	Fe	Ferum (Iron)
Ph.D.	Doctor of Philosophy	B	Boron
m ha	Million hectare	Zn	Zinc
Mm^3	Million cubic meter	Mn	Manganese
Na^+	Sodium ion	MT	Metric tones
K^+	Potassium ion	NO_3-N	Nitrate Nitrogen
Ca^{2+}	Calcium ion	Lbs	Pounds

NO_3^+	Nitrate ion	$acre^{-1}$ yr^{-1}	Per acre per year
N HCl	Normal hydrochloric acid	H_2SO_4	Sulphuric acid
NaCl	Sodium chloride	Kg $plant^{-1}$ $year^{-1}$	Kilogram per plant per year
U.S.	United States	$Plant^{-1}$	Per plant
g L^{-1}	Grams per liter	Mg ha^{-1} $year^{-1}$	Mega gram per hectare per year
r^2	Correlation coefficient	ET	Evapotranspiration
WT	Water table	hr^{-1}	Per hour
RSC	Residual Sodium Carbonate	L day^{-1}	Liter per day
L $year^{-1}$	Liter per year	mmol L^{-1}	Milli mole per liter
M $NaHCO_3$	Molar sodium bi carbonate	Cu	Copper
GIS	Geographical Information System		

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EVALUATION OF THE GROWTH OF DATE PALM SEEDLINGS IRRIGATED WITH SALINE WATER IN SULTANATE OF OMAN

Abstract

The Sultanate of Oman is an arid country (temperature ranges 7 to 50°C) located in the South East corner of the Arabian Peninsula having coastal line of almost 1700km, looking three seas: the Persian Gulf, the Gulf of Oman and the Arabian Sea. Rainfall (scarce and random) ranges between 50mm to 300mm with an annual mean of less than 100 mm. Irrigation water is highly scarce and groundwater (major part saline) is the main resource which ultimately causes soil salinization resulting in growth and yield losses of crops and desertification. Date palm is the major crop. Abandoning of date palm orchards has increased due to very low yields because of soil and water salinity. The situation required a systematic research. Therefore, this experimental work was conducted to investigate; the water salinity tolerance of important date palm varieties, effectiveness of leaching fractions and organic matter as management techniques for safe utilization of saline water and an appropriate N level under saline water irrigation for date palm seedlings. The study comprised of three field experiments; **Screening of date palm varieties for tolerance to water salinity** [Treatments**:** A. Categories of irrigation water: EC_{iw} 3 (Control), 6, 9, 12, 15 & 18 dS m^{-1} B. Date palm varieties; Khalas , Khunaizy and Abunarenjeh], **Managing saline water for growing date palm** [Treatments: A. Categories of irrigation water: EC 6 & 9 dS m^{-1} B. Management practices- control, Leaching Fractions (LF) of 0.15 and 0.22 as well as application of organic matter (crop residues) 10 kg $plant^{-1}$ alone and with both LF] **and Nitrogen fertilizer requirements of date palm seedlings at early stage when irrigated with saline water** [Treatments; A) Categories of irrigation water: EC 3 & 6 d S m^{-1} B) N fertilizer doses (0.00,125, 0.250 and 0.375 Kg $plant^{-1}$ $year^{-1}$) with a uniform dose of P =0.20 and K= 0.30 Kg $plant^{-1}$ $year^{-1}$]. Growth parameters (Pant height, plant girth, Number of new fronds and length of fronds) were recorded annually for two years coupled with soil and plant analysis. The research work was undertaken at Agricultural Research Center (ARC) Rumais, Oman during the years 2006-08 (split plot design with four replications in a low ECe sandy loam soil having very good drainage). Fresh water (EC 1.0 dS m^{-1}) and the saline water (EC 35-40 dS m^{-1}) were mixed in appropriate ratios to get the desired levels of EC. Data indicated significant decrease in growth of all the three date palm varieties during irrigation for two consistent years with saline water of 6-18 dS m^{-1} when compared with 3 dS m^{-1}. However, 50 % decline was recorded only at water EC 18 dS m^{-1}. Therefore, date palm could be regarded as highly salt tolerant. Much difference between salt tolerance potential of three varieties was not recorded, only Khunaizy showed a little edge over the other two. A significant increase in leaf Na and decrease in K was observed while Cl remained unchanged. The physiological basis of salt tolerance in date palm were found as a strict control on Na and Cl concentration in leaves and keeping up the K content with narrow K/ Na ratio. The LF 0.15 and 0.22 as well as organic matter (10Kg $plant^{-1}$ $year^{-1}$) proved partially useful because effectiveness decreased at water EC of 9 dS m^{-1}, especially in the second year. However, coupling of both proved more effective. Application of nitrogen fertilizer did not indicate any material gain in growth of date palm seedlings. It can be recommended that Date palm plants (seedlings of varieties; Khalas, Khunaizy and Abunarinjah) can be irrigated with saline water during vegetative growth. However, significant decline in growth will be expected when the EC of irrigation water exceeds 9 dS m^{-1} that may reach up to 50% with water EC 18 dS m^{-1} (in sandy soil with very good drainage). In the absence of any other option LF coupled with organic matter can be adopted to check deleterious effects during irrigation with water of EC up to 9 dS m^{-1} in sandy soils with good drainage. Application of nitrogen fertilizer will not be required for date palm in early growth of initial two years. The research has to be continued on irrigation with saline water at later stages of growth; the reproductive, fruit setting and maturity stages.

CHAPTER 1

INTRODUCTION

The Gulf Cooperation Council countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) constitute a total area of 259 million hectares. They are characterized by an arid and semi-arid climate. Rainfall is highly erratic in space and time. Annual precipitation ranges from less than 50 mm to 250 mm. Temperatures are generally high, reaching 50°C at times in some places in summer, when the relative humidity is also high. The soils of the region are fragile and subject to erosion by wind and water, as well as degradation through salinization. Over 95% of the total land area in the Arabian Peninsula suffers from some form of desertification, of which 44% is severe to very severe; wind and water erosion account for over 60% of the desertification (ERSKINE *et al*., 2004).

The Sultanate of Oman is located in the south east corner of the Arabian Peninsula. . The country has a coastal line of almost 1700 km, looking three seas: the Persian Gulf, the Gulf of Oman and the Arabian Sea. The climate differs from one region to another. It is hot and humid during summer in the coastal areas and hot and dry in the interior regions while it is moderate in the winter. The highest degrees of temperature range between 35 to 50°C and the lowest vary from 7 to 31°C. Daily sunshine hours typically average about 10 hours annually. It is an arid country where annual rainfall ranges between 50 mm to 300 mm with an annual mean of less than 100 mm. Rainfalls occur scarcely and randomly in the Sultanate with the exception of the south region where rainfall occurs as a result of seasonal storms (July-September).

Groundwater is the main water resource of the country. The net annual natural recharge to the groundwater has been estimated to be around 1260 million cubic meters (MCM). The total water demand is put around 1650 MCM of which 90% is used for agriculture. The deficit of 390 MCM is drawn from the groundwater reserves (ABDEL-RAHMAN AND ABDEL-MAJID, 1993). The cultivable area has been estimated at 2.2 million ha, which is 7% of the total area of the country but is not less keeping in view the population.

Over half of the agricultural area is located in the Batinah Plain in the north that has a total area representing about 3 % of the area of the country. In Batinah, the Mean Annual Temperature is 28.6^{o}C, Relative Humidity is 58%, Wind Speed is 221 km day^{-1}, and Sunshine Hours is 9.7 hours day^{-1}. Rainfall is very irregular from year to year and most of the months around the year can be totally dry. The Batinah Plain is comprised of very thick alluvial, marine and Aeolian sediments (MINISTRY OF AGRICULTURE AND FISHERIES, 1993).

The importance of agriculture is never less even in industrial or oil producing countries. Food security is one of the most important issues of a country for its safe existence and sovereignty. Agriculture has been one of the important sources of income of Oman. It not only provides food and shelter but also employs a bigger portion of its rural population. Some of the agricultural commodities are exported to Arab and overseas countries. About 141,000 people are employed in this national sector that also shares 26.5% in non-oil exports (AL-RIYAMI, 2005). During the last 30 years there has been tremendous growth in agriculture. Excessive usage of groundwater resulted in seawater intrusion into the coastal aquifers and has caused the problem of soil salinity in many parts of the Batinah plain. The land resources are being curtailed rapidly due to soil salinity. According to a study of MINISTRY OF AGRICULTURE AND FISHERIES (1993), 50% of the agricultural area in the South Batinah is affected from slight to moderate salinity (EC_e of > 4 dS m^{-1}). Date palm is the overwhelming crop of the country. Other major crops grown in this area include lime, alfalfa, vegetables, fruits, Rhodes grass and other fodder crops.

It has been reported that major part of the salt affected soils are Gypsiorthids (gypsiferous). Salt affected soils in Oman belong to only two orders; the Aridisols and Entisols and four suborders; Salids, Psamments, Fluvents and Orthents (HUSSAIN *et al.*, 2006 a & b). Such soils are conducive to reclamation in terms of structural stability. The soil pH in South Batinah is mostly alkaline. Calcium and magnesium are the main cations saturating the soil exchange complex. Organic carbon and nitrogen content are usually low ranging in between 1600 and 3000 ppm and 190 and 270 ppm respectively. The average topsoil calcium carbonate content is about 37 percent in Barka area and 26 percent in Masanaa as well as Suwayq (QURESHI, 1995). In North Batinah, about 50%

of the total cultivated land is irrigated with water of salinity of above 3 dS m^{-1} and approximately 38% is irrigated with water of >5 dS m^{-1} salinity (MINISTRY OF AGRICULTURE AND FISHERIES, 1997). With time, salinity of irrigated soils will keep increasing if not properly managed (HUSSAIN, 2005).

Water is considered as the life symbol. None of the living things can survive without water. Besides the fact that water occupies three fourth of the globe, its plant usable component has always been scarce. Water on a global scale is plentiful 97% is saline and 2.25% is trapped in glaciers and ice, leaving only 0.75% available in freshwater aquifers, rivers and lakes. Most of this fresh water (69%) is used for agricultural production, 23% for industrial purposes and 8% for domestic purposes (PRATHAPAR, 2000). The fresh water resources available for agriculture are declining quantitatively and qualitatively. Therefore, the use of lower-quality supplies will inevitably be practiced in future for irrigation purposes to maintain economically viable agriculture. Several countries have adopted the use of marginal water for irrigation to overcome water scarcity (ORON *et al.*, 2002). With the constant increase of population, change in life style and norms and industrial development, the scarcity has increased a lot. Total supply failed to cope with water demand of domestic, agricultural and industrial sectors in the past. This situation focused concentration on tapping other potential sources of water, especially groundwater. This temporary solution aggravated the problem in the long run because those soils were salinized slowly and gradually that were irrigated with relatively saline water continuously, as major part of groundwater had high concentration of salts. This type of salinity caused by man's activities is called secondary salinity. Soil and water salinity has emerged now as a big problem of present world's agriculture. Countries of arid and semi arid regions are the special victims. The area of land affected by secondary salinity is steadily increasing, with recent worldwide estimates that indicted over 70 million ha of agricultural land as salt affected (FAO, 2005).

Water salinity is one of the biggest problems of agriculture in Oman as well. It is more than 3.0 dS m^{-1} at many of the agricultural farms and even may reach 40.0 dS m^{-1} at certain places in the coastal belt of Batinah region, the main seat of agriculture in the country. The categorization of groundwater was found to be 53, 18, 15, 6, 4, 3 and 1% that were having EC of 2, 2-3, 3-5, 5-7, 7-10, 10-15 and more than 15 dS m^{-1}

respectively (HUSSAIN, 2005). The very high concentration of salts in the ground water is increasing further due to more motorized pumping of water with extension in agriculture. The natural balance existing in between annual recharge and pumping in the past has been disturbed a lot. There have been sea water intrusions as well. Resultantly, not only the plant growth and yields are being affected negatively, but also secondary soil salinity is increasing at an accelerated rate.

The salinity problem was rightly highlighted in the integrated study of the Batinah area but needed necessary steps were not taken to tackle this menace. Resultantly, the problem has emerged in the shape of a giant ready to eat the whole agriculture of Oman, that of Batinah in particular. Desertification due to salinity can be seen everywhere. Many farms, especially the vast precious date palms have been destroyed and abandoned. Thus, the earning source and the livelihood of the farmers were snatched by salinity. Many people have become jobless. The farmer's economy and source of living is at stake. The poor rural communities are being unemployed. Yields are gradually decreasing on the farms, which are yet under cultivation and this problem has not become so acute to bring the farming very uneconomical. However, the end result is nearing rapidly. Since no recent data is available which can show the extent of present salinity and the losses occurring to the agriculture of the country due to this menace, some estimates were made by HUSSAIN (2005). To estimate the losses certain assumption were made as the basis e.g. 25 & 50% yield losses and the gross margins coming from crops/trees which could be grown on the abandoned lands due to salinity. The area under different land utilization types and the gross margin values were taken from Integrated Studies of Batinah (1993-97). It was estimated that annual losses occurring from soil salinity to the country range from 6.66 to 13 315 million Omani Rial (OR). If the loss of abandoned date palm farms is included then the estimated losses will increase and may be ranging in between 7.311 and 13.966 million OR per annum.

The date palm is the oldest tree known and cultivated by man. The earliest evidence of date palm cultivation was 4000 BC in Ur, lower Mesopotamia (now Iraq). While in the Nile Valley, date palm cultivation goes back to 3000 BC, as mentioned on old temples where the trunk represent one of the year and the fruit punch represent one of the months. The religious importance of date palm goes back to profit Abraham, where he was grown in Ur, and his love for date. Dates are nutritive foods that are most assimilative. The spread of date palm and/or migration had occurred over many centuries along two main routes; first from Iraq towards east to Iran, Pakistan and India and secondly from Egypt towards west including Spain and the new world. Dates are now cultivated mainly in warmer regions of Asia and Africa. The fruit is also grown in some parts of Europe and the US. Global production of this fruit stands at 5.46 million metric tons per year. The main producers are Egypt, Iran, Saudi Arabia, Pakistan, Iraq, Algeria and the United Arab Emirates. Dates are also produced in large quantities in Oman, Sudan, Libya and China. Modern science has proved that dates are part of a healthy diet. They contain sugar, fat and proteins, as well as important vitamins. Dates are also rich in natural fibers. Modern medicine knowledge has shown that dates are effective in preventing abdominal cancer. These also surpass other fruits in the sheer variety of their constituents. They contain oil, calcium, sulphur, iron, potassium, phosphorous, manganese, copper and magnesium. In other words, one date is a minimum of a balanced and healthy diet. Arabs usually combine dates with milk and yogurt or bread, butter and fish. This combination indeed makes a diet self-sufficient and tasty for both mind and body. There are 450 female cultivars at present. Among the olden varieties of date palm are included; Barhi, Dayri, Deglet Noor, Halawy, Hayany, Khadrawy, Maktoom, Medjool, Saidy, Sayer, Thoory, Zahidi, Amir Hajj, Iteema, Migraf and Manakbir. Khalas, Khunaizy and Abunarenjeh and a few others are the new popular varieties in Oman.

Date palm trees are grown in Oman since centuries long. According to estimates, there are about 7.8 million plants growing at present. The area of date palm plantations has been estimated as 97059 ha (MINISTRY OF AGRICULTURE AND FISHERIES, 2004). Dates are not only rich source of energy and a regular diet of Omani people but also a big source of earning for the farmers. Naturally, this plant has also high tolerance against salinity. Nevertheless, at very high EC of water the plant can be affected negatively. The plants may totally dry out when irrigated continuously with very saline water otherwise their yields may decrease significantly to bring them below the economic level. The date palm production has been recorded as 0.28, 0.30, 0.24 and 0.20 million tons for the years 2000, 2001, 2002 and 2003 respectively while mean yield/ tree was recorded as 280, 265, 219 and 201 kg for the same years indicating quite unhappy situation (MINISTRY OF

AGRICULTURE AND FISHERIES, 2004). Many big and small date palm farms have been abandoned now. A lot of variation in salt tolerance potential among different varieties is expected as well. However, no one knows exactly the salt tolerance limits of the varieties presently growing or being planted newly in the Sultanate of Oman. The causes of low yield or abandoning of date palm orchards are as under.

1. Soil salinity level was raised slowly and gradually beyond the tolerance potential of the plant totally (EC> 20 dS m^{-1}) or partially (15-20 dS m^{-1}), especially besides the coastal areas. Even in case of EC more than 50% yield reduction (ECe>15-18 dS m^{-1}) the orchards did not remain economical.
2. The concentration of salts in the ground irrigation water also increased. The EC of water has been measured up to 21 dS m^{-1}.
3. The soil and water salinity became beyond the tolerable limit of inter- crops practiced with date palm. Hence, the date palm orchards alone were not economical.
4. No management practices for using saline water were adopted.
5. Very low and imbalanced use of fertilizer to meet the good plant nutrition.
6. Miscellaneous factors like pests and diseases.

Soil salinization due to continuous use of saline water and consequent low yields coupled with resultant desertification has become a big challenge and prime priority for the agricultural researchers of the country. However, no research work on these aspects has been conducted in the country so far. The exact salt tolerance limits of the presently growing major varieties as well as those being newly planted are to be investigated. It is also required that some management techniques well fitting the scenario be evolved to minimize the deleterious effects of saline irrigation water on date palm. As most of the groundwater is only saline without any associated prominent sodicity problem, therefore providing excess water (Leaching Fraction, LF) to leach down the accumulated salts was expected to work. Similarly, application of organic matter to hold the water by increasing water holding capacity of the soil and reducing evaporation may also be a good potential technique to manage water salinity. Soil and water salinity not only affects plant growth directly due to osmotic effects as well specific ion effect but also disturbs plant nutrition that becomes inappropriate under utilization of saline water for irrigation. Hence, the fertilizer requirements of this important plant, especially N under saline irrigation are still to be standardized. An investigation problem taking simultaneously the salt tolerance potential of important date palm varieties, management options like leaching concept and application of organic matter (alone or coupled with LF) and response to different levels of applied N was a prioritized option that could bring answer to currently burning questions and make basis for formulation of practicable, economical and easily adaptable package of recommendations. Therefore, this Ph.D. research work was planned and has been conducted to investigate some of these important components. Hence the objectives of this study were:

1. Evaluation of the water salinity tolerance levels of important date palm varieties of Oman
2. Assessment of some management techniques so that saline water can be managed under soil and climatic conditions of Oman to avoid its bad effects on plants and soil
3. Standardization of the N fertilizer levels that may prove effective under saline water irrigation for date palm
4. Formulation of recommendations for majority of the farming community who are growing date palm trees and vastly using saline water for irrigation of this most important crop of Oman

CHAPTER 2

REVIEW OF LITERATURE

Not much research work has been conducted in Sultanate of Oman to explore the tolerance potential of different varieties of date palm to water salinity, management strategies to avoid harmful effects of saline water and N response of date palm plants in early stage of growth when irrigated with saline water. Therefore, a few salient researches completed on these subjects in other parts of the world are being reported.

2.1 Type, origin and extent of soil and water salinity in Oman

Sultanate of Oman is located in the southeastern part of Arab Peninsula. It extends along the Gulf of Oman and the Arabian Sea. The country shares border with UAE, Saudi Arabia and Yemen. Most part of the country is a sub-tropical desert. The coastal areas are hot and humid in summer that extends over major part of the year. Mean annual rainfall is less than 50 mm in the two thirds of the country and is around 100 mm in rest of the areas. However, in mountains the rainfall ranges from 200 to 300 mm. In the major part of the country calcareous sedimentary rocks are the main source of parent material developed in mountainous parts. The soils remain dry for most of the year. Therefore, the influence of the desert environment is visible and the soils are very low in organic matter. Shallow accumulation of calcium carbonate, gypsum and salts that are more soluble is evidence of the low leaching power of the prevailing climate. Saltpans in many soils can be attributed to Aeolian addition originating from the nearby sea through wind flows towards the inland. Many soils have a surface accumulation of secondary lime, which may also be Aeolian. STANGER (1985) examined the coastal salinization of Batinah plain. He reported that due to arid tropical conditions and the absence of surface water created total dependence upon groundwater withdrawals from wells. The initial groundwater equilibrium was upset. First by the transition from animal bailed to pumped wells, and subsequently by agricultural expansion and increasing urban and industrial water demand. The consequent effects of upcoming of saline intrusions have been monitored in selected areas by repeated electrical conductivity surveys over a period of nine years. Despite an apparent excess of fresh water in the Wadi Semail catchment, locally severe salinization has occurred, mainly due to heterogeneous aquifer conditions, thereby detracting from the benefits of agriculture expansion. In the Wadi Rusayl catchment, excess of extraction over recharge has resulted in severe salinization. The situation will probably deteriorate further unless rigorous conservation measures and enhanced aquifer recharge are implemented. In such sensitive coastal areas, even if a catchment water balance has 'excess' groundwater flow seawards, the local sub-catchment response may involve a high salinization risk. Therefore if groundwater extraction is to be increased, the water balance alone may be an insufficient basis for water resource management. The salinization of irrigated soils by groundwater has become a major process of soil formation in many areas of the Sultanate, particularly, in coastal areas (MINISTRY OF AGRICULTURE AND FISHERIES, 1990).

COOKSON AND LEPIECE (2001) warned that date palms could ever disappear from the Batinah due to salinization of the coastal plain. The date palms are an assent symbol of a way of life in the area and are a tradition of centuries. Therefore, date palm cultivation must be made economical for farmers through research for sustained high yields of good quality fruit. The struggle must involve farmers, Agricultural Extension and Research Departments in sound and comprehensive government programs. Over-pumping of wells, unmotivated application of irrigation water, and poor management of the coastal plan will end with or lead to a reduction in the number of palms grown and salinization of even larger areas of once fertile lands.

Soil and water salinity is a very significant problem of the present agriculture in Sultanate of Oman. It has been estimated that 44% soils (13.88 million ha) out of total area (31.43 million ha) of Oman are salt affected. The salinity problem is spread over 70% lands (1.56 million ha) that were evaluated as suitable for agriculture (only 2.22 million ha= 2.5% of the total geographical area). Further classification of salt affected soils according to the severity of the problem is; slightly, moderately, strongly, very strongly and extremely saline as 17.7, 11.3, 9.2, 5.6 and 7.9% respectively (HUSSAIN, 2005).

The genesis and classification studies indicted that salt affected soils in Oman belong to only two orders; Aridisols and Entisols. The suborder are; Salids, Psamments, Fluvents and Orthents while great group is Typic. The subgroups are mostly Typic Aquisalids, Typic Haplogypsids, Typic Calcigypsids, Typic Haplocalcids and Typic Torrifluvents.

In broad classification, these soils are overwhelmingly saline with very little problem of sodicity that is in low-lying pockets. The texture of the soils is mainly sandy loam or loamy sand. The main causes of salinity are the climatic conditions (Scanty rainfall and high temperature), nearness to sea, salty parent material and development of secondary salinity due to consistent usage of very saline water (HUSSAIN *et al*., 2006a).

The total water resources of Oman are insufficient to meet and sustain the domestic and agricultural demand of water in the country. A demand and supply comparison indicated that the Sultanate of Oman is facing a deficit of more than 331 Mm^3 that may increase up to 606 Mm^3 by the year 2020 (MINISTRY OF WATER RSOURCES, 1993). This situation resulted in pumping of more and more water that was significantly higher than the aquifer recharge. Consequently, the salts concentrated and intrusion of seawater increased and salinization of lands enhanced. Similar process may intensify with increasing demands for water in future.

The detailed categorization of groundwater with regards to salinity according to HUSSAIN (2005) and HUSSAIN *et al*. (2006b) is:

1) EC< 3 dS m^{-1} = 48.3%
2) EC 3-5 dS m^{-1} = 12.1%
3) EC 5-10 dS m^{-1} = 9.5%
4) EC > 10 dS m^{-1} = 4.2%
5) Uncovered or mix quality = 25.9%

Another study (ANONYMOUS, 2005) revealed that 51 % aquifers of Oman were with mildly brackish water while respective percentages of moderately and strongly brackish aquifers were 26 and 23. Hence, the consistent use of such water for irrigation purpose converted the soils into saline during past periods and this treat permanently exists for future as well unless managed through appropriate techniques that are still to be generated under the local scenario. Very huge cyclone ‘Gonu’ took place in June 2007. During this event (24 hours), a rainfall of 240 mm fell in the coastal areas of Oman including Batinah. This was more than two and a half of the annual average of the country. The rainfall volume measured was 3797 Mm^3 equal to 19% of the long term average volume while surface runoff was 1870 Mm^3. The calculated recharge of shallow alluvium and fracture limestone aquifers was 1803 Mm^3 which was five times of the long term annual average recharge of the coastal area and approximately 1.5 times the annual recharge of the country (AYSHA AND ATTA, 2008). Hence, more precise and accurate predictions of climate, especially rainfall will highly be important to face hydrological hard situations and critical climatic changes in future (ANONYMOUS, 2009).

2.2 Effects of salts on plant growth, physiological processes and ion uptake

Salinity affects the plants in many ways physiologically; however, over injury symptoms seldom occur except under extreme salinization and these responses vary considerably with the species, growth stage, cultural and climate conditions (MAAS, 1986). Generally, salt-affected plants appear normal although they are stunted and may have dark green leaves, which, in some cases, are thick and are more succulent. Different plant species have different degrees of tolerance to salts in the root medium. In some plant species, for instance in halophytes, salinity sometimes affects growth positively, although except for C_4 species like *Atriplex*, where Na^+ is needed as a micronutrient (FLOWERS AND LAUCHLI, 1983). There appears to be no obligate requirement of salts for growth. The optimum growth in many dicotyledonous species occurs in the range of 100 to 300 mol m^{-3} salts (FLOWERS *et al.,* 1977). Monocotyledonous halophytes are not stimulated by low to medium salinity and grow more slowly at higher concentrations (LEVITT, 1980) whereas; most of the glycophytes can only survive on low salinity.

The typical response of plants to salts in the root medium is the growth inhibition (ASLAM *et al.,* 1989, FLOWERS *et al.,* 1991). The excessive entry of ions though facilitates the osmotic adjustment within plants but they have to pay the price in terms of growth retardation (MARSCHNER, 1986). As salt concentration increases above a threshold level, both the rate of growth and the vigor of plant species are progressively decreased, shoot growth is more severely affected than root (SHARMA, 1986, LONE, 1988, ASLAM *et al.,* 1991). Plant becomes stunted because of reduced cell division than cell expansion (MAAS AND NIEMAN, 1978). However, reduction of vegetative growth is not always related to reduction in fruit or seed production (ASLAM *et al.,* 1993).

In genotypes having salt exclusion as major mechanism of salt tolerance, the synthesis of organic acids (K^+, Ca^{2+}, NO_3^+) must be increased. However, in genotypes in which salt inclusion is the predominant strategy, osmotic adjustment is achieved by the accumulation of salts (mainly NaCl) in the leaf tissue (FLOWERS, 1988). In natrophyllic species, Na^+ can replace K^+ not only in its function as an osmotically active solute, but to some extent also due to its specific functions in cell metabolism. The different strategies for regulating sodium transport to the shoots have important consequences in pasture plants for animal nutrition and in crop plants in general for salt tolerance (GREENWAY AND MUNNS, 1980).

VAN HOORN *et al*. (2001) studied the effect of salinity on yield and nitrogen uptake of four grain legumes and on biological nitrogen contribution from the soil. Broad bean, chickpea, lentil and soybean were grown in a tank and irrigated with waters of three different levels of salinity. The nitrogen uptake of the crop was determined from the yield of aerial biomass, grain and the corresponding nitrogen contents. They observed that soil salinity affected crop yield, crop total nitrogen uptake and the nitrogen contribution of the soil. The latter decreased in per cent of plant uptake at increasing salinity and also decreased stronger than the plant uptake pointing to a salinity effect on the mineral nitrogen production by biological activity in the soil through nitrogen fixation and transformation of organic nitrogen.

ASHRAF *et al.* (2002) studied the evaluation of arid and semi-arid ecotypes of guar (*Cyamopsis tetragonoloba*) for salinity (NaCl) tolerance. The experiment was laid out in completely randomized design with three repeats and three treatments, i.e. 3, 9 and 15 dS m^{-1} in 135 pots lined with polythene bags. However, ecotype/accession 281/3 and 239/2 performed better than others at higher salinity levels. As flowering period was a sensitive period for grain and fruit formation the sensitive crops were all of indeterminate flowering as their longer flowering period could be a cause of their greater sensitivity. The tolerant group according to water stress day index can be divided according to soil salinity in a salt tolerant group of sugar beet, wheat and a moderately sensitive group comprised of maize, sun flower and potato. The sensitive groups according to water stress can be divided according to soil salinity, moderately sensitive group comprised of tomato, soybean and broad-bean and a salt sensitive group comprised of chickpea and lentil. They concluded that salt stress had considerable effect on plant height, root length, roof fresh and dry weights, shoot fresh and dry weights and seed yield per plant.

KATERJI *et al.* (2002) studied salinity effect on crop development, yield and analysis of salt tolerance according to several classification methods. The plants were studied during the whole growing period by measuring the saline stress and analyzing its effect on leaf area, dry matter development and on the crop yield. Salinity affected the pre-dawn leaf water potential, stomata conductance, evapo-transpiration, leaf area and yield. The following criteria were used for crop salt tolerance classification; these include soil salinity, evapo-transpiration deficit and water stress day index. The classification according to soil salinity distinguished the salt tolerant group of sugar beet and wheat, moderately salt sensitive group comprised of broad-bean, maize, potato, soybean, sun flower and tomato, where as salt sensitive group comprised of chickpea and lentil. The water stress day index was based on the pre-dawn leaf water potential, where as tolerant group comprised of sugar beet, wheat, maize, sun flower and potato, the sensitive group comprised of tomato, soybean, broad bean, chickpea and lentil. The classification corresponded with a difference in water use efficiency, as the tolerant crops showed more or less constant water use efficiency. They concluded that the sensitive crops showed a decrease of the water use efficiency with increased salinity as their yield decreased stronger than the evapo-transpiration.

The inhibition of leaf growth in alfalfa growing under salinity conditions may be associated with a reduction in ion concentration in the leaf (ESECHIE AND RODRIGUEZ, 1999). The results of their study showed that salinization significantly reduced the fresh weights of the roots, stem and leaves as well as the concentration of N, K. Ca and Mg in the leaf tissue. With the exception of Cu concentration, which was enhanced by salinity, all the micronutrients (B, Zn, Mn and Fe) had reduced concentration of the leaves of salinized alfalfa. The application of an external nutrient solution, especially the full strength solution, produced an increase in leaf growth and leaf nutrient element concentration. On the basis of these results, it was concluded that reduced leaf nutrient concentration may be one of the primary causes of the inhibition of leaf growth that is characteristic of alfalfa growing under salinity stress.

In a saline environment, plants take up excessive amounts of Na at the expense of K and Ca. In a field-simulated study, ESECHIE (1998) concluded that the imbalance in ion compartmentation (Mg vs. Ca, for instance) in alfalfa plant parts may be an important factor in the nutrient deficiency symptoms exhibited by alfalfa growing under salinity stress. They observed that an increase in Na content generally decreased the K content, suggesting an antagonism between Na and K. ESECHIE *et al*. (2002), in his study, found that the cationic sums in alfalfa petioles were constant when alfalfa was subjected to salinity treatments of 0.0 – 6.4 dS m^{-1} and 8.2 – 12.2 dS m^{-1}. Based on these results they concluded that the *cationic constancy* rule may have a potential in identifying the salinity levels that may seriously affect the normal growth and yield of alfalfa.

KURDALI AND AL-AIN, (2002) studied the effect of different water salinity levels on growth, nodulation and nitrogen fixation by *Sesbania* (Dhaincha) and on growth of sunflower using 15N-tracer technique. The effect of different salinity levels of irrigation water on the nodulation, dry matter production and nitrogen fixation by Dhaincha (*Sesbania aculeata*) was investigated in a pot experiment. The same effect on the growth of sunflower (*Helianthus annuus*), which was also utilized as a reference crop for measuring nitrogen fixation by a legume crop using the (15N) isotope dilution method, was also investigated. Irrigation with water having ECiw of more than 4.03 dS m^{-1} reduced plant growth and the reduction was more pronounced in *Sesbania aculeata* than in *H. annuus*. High levels of water salinity caused more inhibition in shoot than in root growth of both plant species. The indigenous rhizobial strains could form nodules on *Sesbania aculeata* grown under different salinity levels of irrigated water except for those irrigated with high level of groundwater salinity (ECiw 33 dS m^{-1}) where nodulation and nitrogen fixation were completely inhibited. However, per cent nitrogen fixation was significantly enhanced by a moderate salinity level (ECiw of 4.03 dS m^{-1}) in irrigated water, whereas small effects were obtained with higher water salinity levels. They concluded that *S. aculeata* and *H. annuus* grown in saline soils can be irrigated either with saline water up to 8.03 dS m^{-1} and 12.3 dS m^{-1} respectively, or with gradually increased levels of salinity for both of them.

RAO *et al.* (2002) studied the effect of salinity and sodicity on nodulation and nitrogen fixation in chickpea (*Cicer arietinum*). They reported that production of grain legumes was severely reduced in salt-affected soils because their ability to form and maintain nitrogen fixing nodules was impaired by both salinity and sodicity (alkalinity). Genotypes of chickpea (*Cicer arietinum)* with high nodulation capacity under stress were identified by screening in a sodic soil in India. The pH 8-9 was the critical upper limit for most genotypes studied but genotypes with high nodulation outperformed all others at pH 9.0-9.2. The threshold limit of soil salinity for shoot growth was at ECe 3 dS m^{-1}, except for the high-nodulation selection for which it was ECe 6 dS m^{-1}. They found that chickpea genotypes tolerant to salt-affected soil have better nodulation and support higher rates of symbiotic nitrogen fixation than sensitive genotypes.

LOPEZ *et al.* (2007) studied growth and nitrogen fixation in *Lotus japonicus* and *Medicago truncatula* under NaCl Stress. They studied that *Lotus japonicus* and *Medicago truncatula* were model legumes. They examined the effects of 25 and 50 mM NaCl dose on the growth and nitrogen fixation parameters, as well as carbohydrate content, trehalose and carbon metabolism of *M. truncatula* and *L. japonicus* nodules. The leg-hemoglobin (Lb) content and nitrogen fixation rate (NFR) were approximately 10 and 2 times higher respectively, in nodules of *L. japonicus* when compared with *M. truncatula*. Plant growth parameters and nitrogenase activity decreased with NaCl treatments in both legumes. The content of trehalose was low (less than 2.5% of total soluble sugars) to act as an osmolyte in nodules, despite its concentration being increased under saline conditions. *L. japonicus* nodule carbon metabolism was proved to be less sensitive to salinity than in *M. truncatula*, as enzymatic activities responsible for the carbon supply to the bacteroids increased nitrogen fixation.

REJILI *et al.* (2007) conducted their studies on the effect of NaCl on the growth and ionic balance (Na^+/ K^+) of two populations of *Lotus creticus* (Papilionaceae). A laboratory experiment was carried out to assess the physiological behavior of two populations of *L. creticus* (Msarref (Msf) and Oued Dkouk (Odk)) in a solid substratum in the presence of salt. The tested concentrations varied from 0-400 mM NaCl. The presence of salt in the medium affected growth of whole plants for both populations compared to root biomass, the aerial one was more affected by salt. They found that for all treatments, plants of both populations remained capable to produce and to allocate dry matter to the different organs. However, the salinity generated a disruption at the level of water feeding of plants of the two populations. Compared to root organ, water contents in aerial organ proved to be the least affected by salt. They observed that the decrease of growth under saline stress was not associated to (osmotic) effect. The Na^+ / K^+ ratio showed for both populations an increase of Na^+ contents in aerial and root organs, with an excess of accumulation of these ions in the aerial organ particularly more marked at the population of Msarref. It affected mainly at the level of roots where high potassium content was recorded as compared to the aerial organ and reflected probably an inclusive behavior towards salt. This behavior justified the plants to maintain their growth even in very hard salinity conditions.

A greenhouse experiment was conducted by ASHRAF AND ALWEENA (2004) to assess the effect of salt stress on growth and metabolic changes in nodules and other plant parts of two leguminous species, *Phaseolus vulgaris* (salt sensitive) and *Sesbania aculeata* (salt tolerant) with the major objective if nodules play a vital role in salt tolerance. Plants of *P. vulgaris* subjected to 3.5 dS m^{-1} of NaCl and those of *S. aculeata* to 13.0 dS m^{-1} of NaCl showed a significant reduction in fresh and dry weights of shoots and roots, and shoot length and leaf area. The level of NaCl for each species was that at which 50% reduction in growth takes place. Salt stress caused a marked reduction in nodule fresh mass and nodule number in both leguminous species, but nodule dry weight did not decrease significantly in both species under salt stress. Percent reduction in nodule number due to salt stress was more in *P. vulgaris* than that in *S. aculeata*, but the reverse was true for nodule size. Free amino acids, proline, and glycine betaine increased, whereas soluble proteins decreased in all plant parts of both species under salt stress. *Sesbania aculeata* had significantly higher proline content in the leaves and glycine betaine in all plant parts than those in *P. vulgaris* under salt stress. *Phaseolus vulgaris* accumulated higher amounts of Na^+ and Cl^- in the nodules as compared to those in *S. aculeata* under saline conditions. The former species also showed a marked accumulation of Cl^- in the leaves. In contrast, the transport of Cl^- to the leaves of *S. aculeata* was low but vice versa in roots. Salt stress also caused a marked reduction in net CO_2 assimilation rate (P_n), transpiration rate (E) and stomatal conductance (g_s) in both species. Per cent reduction in P_n, E and g_s under saline conditions was higher in *P. vulgaris* than in *S. aculeata*. Although nitrate reductase (NR) activity was reduced in all plant parts in both species, the species did not differ significantly. In conclusion, the nodules of *S. aculeata* seemed to have played an active role in the high salt tolerance of the species because the nodules had a lower accumulation of both Na^+ and Cl^- and a higher one of glycine betaine as compared to that in *P. vulgaris*. Other attributes related with a high salt tolerance of *S. aculeata* were a small reduction in number of root nodules, high proline content in leaves, high amount of glycine betaine in all plant parts, a high photosynthetic rate, and low uptake of Cl^- in the leaves. Salinity, impact on plants is in two main ways: osmotic stress and ion toxicity (MUNNS, 2005).

Osmotic stress is caused by ions (mainly Na^+ and Cl^-) in the soil solution decreasing the availability of water to roots. Ion toxicity occur when plant roots take up Na^+ and/or Cl^- and these ions accumulated to detrimental levels in leaves. , the ions Na+ and Cl- penetrate into plant cells and can be accumulated in the vacuole for the tolerant plants or in the cytoplasm for sensitive cultivars (KEFU *et al*., 2003). PARIDAA *et al*. (2005) illustrated that salinity is the major environmental factor limiting plant growth and productivity. The detrimental effects of high salinity on plants can be observed at the whole-plant level as the death of plants and/or decreases in productivity. Many plants develop mechanisms either to exclude salt from their cells or to tolerate its presence within the cells. During the onset and development of salt stress within a plant, all the major processes such as photosynthesis, protein synthesis, and energy and lipid metabolism are affected. The earliest response is a reduction in the rate of leaf surface expansion, followed by a cessation of expansion as the stress intensifies. Growth resumes when the stress is relieved. Accumulation of salts in the root zone affects plant performance through creation of water deficit and disruption of ion homeostasis (MUNNS, 2002) which in turn cause metabolic dysfunctions.

Salinity also induces changes in the plant hormonal balance not only by the accumulation Abscisic acid (ABA) but also inducing a reduction of the levels of growth-activating hormones such as auxins and cytokinins. Ethylene and other growth regulators like salicylic acid play an important role in the response to salt stress due to its ability to induce a protective effect on plant under stress (GLYAN´KO *et al.,* 2005). In addition, the efficiency of pre-treatments with different phytohormones for restoration of metabolic alterations induced in some legumes by NaCl, such as *Vicia faba, Vigna* and *Phaseolus* *vulgaris* has been reported (KHADRI *et al.,* 2006). Recent research on high salinity responses in *Medicago truncatula* and *Lotus japonicus* implied that a large proportion of the genome is involved in high-salinity stress responses (UDVARDI *et al.,* 2007). Genome-wide identification of genes regulated by drought of high salinity conditions has manifold significance.

The purpose of the study of NAVARRO *et al*. (2007) was to evaluate the physiological and anatomical changes that occur in *Arbutus unedo* plants under saline conditions in order to understand the response of this species to salinity. *A. unedo* plants were grown in a greenhouse and submitted to three irrigation treatments using solutions containing 0, 52, and 105 mM NaCl with an electrical conductivity of 0.85 dS m^{-1} (control treatment), 5.45 dS m^{-1} (S.1) and 9.45 dS m^{-1} (S.2). After 16 weeks, the leaf water relations, root hydraulic conductivity, gas exchange, ion concentrations and leaf ultra-structure were determined. Salinity induced a significant decrease in total biomass, leaf area and plant height. The concentration of Cl^- in leaves increased with increasing salinity and was higher than the corresponding concentration of Na^+. Net photosynthesis (P_n) was reduced and the chloroplast ultra-structure was altered by salinity. Thylakoids were dilated and the number of plastoglobuli was greatly increased in both saline treatments compared with the control leaves. In addition, a reduction in the intercellular spaces of the lagunar mesophyll was observed in the saline treatments, affecting stomatal and mesophyll conductance to CO_2. Root hydraulic resistance increased under saline conditions, affecting the water flow the root system. Pressure–volume analysis revealed osmotic adjustment values of 0.2 MPa at 52 mM and 0.5 MPa at 105 mM of NaCl, accompanied by 31 and 99% increases in the bulk tissue elastic modulus (ε, wall rigidity) and resulting in turgor loss at the same relative water content in control and at 5.45 dS m^{-1} and a higher relative water content at 9.45 dS m^{-1}. Osmotic adjustment and a high ε together are seen as an effective means of counteracting the negative effects of salinity on the water balance of plants.

According to MAHMOOD (2007) soil and water salinity are major problems of present agriculture in the world coupled with limitation of resources for reclamation, water in particular. The alternate approach is to use huge salt affected area by growing salt tolerant plants of economical importance. *Acacia ampliceps* is one of the best options because this plant has not only high salt tolerance but is also rapid growing and very good fodder for sheep and goats. He conducted three separate studies were to find out the tolerance limits of *Acacia ampliceps* against different types of salt stress. Plants survived in all the salinity (EC_e 10 – 50 dS m^{-1}) and sodicity (SAR 20 – 50) levels. The collected and statistically processed data of two years indicated that plant growth parameters (height, stem diameter, number of leaves and branches and canopy volume) and water uptake reduced significantly with increasing levels of salinity (EC_e), sodicity (SAR) and both of these combined. The percent decreases in growth parameters and shoot dry weight were 50% with the EC_e 50 dS m^{-1} or SAR 50 or EC_e 30 + SAR 40. Sodium concentration in plant leaves highly increased while K^+, Ca^{2+} and Mg^{2+} decreased with increasing levels of stresses. The negative effect of salt stress was due to osmotic effect as well as specific ion toxicity, especially Na^+. The plants were successful to tolerate salinity and sodicity stress through ion selectivity (keeping K^+: Na^+ ratio comparatively wider) and compartmentation. Growing *Acacia ampliceps* improved the soil health through decreasing EC_e and SAR of the soil underneath the plants. Transplantation of plants in pits refilled with silt or silt + compost proved highly helpful in avoiding early stage salt stress and keeping the growth intact. The message from his study for the farmers was that they can rear 100 heads of sheep and goats in order to improve their livelihood employment at their farms by growing *Acacia ampliceps* in 4 hectare of salt-affected land supplemented with one hectare of seasonal fodder. This will also decrease further aggravation of lands that occurs if salt-affected lands are abandoned.

In study of YOUNIS AND EL-BIALY (2008), foliar application of urea to lettuce plants induced pronounced changes in the total amount and in the relative composition of the nitrogen pool. As compared with untreated lettuce plants, urease (UR), nitrate reductase (NR), asparaginase (AS) and glutamine synthetase (GS) activities were, in general, increased with an increase in the concentration of urea. On the other hand, salinization of lettuce plants with NaCl induced a significant decrease in the activities of UR, NR, AS and GS, at vegetative and adult growth stages. In general, treatment of lettuce plants with increasing concentrations of urea fertilizer in combination with each of the levels of salinity resulted in significant increases in all enzyme activities. Treatment with increasing concentrations of urea fertilizer induced significant decreases both in glycine and proline contents below control levels. On the other hand, salinization of lettuce plants with NaCl induced significant pronounced increases in the contents of the two amino acids. Further increments in glycine and proline contents were observed in differently salinized lettuce plants foliar sprayed with increasing concentrations of urea at vegetative and adult growth stages. Salinity solely enhanced the occurrence of novel proteins that were detected neither in the water control nor in the urea-treated plants. Protein banding patterns of lettuce plants treated with urea either alone or in combination with NaCl showed different de novo protein bands with different molecular weights, induced by urea and/or NaCl at vegetative and adult growth stages.

2.3 General behavior of fruit plants in saline environment

COOPER *et al.* (1957) determined the cold hardiness and salt tolerance of six avocado varieties on West Indian rootstocks. Some varieties had better salt- tolerance, other were colder hardy, but non-combined maximal resistance to both factors. A Mexican –West Indian hybrid, however did exhibit high salt-tolerance and intermediate cold hardiness. KLEINERMAN (1958) stated that apricot and pear are most tolerant to saline and solenetzic soils, apple and plum are less so, and cherries are most sensitive, usually dying off after a few years. PESSINGHAM (1986) reported that the quandong (*Santalum acuminatum*) is widely distributed across arid land of Australia. This small tree averaging about 4.0 m high has bright red, cherry-sized fruit with edible flesh and stone with edible kernel. The quandong is reported to be highly resistant to drought, high temperature and salinity. An experimental orchard in Southern Australia has been irrigated for seven years with water of 4.7 dS m^{-1}. QURESHI AND RASHID (1988) claimed that *Eugenia jambolana* (Jaman), *Zizyphus jujuba* (Ber) and *Grewia asiatica* (Falsa) were highly salt-tolerant while *Psydium guajava* (guava) was moderately tolerant to salinity and water logging. QURESHI *et al.* (1993) reported that *Syzygium cumini* can tolerate salinity. In a seven and half year adaptation trial on saline-sodic soil at Faisalabad, it had 98% survival and similar vigor to *Psydium guajava* (guava) and *Zizyphus jujuba* (Ber). For *jambolana* (Jaman), ECe and SAR values in upper 90 cm of soil ranged from 15-19 dS m^{-1} and 38-70 $(m\ mol\ l^{-1})^{1/2}$ respectively.

SINGH (1994), evaluated seven fruit tree species including *Psydium guajava* (guava), *Syzygium cumini* (Jaman), *Carrisa carandas* (Karonda), *Achras zapota* (sapota), *Sapindus laurifolius* (Aritha) and *Zizyphus mauritiana* (Ber), at different levels of alkalinity (pH 8.1- 10.0). Three months after planting, all except *Achras zapota* (sapota) and *Carrisa carandas* (Karonda) died at pH 10.0 and 9.4. Sapota proved most promising species for high pH soils based upon survival rate and biomass production. Na: K ratio in plant parts of sapota was almost same at different pH levels, where as it increased with increase in pH, in case of all other species. SINGH *et al.* (1998) in another investigation studied the response of *Psidium guajava* (guava), Jaman (*Syzygium cumini*), karonda (*Carrisa carandas*), chiku (*Achras zapota*) and Aritha (*Sapindus laurifolius*) to soil pH of 8.1, 8.4, 8.7, 9.4 and 10.0 in a pot trial. Within 30 days of planting, 80% of guava, 80% of Jaman (*Jambolana*) and 60% of Aritha plants died at pH 10. *Achras zapota* (chiku) and *Carrisa carandas* (Karonda) showed 100% survival at this stage. Ninety days after planting, all plants of guava and Aritha died at pH 10.0 and 9.4, while *Syzygium cumini* (Jaman) showed 60% survival at pH 9.4. Similarly, 80% of Karonda plants died within three months at pH 10. *Achras zapota* showed 100% survival at pH 10.0 even eleven months after planting. Chemical analysis indicated that had a much lower Na: K ratio and was able to take up more K than Na even at pH 10.0 than guava and Jaman (*Jambolana*). Results indicated that Na competed with K uptake in guava and jaman, resulting in more Na uptake and plant mortality. However, roots of *Achras zapota* (chiku) may have some ion regulation mechanism to avoid such competition for uptake of Na and K from soil.

According to QURESHI AND BARRETT (1998), ber *(Ziziphus mauritiana)* is salt tolerant fruit tree. It can tolerate moderate to high salinity and sodicity. It can also tolerate an extreme range of temperatures (-5 to 50^{0}C). It is frost hardy, has a deep tap root system, and is therefore extremely drought tolerant. It is commonly planted on sand dunes. It also grows on deep, sandy loam soils. HASSAN, *et al.* (2000) observed the effects of soil salinity on yield, growth and Na and Cl contents of three olive cultivars in a 2 years field study. Relative olive fruit yield was unaffected up to a soil salinity 2.2 dS m^{-1}, for “Agizi Aksi” and “Agizi Shami” and 1.2 dS m^{-1} for “Teffahi” cultivar. Yield was reduced by 3.4% for “Agizi Aksi” and 4.8% for “Agizi Shami” with each unit increase in salinity above 2.2 dS m^{-1}. In “Teffahi” cultivar, each unit increase in the salinity above 1.2 dS m^{-1} reduced yield by 5.2%. Vegetative growth was more tolerant to salinity than fruit yield production. The results place olives in moderate tolerance category for salinity. With increasing soil salinity level, Na and Cl concentration in the leaves was increased in all the three cultivars but to different degrees. The accumulation of sodium and chloride in leaves was higher in the least tolerant cultivar (Teffahi) than the most tolerant cultivar (Agizi Aksi). Net return of olive production was reduced by 4%, 5.3% and 5.9% with each unit increase in soil salinity above 2.5, 1.9 and 1.7 dS m^{-1} for "Agizi Aksi", "Agizi Shami" and "Teffahi" cultivars respectively.

The effect of soil salinity on yield, growth, root distribution, leaf elemental concentrations and net return of apricot trees (cv. Amar) was investigated in Egypt. For the two years, relative fruit yield was unaffected up to soil salinity of 0.9 dS m^{-1}. Each unit increase in salinity from 0.9 dS m^{-1} reduced yield by 18.6%. These results placed apricot in the sensitive category. Yield reduction was attributed to reduced vegetative growth. Vegetative growth was more tolerant to salinity than fruit yield. Salinity reduced root growth and the deeper roots were more influenced by increasing soil salinity. As salinity increased, Cl and/ or Na increased, however, K decreased in the leaf tissue. With each unit increase in soil salinity above 0.84 dS m^{-1} net return of apricot production reduced by 21.9%. The results indicated the need to maintain low soil salinity levels which are essential for maximum apricot yield [HASSAN *et al.* (2001)]. RAO and KHANDELWAL (2001) observed that salt-affected soils occurring in Gujarat State are either lying barren or possess some native hardy species and coarse grasses. They studied the physiology of salt tolerance of arid fruit species like Ber (*Zizyphus mauritiana*) and pomegranate, grown on sandy loam, saline and saline- black soils. Results indicated that pomegranate is more tolerant than Ber (*Zizyphus*) in terms of osmoregulation, better tissue tolerance and yielding ability. Ber (*Zizyphus*) yielded better on sandy loam saline soils (salinity up to 6 dS $m^{-1)}$ and pomegranate was found ideal for saline-black soils with salinity up to 12 dS m^{-1}. Results are discussed in relation to the adaptability of these species to salinity of the soils. LATIF AND NABI (2003) concluded that Ber (*Zizyphus*) and Kikar (*Acacia arabica*) grow well on the soil where ECe of the soil profile varies from 18 to 27.9 dS m^{-1}.

SINGH AND PATHAK (1992), carried out experiments with 5-months-old seedlings and 10-months-old budded plants of guava (cultivar Sardar), in earthen pots using sandy loam soil (Entisols). Sodicity levels were maintained at 16, 24 and 32% exchangeable sodium (actual values were 15.5, 22.9 and 30.5% respectively) and salinity at 4.0, 8.0 and 12.0 dS m^{-1} (actual values were 4.5, 8.6 and 12.8 dS m^{-1} respectively). Data on plant establishment, survival and growth were recorded at monthly intervals. Plant establishment rate of 100% was recorded up to 22.9% exchangeable Na and 8.6 dS m^{-1} but above these values establishment was reduced. Plant growth decreased with increasing salinity. Seedling plants showed higher rates of establishment and growth than budded plants. Root moisture content increased with increasing sodicity and salinity.

A pot experiment indicated the effects of soil salinity (ECe values of 4.5, 8.6 and 12.0 dS m^{-1}) on nutrient status and chlorophyll content in guava seedlings and budded plants of cv. Sardar. Total N, P, K and Na concentrations in the dried leaves of guava seedlings and budded plants of cv. Sardar, and the total chlorophyll content, decreased with increasing salinity level. Ca, Mg and Cl concentrations showed the opposite trend. Seedlings generally showed a higher nutrient status than budded plants (SINGH AND PATHAK, 1994). HAGGAG AND MAKSOUD (1996) investigated the effect of salinity (control, 1105, 1465, 2087 and 3220 ppm) on the growth and yield of guava (cv. Montakhab El-Kanater) for trees growing in a sandy soil in Egypt during 1993-94. Fruit weight and size decreased with increasing salinity. Fruit ascorbic acid content was significantly decreased at higher salinities compared with control fruits. Na and Cl contents of leaves increased with increasing salinities.

ALI- DINAR *et al.* (1998) investigated the effects of NaCl salinity (30 mmol Na^{+}) and increasing rates of nitrate N (0, 5, 10 and 15 mmol NO_3) on total biomass production and distribution of white and red-flesh guava cultivars, over a period of 12 weeks. Dry matter production of leaves, shoots and stems, was reduced with NaCl treatment. Root dry weight was increased with NaCl treatment. Substantial increase in biomass production of leaves and shoots was observed with increasing rates of N in the saline media. Stem dry matter production was slightly improved by addition of N. Al-DINAR *et al.* (1999) observed the effects of NaCl (30 mM), in combination with N [5, 10 and 15 mM Ca $(NO_3)_2$] on growth and physiology of two Sudanese guava cultivars. Salinity reduced shoot growth and leaf chlorophyll content, but a moderate N supply improved these parameters. Salinity reduced net photosynthesis rate (PN) and transpiration (T), but a moderate N supply enhanced PN and T. Stomatal resistance (Rs) was high under saline conditions, whereas it was comparatively low for trees moderately supplied with N. The salinity-induced decrease in PN of red guava was attributed to stomatal closure. In white guava, this was due to non-stomatal factors. Xylem flow rates were similar for both cultivars and for all treatments except those supplied with NaCl alone, but the highest flow rates were observed under moderate N supply. It was concluded that red guava is more salt tolerant than white guava.

VERMA *et al.* (1994) studied the effects of fruit species on properties of salt affected Inceptisols in Uttar Pradesh, India. After 5 years, plantations of Falsa (*Grewia subinaequalis*) increased soil organic C, available N, P and K, and reduced $CaCO_3$, pHs, ECe and bulk density, due to greater litter production than other fruits plants. Guava (*Psydium guajava*) plantations were slightly less effective, and plantations of ber (*Ziziphus mauritiana*) and Amla (*Phyllanthus emblica*) did not significantly affect soil properties.

PANDY *et al.* (1993) conducted an experiment in earthen pots with four levels of ECe (control, 5, 10 and 15 dS m^{-1}) to determine the foliar nutrient status. Different mixtures of $CaCl_2$, $MgCl_2$, NaCl and Na_2SO_4 were incorporated to build up different conductivity levels. Six months old seedlings of *Ziziphus mauritiana* (Ber) were planted in each pot. Total N, P and K decreased while concentration of $Ca^{2+,}$ $Mg^{2+,}$, Na^+, Cl^- and SO_4^- increased in the leaves with increase in salinity levels.

GARCIA-LIDON *et al.* (1998) investigated the effect of saline irrigation water (NaCl concentration of 50 mmol) on the accumulation of K, Cl, Na, N, P, Ca, Mn and Mg ions in 3 rootstocks (sour orange*, Citrus macrophylla* and *C. volkameriana*), and in lemons (cultivars Fino, Verna and Eureka) grafted on the 3 rootstocks in Spain. Salinity reduced the growth. The least affected rootstock was *C. macrophylla*. None of the rootstocks was able to exclude Cl^- and Na^+ from the leaves of scions and rootstocks (in un-grafted plants). Salinity and rootstock/scion combinations influenced Macro- and micronutrient concentrations. In general, lemons grafted on *C. macrophylla* contained higher contents of N, Fe and Mn, and exhibited better growth than lemons grafted on the other 2 rootstocks. The best combination for growth under saline conditions was Fino grafted on *C. macrophylla*.

AL-DAWWEY (1998) carried out a pot experiment in 1995 and 1996. Balady mandarin and Manfalouty pomegranate seedlings were grown in soil into which salts ($CaCl_2$, Na_2SO_4, NaCl and a mixture of all 3) had been thoroughly mixed at a rate of 0.0, 0.1, 0.2 and 0.4%. With regard to the type of salt, the results revealed that NaCl, Na_2SO_4 and $CaCl_2$ caused adverse effects in descending order on various growth parameters and Ca uptake. Data are also presented on sodium and chloride uptake and leaf chlorophyll and carbohydrate contents. Pomegranate seedlings were more tolerant to salinity than mandarin seedlings. It was concluded that it is possible to cultivate Balady mandarin and Manfalouty pomegranate seedlings in soils of salt contents up to 0.2 and 0.4%, respectively.

The effect of salinity (0 and 1.2% NaCl) on the growth of cultured cells of fig (cultivars Hourish and Mashi Dauphine) was investigated. Salinity inhibited the growth of both cultivars. Hourish was less sensitive to salinity than Mashi Dauphine. NaCl treatment increased the contents of oxygen free radicals and malonaldehyde (MDA) which was a product of the oxidation of membrane lipids. The specific activities of super-oxide dismutase (SOD), catalase (CAT), ascorbate specific peroxidase (APX) and glutathione reductase (GR), as well as the contents of vitamin C (ascorbic acid) and glutathione, were increased by NaCl treatment. Significant increases in the activities of SOD and CAT were observed in Mashi Dauphine. Higher increases in the activities of APX and GR were observed in Hourish, indicating that these enzymes may have a role in salt tolerance in fig (WANG *et al.,* 1998).

Pot culture experiments were conducted to study the effect of salinity at 14.80 and 20.25 dS m^{-1} on survival and anatomical changes in leaf lamina of wild *Zizyphus mauritiana* seedlings and the cultivars Banarasi Karaka, Kaithali, Umran and Gola, after 18 months of establishment. Histological examination of leaf lamina demonstrated differential responses to graded levels of salinity. Among the budded plants, Banarasi Karaka recorded increases in central vascular bundle size, epidermal cell size, xylem cell size and the size of palisade cells (upper epidermis) at 20.25 dS m^{-1}. Seedlings exhibited marked increases in the size of the central vascular bundle and the number of xylem cells at both salinity levels i.e., 14.80 and 20.25 dS m^{-1}. At 20.25 dS m^{-1}, the central vascular bundle size was 360 nm and the number of xylem cells was 98.0, compared with 330 nm and 44.0 in control (0.82 dS m^{-1}) respectively. Gola proved to be susceptible to salinity at

20.25 dS m^{-1} and at this level, exhibited an increase in the size of the central vascular bundle from 337.5 nm (in control) to 352.5 nm (at 20.25 dS m^{-1}). The number of xylem cells was reduced in Gola from 67 in the control to 50 and 42 respectively at 14.80 and 20.25 dS m^{-1}. Palisade cell (lower epidermis) size decreased with increasing salinity levels. Survival rate decreased significantly with increasing salinity, with very poor survival rate of Umran and Gola (both 17.8%) at 20.25 dS m^{-1} (AWASTHI AND PATHAK, 1999).

PASTERNAK (1987) reported that pear cultivars grafted on a quince rootstock could tolerate irrigation water of EC 6.2 dS m^{-1}. OKUBO *et al.* (2000) studied the growth responses of grafted young pear trees under salinity. Chinese, Japanese and European pear cultivars (*Pyrus ussuriensis* cv. Yari, *P. pyrifolia* cv. Kosui and *P. communis* cv. La France) were grafted on to 3-year-old *P. betulifolia* (BET) and *P. pyrifolia* (PYR) seedlings. They were grown in pots with sand and irrigated with 20% Hoagland's solution plus 0, 25 and 50 mM NaCl. All scions grafted on to BET grew well even under 50 mM NaCl irrigation, while those grafted on to PYR suffered markedly from NaCl toxicity. Flower bud formation was stimulated by NaCl treatment in every scion-rootstock combination. Flowering date and number of flowers per cluster were not affected by NaCl treatment. Mineral analysis suggested that salt-tolerance in BET is due to its ability to restrict Na and Cl ion transport to leaves.

2.4 Date palm behavior under saline environment

Date palm *(Phoenix dactylifera* L.) is the primary crop in Oman occupying 49% of cultivated area and 82% of all fruit crops grown in the country. Oman is currently the eighth's largest world producer of dates. The production of dates of the country in 2005 was 238, 000 metric tones (MT). Oman has diverse topographical and climatic eco-regions that allow for cultivation of various types of date palm cultivars, particularly in the northern coastal and the interior region. There are approximately 180 female and 48 male cultivated varieties of the 7.8 million trees of date palm. Despite the great diversity of the cultivars, over 78% of the total production is from only 10 commercial cultivars. These cultivars are dominant because of their marketable high fruit quality or early and late season production. Physical phenotypic diversity index of selected date palm cultivars indicated large biodiversity among the population. Similarity matrix also indicated high similarity among date palm cultivars ranging from 74 to 90%. The study highlighted the need for chemical and molecular analyses to explore the genetic linkage among cultivars (AL-YAHYAI AND AL-KHANJARI, 2008).

According to criteria of MASS (1986), date-palm plant is included in the group that is tolerant to salinity. Their salinity threshold for reduction of yield is 4.0 dS m^{-1} and has 50% reduction in yield at 17.9 dS m^{-1}. Good yield has been observed where the electrical conductivity of ground water was around 10.0 dS m^{-1}. However, salt tolerance level can vary a lot depending upon texture and drainage of soil, climate and the genetic potential of the variety. AYERS AND WESTCOT (1985) proposed the threshold of date palm as 4.0 and 2.7 dS m^{-1} for soil and water respectively. Whereas respective 50% yield reduction limits were found by them as 18.0 and 12.0 dS m^{-1}. MARCAR *et al*. (1995) reported that date palm (*Phoenix dactylifera*), depending upon variety can tolerate up to at least 18000 ppm salts or even more. However, fruit production usually stops at about 10000 ppm salts. The salt marsh *Phoenix reclinata* of tropical Africa can tolerate full-strength ocean water but it does not produce fruit.

The date-palm plants can successfully grow in arid and hot climate under saline environment. They require sun light and are resistant to heat, withstanding temperature up to 50^{o}C for short periods. They can tolerate low temperatures but do not grow below 10^{o}C. Such plants do not set and develop fruit until temperature is above 25^{o}C. At the time of fruiting, the temperature should be high (45-50^o C) and humidity should be low (QURESHI AND BARRETT- LENNARD, 1998). AL-MANSOORI (2001) conducted research to screen data palm cultivators for salt tolerance and to investigate the physiological mechanisms involved in this tolerance. Different levels of tissue organization and stages of plant life cycle, namely: callus induction, callus fast growing phase, seed germination, one month, three month and two year old plants, were investigated under *in vitro* and *in vivo* conditions. The potential of plantlet regeneration via embryogenesis was confirmed. However, the organogenesis technique needs more investigation. Different cultivar performance was evident at the cellular and the whole plant levels, aside from the two year old plants. The results suggest that *in vitro* screening for salinity tolerance is possible in date palm. However, this cannot be conclusive, as the two year old plants did not show any differential cultivator performance. The characters showing variation were inconsistent and insufficient to assort the cultivars according to their degree of tolerance. Nevertheless, callus induction using immature embryos may offer the potential of selection from the pre-existing date palm gene pool for enhanced salt tolerant cultivars or individuals. The results indicate that date palms may rely on inorganic ion accumulation to maintain osmotic adjustment. Proline accumulation in response to salinity was detected but its role in osmotic adjustment was not clear. The differential cultivar performance was not related to proline. Consequently, proline cannot be used as indicator for salinity tolerance in date palm. The whole plant tolerance may be a result of Na^+ compartmentalization in the root and Na^+ exclusion from the shoot. However, the roots have specific holding capacity, exceeding this capability enhances Na^+ release into the shoot.

Growth and physiological responses of date palm (cv. Barhee) callus to salinity stress were examined by AL-KHAYRI (2002). He found that at 125mM or higher level of NaCl, callus growth was completely inhibited. However, the lowest level (25mM) increased the growth of date palm callus. The K content of callus also increased at this level. Proline accumulation was correlated to callus growth inhibition. In response to increasing external NaCl level, the Na/ K ratio increased. This ratio was positively correlated to proline accumulation and hence callus growth. SHANI AND DOGLAS (2001) related the yield loss to reduced photosynthesis, high energy and carbohydrate expenses in osmoregulation, and interference with cell functions under saline conditions. GHADIRI *et al.* (2005) reported restricted water uptake by salinity due to the high osmotic potential in the soil and high concentrations of specific ions that may cause physiological disorders in the plant tissues and reduce yields**.** The investigations of DJIBRIL *et al.* (2005) were conducted to evaluate date palm (*Phoenix dactylifera* L.) tolerance to osmotic stress induced by polyethylene glycol (PEG) or NaCl during the early stages of plant development. Two varieties Nakhla Hamra (NHH) and Tijib widely cultivated in Mauritania were tested. NHH showed increasing of epicotyl length, primary root length, secondary root number and praline content when water deficit was induced by PEG. In contrast, on the basis of the same developmental and biochemical characters, the Tijib cultivar was more tolerant in salinity stress. It has been reported that environmental stresses, especially water stress and salinity, increase the generation of toxic active oxygen species (O_2^-, H_2O_2 and OH) result in cellular injury or damage which frequently results from impaired or perturbed metabolism (SAIRAM AND SAXENA, 2000 and SREENIVASULU *et al.,* 2000]). In another study it was found that application of anti-stress substances such as gamma aminobutyric acid (GABA), vitamin E, salicylic and acetyl salicylic acids increased survival percentage of 'Khalas' date palm plants during the VP1-satge of the acclimatization program (AWAD *et al.,* 2006).

The study of AL-HAMMADI (2006) aimed to address the current status of the United Arab Emirates date palms. They reported a huge increase in the date palm number in UAE was achieved in the past few decades due to development activities. In the same time, there were critical issues faced this development, such as water demand, salinity, and Red Palm Weevil. In a greenhouse experiment optimal growth was found in control and 3000 ppm of NaCl. Relative growth rate (RGR), biomass, and NL decreased significantly by increasing salinity to 6000, and 12000 ppm. However, no significant differences were observed in the average SGR for any cultivars. Increased NaCl leads to significant decreases in K^+, Mg^{2+} and Ca^{2+} contents of plants. The Na: K ratios were lower in shoots than in roots. Lulu, Fard, Khunaizy, Nabtat Safi, and Razez cultivars showed higher RGR and biomasses whereas Khunaizy, Mesally, and Safri had higher Na: K ratios than other cultivars in the control indicating higher Na^{1+} discriminations from plant parts. The third chapter studied the vegetation change in the eastern region of the UAE. Due to shortage of fresh water resources, the vegetation of the eastern region of the UAE has experienced a series of declines resulting from salinization of groundwater. To assess these changes, field measurements combined with Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) based Soil Adjusted Vegetation Index (SAVI) were analyzed. Images from two dates, 1987 and 2000 were acquired to enable the computation of the greenness anomalies for three sites in the eastern region, Fujairah, Kalba, and Hatta. The results show an overall increase in the agricultural area, associated with a severe decrease in vegetation greenness and health conditions, particularly in the Kalba study area. The SAVI values decreased with increased soil salinity, permitting the identification of salt-affected areas. Potential areas of further research range from studying the effects of tree spacing and understory crops as immediate and potential solutions to maintain productivity and mitigate the salinity problem. YOUSAF AND

AWARD (2007) reported that photosynthetic gas exchange characteristics, salt uptake, pigment contents, and electrolyte leakage were examined in date palm seedlings (*Phoenix dactylifera* L.) subject to seawater treatments at 1, 15, and 30 dS m^{-1} salinity levels in the presence or absence of 0.08% ALA-based (5-aminolevulinic acid-based) functional fertilizer commercially known as Pentakeep-v. Date palm seedlings accumulated significant amounts of Na^+ in the foliage with increasing salinity, about a threefold increase in the accumulated Na^+ between the control and 30 mS cm^{-1} salinity treatments. Electrolyte leakage indicated a significant reduction in membrane integrity as salinity increased. A strong linear correlation was observed between the chlorophyll a/b ratio and assimilation rate throughout salinity treatments. The slope (*b*) and the correlation coefficient between the chlorophyll a/b ratio and assimilation suggested that salinity reduced assimilation predominantly via the reduction in chlorophyll a contents (r^2 = 0.885 and $b = 1.77$, $P < 0.05$). Plants treated with Pentakeep-v showed a similar response with increasing salinity but at higher levels of both chlorophyll a/b ratios and assimilation rates. Mechanistic analysis of *A*: *Ci* response curves showed that photosynthetic gas exchange in seedlings of the date palm was significantly reduced with increasing salinity due to gas phase limitation (S_L) as evident by stomatal conductance (g_s) values. Salinity did not induce any change in the carboxylation efficiency of the rubisco enzyme (Vc,max), or in the rate of electrons supplied by the electron transport system for ribulose 1,5-bisphosphate (RuBP) regeneration (Jmax). Accelerated carbon loss through respiration has significantly contributed to the described reduction in assimilation and increased CO_2 compensation point (Γ). Only at the 30 dS m^{-1} salinity level did treatment with Pentakeep-v reduce Na^+ accumulation in the leaves, and caused a reduction in K^+ selective uptake, leading to a concomitant reduction in K^+/ Na^+ ratios. Pentakeep-v significantly improved chlorophyll-A contents in all treatments, which was subsequently reflected in total chlorophyll and chlorophyll a/b ratios. The non-gas-phase components of the photosynthetic process (biochemical factors limiting gas exchange) were significantly improved by Pentakeep-v applications. Specifically, Pentakeep-v enhanced the biochemical efficiency of carbon fixation (Vc,max) and the rate of electron transport required for RuBP regeneration (Jmax) by 37.4% and 17.8%, respectively, over untreated plants at a salinity level of 15 mS cm^{-1}. In addition, Pentakeep-v reduced S_L to values similar to those of control plants (9.07%) and lowered CO_2 compensation points by reducing respiratory CO_2 loss, with increasing salinity to 30 mS cm^{-1}. We, therefore, conclude that the ALA-based fertilizer Pentakeep-v improves salt tolerance in date palm seedlings by increasing photosynthetic assimilation. The latter is mediated via boosting light-harvesting capabilities of the treated plants by increasing content of chlorophyll A or by reducing stomatal limitation to photosynthetic gas exchange.

Yield and transpiration of juvenile date palms (*Phoenix dactylifera* L., cv. Medjool) were studied by TRIPLER *et al.* (2007) under conditions of increasing salinity and boron in lysimeters. Twenty seedlings were planted and grown in 20 lysimeters and irrigated with combinations of four salinity and five B irrigation concentrations. A linear decrease was found for both yield and for transpiration in response to increased soil saturated paste salinity for the treatments having lower B concentrations (0.0278, 0.185 and 0.4625 mmol 1^{-1}). Yield and transpiration also decreased with increased B concentration. While increases in soil saturated paste B from 0.3 to 1.5 mmol L^{-1} caused substantial declines in yield and transpiration, subsequent increased B to 3 mmol L^{-1} caused only minor reductions. Response to salinity and to excess B was witnessed from the lowest tested levels when each of the variables was isolated. Growth response to combined conditions of salinity and B behaved according to the dominant of the two stress causing factors and did not show additive effects. Dynamics of plant water uptake and tree growth observed for salinity and boron occurring independently and together were summarized by decreased water uptake but not ion accumulation for NaCl and CaCl salts and by boron that was accumulated in leaves and subsequently was associated with reduced tree size. It is suggested that while mechanisms for plant response to salinity are dominated by lowered soil water potential (osmotic stress), boron becomes toxic as it accumulates to a threshold level in plant tissue. ALA-based fertilizer 'Pentakeep-v' improved salt tolerance and growth of date palm seedlings by increasing photosynthetic assimilation. The latter was mediated via boosting light harvesting capabilities of the treated plants by increasing chlorophyll a content and by reducing stomatal limitation to photosynthetic gas exchange (YOUSSEF AND AWARD, 2008).

2.5 Nutritional aspects of date palm under saline environment

PESSARAKLI (1999) reported that nutrient availability and uptake by plants in saline environments is related to

i. The activity of nutrient ion in the solution, which depends upon pH, pE, concentration, and composition.
ii. The concentration and ratios of accompanying elements that influence the uptake and transport of this nutrient by roots.
iii. Numerous environmental factors.

The impact of salinity on nutrient uptake is a secondary negative effect on growth of plants. The passive nutrient uptake is related to water uptake, and any decrease in water availability (Osmotic effects of salinity) should be reflected in reduced nutrient uptake. The imbalance in composition of saline soil solution can affect the absorption of nutrients, e.g. excess of Cl, Na or Mg ions decrease the uptake of NO_3, K, Zn and Ca ions. It has been further suggested that ability of a plant to retain K in the presence of excess Na ion could be an important mechanism in salt tolerance (GHAFOOR *et al.,* 2004). Ion imbalances and nutrient deficiency, particularly for K^+ nutrition, can also occur (TEJERA *et al.,* 2006).

In study of ATTALLA AND HARRAZ (1996), the pits of eleven selected date palm cultivars grown in the Qassim region were analyzed (on dry weight basis) for their elemental composition as well as organic constituents. Regarding the elemental composition, their concentration ranges in the pits of the studied cultivars were as follows: nitrogen 0.81-1.20%; phosphorus 0.186-0.259%; potassium 0.363-0.403%; calcium 0.357-0.422%; magnesium 0.104-0.153%; chloride 0.269- 0.507%; sodium 0.029-0.043%; iron 124.8-172.0 µg g^{-1} manganese 17.0- 24.8 µg g^{-1}; zinc 8.3-18.3 µg g^{-1} and copper, 8.8-17.3 µg g^{-1} while the concentration ranges of the organic constituents were: total carbohydrates 57.645-68.918%; total sugars 3,773-5.830; total proteins 5.11-7.52%; crude fats 8.67-12.31%; and tannins 1.59-3.48%. Significant differences were also observed among the studied cultivars in most of their mineral and organic constituents. Significant correlation coefficients were found among the mineral composition and organic constituents of the pits of the selected cultivars in most cases.

BROSCHAT (1997) reported that all leaves from 10 replicate *Cocos nucifera* L. 'Malayan Dwarf' (COC) and *Phoenix canariensis* Chabaud (CID) trees were sampled for leaf nutrient analysis. In addition, the leaflets of the youngest fully expanded leaves and the third oldest leaves were divided into five groups along the primary leaf axis and these leaflets were then cut into thirds to determine nutrient distribution patterns within leaves and leaflets. Nutrient remobilization rates were calculated for N, P, K, Mg, and Mn. Results showed that N, P, and K were highly mobile within and between leaves of both species of palms. Up to 31% of the N, 66% of the K, and 37% of the total P in the oldest leaves were ultimately remobilized to newer leaves within the palm. Magnesium remobilization rates averaged 71% for CID but only 10% for COC. The middle-aged leaves appeared to be the primary sink for Mg in COC, rather than the youngest leaves as in CID. Manganese was also quite mobile in both species, with up to 44% of the total Mn remobilized in CID. Samples consisting of recently matured leaves were determined to be the most appropriate for Ca, Fe, Mg and Zn, but oldest leaves were found more suitable for N, P, K, and Mn analysis. Al-GHAMIDI *et al.* (1999) reported that date palm seedlings did not indicate any significant differences in growth parameters in response to urea application in the nutrient culture. However root elongation was significantly affected. A clear effect of N sources on leaf N, Ca and chlorophyll content was not observed.

Little is known about nutrient fluxes as a criterion to assess the sustainability of traditional irrigation agriculture in eastern Arabia (BUERKERT *et al.,* 2005). In this study GIS-based field research on terraced cropland and groves of date palm (*Phoenix dactylifera* L.) was conducted over 2 years in two mountain oases of northern Oman to determine their role as hypothesized sinks for nitrogen (N), phosphorus (P) and potassium (K). At Balad Seet 55% of the 385 fields received annual inputs of 100-500 kg N ha^{-1} and 26% received 500-1400 kg N ha^{-1}. No N was applied to 19% of the fields which were under fallow. Phosphorus was applied annually at 1-90 kg ha^{-1} on 46% of the fields, whereas 27% received 90-210 kg ha^{-1}. No K was applied to 27% of the fields, 32% received 1-300 kg K ha^{-1} each unit increase in salinity above 2.2 dS m^{-1} each unit increase in salinity above 2.2 dS m^{-1} each unit increase in salinity above 2.2 dS m^{-1}, and the remaining fields received up to 1400 kg ha^{-1}. At Maqta N-inputs were 61-277 kg ha^{-1} in palm groves and 112-225 kg ha^{-1} in wheat (*Triticum* spp.) fields, respective P inputs were 9-40 and 14-29 kg ha^{-1}, and K inputs were 98-421 and 113-227 kg ha^{-1}. For cropland, partial oasis balances (comprising inputs of manure, mineral fertilizers, N 2-fixation and irrigation water, and outputs of harvested products) were similar for both oases, with per hectare surpluses of 131 kg N, 37 kg P, and 84 kg K at Balad Seet and of 136 kg N, 16 kg P and 66 kg K at Maqta. This was despite the fact that N2-fixation by alfalfa (*Medicago sativa* L.), estimated at up to 480 kg ha^{-1} yr^{-1} with an average total dry matter of 22 t ha^{-1}, contributed to the cropland N-balance only at the former site. Respective palm grove surpluses, in contrast were much higher with 303 kg N, 38 kg P and 173 kg K ha^{-1} at Balad Seet than with 84 kg N, 14 kg P, and 91 kg K ha^{-1} at Maqta. The data show that both oases presently are large sinks for nutrients. Potential gaseous and leaching losses could at least partly be controlled by a decrease in nutrient input intensity and careful incorporation of manure.

Studies of ASEMOTA *et al.* (2007) were conducted to test the effect of different growth regulators, sucrose and nitrogen on *Phoenix dactylifera* L. explants cultured on Eeuwen's basal medium. Naphthalene acetic acid (NAA) was very effective for callus induction. Addition of cytokinins (BAP and Kinetin) to NAA containing media did not enhance actual callus growth. Sucrose influenced callus production. Depending on the auxin concentration of media, callus production could be supported by sucrose within the range 15 - 105 g l^{-1} but the optimum sucrose concentration in the medium in all cases, as determined by size of callus was 30 g l^{-1}. NAA and sucrose tended to interact at relatively high levels of sucrose (45-90 g l each unit increase in salinity above 2.2 dS m^{-1}) to produce roots in culture. KNO_3 was essential as a source of nitrogen for callogenesis and optimum callus formation was observed at 50 mM (combined nitrogen).

The work of KOLSI-BENZINA AND ZOUGARI (2008) was realized in two Tunisian continental palm plantations (Deglet Nour). It aimed at studying the mineral composition of date palms' leaflets to base recommendations for foliar diagnosis on. At pollination, three palms per palm tree were taken at the median position, the lower green palm, and the last open palm. Leaflets were analyzed on the entire palm split into 4 zones. A broad variation of the palm portions leaflets' mineral composition is shown. The median zone leaflet nitrogen (N) and magnesium (Mg) contents were the highest for all of the palm positions. A similar nitrogen and magnesium determination was noticed along each palm. The highest calcium (Ca) content was at the base of the youngest palm and at the apex of the oldest palm; phosphorus (P) content was the reverse. The highest potassium (K) content was determined in the base palm leaflets. For foliar diagnosis, median zone leaflet sampling of median palm at pollination is recommended.

2.6 Techniques to manage saline water utilisation for irrigation

Irrigation is an agricultural practice which cannot be avoided in arid and semi arid regions and supplementation of saline water partially or fully necessarily finds its inclusion, especially countries like Oman where very little good quality water is available. Saline-sodic irrigation water, coupled with the low annual rainfall and high evaporation and transpiration (common in the arid and semi-arid regions) have resulted in accumulation of soluble salts in the soil solution, which can alter the structure and, consequently, affect the soil hydraulic conductivity (SAMENI AND MORSHEDI, 2000). Air temperature and salt stress led to several changes in the plant growth parameters. Plant substantially enhanced the evapo-transpiration at the peak growth stage. Environmental condition along with the growing stage of plants tremendously affected evapo-transpiration and salt accumulation in the soils irrespective of the salt treatments (AL-BUSAIDI *et al*., 2007).

Water availability for irrigation could be enhanced through judicious and proper use of saline water and the recycling of drainage waters for irrigation. Waters generally classified as unsuitable for irrigation can, in fact, be used successfully to grow crops without long-term hazardous consequences to crops or soils, with the use of improved farming and management practices. The development of crops with increased salt tolerance and the adoption of new crop and water management strategies will further enhance and facilitate the use of saline waters for irrigation and crop production, while keeping soil salinity from becoming excessive. (http://www.fao.org/documents/ the use of saline waters for crop production)**.**

Some management practices can be adapted to minimize the bad effects of saline water on crops and soil. Management practices are particularly useful for using waters, which are not too saline and the crops to be grown are not highly sensitive to salinity. Management practices like cyclic use/ alternative use of saline and good quality water, meeting the leaching requirements, mulching for decreasing evaporation or application of organic matter are mostly recommended. A list of selected management practices appropriate to Oman conditions was presented by HUSSAIN (2005).

1. Application of organic matter in the soil (especially composted crop residues and animal manures).
2. Soil conditioners that increase water holding capacity of soil and decrease evaporation.
3. Mulching (plastic/ crop residues/ Neem leaves)
4. Planting on the shoulder of ridges.
5. Appropriate plant densities to be adjusted by number of transplanted plants or higher seed rates.
6. Priming/ Pretreatment of seed (Dipping in saline water and nutrient solutions)
7. Two to three flood irrigations during land preparation for sowing of different crops where drip or bubbler irrigation system has been adapted.
8. Effect of precision land leveling in order to avoid over and under irrigation.
9. Irrigation scheduling/ irrigation depth/ irrigation frequencies.
10. Breaking capillaries by plowing the fields during fallow periods to reduce evaporation and accumulation of salts, especially in loam and clay loam soil.
11. Providing irrigation water in more quantities than crop requirements (Leaching).

Where good quality water is not available and agriculture has to merely depend upon saline water then using more water in excess of water requirements (Leaching Fractions) is the only well known technique but its effectiveness depends upon many other factors also like; soil texture, type of clays, drainage, physical properties of soil (especially infiltration rate and hydraulic conductivity), temperature, rainfall and finally the quality of irrigation water itself. AHMED *et al.* (1999) reported the findings from leaching experiments conducted on some Omani soils. Seven samples from two locations in the Al-Batina plain were analyzed. Repacked soil columns up to 30 cm in length were used in laboratory experiments to estimate the amount of water required for adequate leaching of salts from the soil profile. Two methods of leaching: continuous ponding and intermittent ponding were investigated. Results showed that most of the salts (50-90%) were removed from the soil profile by the application of water equal in amount to the depth of soil to be leached. The results also showed that intermittent ponding method of leaching was more efficient than the continuous ponding if initial salinity level was high. Soil samples were also collected to find out the salinity status under drip irrigation. It clearly demonstrated that drip irrigation proved very effective in removing salts from soil near the emitters, although there was a marked accumulation of salts on the soil surface between emitters.

SINGH *et al.* (1997) observed the performance of 10 fruit species, namely pomegranate (*Punica granatum*), guava (*Psydium guajava*), sapota (*Achras sapota* [*Manilkara zapota*]), Bael (*Aegle marmelos*), Amla (*Emblica officinalis)*, Ber (*Ziyiphus mauritiana*), Karonda (*Carrisa carandas*), date- palm (*Phoenix dactyleform* [*P. dactylifera*]), Jaman (*Syzygium cumini*), and Imli (*Tamarindus indica*), as affected by site preparation and amendment use, in a replicated field trial established in 1992, in a highly alkali soil (pHs=10.5) in Karnal, India. The treatments involved two site preparation methods: (1) auger holes of 20-25 cm diameter and 160-180 cm deep made in the centre of 45 X 45 cm pits in the main plot; and (2) pits of 90 X 90 X 90 cm; variable amendments composition (gypsum, farmyard manure and sand) in the sub-plot and fruit species in the sub-sub-plots. Growth observations recorded 26 months after planting showed that survival rate, height, and girth of all species remained unaffected by site preparation techniques and amendment use. Irrespective of planting techniques and amendment use, Jaman, guava, Ber, and Imli performed best. Date-palm and Bael performed poorly. Initial growth of sapota was satisfactory, but was highly sensitive to frost. Similarly, pomegranate which was performing exceedingly well was very sensitive to prolonged water stagnation. This three year study indicated that out of 10 species tried, 6 fruit species could be established in alkali soils after following appropriate site preparation methods and better management practices. Established species came to fruit bearing 18-24 months after planting, but fruits were damaged by prolonged water stagnation during the monsoon season and chilling temperatures of the 1994-95 winter. This study further indicated that the auger-hole method of root bed preparation was an economical, less laborious, and faster way of planting fruit trees than was the pit method.

According to LEVEY *et al.,* (1998), orchard trials on the effect of salinity on fruit trees (*Citrus sp*.), revealed that rootstock combinations typically call for leaving border trees between treatments, thus limiting the number of combinations that can be evaluated and making these experiments expensive and rare. Five salinity dilution ratios were applied to orchard trees through regular drip lines by different combinations of regulated in-line drippers. This enabled the construction of an orchard experiment without border trees, with the salinity increasing linearly along the orchard rows. Leaf analysis after application of salinity for 150 days revealed significant correlations between the applied dilution ratio and the concentrations of Cl, Na and K in the scion leaves of some of the rootstock combinations.

The impact of straw incorporation (6 Mg ha^{-1} $year^{-1}$) into agricultural soils compared with straw removal on organic matter mineralization and salinity was studied (BADI, 2000). The mineralization coefficient (evolved CO_2/ organic C ratio) was obtained to evaluate organic matter mineralization. Soil salinity was measured as means of electrolytic conductivity of saturation paste extract. Both parameters were measured seasonally during two years in two salt affected soils of the semiarid Central Ebro Valley (northeast Spain), a saline soil and a saline sodic soil. T he electrolytic conductivity (ranging from 2.5 dS m^{-1} to 24.3 dS m^{-1}) and the mineralization coefficient (ranging from 5.9 10^{-4} day^{-1} to 37.9 10^{-4} day^{-1}) varied widely during seasonal samplings of both soils. The lowest electrolytic conductivity values coincided with the highest mineralization coefficient values. Straw mulching and burying decreased significantly the average seasonal electrolytic conductivity of both soils: 2.5 times in the saline soil, and 1.9 times in the saline sodic soil. The EC reduction only increased significantly ($P<0.05$) the mineralization coefficient on saline soil (1.6 times). Straw amendment, followed by rainy periods, allowed the soluble salts leaching but did not modify significantly sodium content. A logarithmic regression was found between mineralization coefficient and electrolytic conductivity ($r^2 = 0.41$), considering both soils. Infiltration, water aggregate stability, and CO_2 were improved with the straw amendment, but only in saline soil. Soil differences showed the existence of a double effect: an osmotic and a specific ion effect.

RIO AND KHANDELWAL (2001) observed salt-affected soils occurring in Gujarat state are either lying barren or possess some native hardy species and coarse grasses. An attempt has been made to study the physiology of salt tolerance of arid fruit species like Ber (*Zizyphus mauritiana*) and pomegranate grown on sandy loam saline and saline black soils. Results indicated that pomegranate is more tolerant than Ber in terms of osmoregulation, better tissue tolerance and yielding ability. Ber yielded better on sandy loam saline soils (salinity up to 6 dS m^{-1}) and pomegranate was found ideal for saline black soils with salinity up to 12 dS m^{-1}. Results are discussed in relation to the adaptability of these species to salinity of the soils.

The effects of irrigation with saline water on yield components of field-grown tobacco (*Nicotiana tabacum*) "Burley" type plants were studied over two growing seasons by SIFOLA *et al.* (2002). Growth, dry matter partitioning and gas exchange were measured either in rain fed or fully irrigated plants growing in sandy clay loam soil. The four fully irrigated treatments received amounts of saline waters at 0.54, 2.5, 5.0 or 10 dS m^{-1} electrical conductivity (EC_w) equal to crop evapotranspiration. They reported that the electrical conductivity of the saturation phase (EC_e) across the 0.6 m topsoil profile increased with increasing salinity of the irrigation water. Soil moisture was markedly lower in the rain fed treatment than in fully irrigated treatments. Different saline concentrations of irrigation water had virtually no effect on soil moisture. Transpiration rates were unaffected by salinity in both years. The highest yield was produced by plants irrigated with good quality water. The number of leaves per unit land area was greater for the normal water plants, whereas there were no differences between the other four treatments. Salinity decreased plant dry matter and height at harvest, increased dry matter partitioning into leaves and stems in both years. Dry matter partitioning to leaves was also greater for the rain fed plants than for the normal watering plants. Tobacco plants grown under field conditions showed a maximum reduction of relative yield of 31% at the highest salinity level. The threshold values (0.56 and 0.96 dS m^{-1}) and the EC_e at which 10% yield reduction was obtained (3.12 and 2.55 dS m^{-1}) calculated from the linear model of response of relative yield to increasing EC_e were typical of moderately sensitive crops. The ECe values at which 50% yield was reduced (13.34 and 8.91 dS m^{-1}) were indicative of moderate tolerance to salinity.

EL-BABLY (2002) quoted the following strategies for proper management in scheduling irrigation and irrigation management under saline conditions in Egypt.

1. Improve the accuracy of the soil water balance components to calculate a reliable estimate of the leaching fraction
2. Estimate the leaching requirements and add that to the irrigation requirement

3. Consider the water distribution uniformity to decide which part of the field should receive at least the leaching fraction for salinity control
4. Take into account that leaching salts periodically is more practical than every irrigation;
5. Consider that there is no need to increase irrigation frequency to control salt concentration except for drip irrigation
6. Monitor the salinity of the root zone, especially prior to the times of periodic leaching

This would result in optimum salt control with minimum losses to deep percolation. Appropriated irrigation systems may be necessary on problematic soils. Sprinklers are well adapted to sandy and loamy soils but less so to heavy or clayey soils. Drip or trickle irrigation system are better adapted to loamy or clayey soils and apply water through many small outlets (emitters) at a rate of 2 to 4 liters per hour. At these low rates they do not disperse the soil particles, as do sprinklers. Drip irrigation provides a greater opportunity for using saline water. Sprinkler irrigation may cause surface sealing and leaf burn of sensitive crops. Leaf burning can be reduced by night irrigation, and by irrigating continually rather than intermittently. Basin irrigation has greater potential for uniform application than other methods of flooding such as border irrigation or wild-flooding irrigation provided that the basins are leveled and sized properly. Furrow irrigation tends to accumulate salts in the seed beds because leaching occurs primarily below the furrows. The length of the furrow, the slope, size of the stream and time of application are factors that govern the depth and uniformity of application. Leaching and salinity control require a proper balance among these factors.

RAJAK *et al.* (2002) assessed the relationship between soil salinity and grain sorghum growth and yield under paddock conditions on the Liverpool Plains. An unevenly salinized area of about one square kilometer sown to strips of sorghum was sampled. They measured plant density, growth, and grain yield and soil salinity at 13 locations. There was a rapid decline in dry matter and grain yield with increasing soil salinity measured as ECe in the top 10 cm of soil especially from 2 to 5 dS m^{-1}. Similar responses were found for both dry matter and grain yield with ECe at other depths because, at this site, ECe was fairly constant with depth. At a second site, the situation was different with high ECe levels at 50cm and low levels at 10cm; reductions in sorghum yield were significant. The decline in yield with increasing ECe was more severe than reported elsewhere for sorghum. From their results they suggested that sorghum was much more sensitive to salinity than commonly accepted.

REDDY *et al.* (2003) illustrated that water is one of the essential inputs for crop production. It affects crop performance not only directly but also indirectly by influencing nutrient availability, timing of cultural operations, and other factors. Fresh weight yields of forage sorghum ranged from 38.3t/ha^{-1} with no irrigation to 88.4t/ha^{-1} with 56mm of irrigation. Barley was most tolerant to soil salinity followed by oats, sorghum, pearl millet, Egyptian clover and maize. In sorghum, salinity decreased seed germination and early seedling growth. Salt stress reduced sorghum leaf weight and CP content. More than 80% of water resource is used for cereals in Northwest China. Spring wheat, the most important irrigated crop in that area, has a high seasonal water requirement for maximum yields. In this area, the most common low yield factor is water deficit (XIE *et al.,* 2005). A more efficient use of irrigation water under limited precipitation will help sustain agricultural production. Under water limited conditions the largest increase in water use efficiency (WUE) of crops comes by altering the balance between evaporation and transpiration. Evaporation (E) from soil surface results in a considerable loss of moisture and has a direct impact on wheat yield. In wheat production, E is usually 30–60% of total ET. Not only agricultural practices including the crop rotation and fertilization but also water quality and irrigation management affect the salinity build-up (DARWISH *et al.,* 2005). No salinity hazard appeared when farmers apply surface irrigation or sprinklers. Regardless of the cropping system, the highest ECe value (8.6dS m^{-1}) was observed under mismanaged drip irrigation and monoculture. The smallest ECe (0.7dS m^{-1}) was under rain fed condition. Very slight salinity levels (1.4–1.7dS m^{-1}) were for soils under furrow irrigation, sprinkler and alternation of drip and sprinkler irrigation systems. With time soil resilience to salt accumulation and resistance to degradation were altered. The farmer's reaction was to abandon the land. Inadequate skills and the absence of effective extension service have been the main cause for it.

RENGASAMY (2006) reported that salts introduced by irrigation water are stored within the root zone because of insufficient leaching. Poor quality irrigation water, low hydraulic conductivity of soil layers as found in heavy clay soils and sodic soils, and high evaporative conditions accelerate irrigation-induced salinity. Use of highly saline effluent water and improper drainage and soil management increase the risk of salinity in irrigated soils. In many irrigation regions, rising saline groundwater interacting with the soils in the root zone can compound the problem. He also reported that low osmotic potentials resulting from soil salinity can restrain water uptake by plants and reduced their ability to survive and produce. Under dry-land conditions, concomitant changes in matric and osmotic potentials determined plant water uptake. The influence of soil texture and type of clay on plant available water compounds the effect of matric and osmotic potentials. In the figure below he illustrated the energy input (equivalent to soil matric plus osmotic potential) needed by plants to remove water as the soil moisture and salinity levels change in a sandy loam soil. When there is no salt, plants are able to take up water until the soil dries to 5% water content. Whereas, when the soil salinity measured in the laboratory as $EC_{1:5}$ (1:5 soil: water extract) is 0.64 dS m^{-1}, plants can get water only up to 14% water content. When the measured salinity increases to 1 dS m^{-1}, plants cease to take up water at 18% water content.

A field experiments was conducted on a saline vertisols during 2000–2002 for evaluating the response of cotton (*Gossypium hirsutum*) to applied irrigation water (IW, 0.8, 1.0, 1.2 and 1.4 times the evapotranspiration, ET) with drip and furrow irrigation method in four different blocks varying in soil salinity (ECe, surface 0.6 m) and water table depths (WT). The initial ECe and average WT (water table) for the blocks I, II, II and IV were 8.0 ± 0.4, 1.25 ± 0.08; 9.1 ± 0.7, 1.15 ± 0.08; 10.4 ± 0.5, 1.05 ± 0.09 and 15.1 ± 0.8 dS m^{-1}, 0.95 ± 0.07 m, respectively (RAJAK *et al.,* 2006). They reported that the growth and yield performance of cotton irrigated through furrows, even though with good quality canal water (ECiw 0.25 dS m^{-1}), was poor when compared with drip irrigation with marginally saline water (ECiw 2.2 dS m^{-1}). The crop responded to applied water and the maximum cotton yield (1.78 Mg ha^{-1}, average for two years) was obtained from block I under drip irrigation applied at 1.2 ET while the lowest yield (0.18 Mg ha^{-1}) was from block IV when applied water equaled 0.8 ET with furrow irrigation. Due to creation of better salt and moisture regimes, water productivity also considerably improved with drip irrigation. Production functions developed could be represented as:

$Y(Mg\ ha^{-1}) = 0.207AW - 0.0012AW_2 + 0.0807ECe - 0.0049ECe2 - 0.0014AW \times ECe - 6.5945$ ($R2 = 0.974^{**}$) for drip irrigation and $Y = 0.3853\ AW - 0.0021\ AW2 + 0.0253\ ECe - 0.0005\ ECe2 - 0.0016\ AW \times ECe - 14.9117$ ($R2 = 0.877^{**}$) for furrow irrigation where AW and ECe represent applied water and time weighted mean soil salinity, respectively. Though the gross income (US$ 223–690 ha^{-1}) was more with drip than furrow (US$ 67–545 ha^{-1}) irrigation, the net profit per unit of applied water was higher with furrow irrigation. It was concluded that the drip system provided opportunities to enhance the use of saline waters in water scarcity areas especially those existing at the tail end of canal commands.

MIYAMOTO *et al.* (2006) identified the soil factors, which can affect salt accumulation, and develop a practical method for estimating potentials for soil salinization. They reported that salt accumulation was minimal in deep sandy soils regardless of their differences in soil forming history. Elevated levels of salt accumulation were, however, found in soils with a thick thatch layer, and in shallow Aridisols developed or placed over the Calcic horizon, which restricts drainage. High and variable salt accumulation (>10 dS m^{-1}) was found in compacted clayey Entisols in municipal parks, yet salt accumulation in golf course fairways with comparable soil texture was minimal. KARLBERG *et al.* (2007) in their study investigated the effect of two drip irrigation systems with low and high discharge rates (0.2 and 2.5 l hr^{-1}) that were used to irrigate tomatoes with water of three different salinity levels (0, 3 and 6 dS m^{-1}). These treatments were repeated with plastic mulch and under bare soil conditions. They reported that even at the highest irrigation water salinity (6 dS m^{-1}), a yield above the average marketable yield was achieved. Furthermore, the study showed that yield was significantly higher at low irrigation water salinity than at high salinity levels ($p < 0.0001$). Despite the reduction in yield under highly saline conditions (6 dS m^{-1}), these treatments still yielded on average 66 Mg ha^{-1} as compared with 80 Mg ha^{-1} for the fresh water treatments. There was no significant difference in yield between the high and the low discharge rate systems, irrespective of salinity level. Comparing only the data from the soil close to the emitters, it was found that soil water content was higher at high salinities ($p < 0.0001$). Soil water salinity was higher at high irrigation water salinity than at low ($p < 0.0001$).

However, no significant difference in mean soil water salinity was found between the two systems.

Al-WAHAIBI *et al.* (2007) conducted a field experiment to investigate the effect of mulching on tomato (Ginan variety) crop and probabilities of checking salt accumulation in soil when irrigated with saline water. The objective of the study was to manage the saline water for avoiding bad effect on crop yields and soil health. Two mulching materials; organic matter (from date palm residues) and black plastic sheet, were tested in comparison to control (without any mulch). Two saline waters (EC=3 & 6 dS m^{-1}) were used for irrigation. Uniform dose of fertilizers was applied. Four pickings of tomato were obtained and yield data were recorded. EC, moisture % age and temperature of soils were recorded after harvesting of crops. About 36% decrease in fruit yield was recorded with saline water of EC 6 dS m^{-1}. Continuous irrigation with water of EC 6 dS m^{-1} increased soil EC up to 11.56 dS m^{-1}. This magnitude of soil EC was beyond the safe limits for tomato that caused this cut in yield. It was observed that data palm mulch proved as the most superior in terms of tomato fruit yield and controlling increase in soil EC and temperature. It was followed by black plastic mulch. Both types of mulches indicated significant differences over control as well as among each other.

A field experiment was conducted in a completely randomized design, with factorial arrangement on tomato (*Lycopersicon esculentum* cv. AL-Wadi) by (AL-HABSI *et al,* 2006). The effect of cyclic irrigation with good quality and saline waters and fertilizer application on yield and mineral constituents of tomato was examined. The experiment consisted of two irrigation practices (IR1= Continuous irrigation with water of EC 0.70 d S/m and IR2= One irrigation with water of EC 0.7 and two irrigations with water of EC 6.0 dS m^{-1}) and three levels of potassium (K0 = 0, K1= 70kg K_2O ha^{-1} and K2=145 kg K_2O ha^{-1}) split into 2 doses. There were four nitrogen levels (N0= 0, N1=145, N2=215 and N3=285 kg N ha^{-1}) split into three doses. A basal dose of phosphorus at the rate of 95kg P_2O_5 ha^{-1} was added at the beginning of the experiment. One healthy seedling of tomato was transplanted in the field 3 weeks after germination. The texture of the soil was loamy sand. The treatments were replicated thrice and the experiment was completed in field of Agricultural Research Station Rumais, Sultanate of Oman. Equal quantities of good quality water and good + saline (cyclic) waters were applied per treatments. The cyclic irrigation was started 30 days after transplanting. Mature fruit was plucked, yield was recorded and total soluble solids (TSS) were determined. The results indicated that cyclic irrigation (IR2) decreased overall yield only by 16% in the first year and 24% in the second year indicating cumulative effect of salt accumulation. These effects were found to be non-significant in control treatment (no fertilizer added). However, addition of fertilizer created significant differences when both the irrigation strategies were compared. Effects were more pronounced in plots irrigated with fresh water. The first dose of N (145kg ha^{-1}) as well as K (70kg ha^{-1}) proved more responsive.

The effect of alternate irrigation with good quality and saline waters and mineral fertilization on yield and mineral constituents was examined in a pot experiment in a completely randomized design, with factorial arrangement (three replications) on tomato (*Lycopersicon esculentum* cv Tatto) in Oman.. The experiment consisted of two irrigation practices (IR1= Continuous irrigation with water of EC 1.0 dS m^{-1} and IR2= Alternate irrigation with waters of EC 1.0 and 5.1 dS m^{-1}) and two levels of phosphorous (P1=160 and P2= 215kg P_2O_5 ha^{-1}) added at the beginning of the experiment. There were three nitrogen levels (N0= 0, N1=370 and N2= 735kg N ha^{-1}) split into six doses. A basal dose of potassium was added at the rate of 175 kg K_2O ha^{-1}. One healthy seedling of tomato was transplanted 3 weeks after germination in each pot filled with soil (Torrifluvents). Equal quantities of good water and good + saline (alternatively started after 15 days of transplantation) waters were applied per treatments. Mature fruit was plucked; yield, total soluble solids (TSS) and mineral constituents were determined. The results indicated that alternate irrigation (IR2) increased overall yield by 21% in the first year but decreased it by 21% in the second year indicating a cumulative effect of salt accumulation. Nitrogen showed a significant linear response in tomato fruit yield. The effect of P was non-significant in both the years. Alternate irrigation and mineral fertilization increased the total soluble solids significantly. Nitrogen application at the rate of 370kg N ha^{-1} gave the highest total soluble solids (TSS) in the two water treatments with phosphorus application rate of 215kg P_2O_5 ha^{-1}. On the other hand, when nitrogen rate was increased to 735kg N ha^{-1} it reduced TSS. Nitrogen application enhanced N and decreased phosphorus and potash concentration in shoot of tomatoes (AL-WAHAIBI, 2007).

CHAPTER 3

Material and Methods

The Ph. D. study being presented comprised of three field experiments on date palm. The growth rate of seedlings of different varieties under various irrigation water salinity levels was studied in these experiments for two years. Some management techniques to minimize the deleterious effects of saline water on plant growth and soil health were also evaluated. Response of the growing seedlings to different N levels when these were irrigated with saline water was also investigated. The three experiments:

1. **Screening of date palm varieties for tolerance to water salinity**
2. **Managing saline water for growing date palm**
3. **Nitrogen fertilizer requirements of date palm at early stage when irrigated with saline water**

The research work was undertaken at Agricultural Research Center (ARC) Rumais (latitude 23^{o}, 68' N, and longitude 58^{o} , 01' E), Sultanate of Oman during the years 2006-07. Subsequent soil and plant analyses were completed in 2008.

The details of treatments and methodologies of each experiment are as under.

3.1 Experiment No. 1: Screening of date palm varieties for water salinity tolerance

The objective of this experiment was identification of the comparatively more salt tolerant varieties of date palm that can give good growth and be recommended to the farmers having saline water of various categories. Duration of this field experiment was two years.

3.1.1 Treatments:

A) Categories of irrigation water: EC_{iw} 3 (Control), 6, 9, 12, 15 & 18 dS m^{-1}

B) Date palm varieties; three (Khalas Adhahirah (**To be designated as only Khalas in subsequent writing**), Khunaizy and Abunarenjeh.

Statistical design was split plot with four replications. Total number of plants was 72 (6 x 3 x 4 = 72). A low ECe soil was selected, leveled and prepared for transplantation of seedlings obtained from tissue culture laboratory in interior of Oman. Soil samples were collected just before transplantation and twice subsequently with one year interval. These samples analyzed for ECe and pH. The required levels of EC of water (EC_{iw}) were synthesized through mixing of fresh water (EC 1.0 dS m^{-1}) and the saline water (EC 35-40 dS m^{-1}) in appropriate ratios. Plants were maintained through proper irrigation, weeding and protection. Following growth data were recorded annually.

1) Height
2) Trunk girth
3) Number of new fronds (leaves)
4) Length of fronds
5) Leaf analysis for N, P, K, Na, Ca, Mg and Cl

3.2 Experiment No. 2: Managing saline water for growing date palm

The objective of this experiment was to standardize some management practices that are effective to minimize the deleterious effects of saline groundwater. Duration of the field experiment was two years with following treatments.

Treatments:

A) Categories of irrigation water: EC 6 & 9 dS m^{-1}

B) Management practices

1. Control (No leaching fraction and no organic matter)
2. Application of irrigation water including leaching fractions of 0.15
3. Application of irrigation water including leaching fractions of 0.22
4. Application of organic matter 10 kg $plant^{-1}$ (crop residues)
5. Leaching fraction 0.15 + Organic matter (Treatments 1 + 3)
6. Leaching fraction 0.22 + Organic matter (Treatments 2 + 3)

Statistical design was Two Factorial split plot with four replications and forty eight plants (2 x 6 x 4 = 48). Seedlings of Khalas variety of date palm were transplanted. A uniform quantity of fertilizer (as mentioned under experiment 1) was applied to fulfill the major nutrient requirements of the crop. Irrigation category was kept in main plots while management techniques were placed in sub-plots. Volume of irrigation water was fulfilled to meet the treatment requirements by adjusting opening time of drippers. Other methodologies and recording of data were the same as described under experiment 1.

3.3 Experiment No. 3: Nitrogen fertilizer requirements of date palm at early stage when irrigated with saline water

Standardization of the N doses for date palm during seedling establishment and early stages of growth when irrigated with saline groundwater was the main objective of this experiment. Duration of this field experiment was two years and it consisted of the following treatments.

Treatments

A) Categories of irrigation water: EC 3 (Control) & 6 d S m^{-1}

B) Fertilizer doses.

1. Control= NPK 0.0-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
2. NPK= 0.125-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
3. NPK= 0.250-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
4. NPK= 0.375-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
5. NPK = 0.500-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$

Statistical design of this experiment was two factorial (Factor A= Categories of water Factor B= fertilizer doses) Split Plot with four replications and 60 total number of plants (3 x 5 x 4 = 60). Seedlings of Khalas Adahirah variety of date palm were transplanted. A uniform quantity of irrigation water was applied to fulfill the requirement of the crop. Irrigation category was kept in main plots while fertilizer doses were placed in sub-plots. Whole of P and half of K was applied in the month of February. Remaining half of K was applied in the month of September. Urea (as nitrogen source) was applied weekly in equal split doses. Other methodologies and recording of data was the same.

3.4 Detailed methodology:

A soil having low ECe was selected. The soil was leveled and prepared for transplantation of seedlings. Soil samples were collected before transplantation and analyzed for ECe, pH and SAR. The groundwater to be used for irrigation after dilution per treatments was also analyzed for EC, pH, SAR & RSC. The required levels of EC of water (EC_{iw}) were synthesized through mixing of fresh water (desalinized) and the saline water in appropriate ratios. Seedlings of three varieties; Khalas, Khunaizy and Abunarenjeh in experiment 1 and only one variety Khalas in experiment 2 and 3 were transplanted. Pants of same age (16 months) and almost uniform size were selected for all the tree experiments. Seedlings were obtained from tissue culture laboratory and transplanted at a distance of 2 x 2 m. Three meter buffer plot was left fallow in between two treatment plots to protect and keep separate the effect of different irrigation regimes. After the first year, trenches of 115cm deep were made to separate each treatment. The blocks were separated by thick polythene black color sheets to make sure that no interference occurs between the treatments. Uniformly measured irrigation water was applied to all the plants in experiments 1 and 3 while its quantity was adjusted to fulfill the requirement of each treatment (with or without leaching fraction) separately in experiment 2 by adjusting time of drippers. Total quantity of water applied to each plant depended upon age and season, as proposed by ALNADI (2001) for date palm and different crops under Oman conditions. For the first year it was 3218.391 L (8.82 L per day) in all the experiment, except LF treatments of experiment 2. This amount was distributed over the months of the year according to the climate conditions. The winter months took the least and the summer months took the maximum amounts. For the second year the amount was 4827.59 liters. Thus there was an increase by fifty percent. This total water was distributed at the rate of 13.23 L day^{-1}. However, in experiment 2, LF of 15% received an amount of 3701.5 L of saline water per year. The palms of 22% LF received an amount of 3926.44 L of both qualities of saline water per palm per year. The amount of irrigation for the second year was increased by 50% as the amount needed by the palm increased by 50%. In the 15% treatment, individual palm received 5552.3 L saline water per year. In the 22% LF, individual palm received an amount of 5889.7 L of saline water year.

Irrigation water qualities were kept in main plots while varieties/ management practices/ N levels were placed in sub-plots. The system of irrigation was drip. There was no stagnation of water except for 24 hours during Gonu cyclone in June 6, 2007. Organic matter was applied at the rate of 10 kg $plant^{-1}$ twice in two years during month of February to all the plants in experiment 1 and in the respective treatment plants only in experiment 2. However, no organic matter was added to any palm of the experiment 3. A uniform dose of fertilizer (NPK at the rate of 0.375 – 0.20 – 0.30 kg/ha) was applied to all the plants in experiment 1 and 2 whereas N (Urea) was applied per treatments in experiment 3. Whole of P (Triple super phosphate) and half of K (Potassium Sulphate) were applied in the month of February. Remaining half of K was applied in the month of September. Nitrogen was applied to the soil and mixed weekly in equal splits before irrigation. Plants were maintained through appropriate weeding, irrigations and plant protection measures. There was no insect attack but *Fusarium* fungus attacked plants that was controlled by twice spray of a fungicide carbon dizine (1.5 ml L^{-1} and 3.5 L $plant^{-1}$). Growth data was recorded annually (twice during the study) and each plot was analyzed for soil EC, pH and SAR simultaneously. For plant analysis, 25 leaflets were taken from most recently developed 5 fronds (leaves) of each palm/sucker. Leaf length was measured from the base of each frond. The height of trunk was taken from the lowest bottom of trunk base to the top end of trunk (base of the growing tip). In general, the following data were recorded.

1. Growth data (Height, number and length of fronds, leaflets $frond^{-1}$ and girth)
2. EC and pH of soil up to the depth of one meter
3. Climatic data, especially pan evaporation, temperature and rainfall
4. Leaf analysis for N, P, Na, K, Ca, Mg and Cl

Growth data (Height, number of leaves and trunk girth) were reported as increases (Numerical value of parameter at the time of observation minus numerical value at the time of transplantation for each plant) so that individual differences at the start of experiment are separated and date is more refined. Data for first and second year of the study has been presented separately. All the recorded data were processed statistically.

3.5 Experimental soil

A coarse textured soil with good drainage was selected for the study because it represented the major soils of the country of Oman. It was a low EC soil (Table 3.1) with alkaline pH and free from sodicity, as the effect of saline water was to be investigated. Generally, fertility of the soil was low with comparatively lesser values of organic carbon and total N whereas available P indicted moderate values.

3.6 Irrigation water and system

Special irrigation system comprising of tanks, pumps, distribution pipes, drippers and separate supply lines of good quality (EC 1.0 dS m^{-1}) and ground saline water (EC 35.0 – 45.0 dS m^{-1}) were set up. Uniform quantity of water was applied to all the plants in the field except experiment 2, in which different volumes of water were applied to meet requirements of various treatments (leaching fractions, LF). Waters of different qualities required in various treatments of the experiment were synthesized by mixing calculated volumes of saline and desalinized water. The tanks were refilled by remixing both types of water when these became empty. All water samples were analyzed in the laboratory (Table 3.2). According to the analysis, all synthesized waters were having Sodium Adsorption Ratio (SAR) approximately 10 (mmol L^{-1}) ^{½} except EC_{iw} 3 dS m^{-1} and no residual sodium carbonate (RSC). Hence, there was no sodicity potential problem. The predominant salts were chlorides and sulphates of sodium, calcium and magnesium.

3.7 Selection of varieties

The selection of date palm varieties for investigation was based upon future trend and demand of farmers. Variety Khalas Adhahirah is very famous all over the Arab world for its quality and good yields and therefore, grown on larger areas in Oman. This variety is now being propagated through tissue culture techniques besides suckers. The other famous varieties in Oman are Khunaizy and Abunarinjah. Hence, these three varieties were selected for the present studies so that results can be of practical importance and can be recommended to the farmers who can benefit from these findings.

3.8 ANALYTICAL PROCEDURES

3.8.1 Soil Analysis

Soil samples were collected up to 60cm at the end of the first growth year and up to 90cm at the end of the second growth year in all the experiments. These samples were air dried and passed through 2 mm sieve. Analysis work was carried out in the Soil Laboratories of Agriculture Research Center, Rumais, Oman. Analytical methods of U.S. Salinity Laboratory Staff (1954) were followed unless otherwise mentioned. All the calculations were made on oven dried soil weight basis.

3.8.1.1 Preparation of saturated soil paste

Saturated soil paste was prepared according to method 2.

3.8.1.2 Saturation percentage

Saturated soil paste was prepared and saturation percentage was determined by drying the paste in an oven at 105^{o}C to a constant weight (Method 27a).

3.8.1.3 pH of saturated soil paste

Soil pH of the saturated paste was determined by pH meter having combination electrode after calibrating with buffer solutions of pH 7.0 and 9.0 (Method 21a).

3.8.1.4 Saturation soil extract

Saturated soil extract was obtained by vacuum pump (Method 3a).

3.8.1.5 Electrical conductivity of saturation extract

After calibrating the instrument with 0.01 N KCl, the EC_e was measured with (WTW conductivity meter 197i) conductivity meter (Method 4b).

3.8.1.6 Soluble calcium + magnesium

By titration of sample against 0.01N EDTA solution using NH_4Cl + NH_4OH buffer solution and Eriochrome Black T (EBT) indicator (Method 7).

3.8.1.7 Soluble sodium

It was determined with the help of a flame photometer (Sher Wood M410). The instrument was first standardized with a series of standard solutions of Na using analytical reagent NaCl salt. Na was determined in the saturation extract (Method 10a).

3.8.1.8 Soluble potassium

It was determined with the help of a flame photometer (Sher Wood M410). The instrument was first standardized with a series of standard solutions of K using analytical reagent KCl salt. After this, K was determined in the saturation extract (Method 11a).

3.8.1.9 Carbonates

By titration with 0.01N H_2SO_4 using phenolphthalein as an indicator to a colorless end point (Method 12).

3.8.1.10 Bicarbonates

After carbonate titration, the sample was titrated with 0.01N H_2SO_4 using methyl orange as an indicator to a light pink end point (Method 12).

3.8.1.11 Chlorides

The same sample after bicarbonate determination was titrated against 0.05 N silver nitrate using potassium chromate as an indicator to a brick red end point (Method 13)

3.8.1.12 Sulphates

These were determined by the difference method i.e.

$$SO_4 = TSS - (CO_3 + HCO_3 + Cl)$$

Where all ions being expressed in $mmol_c\ L^{-1}$

3.8.1.13 Sodium adsorption ratio (SAR)

It was calculated by the following formula:

$$SAR = \frac{Na}{[(Ca + Mg)/ 2]^{1/2}}$$

Where all cations are expressed in $mmol_c\ L^{-1}$ concentration

3.8.1.14 Calcium carbonates ($CaCO_3$)

It was determined by the calcimeteric method using 6 N HCl solutions. Five g soil sample was treated with 1:1 HCl and volume of CO_2 liberated from $CaCO_3$ present in the soil was noted (MOODIE *et al*., 1959).

$CaCO_3$ (%) = CO_2 released (ml) X (0.00399)/weight of soil sample taken (g)

3.8.1.15 Organic carbon and organic matter

Organic carbon was determined by titration of the sample containing soil, potassium dichromate and sulphuric acid using ferroin indicator (Method 24).

Organic matter was determined by applying following formula:

Organic matter in percent = organic carbon in percent X 1.72

3.8.1.16 Total nitrogen

Ten (10) grams of soil, 10 grams of digestion mixture ($K_2\ SO_4$: Fe SO_4: Cu SO_4 = 10: 1: 0.5) and 30 ml of concentrated H_2SO_4 was added in Kjeldahl's digestion tubes. The Kjeldahl Tubes were placed in a digestion block a long with along with a reference and a blank sample and digested until material became milky in color. After cooling the digested solutions were then distilled and titrated automatically through the Testator Kejeltec 2400 system. An aliquot of 10 ml was taken from it for distillation of ammonia, in a receiver containing 4 % boric acid solution and mixed indicator (bromocresol green and methyl red). Sodium hydroxide was added to the distillation flask to make the contents alkaline. After distillation, the material in the receiver was titrated against standard (N/10) H_2SO_4 (Gunning and Hibbard's method of H_2SO_4 digestion and distillation with micro Kjeldahl's apparatus (CHAPMAN AND PRATT, 1961).

3.8.1.1.17 Available phosphorus

OLESON's method was followed to determine the available phosphorus contents in the soil using $NaHCO_3$ solution as extracting agent. Soil sample of 2.5 g was weighed and 50 ml Oleson's reagent (0.5 M $NaHCO_3$, pH = 8.5) was added and this suspension was shaken for 30 minutes and filtered. Five ml of the filtrate was transferred into 25 ml flask. An amount of 5 ml of ammonium molybdate diluted solution (15g of ammonium molybdate in 300 ml of distilled water with 342 ml HCl and diluted to one liter in a conical flask) was added to each sample. Five ml of stannous solution from diluted stock (15g into 25 ml of HCl) was added to develop color and then reading was noted using spectrophotometer (Milton Roy Spectronic 1201). To standardize the spectrophotometer a standard stock P solution was prepared by dissolving exactly 0.439 g potassium dihydrogen orthophosphate (KH_2PO_4) analytical grade in one liter distilled water. From the P stock solution different dilutions were made to develop a linear curve against which the unknown samples were measured (CHAPMAN AND PRATT, 1961; Method 18-4).

3.8.1.18 Particle size analysis

Bouyoucos hydrometer technique (MOODIE *et al*., 1959) technique was used to determine this parameter. Dispersion was made with 1 % sodium hexametaphosphate solution and soil texture was determined by using International Textural Triangle.

3.8.2 Water analysis

For water analysis, all the methods used were same as in soil analysis except RSC.

3.8.2.1 Residual sodium carbonate (RSC)

RSC of irrigation water was determined by the following formula (EATON, 1950):

RSC= (CO3 + HCO3) – (Ca + Mg)

Where all ions are expressed in $mmol_c\,L^{-1}$ concentration

3.8.3 Plant analysis

Leaf samples were obtained twice after an interval of one year for determination of chemical parameters. Twenty five leaflets were collected from the bottom of each third frond of from most recently fully developed five fronds. Plant samples were ground to pass through 35 mesh) after mixing of plant material obtained separately from each treatment. The ground material was preserved dry for subsequent plant analysis.

3.8.3.1 Wet digestion

An amount of 0.5g of dried ground plant leaves of each sample was weighed into 100 ml Kjeldihal's tubes. A mixture of three acids; 1 ml of 60% $HClO_4$, 5 ml of HNO_3 and 0.5 ml of H_2SO_4 were added to each tube. The mixture was digested at 420^0C until content became transparent, cooled and filtered through Whatman filter paper No. 42 into 100 ml volumetric flask and volume was made. This solution was used for the determinations of P, K, Ca, Mg, Zn, Mn, Cu, and Fe (STEWART *et al.,* 1974; Method 12-5).

3.8.3.2 Digestion for total N determination (Kjeldahl)

Subsamples of 0.2 g were weighed into separate 100 ml glass testator tubes. To each tube one Kjeltab (1.5 g K_2SO_4 and 7.5 mg Se) and 6 ml of conc. H_2SO_4 were added. Along with every batch of 20 tubes, one blank and one reference sample were run. Batches of 40 samples were digested in an electrical digestion block (2020 Digester), fitted with a temperature and time controller. During digestion, tubes were covered with tight glass connectors linked to a plastic hose to help removal of the fumes. Vacuum was created by flowing tap water. Digestion temperature was set at 420^oC and time was adjusted to continue for one hour after reaching this temperature. For distillation and titration, the same steps were followed as for the soil samples. Analytical results were expressed as % on an oven dry basis (CHAPMAN AND PRATT, 1961; Method 17-1).

3.8.3.3 Potassium

Potassium was determined from solution of the mixed acid digest through the flame photometer (Sher Wood M410). The instrument was calibrated before using. Standards of known K concentration were prepared using 100 ppm standard solution obtained by 10 times dilution from 1000mg K L^{-1} (CHAPMAN AND PRATT, 1961; Method 23-1).

3.8.3.3 Phosphorus

An amount of one ml from the plant extract was diluted in 50 ml conical flask. Two ml of ammonium molybdate and two ml of stannous chloride plus one ml of concentrated hydrochloric acid were added to the solution in the conical glass flask. After the addition of the stannous chloride the sample solution was let stand for 30 minutes for the color to develop. After 30 minutes the samples were read by the spectorophtometer (Milton Roy

Spectronic 1201). The instrument was standardized through preparation of different concentrations of P standards to get a linear line. Results were expressed in percentage (STEWART *et al.,* 1974; Method 32.4).

3.8.3.4 Sodium

Sodium was determined from solution of mixed acid digest through the flame photometer (Sher Wood M410). The instrument was calibrated using a dilution of 100 ppm from 1000mg Na L^{-1} standard solution (CHAPMAN AND PRATT, 1961; Method 23-1).

3.8.3.5 Calcium

To determine calcium the plant digest solution was titrated using EDTA 0.01N (STEWART *et al.,* 1974; Method 22.2)

3.8.3.6 Magnesium

To determine magnesium, the plant digested solution was titrated using EDTA 0.01N (STEWART *et al.,* 1974; Method 28.2).

3.8.3.7 Cu, Mn, Zn, and Fe

These elements were read straight by feeding the extracted solutions to the Atomic Absorption Spectrophotometer Unicam 989.

3.9 Statistical analysis

All the data collected were subjected to analysis of variance (ANOVA) [STEEL and TORRIE, 1980). Individual comparisons between treatments were made using LSD (Least Significant Difference). Some Correlation Coefficients (R^2) were also worked out.

3.10 Guidance, funding and sponsorship

University of Kassel, Germany (Professor Helge Schmeisky), Ministry of Agriculture, Forestry and Livestock (General Directorate of Agriculture and Livestock Research), Oman and Soil Salinity Research Institute (SSRI), Pindi Bhattian, Pakistan (Dr. NAZIR HUSSAIN) jointly sponsored the reported studies. Director General (Dr. AHMAD AL-BAKRI), Agricultural Research Center, Rumais Oman on behalf of the ministry provided all the research facilities required for this study. University Of Kassel and SSRI provided technical support and guidance for the study. University of Kassel also afforded the cost of visit of the professor to Oman.

Table 3.1: Original soil analysis of three field experiments

Sr. No.	Determinations	Unit	Experiment 1	Experiment 2	Experiment 3
1	Saturation percentage	%	22.7	24.1	27.3
2	pH_s	-	7.7	7.6	7.6
3	EC_e	$dS.m^{-1}$	2.77	3.3	3.5
4	CO_3^{-2}	Meq L^{-1}	Nil	Nil	Nil
5	HCO_3^{-1}	Meq L^{-1}	10	7.5	7.5
6	Cl^{-1}	Meq L^{-1}	22.5	22.5	30
7	SO_4^{-2}	Meq L^{-1}	8	10	14.4
8	Ca^{+2}	Meq L^{-1}	10	9.5	18
9	Mg^{+2}	Meq L^{-1}	17.5	2.5	27
10	Na^{+1}	Meq L^{-1}	6.6	5.7	6.4
11	K^{+1}	Meq L^{-1}	0.5	0.45	0.5
12	SAR	$(m\ mol\ L^{-1})^{1/2}$	0.89	0.82	0.95
13	Sand	%	88.4	89.3	88.5
14	Silt	%	4.3	5.9	8.6
15	Clay	%	7.3	4.8	2.9
16	Textural class	-	Loamy sand	Sand	Sand
17	Organic carbon	%	0.12	0.10	0.204
18	Organic matter	%	0.21	0.33	0.35
19	Total nitrogen	%	0.003	0.007	0.03
20	Available phosphorus	mg Kg^{-1}	12.4	11.7	11.3

Table 3.2: Analysis of irrigation water used in the experiments

Sr. No.	Determinations	Units	EC 3 dS m^{-1}	EC 6 dS m^{-1}	EC 9 dS m^{-1}	EC 12 dS m^{-1}	EC 15 dS m^{-1}	EC 18 dS m^{-1}
1	Electrical Conductivity (EC)	dS m^{-1}	3.2	6.1	8.9	11.9	15.1	18.1
3	pH	-	6.2	6.5	6.7	6.9	7.0	7.4
4	Carbonates (CO_3^{-2})	$mmol_c$ L^{-1}	Traces	Traces	Traces	Traces	Traces	Traces
5	Bicarbonates (HCO_3^{-1})	$mmol_c$ L^{-1}	0.7	0.8	0.7	0.7	0.9	0.9
6	Chlorides (Cl^{-1})	$mmol_c$ L^{-1}	28	56	83	113	154	180
7	Sulphates (SO_4^{-2})	$mmol_c$ L^{-1}	10.4	8.5	5.3	12	13.5	16
8	Calcium	$mmol_c$ L^{-1}	2.6	5.6	8.2	12.4	14.4	14
	Magnesium	$mmol_c$ L^{-1}	10	21.8	34.2	46.8	59.2	76
9	Sodium (Na^{+1})	$mmol_c$ L^{-1}	26.3	37.4	45.9	54.1	62.8	71.5
10	Sodium Adsorption Ratio (SAR)	$(mmol\ L^{-1})^{1/2}$	7.4	10.1	10.0	9.9	10.4	10.7
11	Residual Sodium Carbonate (RSC)	$mmol_c$ L^{-1}	Nil	Nil	Nil	Nil	Nil	Nil

Table 3.3: Climatic Data of Agricultural Research Station Rumais, Oman (January 2006 to December 2007)

Month	Temperature (C^0) (Minimum)	Temperature (C^0) (Maximum)	Rainfall (mm)	Relative Humidity (Maximum)
January, 2006	13.1	23.6	0.24	75.3
February, 2006	17.8	27.4	0.42	83.7
March, 2006	19.3	29.0	0.02	77.9
April, 2006	23.4	34.4	-	68.1
May, 2006	27.5	39.5	-	68.3
June, 2006	29.3	39.2	-	76.8
July, 2006	30.0	38.1	-	76.6
August, 2006	28.3	36.7	0.01	83.9
September, 2006	26.9	36.4	-	80.9
October, 2006	25.0	34.9	-	76.5
November, 2006	21.8	30.7	0.05	76.3
December, 2006	17.5	24.6	0.24	79.0
January, 2007	15.3	25.3	0.23	76.2
February, 2007	15.5	23.6	0.01	71.6
March, 2007	18.0	26.3	-	82.5
April, 2007	19.6	28.6	0.43	82.0
May, 2007	23.5	35.3	-	69.9
June, 2007	28.0	39.4	240	66.2
July, 2007	29.3	36.9	2.40	79.9
August, 2007	30.0	37.9	-	80.1
September, 2007	27.8	36.2	0.01	83.8
October, 2007	25.6	36.1	-	82.8
November, 2007	20.8	33.2	0.01	75.3
December, 2007	20.6	30.1	-	80.3

Note: There was a Gono Cyclone on June 6, 2007 and the precipitation water amounted 240 mm

CHAPTER 4

RESULTS AND DISCUSSION

This study was completed on a very important crop of the Sultanate of Oman in particular and Arab countries in general. There were three components of the study on different but interlinked aspects and all were conducted under the field conditions.

- **Screening of date palm varieties for tolerance against water salinity**
- **Managing saline water for growing date palm**
- **Nitrogen fertilizer requirements of date palm at early stage when irrigated with saline water**

Results of each experiment are being presented and discussed separately under different subtitles.

4.1 EXPERIMENT 1: Screening of date palm varieties for tolerance against water salinity

Salt affected soils originate under natural processes as well as man's activities. Whenever the natural ecosystem is disturbed or changed, some adverse outcomes necessarily emerge. The natural sources of salts are oceans, lacustrine and marine deposits, fossil salts, floods and parent material through weathering processes while man's activities are like consistent irrigations with saline water, waste effluents, chemical fertilizer and amendments and soil/ salt removal and piling salty material. The main causes of salinity are nearness to sea or any source of salts, disposal of municipal and industrial effluent, aridity, unleveled fields, shallow water table and continuous irrigation with saline water. Whenever the salt input increases over salt output, the genesis of salt affected soils starts, of course it rate will depend upon the difference of above two parameters.

The systems created by nature are perfect. If the salt affected soils were emerging, there was also evolution of salt tolerant plants able to tolerate such conditions. There is natural biodiversity in plants regarding their salt tolerance potential. According to QURESHI *et al.* (1998) broad grouping of plants with respect to salt tolerance is as under.

- Halophytes: these plants have increased growth at low salt concentrations when compared with normal conditions but their growth decreases at a very high level of salinity. River salt bush (*Atriplex amnicola*) and *Salicornia bigelovii* are the typical examples.

- Salt tolerant non-halophytes: These plants indicate good growth at low concentration of salts but their growth decreases at higher quantities of salts in the soil. All salt tolerant crop plants are classified under this category. Date palm is also included in this group.
- Salt sensitive non-halophytes: These plants are also called as glycophytes. The growth of these plants is sensitive to even lower concentration of salts. Common beans (*Phaseolus vulgaris*) are typical example that has 50% decreases in growth just at EC of 3.6 dS m^{-1}.

The tolerance against salts does not only vary from species to species but also within varieties as well as the growth stage (germination/ seedling, vegetative and reproductive). Three varieties of date palm; Khalas, Abunarenjeh and Khunaizy famous in Oman were therefore, included in this study. The growth performance of each variety under increasing levels of water salinity (3 to 18 dS m^{-1}) is as under.

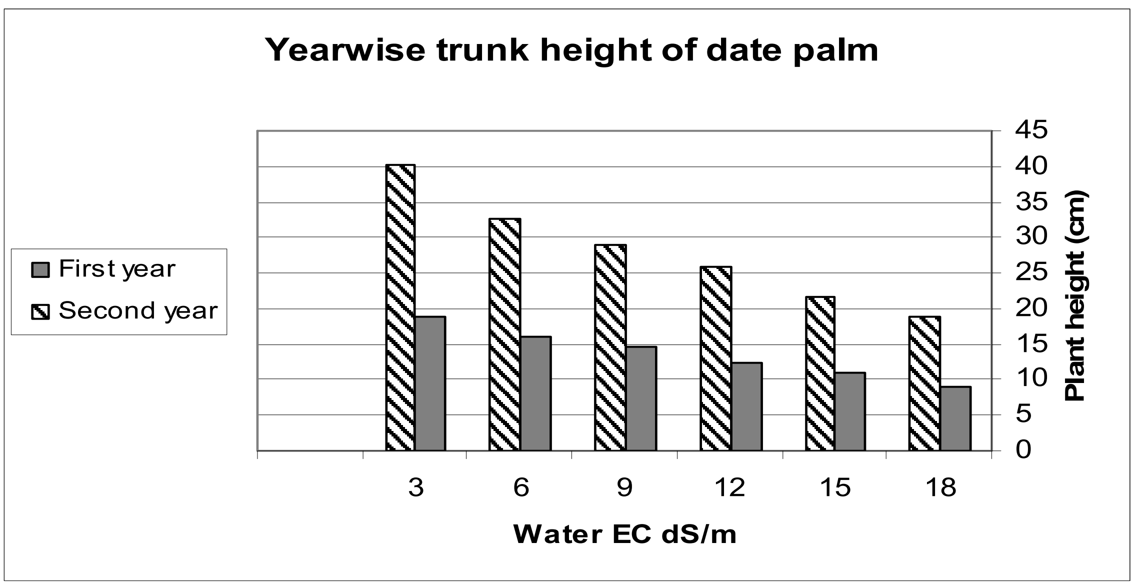
4.1.1 Growth parameters

4.1.1.1 Results of growth parameters

4.1.1.1.1 Trunk height

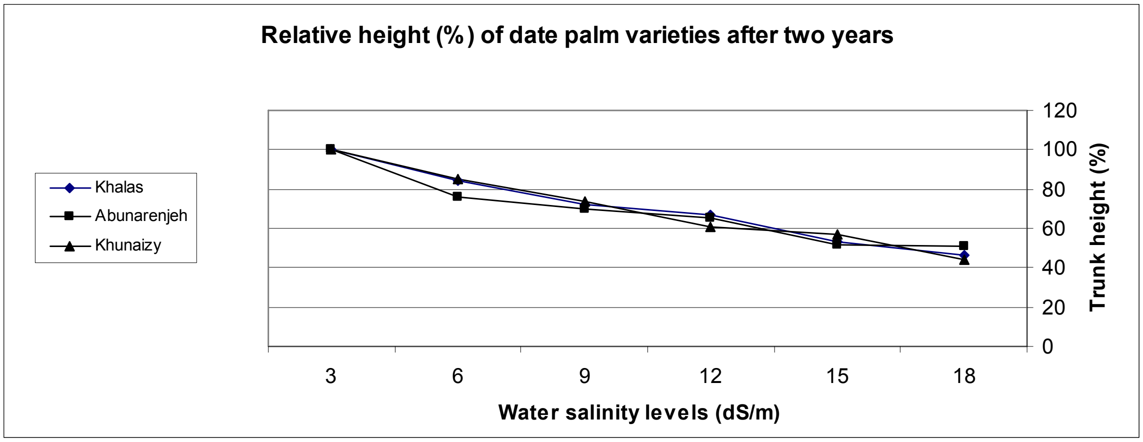
Height of a plant is the final outcome of its growth within its genetic limits. Mostly plants become stunted under different stresses, especially salt concentration. A significant decrease in trunk height was recorded due to increasing water salinity levels during both the years of the study (Table 4.1). Overall increase in plant height was gradually but significantly retarded with all water salinity levels (EC_{iw} 6, 9, 12. 15 and 18 dS m^{-1}) when compared with control (EC_{iw} 3 dS m^{-1}) whereas each consecutive level remained similar statistically in the first year (Fig. 1). Differences between varieties (Khalas, Abunarenjeh and Khunaizy) were also evaluated as significant, Khalas was found taller than Khunaizy while both proved alike to Abunarenjeh. The interactions of water salinity levels and varieties were also statistically measureable as different; Khalas remained taller than the other two in various water salinity levels as well. The important point to be observed here was that increase in height was statistically more in case of Khalas even under control conditions indicating its genetic nature to grow taller in the same time when compared with other two varieties (Fig. 2).

At the end of the second year of study, overall deviations still extended and each water salinity level became different to the subsequent one in the increasing order of water salinity quantum. Thus, the impact of water salinity became more pronounced (Fig. 2). The varietal behavior also changed a little bit and all the tree varieties were found to be deviating significantly from each other. Khalas was observed to be taller than Abunarenjeh while latter was taller than Khunaizy. The individual interactions of water salinity levels and varieties were also assessed significant in the second year too and generally Khalas was having higher values of height increase as compared to the other two varieties. However, differences of varieties in control treatment also proved significant and Khalas was having more values revealing that rapid growth may be the genetic character of this variety. Therefore, relatively higher values of increase in plant height may not be true indication of its tolerance and some other measure has to be brought in for more precise comparison. The percent decrease due to water salinity levels may be more appropriate instrument in this regard (section 4.1.1.2).



Water salinity levels:	**3**	**6**	**9**	**12**	**15**	**18**
First year :	**A**	**B**	**BC**	**CD**	**DE**	**E**
Second year :	**A**	**B**	**C**	**D**	**E**	**F**

Fig. 1: Gradual effect of water salinity on trunk height of date palm seedlings (n= 4)



Varieties :	Khalas	Abunarenjeh	Khunaizy
First year :	A	AB	B
Second year:	A	B	C

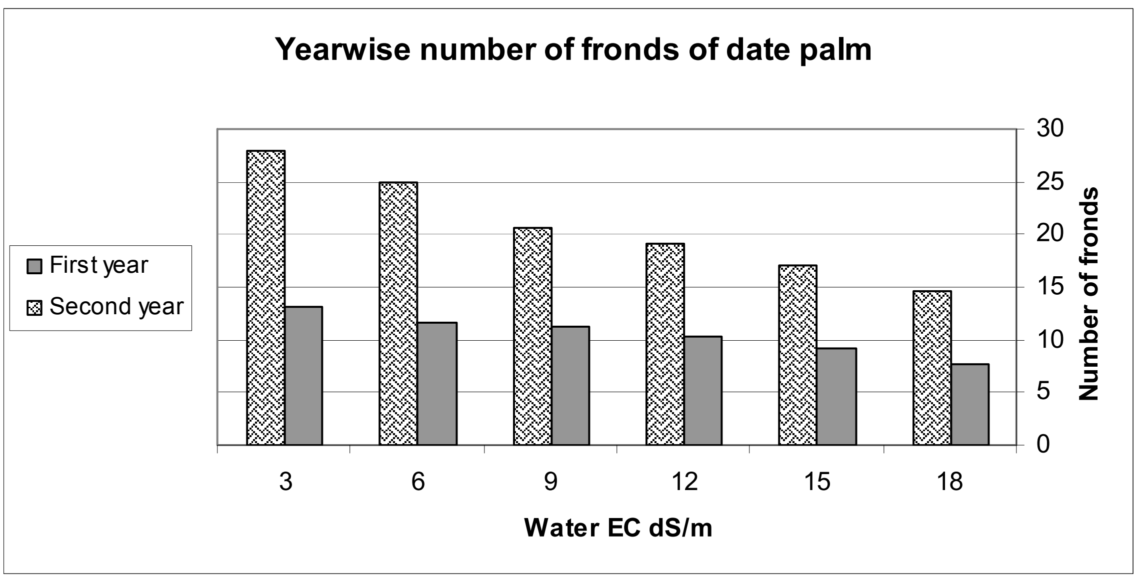
Fig. 2: Effect of water EC on date palm trunk height (n= 4)

4.1.1.1.2 Number of leaves (fronds)

The leaves are called fronds in case of date palm. Leaf bearing phenomenon is a healthy symbol of a plant and indicates its growth status. If the plant is growing under normal conditions it brings new leaves according to its genetic character but in the presence of stresses, may be environmental, soil or biological (diseases or insects) this peculiar behavior is disturbed and bearing of leaves is curtailed tremendously. Of course the quantum of this reduction depends upon the magnitude of the stress. Soil and water salinities are stresses of permanent nature unless addressed otherwise. Hence, bearing of leaves is then controlled by type and level of salinity in which the plant is growing. The negative effect of water salinity (ECiw) is always gradual because it keeps increasing with the accumulation of salts within the rhizosphere. Such a pattern was also observed in the present study. Reduction in bearing of new fronds by the date palm plants due to increasing water salinity levels was more pronounced in the second year of the investigation (Table 4.2). The less bearing of fronds was found to be significant even in the first year with each increasing level (Fig. 3). However, differences between EC_{iw} 6 and 9 dS m^{-1} were not appreciable statistically at that time.

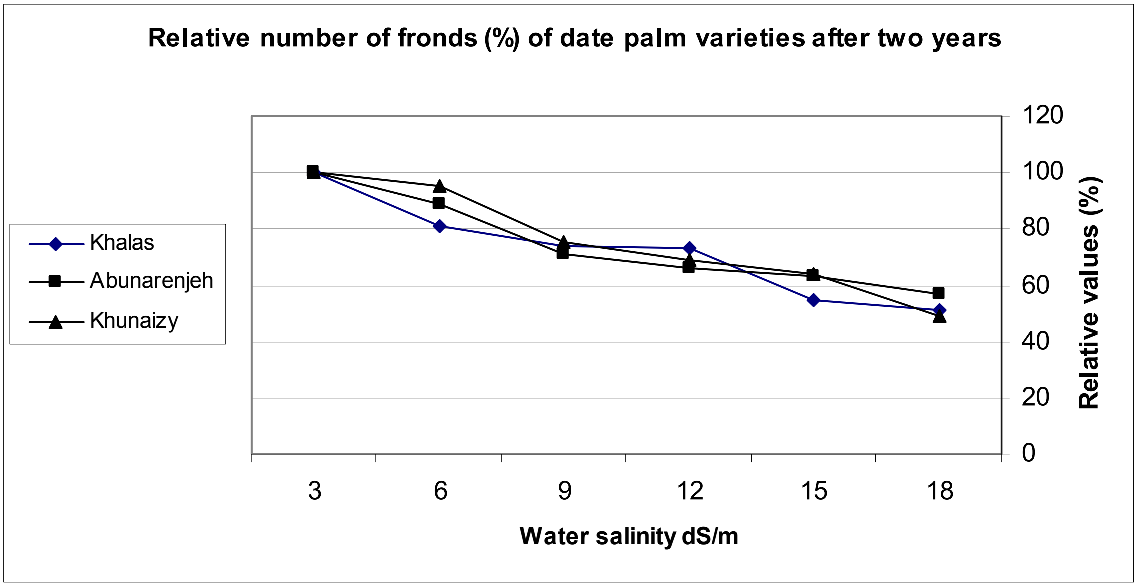
The differences among the studied varieties were also not mentionable. The overall reduction of 8, 11, 21, 29 and 39% during the first year (2007) for water salinity levels of

6, 9, 12, 15 and 18 dS m^{-1} respectively increased to 12, 27, 32, 39 and 48% with relative percent values of 88, 73, 68 and 52 considering 100 % for control in the second year. The effect of each EC_{iw} level was found as significantly decreasing number of fronds. The differences among varieties also became significant during the second year; Khalas remained superior over Khunaizy while Abunarenjeh proved similar to both in statistical terms (Fig 4). The interactions of EC_{iw} and varieties were also recorded as significant. Number of fronds in case of Khunaizy at the end of the second year was significantly lesser than Khalas even in control. This indicated its genetic character bearing relatively less number of fronds annually. Therefore, overall reduction in number of fronds for each variety was also calculated for all the five water salinity levels that indicted curtailment values of 33, 31 and 30% in case of Khalas, Abunarenjeh and Khunaizy respectively.



Water salinity levels:	3	6	9	12	15	18
First year :	A	B	B	C	E	E
Second year :	A	B	C	CD	D	E

Fig. 3: Gradual effect of water salinity on number of fronds of date palm (n= 4)



Varieties	**:**	**Khalas**	**Abunarenjeh**	**Khunaizy**
First year	**:**	**NS**		
Second year:		**A**	**AB**	**B**

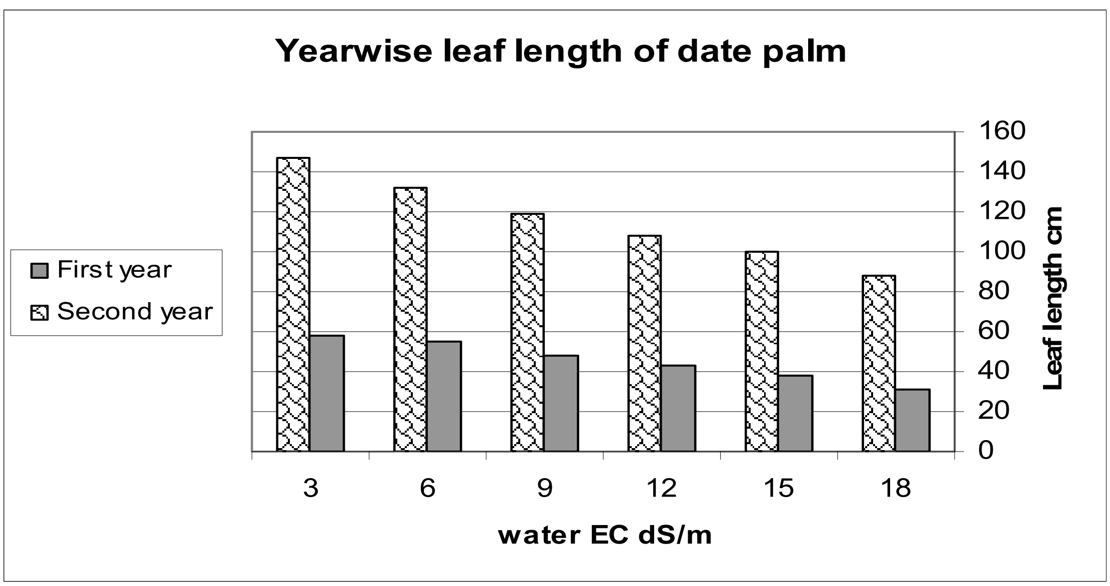
Fig. 4: Effect of water EC on number of fronds of date palm varieties (n= 4)

4.1.1.1.3 Leaf length

New leaves after bearing slowly and gradually increase their length if the plants are growing free from any stress. When plants are imposed to any environmental, soil or water stress like salinity, the increasing of leaf length does not remain normal. The leaf growth may be reduced or totally stopped depending upon the magnitude of stress. Water salinity is the stress that depresses the plant growth in all aspects including increase of leaf length. Leaves seem to be the first one among the above ground plant parts that are negatively affected these may not receive water in required quantities. Water uptake by the roots may be decreased due increase in osmotic pressure in the soil solution as result of salt concentration in the rhizosphere. This may happen beyond a certain limit even in case of salt tolerant plants like date palm. The data of the present study (Table 4.3) also support this view point. The average leaf length, when recorded at the end of first year after transplantation of date palm seedlings, indicted a significant decrease by levels of water salinity beyond 6 dS m^{-1} (Fig. 5). The effect of 6 dS m^{-1} was not found to be significant in comparison to control. The highest investigated level of 18 dS m^{-1} caused maximum decrease in leaf length and differentiated statistically from all the other levels.

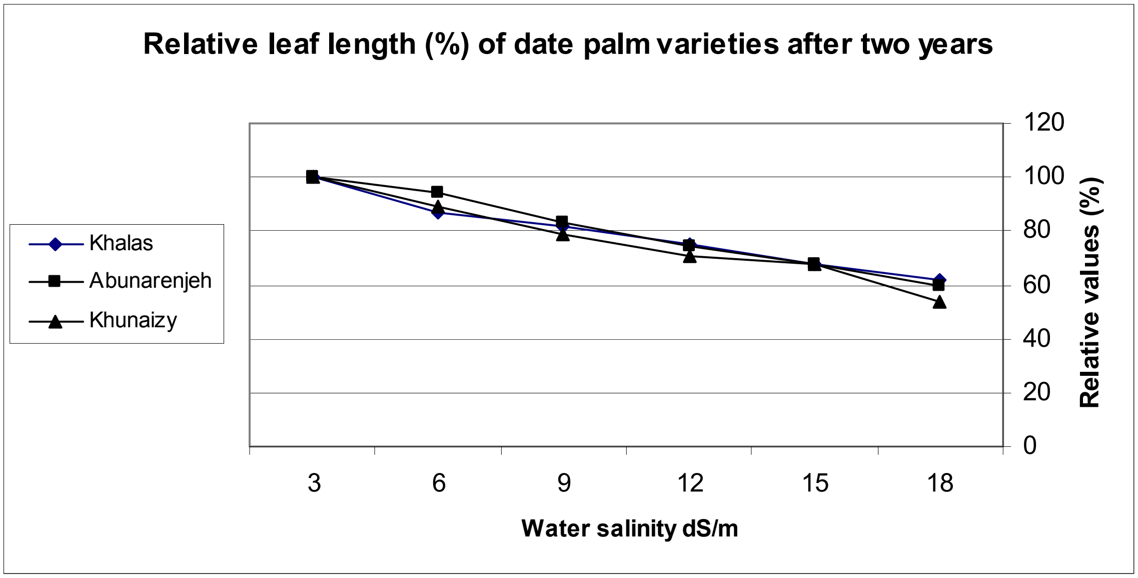
The levels of 9, 12 and 15 dS m^{-1} were alike in their negative effect on leaf length during the first year. The interactions of these levels with varieties and the overall varietal differences remained non-significant.

At the end of the second year, varieties differentiated significantly; Khunaizy remaining at the top in leaf length (122.7 cm) followed by Khalas (108.4 cm) and Abunarenjeh (108.4 cm). However, Khunaizy was similar to Khalas and the latter was alike to Abunarenjeh by statistics (Fig. 6). Nevertheless, individual interactions of water salinity levels and varieties were evaluated as non-significant in second year as well. On overall, water salinity proved negative and checked leaf growth significantly. All the levels allowed lesser leaf extension when compared with control but each salinity level on the lower side proved similar to the next higher level and different to the further next one in the ascending order. For example 3 dS m^{-1} was similar to 6 dS m^{-1} but differentiated statistically from 9 dS m^{-1}. The whole variation of this parameter followed the same pattern. Relative percent values decreased consistently with increase in water salinity.



Water salinity levels:	**3**	**6**	**9**	**12**	**15**	**18**
First year :	**A**	**A**	**B**	**BC**	**C**	**D**
Second year :	**A**	**B**	**BC**	**CD**	**DE**	**E**

Fig. 5: Gradual effect of water salinity on leaf length of date palm (n= 4)



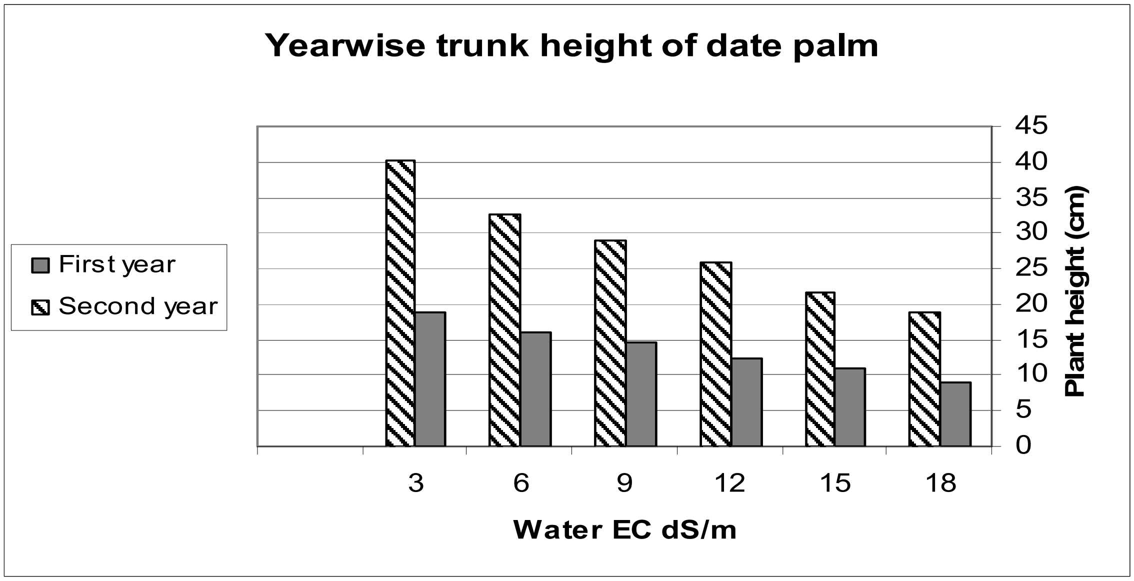
Varieties : Khalas Abunarenjeh Khunaizy
First year : NS
Second year: BC C AB

Fig. 6: Effect of water EC on leaf length of date palm varieties (n= 4)

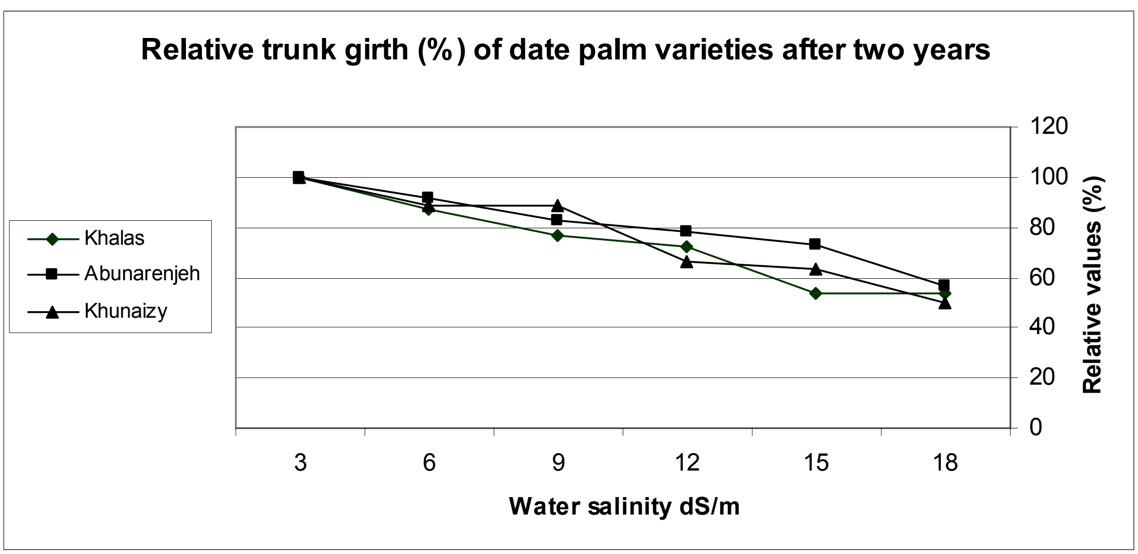
4.1.1.1.4 Trunk girth

Like the plant height, trunk girth is the outcome of many factors and indicates the growth directly. Under abnormal conditions, plants do not gain much girth and remain spindly and thin. Because this plant measure is differentiated relatively in longer time, therefore at the end of first year the negative effect of water salinity levels of 6, 9 and 12 dS m^{-1} could not be assessed as significant compared with control (Table 4.4) whereas levels of 15 and 18 dS m^{-1} still checked the thickening of plants and recorded girth was significantly lesser than the lower salinity levels (Fig. 7). These two levels were also statistically different. The varietal variation pattern as well as their individual interactions with water salinity levels could not be found significant.

The variation behavior changed at the end of second year of study and all the water salinity levels deepened in their negative effect. Each level was observed as having measurably lesser trunk girth when quantity of salts in water increased within the study. Even varietal differences became significant and overall trunk girth of Abunarenjeh was lesser than Khalas and Khunaizy, the latter two remained similar. However, interactions of EC_{iw} and different varieties could not be regarded as significant. Relative percent values in comparison to control were not much different for date palm varieties (Fig 8).



Water salinity levels: 3 6 9 12 15 18
First year : NS
Second year : A B C D E F
Fig. 7: Gradual effect of water salinity on trunk girth of date palm (n= 4)



Varieties : Khalas Abunarenjeh Khunaizy
First year : NS
Second year: A B A
Fig 8: Effect of water EC on trunk girth of data palm varieties (n= 4)

4.1.1.2 Discussion on growth parameters

Changes in four growth parameters of date palm; trunk height, number of fronds, leaf length and trunk girth were monitored for two years consistently in this study. It was observed that deleterious effects of various water salinity levels (6, 9, 12, 15 and 18 dS m^{-1} on all these parameters increased with time because the salts being added through irrigation water kept concentrating gradually and increased soil ECe significantly (Table 4.15). The quanta of percentage decrease in various growth characters when compared with control (EC_{iw} 3 dS m^{-1}) were lesser at the end of first year than the second year. The overall respective decrease values for trunk height were 14, 21, 31, 47 and 50% for water salinity levels of 6, 9, 12, 15 & 18 dS m^{-1} at the end of first year while these were 18, 28, 36, 46 and 53% at the end of second year, although the salinity effect was diluted a little in the second year because salts were removed partially in the middle of the year by a natural cyclone 'Gonu'. Similar trend was found in case of number of fronds $plant^{-1}$. The curtailment was 8, 11, 21, 29 and 39% during first year and 12, 27, 32, 39 and 48% in the second year in EC_{iw} of 6, 9, 12, 15 and 18 dS m^{-1} respectively. Overall mean leaf length was a little bit different in behavior and indicted decrease of 6, 17, 26, 34 and 46% in the first year and 10, 19, 27, 32 and 41% in the second year for the above mentioned respective water salinity levels. Thus, there was more decrease due to lower levels (6 & 9 dS m^{-1}) in the second year but higher levels almost became stable in this regard and no further loss in the leaf length occurred. Fourth observed parameter, the trunk girth, also revealed a pattern like trunk height and number of fronds because determined decreases in this plant character were 11, 17, 28, 40 and 46% in the second year as against 4, 10, 15, 24 and 38% for EC_{iw} 6, 9, 12, 15 and 18 dS m^{-1} respectively during first year of observations.

If overall growth pattern of date palm is examined, it may be regarded that EC_{iw} of 18 dS m^{-1} is the water salinity level that caused nearly 50% decrease of various plant parameters. The 50% reduction is considered the minimal economical value acceptable in salt tolerance studies because beyond that there is no benefit to grow plants under consideration. Hence, it may be concluded that when date palm is planted in coarse textured soils (sandy loam, loamy sand and sand that are dominated in Oman) with very good drainage it can be irrigated with water of EC up to 18 dS m^{-1} during vegetative growth. At this level, the growth reduction will not be more than 50%. Of course losses will be lesser if water is having EC lower than 18 dS m^{-1} (Fig 9).

The interaction of varieties and water salinity levels was found to be significant only in case of plant height during first year and plant height as well as number of fronds during the second year. The higher levels of EC_{iw} 15 and 18 dS m^{-1} proved detrimental for all the varieties. All the three varieties were approaching almost 50% reduction in various studied growth characters when exposed to water salinity stress of 18 dS m^{-1}. However, overall differences between varieties were significant after second year of study for all the four parameters. Overall mean reductions due to water salinity for trunk height, number of fronds, length of leaves and trunk girth for Khalas were 47, 36, 33 and 25% respectively at the end of second year while respective values for Abunarenjeh were 37, 31, 24 and 25%. The values for same characters of Khunaizy were respectively 36, 30, 28 and 28%. Thus, there were more percentage reductions in the three growth characters out of four for Khalas in comparison to other two varieties. When Abunarenjeh was compared with Khunaizy, each variety was found superior over the other in two characters. However, the observed differences were not very larger and non-significant statistically. Hence, it may be concluded that although Khunaizy was having a little edge over other two varieties as regards salt tolerance potential but differences were not much wider between three varieties (Fig 10).

Consistent irrigation with saline water of different EC levels affected the plants in two ways; direct effect of saline water and gradual accumulation of salts in the soil profile that ultimately increased soil EC (Table 4.15). Accumulation of salts in the root zone affects plant performance through creation of water deficit and disruption of ion homeostasis (MUNNS, 2002) which in turn cause metabolic dysfunctions. When correlations of different growth parameters with salinity of water (EC_{iw}) and soil (ECe) were worked out (Tables 4.5 & 4.6), it was noticed that both the salinity measures were negatively and significantly correlated. This clearly indicated that salinity of irrigation water and the resultant secondary salinity arising from this field operation had growth retarding effect on date palm plants.

Table 4.5: Correlation of water salinity (EC_{iw}) with growth parameters

Sr. No.	Parameter	Coefficient of Corr. (r^2)	Slope	Significance
1	No. of fronds	-0.909	-2.432	**
2	Length of frond	-0.539	-8.020	*
3	Height of trunk	-0.847	-3.587	**
4	Dry wt. of leaflets	-0.477	-	**
5	Leaf moisture	-0.560	-	**

Table 4.6: Correlation of soil ECe with growth parameters

Sr. No.	Parameter	Coefficient of Corr. (r^2)	Significance
1	No. of fronds	-0.695	**
2	Length of frond	-0.318	**
3	Height of trunk	-0.655	**
4	No. of leaflets	-0.454	**
5	Trunk girth	-0.682	**

The mechanisms of this negative effect may be; osmotic effects that restricted water and nutrient uptake, specific ion effect of Na and Cl ions, nutritional imbalance and inhibition of physiological processes like photosynthesis, transpiration, energy reactions, metabolism of nutrients and use of extra energy in osmoregulation. SHANI *et al.* (2001) related the yield loss in date palm to reduced photosynthesis, high energy and carbohydrate expenses in osmoregulation, and interference with cell functions under saline conditions while GHADIRI *et al.* (2005) reported restricted water uptake by salinity due to the high osmotic potential in the soil and high concentrations of specific ions that may cause physiological disorders in the plant tissues and reduce yields**.** It has been reported that environmental stresses, especially water stress and salinity, increase the generation of toxic active oxygen species (O_2^-, H_2O_2 and OH) that result in cellular injury or damage which frequently results from impaired or perturbed metabolism (SAIRAM AND SAXENA, 2000 and SREENIVASULU *et al.,* 2000). Salinity also induces changes in the plant hormonal balance and reduction of the levels of growth-activating hormones such as auxins and cytokinins (GLYAN´KO *et al.,* 2005). YOUSAF AND AWARD (2007) observed a strong linear correlation between the chlorophyll a/b ratio and assimilation rate throughout salinity treatments. The slope and the correlation coefficient between the chlorophyll a/b ratio and assimilation suggested that salinity reduced assimilation predominantly via the reduction in chlorophyll a contents.

According to criteria of MASS (1986), date-palm plant is included in the group that is tolerant to salinity with threshold for reduction of yield at soil EC of 4.0 dS m^{-1} and has 50% reduction in yield at 17.9 dS m^{-1}. He observed good yield at EC_{iw} of ground water around 10.0 dS m^{-1}. Whereas AYERS AND WESTCOT (1985) proposed the threshold of date palm as 4.0 and 2.7 dS m^{-1} for soil and water respectively and respective 50% yield reduction limits were found by them as 18.0 and 12.0 dS m^{-1}. However, salt tolerance level can vary a lot depending upon texture and drainage of soil, climate and the genetic potential of the variety. MARCAR *et al*. (1995) reported that date palm (*Phoenix dactylifera*), depending upon variety can tolerate up to at least 18000 ppm salts (28.1 dS m^{-1}) or even more. However, fruit production usually stops at about 10000 ppm (15.6 dS m^{-1}) salts. In a relatively recent greenhouse experiment of AL-HAMMADI (2006) optimal growth was found in control and 3000 ppm (4.7 dS m^{-1}) of NaCl. Relative growth rate (RGR) and biomass decreased significantly by increasing salinity to 6000 (9.4 dS m^{-1}) and 12000 ppm (18.8 dS m^{-1}). Results of their study were closer to the present investigations because the soil was coarse with very good drainage, hence higher water salinity level (18 dS m^{-1}) caused only 50% reduction in various growth parameters. The soil texture and drainage play an important role in determining the potential of salt tolerance in a plant. The supporting effect is in two ways; through ease in leaching of salts with irrigation water (or rainfall, if any) into deep percolation thus causing comparatively lesser net salt accumulation and better physical properties that are rapidly deteriorated in a fine textured soil.

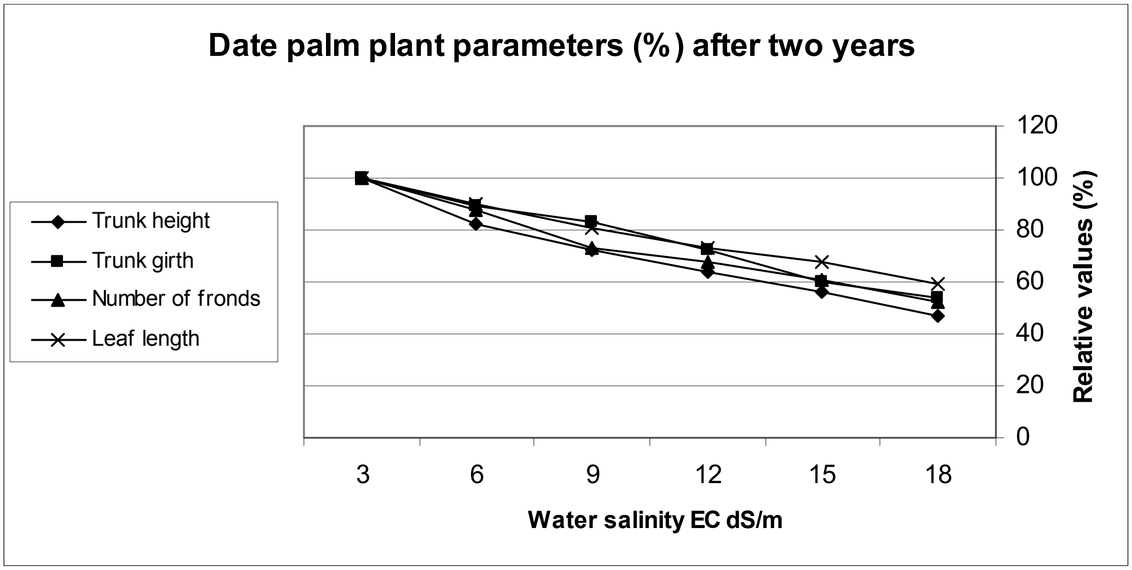


Fig. 9: Effect of water salinity on plant characters of date palm varieties (n= 4)

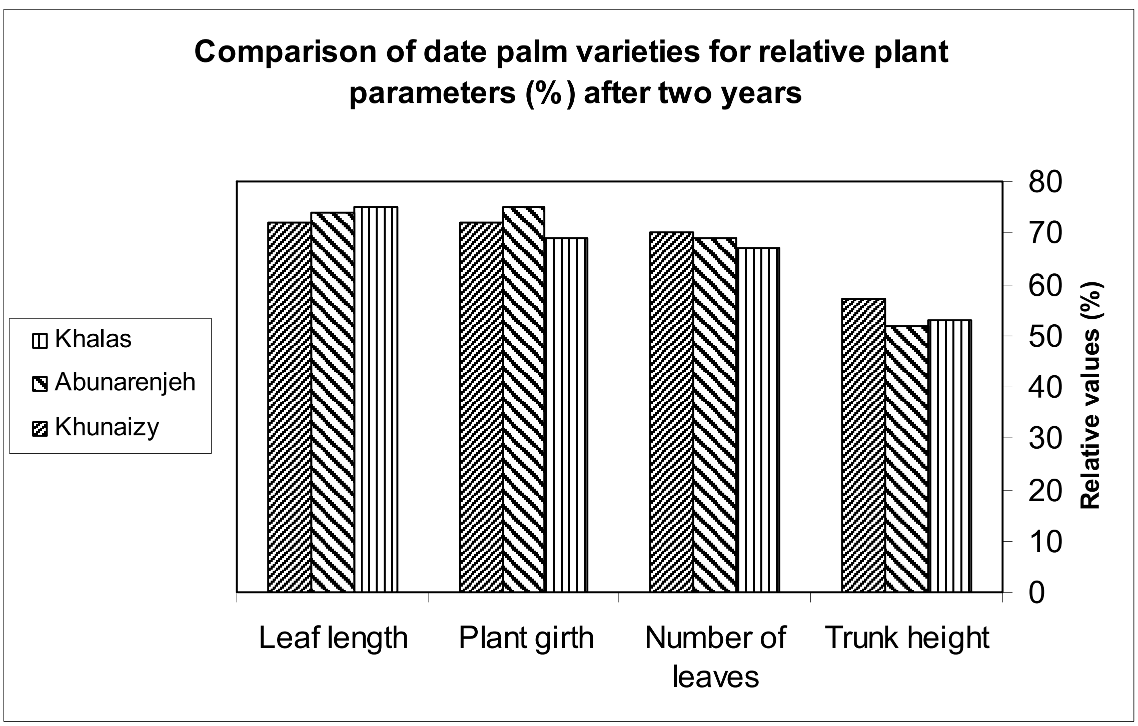


Fig. 10: Overall effect of water salinity (3-18 dS m^{-1}) on plant parameters of date palm varieties (n= 4)

4.1.2 Ionic concentration in date palm leaves

4.1.2.1 Results

4.1.2.1.1 Sodium

Sodium is the ion that has prime importance when the plants are growing under saline environment. Overwhelmingly soluble salts are of Na; these may be carbonate or bicarbonates when sodicity dominates or chlorides and sulphates where only neutral salts create salinity. Carbonates or bicarbonates salinity is more harmful than chlorides and sulphates when Na is the cation attached with these. In case of exceeding Na of certain concentrations (particular to each type of plant) may exert specific ion effect and plant may suffer largely. The concentration of Na in date palm leaves of different varieties increased with increasing level of water salinity when determined for the plants of one year age (Table 4.7). Each consecutive level was similar to lower or upper level but significantly different with alternative level. But as the plants became relatively of more age (two years) they seemed to had become stronger and more salt tolerant. Sodium concentration in plant leaves did not differ statistically at this stage up to the level of EC_{iw} 9 dS m^{-1}. However, the level of 12 dS m^{-1} became statistically different than control but remained similar to 6 and 9 dS m^{-1} as well as 15 dS m^{-1} on the upper side. The highest saline water (18 dS m^{-1}) caused significantly higher concentration of Na in leaves as compared to control and all the other water salinity levels (6, 12 & 15 dS m^{-1}). Differences between varieties were remained non-significant in both years. Similarly, individual interactions of varieties and various water salinity levels were found to be insignificant (Table 4.7).

The gradual increase of Na concentration in soil solution especially rhizosphere, due to continuous irrigation with saline water caused more uptake of Na by the plant roots. The increased uptake of Na became responsible of higher concentration of this ion in plant leaves. Although salt tolerant plants like date palm possess ion selectivity phenomenon but when concentrations of salts and Na become very high this potential of the plants is weakened and they cannot exercise ion selectivity effectively. This trend was observed in the present investigations as well because clearly higher concentrations of Na were determined in leaves of date palm that were collected from plants irrigated continuously with water of EC 15 and 18 dS m^{-1}. Sodium could accumulate in cell walls of leaves or increase intercellular concentrations, leading to specific ion toxicity. High Na in leave cells could easily cause loss of turgor (GHAFOOR *et a*l., 2004).

4.1.2.1.2 Potassium

Potassium is the third macro element of plant nutrition and found in different concentration within the plants. Besides other very important functions in the plant life cycle, K plays a metabolic role as well and mediates many important processes. The role of K increases manifold when plants are growing under saline environment. It is then used by the plants for osmoregulation and then it performs as an osmoticum. It neutralizes the negative effect of higher concentrations of Na in the tissues and controls its specific toxic effect. Salt tolerant plants exercise preferred uptake of more K over Na through ion selectivity phenomenon. The data of the present study also support this view point. The effect of all the water salinity levels was observed as non-significant during the first year (Table 4.8) indicating ion selectivity phenomenon, although Na concentrations enormously increased in the rhizosphere due to continuous irrigation with saline water.

However, at the end of the second year, the K concentrations in the date palm leaf tissue decreased significantly, in particular when the levels of water salinity were like 15 and 18 dS m^{-1}. The varietal differences after the first year were also significant. Khunaizy and Abunarenjeh were having more K in their leaf tissues as compared to Khalas. This may be the reason that Khalas indicated relatively lesser salt tolerance than other two varieties of date palm (Section 4.1.1.2).

4.1.2.1.3 Calcium

Calcium is very important secondary element in plant nutrition. It is an integral part of cell walls and membranes. When Na gets concentrated under saline conditions in the rhizosphere it disturbs the uptake of calcium as well, especially in salt sensitive plants. However, salt tolerant plants tend to control this suppressing effect. The data of this experiment (Table 4.9) revealed that there was an increase during first year in Ca content of leaves with comparatively less water salinity (up to 12 dS m^{-1}). Nevertheless, overall decrease was recorded with levels of 15 and 18 dS m^{-1}. The differences were non-significant to control but significant to EC_{iw} 6 dS m^{-1}. The plant plants became even more tolerant after attaining the age of two years and no mentionable differences existed at that time in respects of Ca in date palm leaves. The varietal differences and all the interactions also remained insignificant. The correlation between EC_{iw} and leaf Ca content also indicated negative but non-significant value (r^2= -0.093, Table 4.14).

4.1.1.1.4 Magnesium

This ion is also included in secondary elements necessarily required by a plant. This ion performs many vital functions in the plant and is an integral part of chlorophyll molecule. The excess of Na ion in the soil solution and subsequently in the rhizosphere also retards mg transport to the plant through roots. However, when Mg ion is also present in excessive quantities in irrigation water, as is the case in this study (Table 3.2) this suppressing effect is overcome and opposite trend is observed. The increasing level of salinity in the water with relatively high Mg content increased constitution of this element in date palm leaves (Table 4.10). The differences were not found to be significant after one year but with more and progressive concentration in the soil, the estimated quantities in leaves became statistically appreciable in the second year due to treatment effects, especially in EC_{iw} 18 dS m^{-1} irrigated plants.

The varietal differences also became important at this time; Khalas plants had more Mg content than the other two varieties. The individual interactions of EC_{iw} and varieties were assessed significant as well. The computation of correlation also indicated highly significant and positive relationship between EC_{iw} and leaf Mg content (Table 4.14).

4.1.1.1.5 Nitrogen

Nitrogen is the first essential macronutrient and an integral constituent of all the plant parts. It is structural unit along with H_2 in the form of amino acids and proteins. The data of the present study did not indicate any important change in N content of date palm leaves due to increasing levels of EC_{iw} that could be measured statistically (Table 4.11). None of the individual interactions was found significant. However, varietal differences were significant but not much conclusive that could transmit a clear message because N content of Khalas were recorded as the minimum after one year but these were found to be maximum in the second year as compared with Abunarenjeh and Khunaizy. The correlation also did not reveal any significant relationship (Table 4.14).

4.1.1.1.6 Phosphorus

Phosphorus being the second major essential macronutrient is also required by the plants for some of the vital functions, especially energy transformations. The availability of this nutrient is dependent on many factors like; soil pH, calcareousness, organic matter and clay content as well as salinity/ sodicity. Depending upon the set of conditions, its concentration in the plant parts either increase or decrease as compared with normal situations. If the salts are dominantly carbonates or bicarbonates, these may reduce P uptake significantly but chlorides and sulphates may increase it. The second phenomenon was operative under the conditions of present study. During the first year of experimentation P concentration in the date palm leaves was not changed significantly, although plants were irrigated with saline water up to 18 dS m^{-1} (Table 4.12).

However, gradual salt concentration in the rhizosphere increased during the two years up to the level where leaf P contents were increased significantly. Nevertheless, none of the consecutive levels differed significantly after second year of the study except 18 dS m^{-1} that was found to higher and statistically different than all the other levels. The correlation also indicated that EC_{iw} and P content of date palm leaves were inter-related significantly (Table 4.14) with positive value (r^2 = +0.305). The differences in between varieties and individual interactions remained non-significant in both the years of investigation.

4.1.1.1.7 Chlorides

Although chloride is an essential micronutrient but its higher concentration in the rhizosephere or within the plant prove toxic and specific ion effect of chloride retards plant growth. In acute cases the plants even may die. This concentration of chloride is specific for each plant. Generally salt tolerant plants have higher limits of chloride toxicity. Some plants even check its entry into the root cortex and thus exercise ion selectivity. The data of the present experiment indicated that date palm has very strict check of Cl absorption from soil solution even though it may be highly saline. Non-significant effect on Cl concentration in date palm leaves was recorded in both the years (Table 4.13). The differences between varieties as well as all interactions were also found insignificant. The correlation in between water salinity and leaf Cl content as well as soil salinity and leaf Cl concentration were computed as non-appreciable in statistical terms.

This indicated that a strict control on Cl content within the plant is the mechanism of salt tolerance in date palm.

4.1.1.2 Discussion on plant ionic parameters

Salt accumulation occurs when the saline water is used for longer times without any remedies or management practice. The salts when solubilize in soil water give rise to a swarm of ions around the plant roots. Thus the ionic concentration increases manifold. Of course the kinds of ions depend upon the chemical composition of irrigation water. The irrigation water of present study was mainly constituted of chlorides and sulphates of Na, Ca and Mg (Table 3.2). Therefore, accumulation of these ions in the soil solution and subsequently in the plant parts was expected unless date palm saplings exercised ion selectivity and blocked entry of unwanted ions. The results presented on ionic concentrations in date palm leaves (Tables 4.7 to 4. 13 and sections 4.1.2.1.1 to 4.1.2.1.7) indicted that in general uptake of Na, Mg and P increased significantly while that of K decreased whereas Ca, N and Cl remained non-significant. Despite check on entry of Na, as revealed by lower levels of EC_{iw} (differences with control non-appreciable), there was more uptake of Na by the plants that accumulated in leaves of date palm, in particular at the higher water salinity levels (15 and 18 dS m^{-1}). The correlation of EC_{iw} and leaf Na was also found to be highly significant and positive (Table 4.14). Similarly, Mg uptake by plant roots also increased in accordance with its concentration in the soil solution as result of continuous irrigations with high Mg water. Although date palm plants exercised preferred uptake of K but very high concentrations of Na in the rhizosphere shattered this potential of the plant and K ion uptake decreased resultantly (Fig. 11). The plants indicated very strict control on Cl uptake and its concentration in the leaves did not increase significantly. Hence plants were saved from severe toxic effects of Cl. The computation of correlation between plant Cl and EC of irrigation water also indicted non-significant values (Table 4.14).

This ionic variation pattern in date palm can also be supported by evidences from the literature. ESECHIE (1998) reported that in a saline environment, plants took up excessive amounts of Na at the expense of K and Ca. He observed that an increase in Na content generally decreased the K content, suggesting an antagonism between Na and K. ESECHIE AND RODRIGUEZ (1999) reported that salinization significantly reduced the concentration of N, K. Ca and Mg in the leaf tissue. With the exception of Cu concentration, which was enhanced by salinity, all the micronutrients (B, Zn, Mn and Fe) had reduced concentration in leaves of plants. On the basis of these results, it was concluded that reduced leaf nutrient concentration may be one of the primary causes of the inhibition of leaf growth. HASSAN *et al.* (2000) observed that with increasing soil salinity level, Na and Cl concentration in the leaves was increased in all the three cultivars of olive but to different degrees. Similarly HASSAN *et al.* (2001) found that as salinity increased, Cl and/ or Na increased, however, K decreased in the leaf tissue of apricot. AL-MANSOORI (2001) claimed that date palm roots have specific holding capacity, exceeding this capability enhances Na release into the shoot. AWARD (2007) reported that date palm seedlings accumulated significant amounts of Na in the foliage with increasing salinity, about a threefold increase in the accumulated Na between the control and 30 dS m^{-1} salinity treatments. Electrolyte leakage indicated a significant reduction in membrane integrity as salinity increased. The imbalance in composition of saline soil solution can affect the absorption of nutrients, e.g. excess of Cl, Na or Mg ions decrease the uptake of NO_3, K, Zn and Ca ions. It has been further suggested that ability of a plant to retain K in the presence of excess Na ion could be an important mechanism in salt tolerance (GHAFOOR *et al.,* 2004). Ion imbalances and nutrient deficiency, particularly for K nutrition, can also occur under saline environment (TEJERA *et al.,* 2006).

TRIPLER *et al.* (2007) found a linear decrease for both yield of date palm and transpiration in response to increased soil saturated paste salinity for the treatments having lower B concentrations (0.0278, 0.185 and 0.4625 mmol L^{-1}). Yield and transpiration also decreased with increased B concentration. While increases in soil saturated paste B from 0.3 to 1.5 mmol L^{-1} caused substantial declines in yield and transpiration, subsequent increased B to 3 mmol L^{-1} caused only minor reductions. Response to salinity and to excess B was witnessed from the lowest tested levels when each of the variables was isolated. Growth response to combined conditions of salinity and B behaved according to the dominance of the two stresses and did not show additive effects. Hence, role of B can be far reaching when a plant is exposed to salinity stress, especially in pollination and fertilization during reproductive stage in case of date palm.

Table 4.14: Correlation of water salinity (EC_{iw}) with different parameters

Sr. No.	Parameter	Coefficient of Corr. (r^2)	Slope	Probability	Significance
1	Leaf N	+0.090	+0.007	0.51	NS
2	Leaf P	+0.305	+0.003	0.02	*
3	Leaf K	-0.090	+0.008	0.52	NS
4	Leaf Na	+0.503	+0.012	0.00	**
5	Leaf Na/ K	+0.532	+0.007	0.00	**
6	Leaf Ca	-0.093	-0.004	0.503	NS
7	Leaf Mg	+0.386	+0.016	0.004	**
8	Leaf Cl	-0.096	-0.005	0.49	NS
9	Leaf Mn	+0.717	+0.384	0.00	**
10	Leaf Fe	-0.062	-2.289	0.65	NS
11	Leaf Zn	-0.503	-1.371	0.00	**
12	Leaf Cu	+0.058	+0.93	0.68	NS
13	Soil ECe	+0.786	-	-	**
14	Soil pH	-0.885	-	-	**

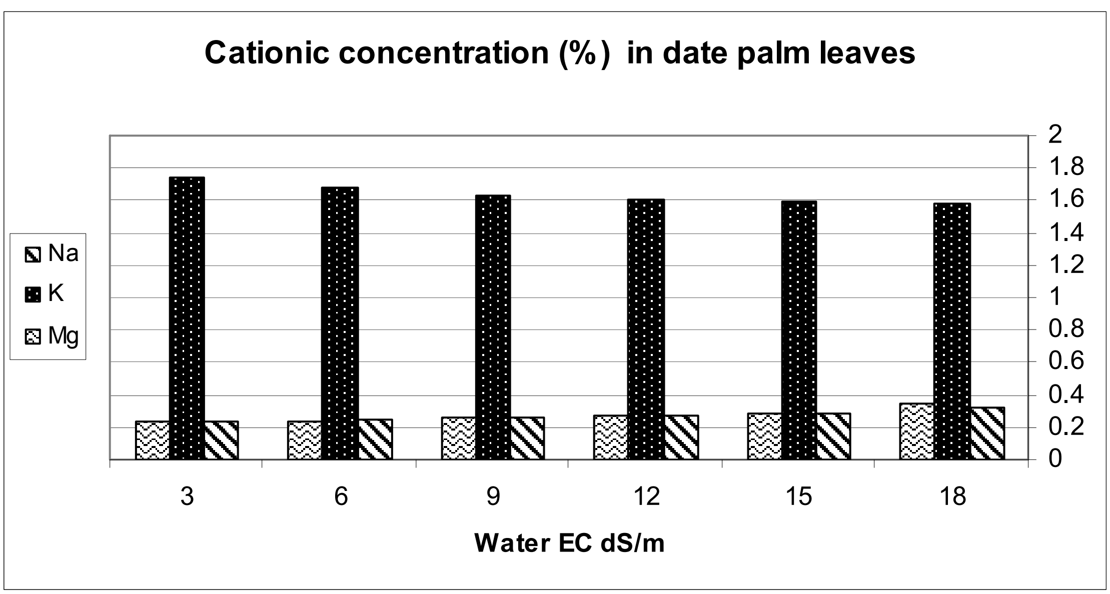


Fig. 11: Leaf concentrations of different cations in date palm seedlings after two years (n= 4 SD K= 0.10 SD Na= 0.03 SD Mg= 0.05)

4.1.3 Soil parameters

4.1.3.1 Soil EC_e

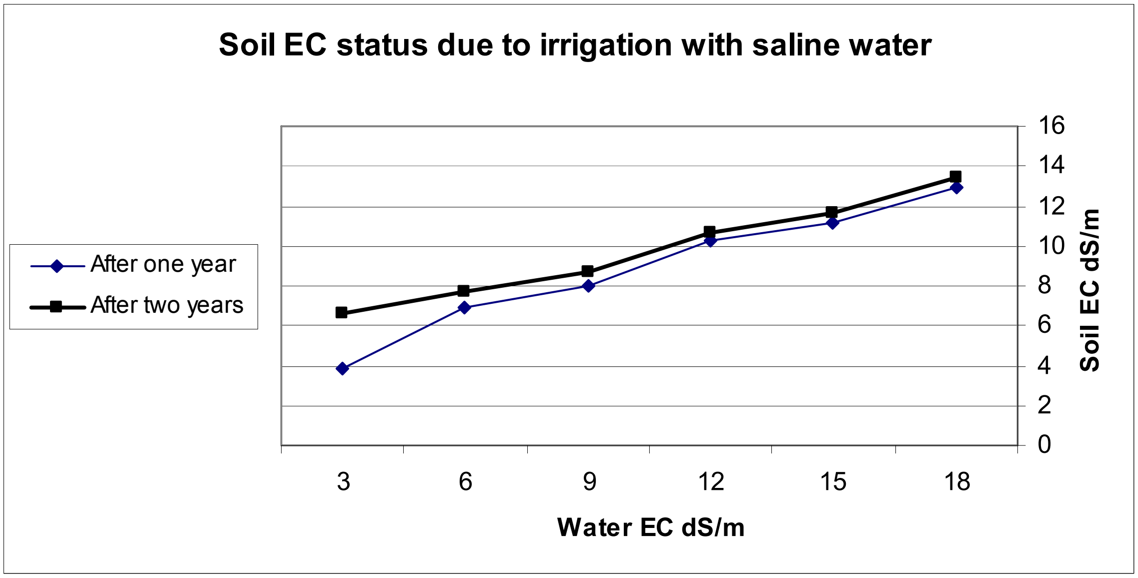
When saline water is applied to a soil consistently without any management practices (Like; leaching, cyclic use or application of organic matter) the soil EC starts gradually increasing until it reaches steady state when EC of soil equals that of irrigation water. However, the quantum of increase and its rate will depend upon magnitude of salts in irrigation water, quantity of water used (frequency and volume), soil texture, structure and drainage as well as climatic conditions (rainfall and temperature) etc. This phenomenon was also observed in present studies. Soil EC_e increased significantly with each level of water salinity as compared with control when either observed after one year or two years (Table 4.15). Nevertheless, EC_{iw} 6 dS m^{-1} was found to be similar with 9 dS m^{-1} while 12 dS m^{-1} was alike with 15 dS m^{-1} during second year. The reason could has been that Gonu cyclone removed salts partially in the middle of the second year due to excessive and unusual rainfall (cm). Varietal differences regarding soil EC_e as well all interactions were evaluated as non-significant.

Gradual increase of soil EC is the logical outcome when saline water is being constantly used for irrigation without leaching fractions because salts coming with irrigation water accumulate slowly and consistently (Fig 12-A). SAMENI AND MORSHEDI (2000) also reported that saline-sodic irrigation water, coupled with the low annual rainfall and high evaporation and transpiration (common in the arid and semi-arid regions) resulted in accumulation of soluble salts in the soil solution, which altered the structure and, consequently, affected the soil hydraulic conductivity. SIFOLA *et al.* (2002) found as well that the electrical conductivity of the saturation paste (EC_e) across the 0.6 m topsoil profile increased with increasing salinity of the irrigation water. However, net salt accumulation is highly dependent upon soil texture and drainage. If the soil is light in texture with good drainage, there will less seasonal salt accumulation in comparison to soil with fine texture and restricted drainage, although climatic conditions especially rainfall also play very important role in leaching of salts.

The resulting increase in soil EC retarded plant growth (Sections 4.1.1.1 to 4.1.1.1.4). This was mainly due to osmotic effects of accumulated salts that reduced water uptake of water and nutrients. An imbalanced ionic uptake also occurred that affected plant nutrition negatively, especially K (Table 4.8) whereas Mn and Zn indicted negative and significant correlation with soil EC (Table 4.14). MUNNS (2002) found that accumulation of salts in the root zone affected plant performance through creation of water deficit and disruption of ion homeostasis which in turn caused metabolic dysfunctions. PARIDAA *et al*. (2005) illustrated that salinity is the major environmental factor limiting plant growth and productivity. The detrimental effects of high salinity on plants were observed at the whole-plant level as well. The growth rate directly depends upon the products of various metabolic processes. Therefore any disruption in normal metabolism will naturally be translated into curtailed growth and less yield.

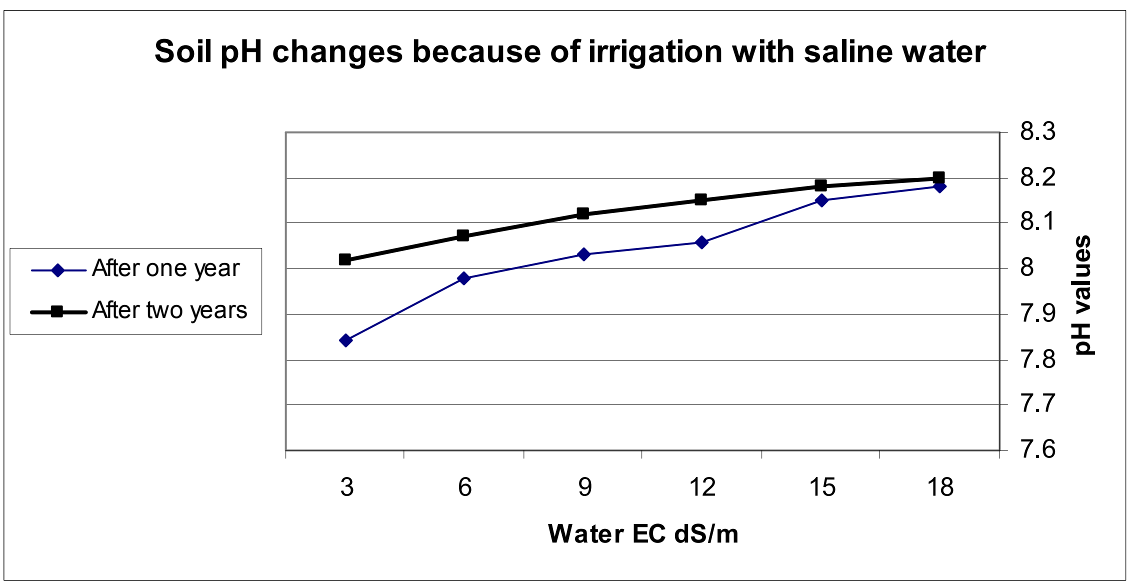
4.1.3.2 Soil pH

Soil pH is the single parameter that tells about overall conditions of a soil that is prevailing for plant growth. It tells not only whether the soil is suitable for growing a plant or not but also predicts about nutrient availability and behavior of applied fertilizers. Highly acidic or alkaline soils present many problems for normal growth of the plants and limit their nutrient supplying capacity. The experimental soil was slightly alkaline with a pH of 7.7. The irrigation with saline water for two years indicated a significant increase in this important soil characteristic and made it more alkaline. The EC_{iw} 6 dS m^{-1} was assessed similar to control (3 dS m^{-1}) on lower side and alike 9 dS m^{-1} on the upper side (Table 4.16). The water salinity level of 9 dS m^{-1} was statistically similar to 12 dS m^{-1} that in turn resembled 15 and 18 dS m^{-1}. Thus, consecutive levels were found to be non-significant while alternating levels deviated generally significantly. All the water salinity levels were found to be significant in comparison to control except 6 dS m^{-1}. Such a trend was noticed in both the years. The differences of varieties and all the interactions were evaluated as non-appreciable. Soil pH was found to be positively correlated with EC (Table 4.17). The soil EC increased with lapse of time as well as increasing levels of water salinity (Table 4.15, Section 4.1.3.1). Hence soil pH also increased accordingly (Fig 12-B).



Water salinity levels:	**3**	**6**	**9**	**12**	**15**	**18**
Significance first year:	**E**	**D**	**C**	**B**	**B**	**A**
Significance second year:	**D**	**C**	**C**	**B**	**B**	**A**

Fig. 12-A: Effect of water salinity on soil EC after two years (n= 4)



Water salinity levels:	**3**	**6**	**9**	**12**	**15**	**18**
Significance first year:	**C**	**BC**	**AB**	**AB**	**A**	**A**
Significance second year:	**D**	**CD**	**BC**	**AB**	**A**	**A**

Fig. 12-B: Effect of water salinity on soil pH after two years (n= 4)

Table 4.17: Correlation of soil ECe with different parameters

Sr. No.	Parameter	Coefficient Of Corr. (r^2)	Significance
1	Leaf N	+0.077	NS
2	Leaf P	+0.300	*
3	Leaf K	+0.096	NS
4	Leaf Na	+0.424	**
5	Leaf Na/ K	+0.409	**
6	Leaf Ca	-0.232	NS
7	Leaf Mg	+0.223	NS
8	Leaf Cl	-0.256	NS
9	Leaf Mn	+0.492	**
10	Leaf Fe	-0.196	NS
11	Leaf Zn	-0.308	**
12	Leaf Cu	+0.037	NS
13	Soil pH	+0.620	**

4.1.2 Physiological basis of salt tolerance in date palm

4.1.4.1 Maintaining Na/ K Ratio

Plants are of two types regarding ion uptake under salt affected conditions; those which allow salty ions to enter plant root freely (salt sensitive) and are resultantly affected negatively in even lower concentrations while the other are selective in ion uptake (salt tolerant) and can withstand higher concentrations of Na. The Na/ K ratio is considered very important in this regard when dealing with salt tolerant studies. The salt tolerant plants tend to keep this ratio closer due to ion selectivity phenomenon developed in such plants through genetic makeup while the sensitive plants lose their control to keep this ratio closer because ion selectivity has not strongly developed in their genesis. REJILI *et al.* (2007) studied ionic balance through determination of Na^+/ K^+ in *Lotus creticus* plants grown under dominating NaCl environment. It was affected mainly at the level of roots where high potassium content was recorded as compared to the aerial organs reflecting probably an inclusive behavior towards salts. This behavior justified the plants to maintain their growth even in very hard salinity conditions. In studies of SINGH *et al.* (1998) Chico showed 100% survival at pH 10.0 even eleven months after planting. Chemical analysis indicated that Chico had a much lower Na/ K ratio and was able to take up more K than Na even at pH 10.0 than guava and *Jambolana* (Jaman). There was more Na uptake compared with K in guava and *Jambolana* (Jaman), resulting in plant mortality. However, roots of Chico may have some ion regulation mechanism to avoid such competition for uptake of Na and K from soil. MAHMOOD (2007) reported maintenance of K: Na as the mechanism of salt tolerance in *Acacia ampliceps*.

The Na: K ratio in date palm leaves was also calculated in the present studies (Table 4.18) in order to evaluate behavior of such a high salt tolerant plant for this parameter. It was noticed that not only this ratio was very close but also efficiently maintained by all the three varieties (Khalas, Khunaizy and Abunarenjeh) although water salinity levels were increased up to 18 dS m^{-1}. When comparison was made in between control and water salinity treatments; it was noticed that there was no statistical difference at all during first year while numerical values of this ratio were similar up to the EC_{iw} 12 dS m^{-1} after two years (Fig. 13). The level 12 dS m^{-1} was found to be alike with 15 dS m^{-1} whereas the latter did not differed 18 dS m^{-1}. Nevertheless, the highest level (18 dS m^{-1}) was different than all the studied levels except 15 dS m^{-1}. Thus, date palm plants were able to maintain Na/ K ratio to the water salinity level 12 dS m^{-1}. This indicated that maintaining Na/ K ratio may be regarded as the major salt tolerance mechanism in date palm. The Khunaizy variety was having the least values of this parameter in both the years therefore can be regarded as more salt tolerant than Khalas and Abunarenjeh (Fig. 14). The data on plant parameters also support more salt tolerance of this variety (Section 4.1.1.2). AL-MANSOORI (2001) indicated that date palms may rely on inorganic ion accumulation to maintain osmotic adjustment. The whole plant tolerance may be a result of Na^+ compartmentalization in the root and Na^+ exclusion from the shoot. However, the roots have specific holding capacity, exceeding this capability Na^+ is released into the shoot. AL-KHAYRI (2002) maintained that in response to increasing external NaCl level, the Na/ K ratio increased. The study of AL-HAMMADI (2006) reported that increased NaCl leads to significant decreases in K^+, Mg^{2+} and Ca^{2+} contents of plants. The Na: K ratios were lower in shoots than in roots. Lulu, Fard, Khunaizy, Nabtat Safi, and Razez cultivars showed higher RGR and biomasses whereas Khunaizy, Mesally, and Safri had higher Na: K ratios than other cultivars in the control indicating higher Na^{1+} discriminations from plant parts.

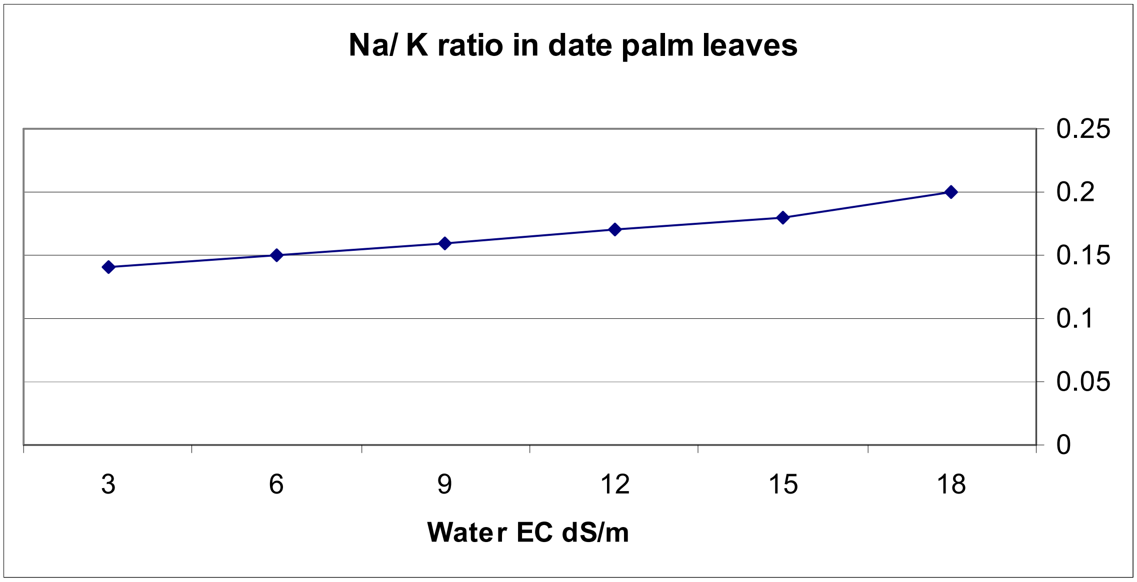


Fig. 13: Effect of increasing water salinity on Na/ K ratio in date palm seedlings after two years (n= 4 SD= 0.03)

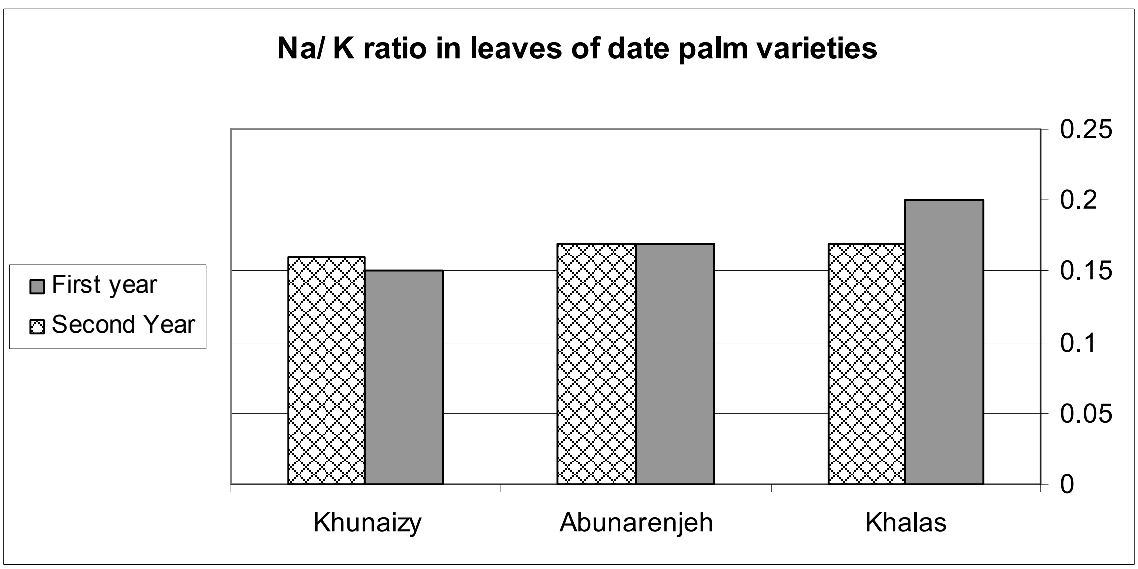


Fig. 14: Effect average water salinity on Na/ K ratio in date palm seedlings of different varieties (n=4 SD First year= 0.03 SD Second year= 0.02)

4.1.4.2 Control on chloride uptake

The anions attached with Na are very important because negative effects of salinity on plants are also determined by them. Same quantity of Na when attached with chlorides prove more toxic than sulphates, but lesser than carbonates and bicarbonates. However, the quantities of the latter two are generally lower in the saline soil than the former two but it was specifically true for the experimental soil (Table 3.1). The irrigation water also contained very large quantities of chlorides, particularly when its EC was very high in last two three treatments (Table 3.2). Hence, the detrimental effect of chlorides could greatly harm the date palm plants but surprisingly amounts determined in the plant leaves were very low and treatment effect was found to be non-significant (Section 4.1.1.1.7, Table 4.13). The correlation of leaf chloride was also determined to be non-significant (Table 4.17). Therefore, it can be concluded that date palm exercises a strict control on Cl uptake as a salt tolerance mechanism.

4.2 Experiment 2: Managing saline water for growing date palm

Utilization of brackish water for crop production in arid and semiarid regions cannot be avoided due to scarcity of good quality water; rather it has become a usual practice. Therefore, the deleterious effects are bound to appear in the long run if some management practices are not adopted. Leaching fractions (LF) and application of organic matter are the usually recommended techniques where good quality water is not available at all so that cyclic use strategy can be choice. However, usefulness of these management techniques has not proved universal investigations under site specific conditions are required. This experiment was conducted to thrash out successes and failures of these management practices under conditions of Oman.

4.2.1 Results of experiment 2

4.2.11 Plant growth parameters

Growth of plants is retarded when saline water is use for irrigation consistently while adoption of management practices helps in controlling bad effects of salinization.

4.2.1.1.1 Trunk height

The data of this experiment indicated that water salinity level of 9 dS m^{-1} significantly decreased trunk growth of date palm compared with 6 dS m^{-1} in both the years of study (Table 4.19). Leaching fractions were similar with control with water of EC 6 dS m^{-1} but significantly different when EC_{iw} was 9 dS m^{-1} during first year. Only leaching fraction of 0.22 proved effective and trunk height was recorded significantly higher than control as well as LF 0.15. However, both the LF were useful with water EC of 6 dS m^{-1} but became partially ineffective with water EC of 9 dS m^{-1} during the second year (Fig. !5). Effect of organic matter application within each water EC level was not statistical during first year but significant during second year. Nevertheless, the overall effects of organic matter were found significant during both the years of study. Interactions of organic matter and LF were non-significant during first year but statistically measureable during the second year. The overall conclusion depicted from these data was that combination of LF and organic matter is useful to keep up the growth (height) of date palm but at higher water EC the usefulness of this combination decreases.

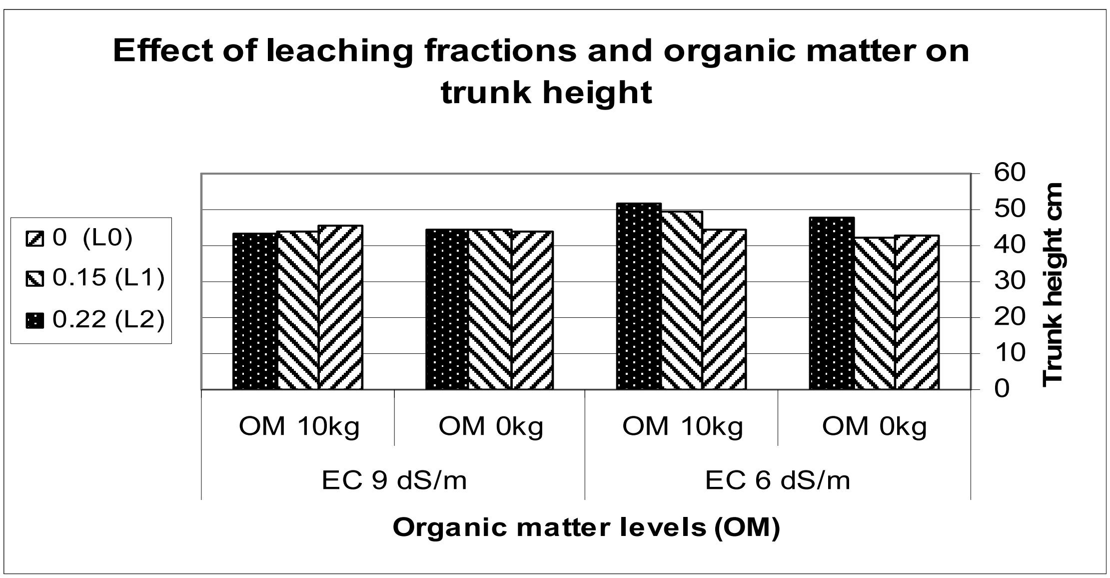


Fig. 15: Comparison of trunk height of date palm seedlings after two years under different treatments (n= 4)

4.2.1.1.2 Number of fronds

None of the treatments and interactions was found significant during first year as far as this parameter was concerned. However, during the second year the effects of treatments became pronounced and measureable statistically. A significant decrease in number of fronds was recorded with consistent use of water of EC 9 dS m^{-1} for two years as compared with water of EC 6 dS m^{-1} (Table 4.20). The reason may be that soil EC did not reach to the extent that could retard bearing of new leaves (fronds). The management strategies; leaching fractions as well as application of organic matter proved significantly useful and overall effects were assessed significant (Fig. 16). In general, the combination of leaching fractions and organic matter proved superior to alone application of each. Provision of extra water in the form of leaching fractions helped to leach down the salts up to certain limit. Similarly organic matter helped in holding water and checking evaporation which ultimately results in accumulation of salts on or near underneath surface of the soil. However, the efficiency of both the factors declined in the second year when EC of irrigation water was 9 dS m^{-1}. Thus, usefulness of both the treatments and their combinations was found partial and restricted to certain limit of water EC for example 9 dS m^{-1} in present study. It can decrease further with increasing EC of water.

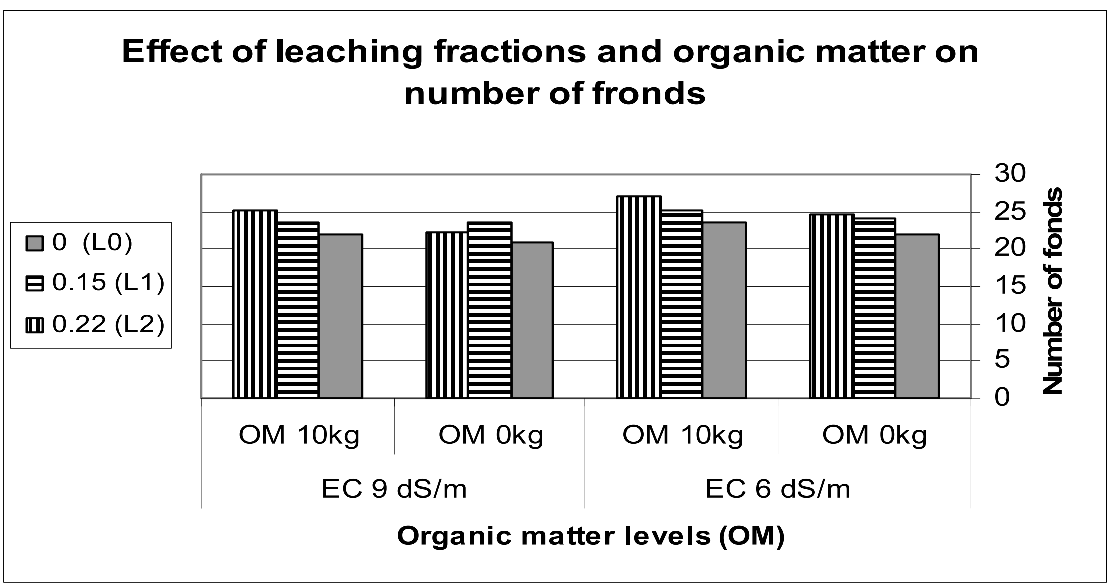


Fig. 16: Comparison of number of fronds of date palm seedlings after two years under different treatments (n= 4)

4.2.1.1.3 Trunk girth

Under normal functioning of plants, trunk girth keeps increasing constantly but in the presence of a stress this parameters is retarded. If the salinity stress is severe, attaining girth by plants totally stops and plants remain thin and spindly. The data from present experiment on this parameter (Table 4.21) also indicted the same trend. Trunk girth was significantly lesser in treatment of water EC 9 dS m^{-1} as compared with 6 dS m^{-1} in both the study years. However, management techniques helped to decrease this negative effect (Fig. 17). The overall effects of 0.22 LF and organic matter application were significant during the two years. When effectiveness was evaluated under water salinity levels separately, it was noticed that with EC 6 dS m^{-1} both LF; 0.15 and 0.22 were significant with control as well as among each other in second year but differences were non-significant in first year. However, none of LF was significant when water EC increased to 9 dS m^{-1}. The interactions of organic matter, LF and water salinity levels remained non-appreciable in both the years.

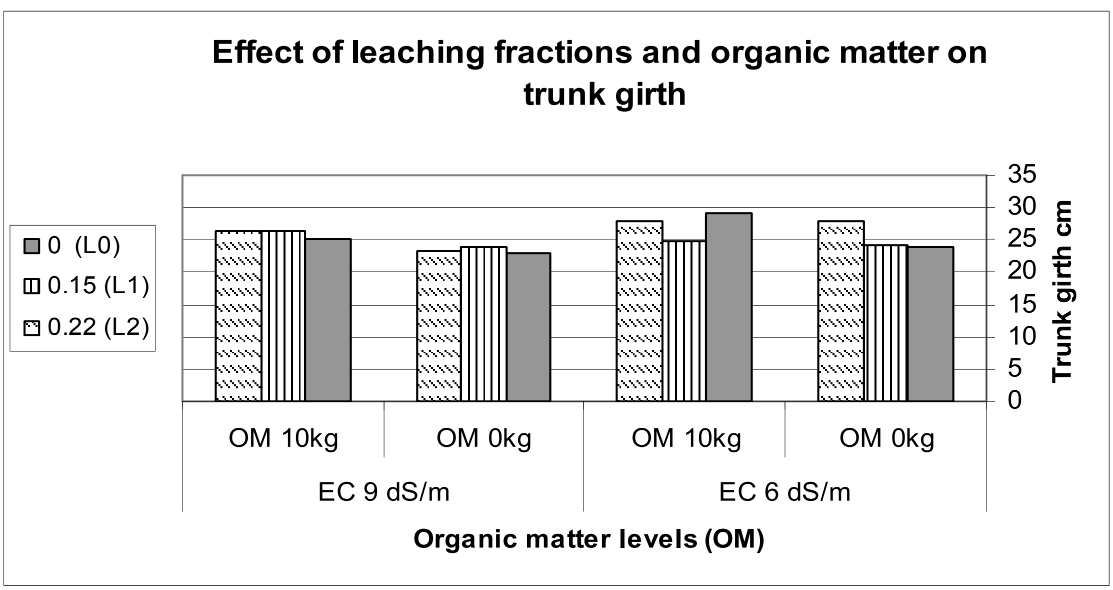


Fig. 17: Comparison of number of trunk girth of date palm seedlings after two years under different treatments (n= 4)

4.2.1.1.4 Leaf length

The pattern of variation of this parameter was somewhat different than the other three plant characters; trunk height, trunk girth and number of fronds. The leaf length was not significantly decreased with increasing water salinity up to 9 dS m^{-1} (Table 4.22). Therefore, effects of both LF and all the interactions were also found as non-significant except the individual interaction of LF and organic matter after one year and overall interaction of organic matter and LF which were found as significant statistically in both the years. Hence effect of organic matter application was recorded as positive (Fig. 18).

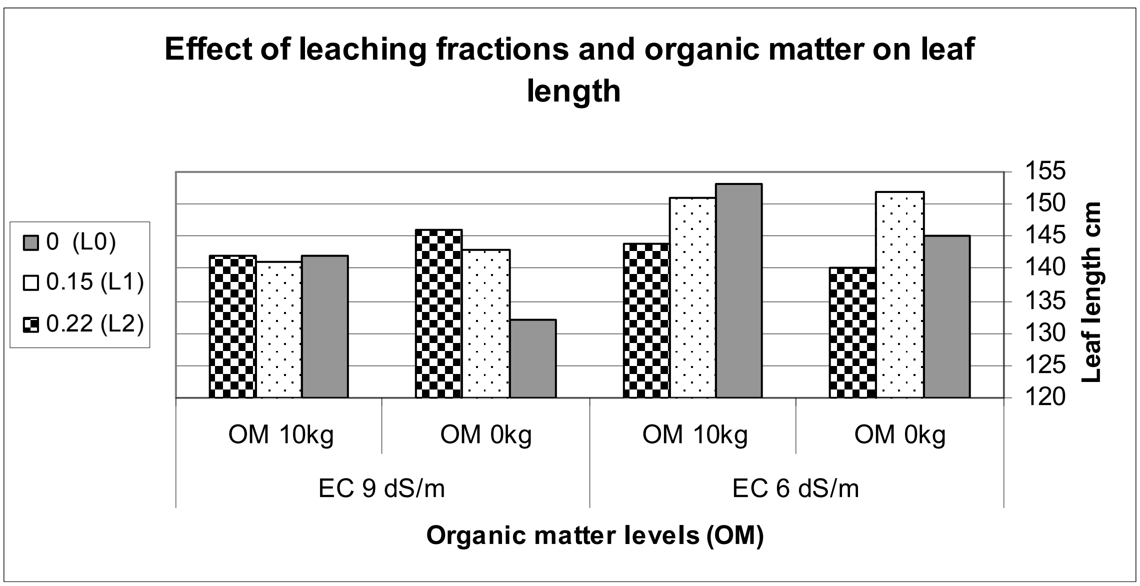


Fig. 18: Comparison of leaf length of date palm seedlings after two years under different treatments (n= 4)

4.2.1.2 Ionic parameters

4.2.1.2.1 Sodium, Potassium, Calcium and Magnesium

The water EC of 9 dS m^{-1} increased leaf Na and Mg significantly while K and Ca remained unaffected during the course of study of two years as compared with 6 dS m^{-1} (Table 4.23, 4.26, 4.24 and 4.25). Because date palm maintains K as mechanism of salt tolerance (Section 4.1.3.1), therefore this ion was not affected at this level of water salinity. a Application of organic matter and leaching fractions remained non-significant in respect of affecting K and Ca, decreased Na but leaves Mg percentage increased significantly. The individual interactions of leaching and organic matter were also not found to be significant in any of the parameters. However, overall leaching effect was noted as significant and positive decreasing Na accumulation in leaves. Similarly, overall interaction of leaching and organic matter application decreased Na and increased Mg significantly while in case of K and the effects of these combinations were not appreciable statistically (Fig. 19 & 20) .

4.2.1.2.2 Chloride, nitrogen and phosphorus

As already observed that date palm have adopted maintenance of chloride content as a physiological mechanism of salt tolerance (Section 4.1.3.2), hence leaf constitution of this ion was not disturbed significantly when level of water EC increased from 6 dS m^{-1} to 9 dS m^{-1} (Table 4.27). The leaching fractions did not play any significant role but effect of organic matter application was positive in keeping the chloride content low as compared to non-organic matter treatments When EC of water was 6 dS m^{-1} during the first year but this effect disappeared during the second year.

Nitrogen content of leaves were not affected with increase in water salinity to 9 dS m^{-1} during the first year but decreased significantly in the second year. There was no role of leaching fractions in helping N content (Fig. 19) but application of OM proved beneficial in this regard (Table 4.28). During first year this treatment increased N % in case of both saline waters (6 and 9 dS m^{-1}) but in the second year usefulness was found only with 6 dS m^{-1}. Overall effect of organic matter in keeping up the leaf N was observed only in the second year when the saline water irrigation depressed N in leaves of date palm (Fig 20).

The P content of date palm leaves decreased significantly during first year when water EC increased to 9 dS m^{-1} but this negative effect was overcome in the second year when plants grew bigger and became more hardy (Table 4.29). No role of leaching fractions was seen in this parameter. Nevertheless, organic matter application helped to increase it in the first year when water EC was 6 dS m^{-1} but remained non-significant in 9 dS m^{-1}. However, overall effect of OM was significant and positive in both the years.

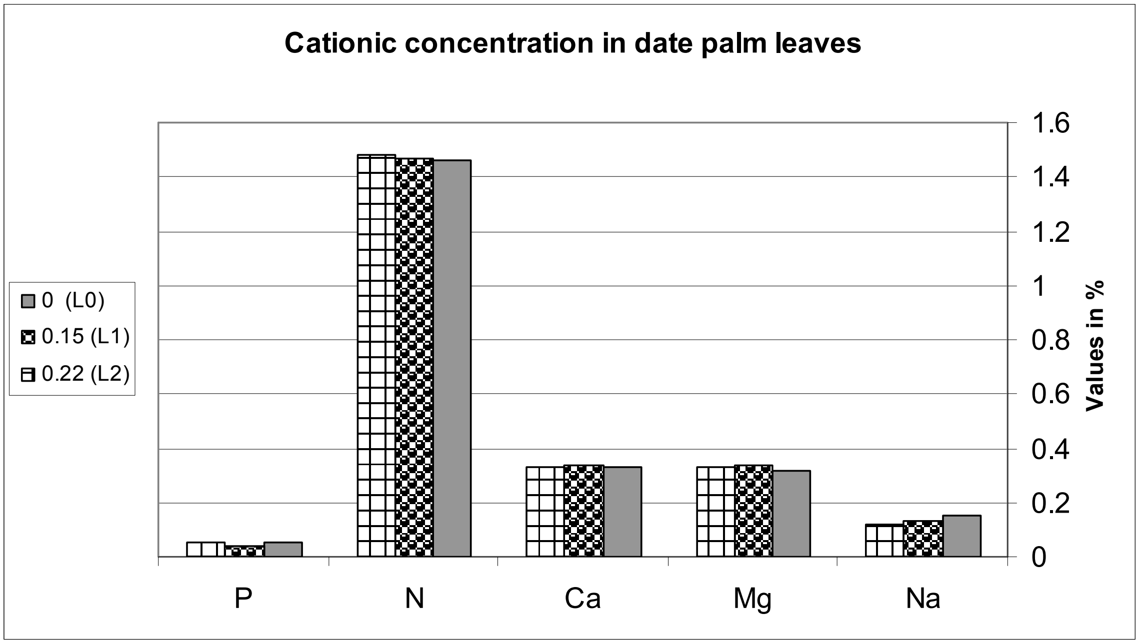


Fig. 19: Effect of leaching fractions on ionic concentration of date palm leaves after two years (n= 4)

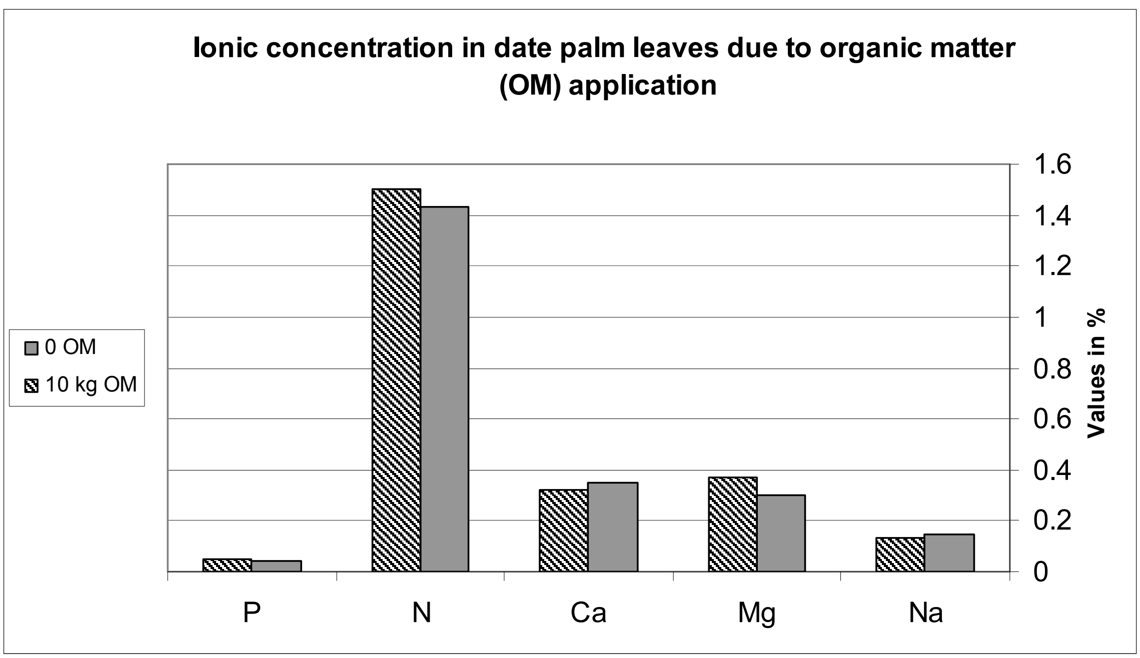


Fig. 20: Effect of organic matter application on ionic concentration of date palm leaves after two years (n= 4)

4.2.1.3 Soil parameters

The major objective of this experiment was to control increase in soil EC and pH that could occur due to continuous irrigation with saline water of EC 6 and 9 dS m^{-1}. The data collected on soil EC and pH during two years of study indicated that the target was achieved partially (Fig. 22 & 23). Soil pH was not increased significantly (Table 4.31) because both waters (6 and 9 dS m^{-1}) were not having high SAR while RSC was nil (Table 3.2). Therefore, effect of management techniques; leaching fractions and application of organic matter was also evaluated to be significantly positive. Although soil EC was disturbed a lot (Table 4.30), but leaching and OM also helped to keep the increase in soil EC lesser compared with no management practice (control). However, negative effects could not be controlled. Both the waters increased soil EC that reached 10.72 and 11.55 dS m^{-1} respectively with water EC of 6 and 9 dS m^{-1} without any management practice but these were restricted to 5.63 and 7.90 dS m^{-1} when higher leaching fraction (0.22) was combined with organic matter application (10 kg per plant per year). As is clear from the magnitude of values, these exceeded the critical limit of 4 dS m^{-1}. Nevertheless, these values were within the salt tolerance limit of date palm. From this view point the success of management techniques could be claimed because objective is to keep the soil profile EC within tolerable limits of the plants grown.

In statistical terms soil EC was significantly increased in both the years with water EC 9 dS m^{-1} compared with 6 dS m^{-1} (Table 4.30). Overall effects of leaching fractions were significant with lower values in comparison to provision of no LF but both were similar to each other in numerical values. The effectiveness of this strategy decreased when water EC increased to 9 dS m^{-1}, especially in the second year. The benefits of application of organic matter were also recorded as significant in both the years. However, best results were obtained when additional water was applied as leaching fractions coupled with application of organic matter. This combination proved effective even with water of 9 dS m^{-1} in both the years. Minimum values of soil EC were observed when LF and OM were combined to manage water EC of 6 dS m^{-1}. The overall effects of organic matter were also assessed as significant but individual interactions of LF and OM were non-significant. The mean soil EC value after two years including both waters without any management strategy was computed as 11.13 dS m^{-1} that was restricted to only 6.76 dS m-

^{1} using combined strategy (LF 0.22 and OM (10 kg per plant per year). Therefore, it could be concluded that the investigated management techniques were useful to minimize soil salinization but fully controlling increase in EC was not possible.

4.2.2 Discussion

4.2.2.1 Effect leaching fractions

Salt accumulation and soil salinization are the ultimate consequences of irrigation with saline water but concentration of salts in the rhizosphere must remain within tolerance potential of the plants to be grown otherwise significant reduction in growth and yield may occur. Therefore, accumulated salts must necessarily be leached either into down profile or horizontal drainage system, either through rainfalls or deep and continuous irrigations with good quality water. When irrigation with brackish water is a continuous practice and good quality water is not available at all then extra water over consecutive use of crops has to be utilized for preventing salt accumulation and keeping their flow into lower soil depths so that rooting zone of soil remain salt free or within tolerable limit of plants being grown. The additional water is called leaching water (Leaching fraction; LF or Leaching requirement LR). The exact quantity of LF depends upon quality and quantity of irrigation water in use and tolerance of plant for salt stress. In the present study leaching fractions of 0.15 and 0.22 have been used which indicate that saline water of same quantity as being used for irrigation was used 15 and 22 % more than the normal practice (to meet the actual requirement of date palm plants). The data of the present study indicated partial usefulness of this technique which was limited to lower EC level (6 dS m^{-1}) of water. The effectiveness of LF was not so pronounced in case of water with higher EC of 9 dS m^{-1} (Tables 4.19 to 4.22). During the first year, LF of 0.15 and 0.22 kept the plant parameters (Trunk height, girth and number of fronds) at significantly higher magnitude but during second year differences between leaching fractions including control (No LF) became non-significant in case of water EC 9 dS m^{-1}, although overall differences still remained significant (Fig 21). This may be due to the reason that when water EC crosses a limit depending upon soil conditions, the salt addition and accumulation through irrigations exceeds salt removal provided in the shape of excess water (LF). Thus, there was an ultimate increase in salt EC (Table 4.30) that restricted date palm growth. The lesser end vales of EC in LF treatments revealed its usefulness

(Fig 22). However, crossing the critical limit of 4 dS m^{-1} indicated its limitation. Nevertheless, the target was not to restrict soil EC lesser than 4 dS m^{-1} rather it was to keep it within the salt tolerance potential plant of date palm in the present study. Therefore, partial usefulness can be claimed safely with lesser losses to plant growth. The Na content in plant leaves were also restricted by LF (Table 4.23) indicating a positive sign as well. Higher LF (0.22) was more effective when water EC was 9 dS m^{-1}. However, supplementation of organic matter improved further the effectiveness and usefulness of LF and soil EC as well as pH was kept as the lowest (Fig. 22 & 23). Various LF were found to be positively correlated with No. of fronds, height of trunk and trunk girth while leaf Na was negatively and significantly correlated (Table 4.33). Thus, in the absence of any other option LF can be regarded useful techniques but may not be adopted blindly. This technique can usefully be used when water EC is not too high (Exceeds 9 dS m^{-1}) and texture is light with good soil drainage.

RENGASAMY (2006) reported that salts introduced by irrigation water are stored within the root zone because of insufficient leaching. Poor quality irrigation water, low hydraulic conductivity of soil layers, and high evaporative conditions accelerate irrigation-induced salinity. Use of highly saline effluent water and improper drainage and soil management increase the risk of salinity in irrigated soils. He also reported that low osmotic potentials resulting from soil salinity can restrain water uptake by plants and reduced their ability to survive and produce. Under dry-land conditions, concomitant changes in matric and osmotic potentials determined plant water uptake. EL-BABLY (2002) reported that leaching and salinity control requires a proper balance among these factors.

Table 4.33: Correlation of leaching fractions with different parameters

Sr. No.	Parameter	Coefficient Of Corr. (r^2)	Slope	Probability	Significance
1	No. of fronds	+0.332	+0.708	0.048	*
2	Length of frond	+0.136	+1.013	0.429	NS
3	Height of trunk	+0.398	+1.417	0.016	**
4	No. of leaflets	+0.261	+1.463	0.123	NS
5	Trunk girth	+0.220	+0.567	0.019	*
6	Leaf N	+0.303	+0.040	0.072	NS
7	Leaf P	+0.229	+0.004	0.179	NS
8	Leaf K	+0.014	+0.001	0.935	NS
9	Leaf Na	-0.053	+0.000	0.051	*
10	Leaf Na/ K	-0.053	+0.000	0.758	NS
11	Leaf Ca	-0.033	-0.002	0.848	NS
12	Leaf Mg	+0.039	+0.004	0.821	NS
13	Leaf Cl	-0.331	-0.002	0.048	*

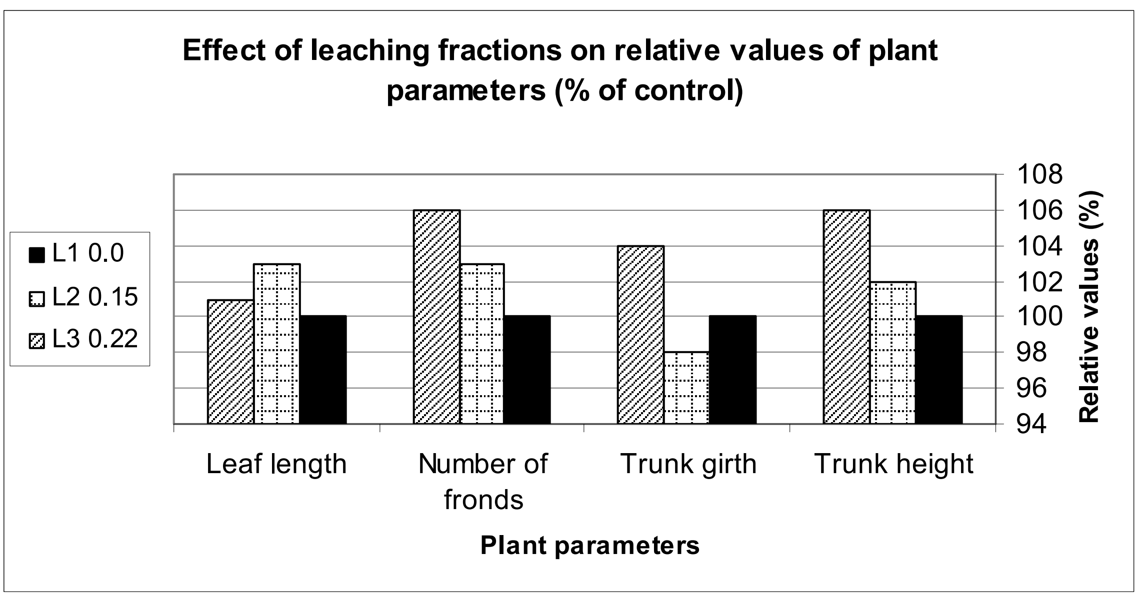


Fig 21: Comparison of plant characters of date palm seedlings provided with leaching fractions when irrigated with saline water (n= 4)

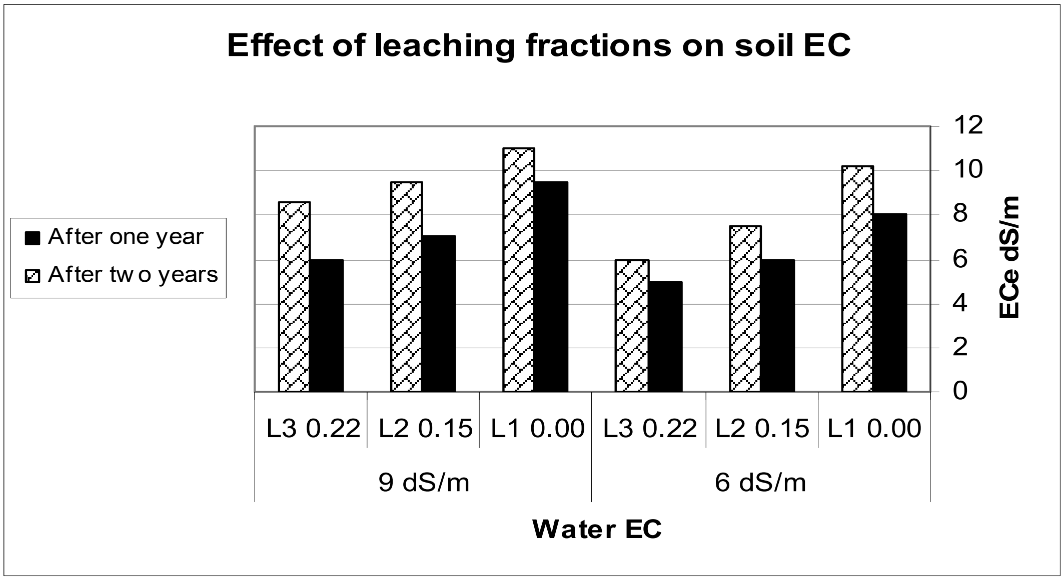


Fig. 22: Effectiveness of leaching fractions in controlling increase in soil EC during irrigation with saline water (n= 4)

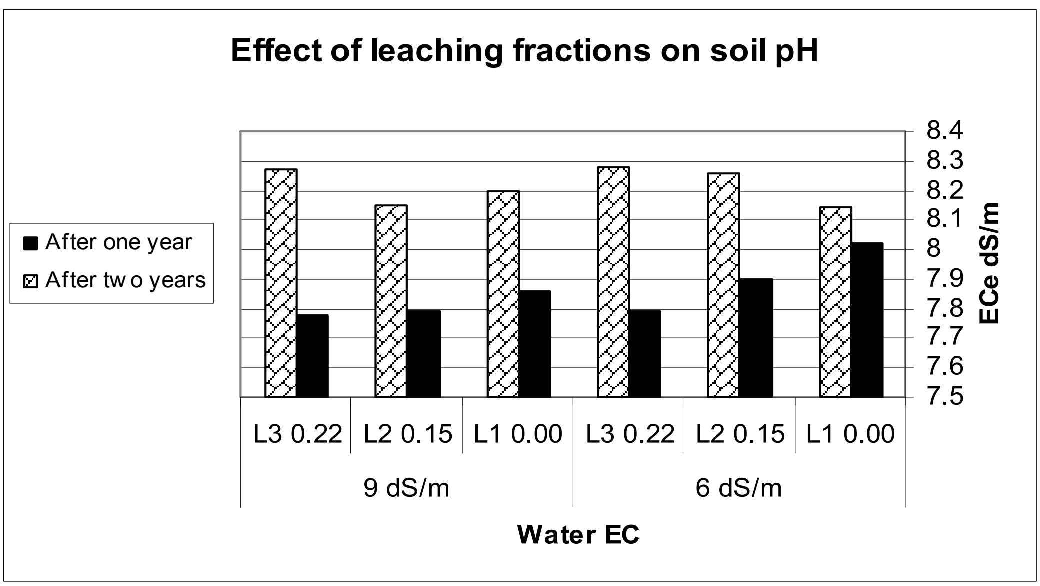


Fig. 23: Effectiveness of leaching fractions in controlling increase in soil pH during irrigation with saline water (n= 4)

4.2.2.2 Effect of organic matter

Low organic matter is the peculiarity of soils of arid and semiarid regions but it is very particularly true for Arab Peninsula where the soils are mostly sandy as well. Resultantly, these soils have very less water holding capacity and rapid drainage that does not permit holding of water content for longer times. The applied irrigation water disappears in couple of days leaving the lands dry and plants to suffer for availability of water. This situation is aggravated further if the water is saline. Then two more impacts on plants appear; physiological unavailability of water for plants and accumulation of salts on or near the soil surface due to more evaporation under high temperature that remains in major part of the year. (DARWISH *et al.* (2005) found that under water limited conditions the largest increase in water use efficiency (WUE) of crops comes by altering the balance between evaporation and transpiration. Evaporation (E) from soil surface results in a considerable loss of moisture and has a direct impact on wheat yield. In wheat production, E is usually 30–60% of total ET. Not only agricultural practices including the crop rotation and fertilization but also water quality and irrigation management affect the salinity build-up. Hence, application of organic matter can ease the situation and may help a lot to minimize ill effects of saline water, if cannot control fully. Recorded data and inferred results of this experiment supported this hypothesis. The determined soil EC after two consistent year's irrigation with water EC of 9 dS m^{-1} was significantly lesser in the organic matter applied treatment (Table 4.30 & Fig 25)). The overall effect of organic matter application in comparison to no-organic matter was also found to be significant. Such type of results was through controlling transpiration that resulted in less concentration of salts. The increase in soil pH was also controlled (Fig. 26). This effect was translated into better growth of date palm seedlings (Fig. 24) because magnitude of all the growth parameters was higher in organic applied treatments. The correlation of organic matter application was found to be positive and significant with leaf Ca and Mg while it was negative with Na and Cl indicting favorable combination that was conducive for better growth of plants. Therefore, correlation was determined as significantly positive between organic matter application and values of most the growth parameters except trunk height which, although was positive but non-significant. RAJAK *et al.* (2002) assessed the relationship between soil salinity and grain sorghum growth and yield. There was a rapid decline in dry matter and grain yield with increasing soil salinity measured as ECe in the top 10 cm of soil especially from 2 to 5 dS m^{-1}.

The impact of straw incorporation (6 Mg ha^{-1} $year^{-1}$) into agricultural soils compared with straw removal on organic matter mineralization and salinity was studied (BADI, 2000). The mineralization coefficient (evolved CO_2/ organic C ratio) was obtained to evaluate organic matter mineralization. The lowest electrolytic conductivity values coincided with the highest mineralization coefficient values. Straw mulching and burying decreased significantly the average seasonal electrolytic conductivity of both soils: 2.5 times in the saline soil, and 1.9 times in the saline sodic soil. The reductions in EC resulted in decrease of mineralization coefficient of saline soil by 1.6 times. Straw amendment, followed by rainy periods, allowed the soluble salts leaching but did not modify significantly sodium content.

Tale 4.34: Correlation of application of organic matter with different parameters

Sr. No.	Parameter	Coefficient Of Corr. (r^2)	Slope	Probability	Significance
1	No. of fronds	+0.447	+1.556	0.006	**
2	Length of frond	+0.483	+5.872	0.003	**
3	Height of trunk	+0.124	+0.722	0.470	NS
4	No. of leaflets	+0.573	+5.239	0.00	**
5	Trunk girth	+0.552	+2.317	0.000	**
6	Leaf N	+0.118	+0.032	0.492	NS
7	Leaf P	+0.187	+0.005	0.274	NS
8	Leaf K	+0.177	+0.017	0.300	NS
9	Leaf Na	-0.130	-0.002	0.045	*
10	Leaf Na/ K	-0.130	+0.002	0.429	NS
11	Leaf Ca	-0.324	-0.027	0.053	*
12	Leaf Mg	+0.402	+0.070	0.015	**
13	Leaf Cl	-0.442	-0.047	0.007	**

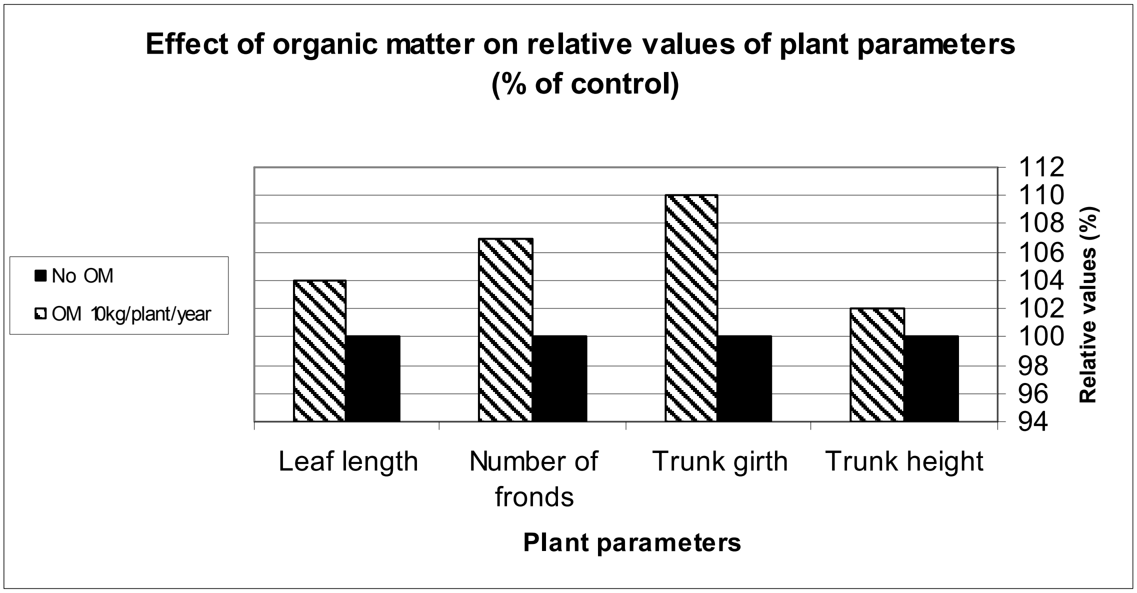


Fig. 24: Efficiency of organic matter application in maintaining plant growth parameters during saline water irrigation (n=4)

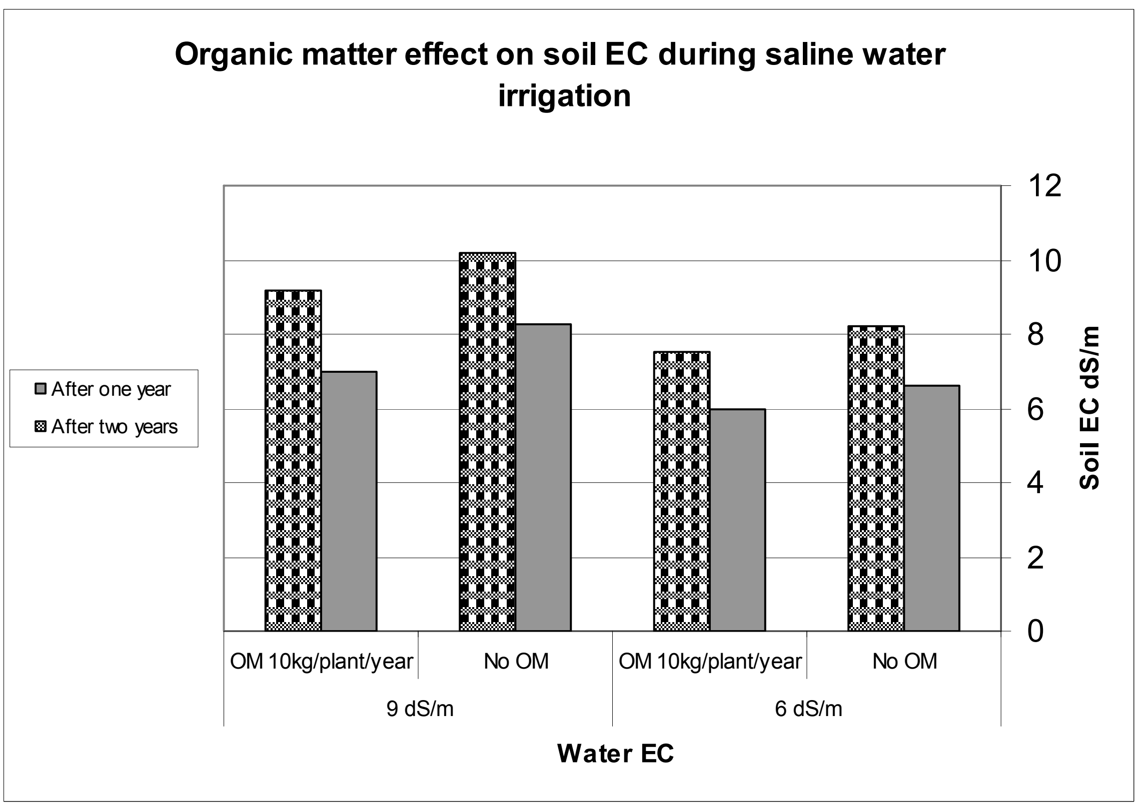


Fig. 25: Effectiveness of organic matter application for soil EC (n= 4)

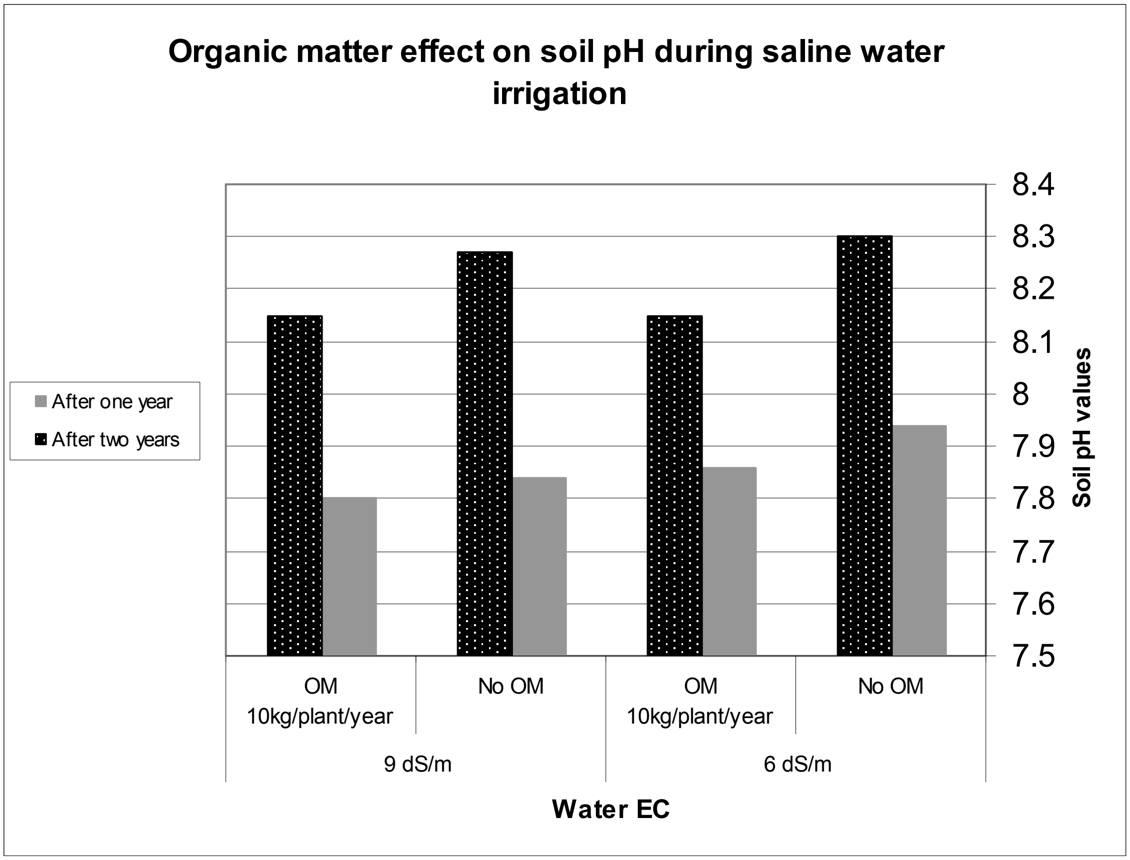


Fig. 26: Effectiveness of organic matter application for soil pH (n= 4)

4.3 EXPERIMENT 3: Nitrogen fertilizer requirements of date palm at early stage when irrigated with saline water

4.3.1 Plant parameters

Consideration of nutritional aspects is important when plants are grown under salinity stress because many imbalances and disorders have been recorded during salinization (GHAFOOR *et al.,* 2004; TEJERA *et al.,* 2006; BUERKERT *et al.,* 2005 & ASEMOTA *et al.,* 2007). This experiment was conducted to determine N requirement of date palm during early stage so that its behavior could be understood for optimal growth. A balanced nutrition enables the plant to withstand stresses like salinity. However, surprisingly effect of N application was found slightly increasing plant growth but there was not a clear significant response. The computation of correlation coefficient also indicted that only No. of leaves length and trunk girth significantly correlated with N application (Table 4.50). The effect of N application at either rate was found to be non-significant on trunk height (Table 4.35) as well as leaf length (Table 4.37) whereas number of fronds (Table 4.36) and plant girth (Table 4.38) were affected positively and significantly only during second year. The number of fronds (leaves) was statistically similar within all applied levels of N (0.125, 0. 250, 0. 375 and 0.500 Kg plant^{-1} year^{-1}) but was significantly higher than control (Table 4.36, Fig. 27). Hence, there is no material gain if N is applied at the rates higher than 0.125 Kg plant^{-1} year^{-1}. Trunk girth was significantly increased in comparison to control when N was applied as 0.250 Kg plant^{-1} year^{-1} (Fig. 28). This rate proved alike with 0.125 Kg plant^{-1} year^{-1} and superior to 0.375 Kg plant^{-1} year^{-1} whereas the former as well as the latter remained similar to control in respect of this parameter (Table 4.38). No difference was found within two water salinity levels in respect of any parameter.

The role of N in early growth of date palm has not been found always positive and consistent in other studies as well. Al-GHAMIDI *et al.* (1999) reported that date palm seedlings did not indicate any significant differences in growth parameters in response to urea application in the nutrient culture. However, root elongation was significantly affected. Nutrient availability and uptake by plants in saline environments could relate to different factors; the activity of nutrient ion in the solution which depended upon pH, the concentration and ratios of accompanying elements that influence uptake and transport by roots and numerous environmental factors (PESSARAKLI, 1999).

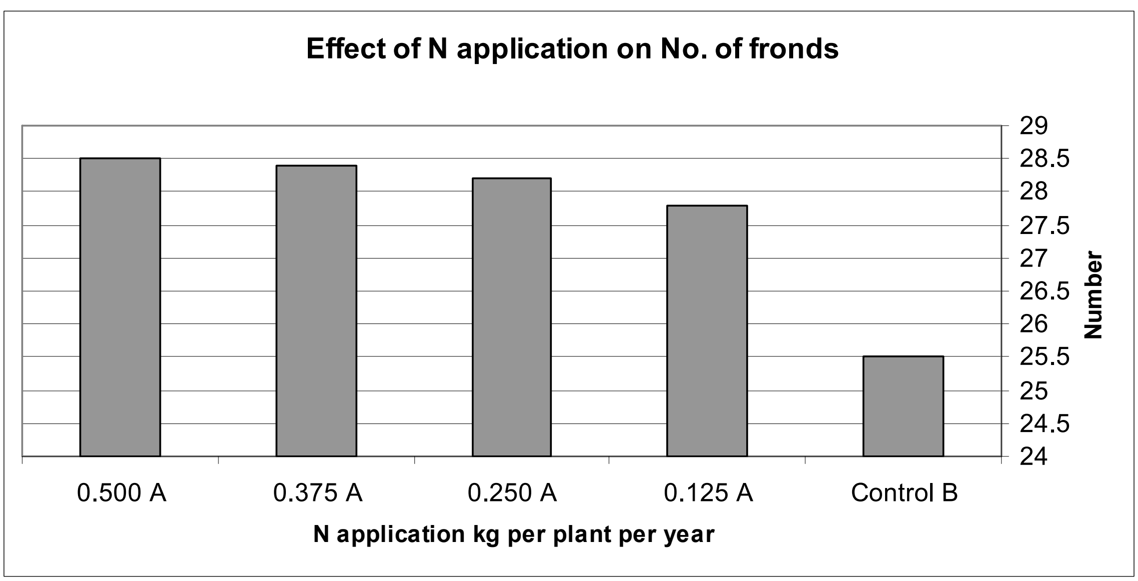


Fig. 27: Number of fronds of date palm seedlings after two years (n= 4)

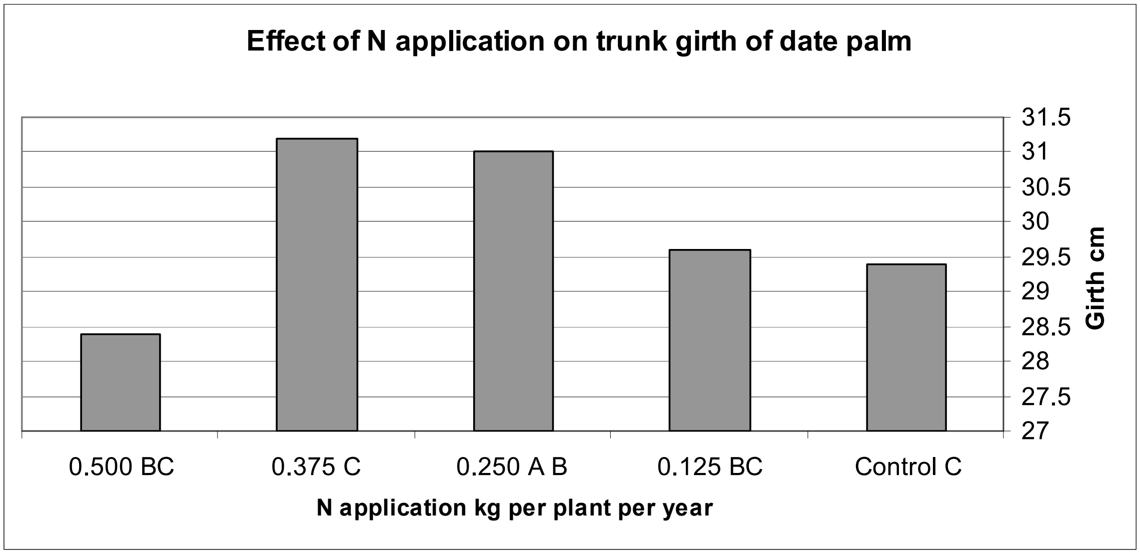


Fig. 28: Trunk girth of date palm seedlings after two years (n= 4)

4.3.2 Ionic parameters in date palm leaves

Ion uptake does not remain normal when a plant is grown under stressed environment, especially salinity. Some of the ions like Na, Ca, Mg, Cl and SO_4 tremendously increase around the roots while plant nutrients; NH_4, H_2PO_4, HPO_4, K, Zn. Cu, Fe and Mn decrease due to their either restricted solubility or antagonistic effect by other ions or salts. Thus the plant cannot take nutrients according to their requirements which results in suffering of growth and ultimately the yields. Some of the compulsory ions are needed in metabolic processes while others make integral part of structural constituents. HASSAN *et al.,* (2000) observed that with increasing soil salinity level, Na and Cl concentration in the leaves was increased in all the three cultivars of olive but to different degrees. The accumulation of sodium and chloride in leaves was higher in the least tolerant cultivar (Teffahi) than the most tolerant cultivar (Agizi Aksi), however, K decreased in the leaf tissues. Similarly, in the present studies the water salinity level of EC 6 dS m^{-1} significantly increased Na (Table 4.39), Cl (Table 4.44) whereas K/ Na ratio, Ca (Table 4.42), Mg (Table 4.43) decreased. However, N (Table 4.45), K (Table 4.40) and P (Table 4.46) remained unaffected in date palm because water salinity level of EC 6 dS m^{-1} did not prove too high for this plant being salt tolerant. The effect of N application was found significant only in case of leaf N (Table 4.45), P (Table 4.46) and Mg Table 4.43) contents of leaves while all the other ions were not affected significantly (Fig. 29 & 30). The relationship between applied N and leaf content of N, P and K were found significant and positive as well (Table 4.50). There was no material benefit of applying N at the rate of 0.500 Kg $plant^{-1}$ $year^{-1}$ even in ionic parameters which were affected significantly. The level of 0.125 Kg $plant^{-1}$ $year^{-1}$ was observed to be effective in case of N and Mg while 0.250 Kg $plant^{-1}$ $year^{-1}$ in case of P in leaf constitution of these parameters. The reasons for such pattern of variations may be high salt tolerance of date palm that did not permitted major nutrient disturbances under water salinity up to 6 dS m^{-1} as well as low N requirement of N by date palm seedlings in early age of two years. Nutrient could even remobilize from older to younger leaves for making up the deficiency or irregularity occurring, if any. Al-GHAMIDI *et al.* (1999) reported that in date palm seedlings a clear effect of N sources on leaf N, Ca and chlorophyll content could not be observed. BROSCHAT (1997) calculated nutrient remobilization rates for N, P, K, Mg, and Mn. His results showed that N, P, and K were highly mobile within and between leaves of both species of palms. Up to 31% of the N, 66% of the K, and 37% of the total P in the oldest leaves were ultimately remobilized to newer leaves within the palm. Therefore, the position and age of leaves is also very important for leaf analysis. The work of KOLSI-BENZINA AND ZOUGARI (2008) indicated a broad variation of the palm portions leaflets' mineral composition. The median zone leaflet nitrogen (N) and magnesium (Mg) contents were the highest for all of the palm positions. A similar nitrogen and magnesium determination was noticed along each palm. The highest calcium (Ca) content was at the base of the youngest palm and at the apex of the oldest palm; phosphorus (P) content was the reverse. The highest potassium (K) content was determined in the base palm leaflets.

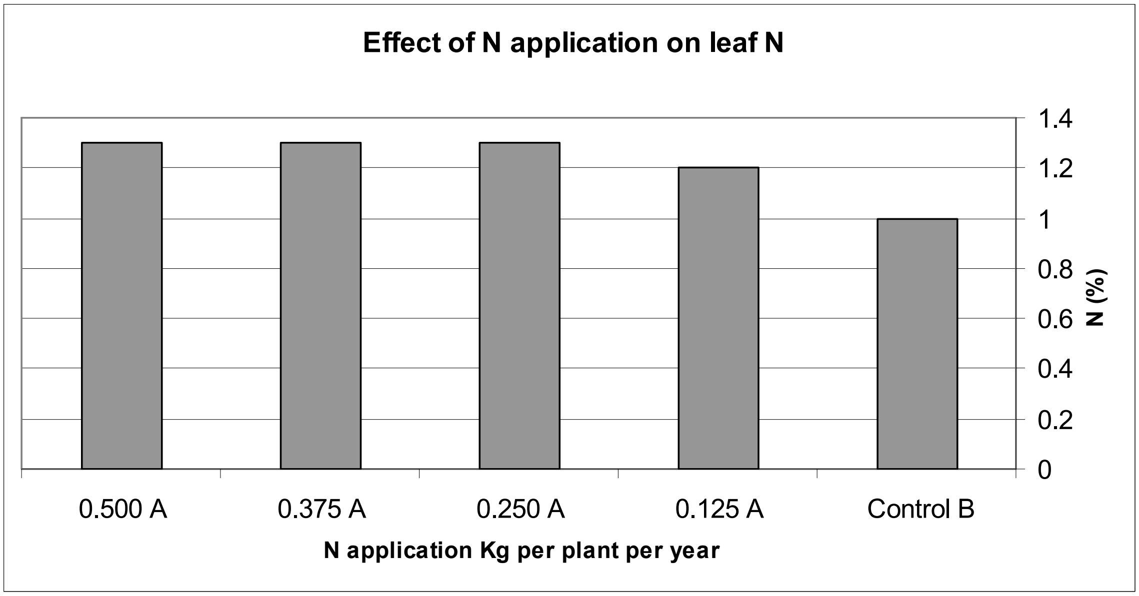


Fig. 29: Leaf N of date palm seedlings after two years (n= 4)

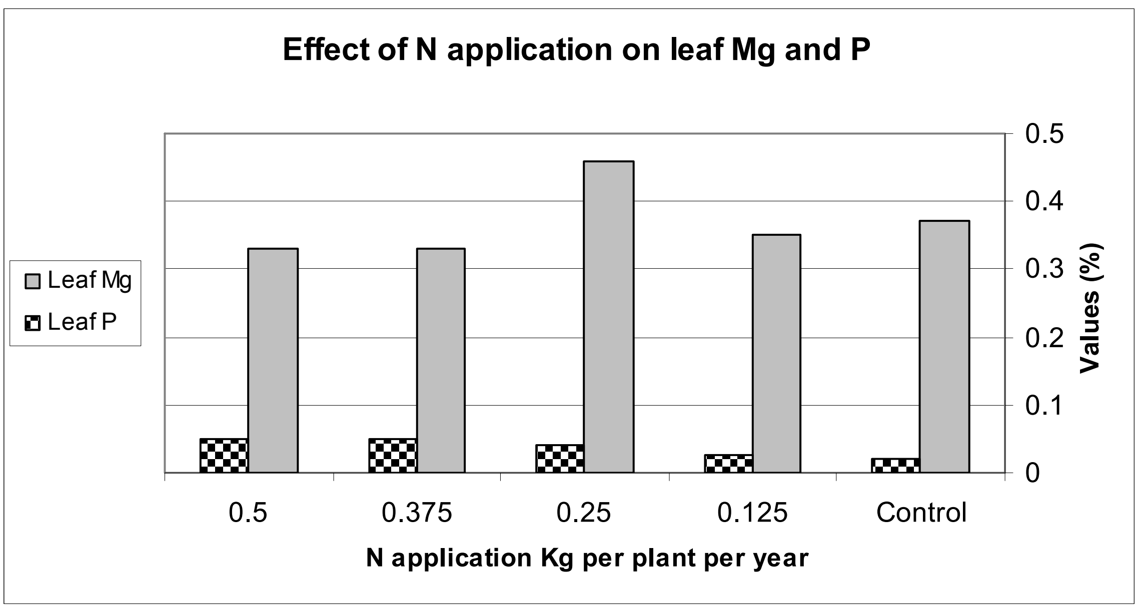


Fig. 30: Leaf Mg and P of date palm seedlings after two years (n= 4 SD Mg= 0.03 and SD P= 0.002)

4.3.3 Soil parameters

Nutrient supplying capacity of a soil is disturbed a lot besides enormous changes in EC and pH when saline water is continuously used for irrigation as in the present experiment.

Soil EC was significantly increased with water EC of 6 dS m^{-1} but pH was not affected because water was not sodic. There was no statistical effect on soil EC and pH due to application of N at any level (Table 4.47, 4.48 & 4.49). The increase in soil N was just slight. However, the highest two levels (0.375 and 0.500 kg per plant per year) increased it significantly (Fig. 31). The reason for lesser increase may be that texture of the soil was light and drainage was very good which were conductive for high leaching losses of this nutrient although N application was not in a few doses. Rather N application was split into equal bits which were added before irrigation each time. Hence, net increase in soil N could not be assessed as significant. BUERKERT *et al.* (2005) studied GIS-based terraced cropland and groves of date palm (*Phoenix dactylifera*) in two mountain oases of Northern Oman to determine their role as hypothesized sinks for nitrogen (N), phosphorus (P) and potassium (K) despite high application of these nutrients. Their data showed that both oases presently are large sinks for nutrients and potential gaseous and leaching losses have to be controlled.

Table 4.50: Correlation of N application with different parameters

Sr. No.	Parameter	Coefficient Of Corr. (r^2)	Slope	Probability	Significance
1	No. of fronds	+0.403	+0.200	0.041	*
2	Length of frond	+0.212	+2.230	0.053	Ns
3	Height of trunk	+0.345	+1.072	0.062	NS
5	Trunk girth	+0.409	+0.237	0.031	*
6	Leaf N	+0.690	+0.061	0.000	**
7	Leaf P	+0.783	+0.009	0.000	**
8	Leaf K	-0.114	-0.036	0.054	NS
9	Leaf Na	-0.017	0.000	0.928	NS
11	Leaf Ca	-0.073	-0.003	0.700	NS
12	Leaf Mg	+0.319	+0.008	0.031	*
13	Leaf Cl	-0.085	-0.009	0.657	NS

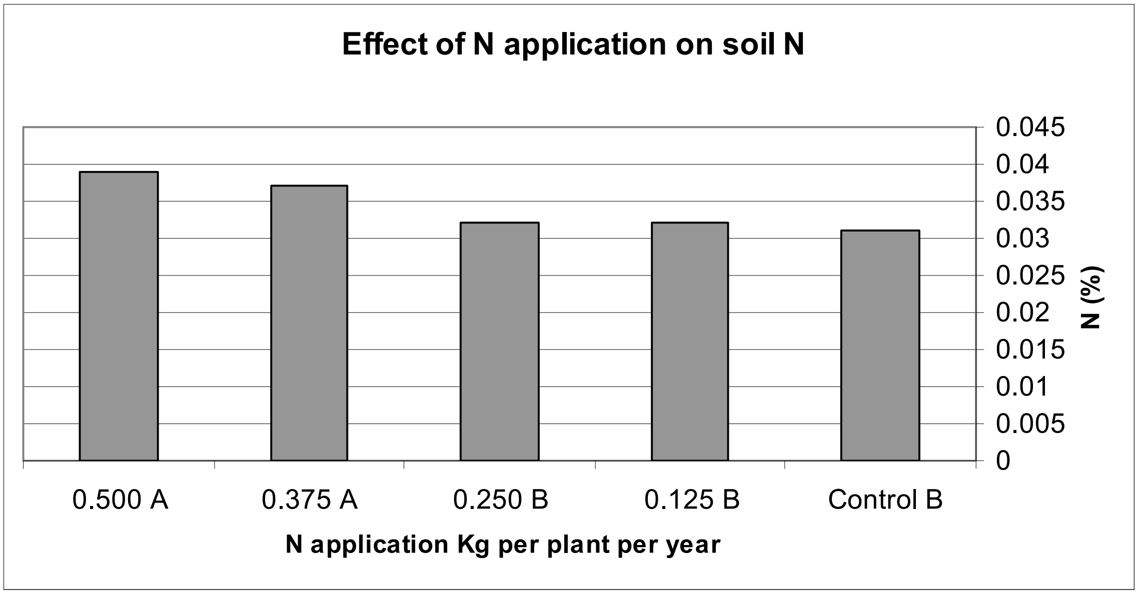


Fig. 31: Soil N after completion of two years experiment (n= 4)

Data Tables
Experiment 1

Table 4.1: Effect of water salinity on increase of trunk height (cm) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	Increase after one year (February 2007)				Increase after two years (February 2008)			
	Khalas	Abuna renjeh	Khunai zy	Mean	Khalas	Abuna renjeh	Khunai zy	Mean
3 (Control)	22.5a	16.5 Bcd	17.5bc	18.8 A	45.5a	42.0b	32.8d	40.1 A
6	19.0ab	15.3 Bcde	14.0 cdef	16.1 B	38.0c	32.0d	28.0b	32.7 B
9	16.2 Bcd	15.0 Bcde	13.0efg	14.7 BC	32.8d	29.7de	24.3ef	28.9 C
12	13.6 Defg	13.2 Defg	11.2ghi	12.5 CD	30.7d	27.3e	20.0ef	26.0 D
15	11.9 efg	10.5i	10.5i	11.0 DE	24.3ef	21.7ef	18.8f	21.6 E
18	9.0h	9.2gh	9.2gh	9.1 E	20.8ef	21.3ef	14.5g	18.9 F
Mean	15.4 A	13.3 AB	12.6 B	-	32.0 A	29.0 B	23.1 C	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.2: Water salinity effect on increasing number of fronds (per plant) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	Increase after one year (February 2007)				Increase after two years (February 2008)			
	Khalas	**Abunarenjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunarenjeh**	**Khunaizy**	**Mean**
3 (Control)	13.7	12.0	13.7	13.1 A	29.3a	28.0ab	26.7bc	28.0 A
6	11.0	12.0	12.0	11.7 B	23.7de	25.7cd	25.3cd	24.9 B
9	11.0	11.7	11.3	11.3 B	21.7ef	20.0fgh	20.0fgh	20.6 C
12	11.0	10.0	10.0	10.3 C	21.3fg	17.7ijk	18.3hij	19.1 CD
15	9.0	9.0	9.7	9.2 D	16.0jk	18.3ghi	17.0hijk	17.1 D
18	7.3	8.3	7.7	7.7 E	15.0jk	16.0k	13.0i	14.7 E
Mean	10.5 NS	10.5	10.7	-	21.2 A	21.1 AB	20.2 B	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.3: Effect of water salinity on leaf length (cm) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	Increase after one year (February 2007)				Increase after two years (February 2008)			
	Khalas	Abuna renjeh	Khunai zy	Mean	Khalas	Abuna renjeh	Khunai zy	Mean
3 Control	58.2	55.1	61.0	58.1 A	146.7	136.4	158.7	147.3 A
6	55.2	49.1	59.7	54.7 A	127.9	127.8	140.7	132.2 B
9	49.3	42.1	52.1	47.8 B	120.1	112.7	125.3	119.4 BC
12	46.3	42.2	30.9	42.8 BC	109.6	100.3	113.5	107.8 CD
15	37.5	36.3	41.6	38.4 C	100.4	91.5	107.5	99.8 DE
18	30.1	30.6	33.3	31.3 D	90.7	81.4	90.6	87.6 E
Mean	46.1NS	42.6	47.9	-	115.9 BC	108.4 C	122.7 AB	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.4: Effect of water salinity on increase of trunk girth (cm) of date palm (Exp.1)

Water salinity levels EC (dSm^{-1})	Increase after one year (February 2007)				Increase after two years (February 2008)			
	Khalas	Abunarenjeh	Khunaizy	Mean	Khalas	Abunarenjeh	Khunaizy	Mean
3 Control	10.9	10.1	11.7	10.9 A	30.3	26.6	29.6	28.8 A
6	10.3	9.8	11.4	10.5 A	26.3	24.9	26.4	25.9 B
9	9.2	0.0	11.3	10.2 A	23.2	22.2	26.2	23.8 C
12	9.6	8.2	10.0	9.3 B	21.7	20.8	19.4	20.6 D
15	8.1	7.6	9.1	8.3 B	16.4	16.9	18.6	17.3 E
18	6.4	7.4	6.5	6.7 C	16.4	15.1	14.9	15.4 F
Mean	9.1 NS	8.7	10.0	-	22.4 A	21.1 B	22.5 A	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.7: Effect of water salinity on leaf Na (%) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abuna renjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunar enjeh**	**Khunaiz y**	**Mean**
3 (Control)	0.19	0.23	0.17	0.20 D	0.23	0.25	0.25	0.24 D
6	0.33	0.27	0.21	0.27 CD	0.25	0.25	0.26	0.25 CD
9	0.34	0.28	0.28	0.30 C	0.25	0.30	0.24	0.26 CD
12	0.35	0.33	0.33	0.33 BC	0.25	0.29	0.28	0.27 BC
15	0.46	0.37	0.38	0.40 AB	0.31	0.29	0.27	0.29 B
18	0.47	0.45	0.38	0.43 A	0.31	0.29	0.36	0.32 A
Mean	0.36 NS	0.32	0.29	-	0.27 NS	0.28	0.28	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.8: Effect of water salinity on leaf K (%) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunar enjeh**	**Khuna izy**	**Mean**	**Khalas**	**Abunar enjeh**	**Khunaizy**	**Mean**
3 Control	1.73	1.86	1.73	1.77 NS	1.53	1.77	1.93	1.74 A
6	1.84	1.93	1.93	1.90	1.63	1.67	1.73	1.68 AB
9	1.85	1.86	2.02	1.91	1.57	1.63	1.70	1.63 AB
12	1.65	1.84	1.84	1.78	1.53	1.70	1.57	1.60 B
15	1.88	1.91	1.87	1.84	1.47	1.60	1.70	1.59 B
18	1.77	1.89	1.87	1.84	1.60	1.57	1.57	1.58 B
Mean	1.79 B	1.88 A	1.88 A	-	1.56 B	1.66 A	1.70 A	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.9: Effect of water salinity on leaf Ca (%) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunarenjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunarenjeh**	**Khunaizy**	**Mean**
3 Control	0.24	0.35	0.29	0.29 B	0.26	0.40	0.23	0.30 NS
6	0.40	0.39	0.56	0.45 A	0.25	0.29	0.28	0.28
9	0.48	0.37	0.40	0.42 A	0.35	0.23	0.23	0.27
12	0.48	0.32	0.32	0.37 AB	0.29	0.23	0.28	0.27
15	0.27	0.36	0.37	0.33 AB	0.27	0.24	0.23	0.24
18	0.21	0.32	0.27	0.27 B	0.25	0.21	0.24	0.24
Mean	0.35	0.35	0.37	-	0.28	0.27	0.25	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.10: Effect of water salinity on leaf Mg (%) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunarenjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunarenjeh**	**Khunaizy**	**Mean**
3 Control	0.45	0.42	0.37	0.41	0.28 Cdef	0.22ef	0.23ef	0.24 C
6	0.37	0.43	0.41	0.40	0.25def	0.27cdef	0.21f	0.24 C
9	0.43	0.46	0.41	0.43	0.32bc	0.21f	0.23def	0.26 BC
12	0.43	0.56	0.30	0.43	0.37ab	0.22ef	0.22ef	0.27 BC
15	0.59	0.32	0.59	0.50	0.30bcd	0.29cde	0.29cde	0.29 B
18	0.57	0.57	0.62	0.59	0.42a	0.37ab	0.27cdef	0.35 A
Mean	0.47	0.46	0.45	-	0.32 A	0.26 B	0.24 B	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.11: Effect of water salinity on leaf N (%) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunar enjeh**	**Khunaiz y**	**Mean**	**Khalas**	**Abunar enjeh**	**Khunaiz y**	**Mean**
3 (Control)	1.29	1.53	1.46	1.43 AB	1.63	1.60	1.37	1.53 NS
6	1.36	1.61	1.65	1.54 A	1.53	1.43	1.43	1.47
9	1.34	1.48	1.48	1.43 AB	1.43	1.37	1.43	1.41
12	1.27	1.50	1.23	1.33 B	1.50	1.47	1.47	1.48
15	1.23	1.43	1.40	1.36 B	1.60	1.57	1.37	1.51
18	1.43	1.37	1.43	1.41 B	1.53	1.67	1.43	1.54
Mean	1.32 B	1.49 A	1.44 A	-	1.54 A	1.52 A	1.42 B	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.12: Effect of water salinity on leaf P (%) of date palm (Exp.1)

Water EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	Abunarenjeh	Khunaizy	Mean	Khalas	Abunarenjeh	Khunaizy	Mean
Control 3	0.05	0.04	0.05	0.05	0.03	0.03	0.03	0.03 C
6	0.05	0.04	0.04	0.05	0.03	0.03	0.03	0.03 C
9	0.04	0.03	0.04	0.04	0.02	0.02	0.03	0.03 C
12	0.05	0.03	0.05	0.04	0.03	0.04	0.03	0.03 BC
15	0.04	0.04	0.03	0.04	0.03	0.04	0.05	0.04 B
18	0.04	0.04	0.05	0.05	0.06	0.05	0.05	0.05 A
Mean	0.05	0.04	0.04	-	0.03	0.03	0.04	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.13: Effect of water salinity on leaf Cl (%) of date palm (Exp.1)

Water s EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	Abuna renjeh	Khuna izy	Mean	Khalas	Abunare njeh	Khuna izy	Mean
3 Control	1.26	1.21	1.18	1.22	1.07	0.95	0.95	0.99 NS
6	1.26	1.26	1.18	1.23	1.01	1.04	0.95	1.00
9	1.26	1.26	1.40	1.31	1.04	0.86	1.12	1.01
12	1.33	1.18	1.41	1.31	1.11	1.09	0.92	1.04
15	1.33	1.18	1.48	1.33	1.04	1.04	1.10	1.06
18	1.40	1.40	1.33	1.37	1.01	1.07	1.15	1.08
Mean	1.31 NS	1.25	1.33	-	1.05	0.99	1.03	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.15: Effect of water salinity on soil EC (dS/m) (Exp.1)

Water salinity levels EC (dS m^{-1})	**After one year (February 2007)**				**After two years (February 2008)**			
	Khalas	**Abunarenjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunarenjeh**	**Khunaizy**	**Mean**
3 Control	3.00	4.45	4.03	3.83 E	5.37	6.30	8.16	6.61 D
6	6.52	6.89	7.39	6.94 D	6.45	7.29	9.46	7.74 C
9	9.28	8.63	6.19	8.03 C	7.19	9.39	9.36	8.65 C
12	10.68	10.14	10.05	10.29 B	10.07	12.27	9.72	10.69 B
15	11.27	11.13	11.02	11.14 B	11.43	12.56	11.07	11.69 B
18	13.07	12.63	13.14	12.95 A	13.57	13.50	13.33	13.47 A
Mean	8.92 NS	8.97	8.64	-	9.01 NS	10.05	10.33	-

Values are mean of four replications

Original soil EC of composite sample= 2.77 dS m^{-1}

Values sharing same letters are non-significant at 5 % level of significance

Table 4.16: Effect of water salinity on soil pH (Exp.1)

Water EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunar enjeh**	**Khuna izy**	**Mean**	**Khalas**	**Abunar enjeh**	**Khunaiz y**	**Mean**
3 Control	7.82	7.93	7.78	7.84 C	8.01	8.06	7.99	8.02 D
6	7.98	7.97	8.00	7.98 BC	8.07	8.08	8.07	8.07 CD
9	7.98	8.10	8.02	8.03 AB	8.09	8.12	8.15	8.12 BC
12	8.1o	7.97	8.12	8.06 AB	8.13	8.15	8.16	8.15 AB
15	8.10	8.10	8.25	8.15 A	8.17	8.18	8.18	8.18 A
18	8.17	8.07	8.30	8.18 A	8.19	8.20	8.21	8.20 A
Mean	8.03 NS	8.03	8.02	-	8.11 NS	8.13	8.13	-

Values are mean of four replications; Original soil pH of composite sample= 7.7
Values sharing same letters are non-significant at 5 % level of significance

Table 4.18: Effect of water salinity on leaf Na/ K (ratio) of date palm (Exp.1)

Water salinity levels EC (dS m^{-1})	After one year (February 2007)				After two years (February 2008)			
	Khalas	**Abunarenjeh**	**Khunaizy**	**Mean**	**Khalas**	**Abunarenjeh**	**Khunaizy**	**Mean**
3 Control	0.12	0.12	0.10	0.11 D	0.15	0.14	0.13	0.14 D
6	0.18	0.14	0.11	0.14 CD	0.15	0.15	0.15	0.15 CD
9	0.20	0.15	0.14	0.16 BC	0.16	0.18	0.14	0.16 BCD
12	0.21	0.18	0.18	0.18 B	0.16	0.17	0.18	0.17 BC
15	0.24	0.19	0.20	0.22 A	0.21	0.18	0.16	0.18 AB
18	0.26	0.24	0.20	0.23 A	0.17	0.18	0.23	0.20 A
Mean	0.20 A	0.17 B	0.15 B	-	0.17 A	0.17 A	0.16 B	-

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Experiment 2

Table 4.19: Effect of water salinity management techniques on trunk height of date palm plants (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for	Means for	Overall leaching	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}		EC_{iw} 6 dS m^{-1}	EC_{iw} 9 dS m^{-1}	Means	O_0	O_1
	(O_0)	(O_1)	(O_0)	(O_1)					
0 (L_0)	28.3	30.3	23.2	29	29.3a	26.1b	**27.7 NS**	25.7	29.7
0.15 (L_1)	27.8	34.5	21.8	28.2	31.2a	25.0 b	**25**	24.8	31.3
0.22 (L_2)	26.8	31.5	27.3	32.8	29.2a	30.1a	**29.6**	27.1	32.2
Means	**27.6 NS**	**32.1**	**24.1**	**30**	**29.9 A**	**27.1 B**	**-**	**25.9 B**	**31.1 A**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for	Means for	Overall leaching	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}		EC_{iw} 6 dS m^{-1}	EC_{iw} 9 dS m^{-1}		O_0	O_1
	(O_0)	(O_1)	(O_0)	(O_1)					
0 (L_0)	42.7 de	44.3 cd	43.7 cde	45.0 c	43.5 c	44.3 c	**43.9 C**	43.2 d	44.7 c
0.15 (L_1)	42.0 e	49.3 b	44.7 c	43.7 cde	45.7 b	44.2 c	**44.9 B**	44.3 d	46.5 b
0.22 (L_2)	47.7 b	51.7 a	44.3 cd	43.3 cde	49.7 a	43.8 c	**46.8 A**	46.0 a	47.5 bc
Means	**44.1 B**	**48.4 A**	**44.2 B**	**44.0 B**	**46.3 A**	**44.1 B**	**-**	**44.5 B**	**46.2 A**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.20: Effect of water salinity management techniques on number of fronds (per plant) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	10.7	12.7	13.0	12.7	11.7	12.8	**12.3 NS**	11.8	12.7
0.15 (L_1)	12.0	12.0	11.7	12.3	12.0	12.0	**12.2**	11.8	12.2
0.22 (L_2)	12.3	14.0	12.3	12.0	13.2	12.2	**12.7**	12.3	13.0
Means	**11.7NS**	**12.9**	**12.3**	**12.3**	**13.2 NS**	**12.2**	**-**	**12.0 NS**	**12.6**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	22.0de	27.0a	21.0e	22.0 de	24.5ab	21.5c	**23.0 C**	21.5d	24.5 ab
0.15 (L_1)	24.0c	23.7c	23.7c	23.7c	23.8b	23.8b	**23.8 B**	23.8bc	23.8bc
0.22 (L_2)	24.7bc	25.3b	22.3d	25.3b	25.0a	23.8b	**24.4 A**	23.5c	25.3 a
Means	**23.6 NS**	**25.3**	**22.3**	**23.7**	**24.4 A**	**23.0 B**	**-**	**22.9 B**	**24.5 A**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.21: Effect of water salinity management techniques on trunk girth (cm) of date palm plants (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	10.1 bcde	11.0 ab	9.0ef	10.3abcd	10.5	9.7	**10.1 AB**	9.5b	10.6 ab
0.15 (L_1)	10.1 bcde	10.5abc	9.3def	8.8f	10.3	9.1	**9.7 B**	9.7b	9.7b
0.22 (L_2)	9.8 cdef	11.2a	9.5 cdef	11.3a	10.5	10.4	**10.5 A**	9.7b	11.3 a
Means	**10.0 NS**	**10.9**	**9.3**	**10.3**	**10.4 A**	**9.7 B**	**-**	**9.6 B**	**10.5 A**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	23.9 cd	29.2a	22.8 d	25.1 bc	26.6 b	24.0 d	**25.3 B**	23.4 c	27.2 a
0.15 (L_1)	24.1 cd	24.8c	23.9 cd	26.3 b	24.5 cd	25.1 cd	**24.8 B**	24.0 c	25.6 b
0.22 (L_2)	27.9 a	28.0a	23.3 d	26.4 b	28.0 a	24.8 cd	**26.4 A**	25.6 b	27.2 a
Means	**25.3 NS**	**27.3**	**23.3**	**25.9**	**26.3 A**	**24.6 B**	**-**	**24.3 B**	**26.7 A**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.22: Effect of water salinity management techniques on leaf length (cm) of date palm plants (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	**(O_1)**	**(O_0)**	**(O_1)**				**O_0**	**O_1**
0 (L_0)	45.3	58.1	49.7	58.4	51.7	54.1	**52.9 NS**	47.5d	58.3b
0.15 (L_1)	50.4	56.0	52.7	62.9	53.2	57.8	**55.5**	51.5c	59.5b
0.22 (L_2)	52.7	69.7	49.8	63.1	61.2	56.4	**58.8**	51.2c	66.4a
Means	**49.4 B**	**61.3 A**	**50.7 B**	**61.5 A**	**55.4 NS**	**56.1**	**-**	**50.1 B**	**61.4 A**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	**(O_1)**	**(O_0)**	**(O_1)**				**O_0**	**O_1**
0 (L_0)	145	153	132	142	149	137	**143 NS**	138 d	147 b
0.15 (L_1)	152	151	143	141	152	142	**147**	147 b	152 a
0.22 (L_2)	140	144	146	146	142	146	**144**	143 bc	145 b
Means	**146 NS**	**149**	**140**	**143**	**148 NS**	**142**	**-**	**143 B**	**148 A**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.23: Effect of Effect of water salinity management techniques on leaf Na (%) of date palm (Exp.2)

A. **After one year (2007)**

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.11	0.10	0.15	0.13	0.11	0.14	**0.12 NS**	0.13	0.11
0.15 (L_1)	0.13	0.10	0.16	0.12	0.11	0.14	**0.13**	0.15	0.12
0.22 (L_2)	0.12	0.09	0.15	0.15	0.11	0.15	**0.13**	0.14	0.12
Means	**0.12 BC**	**0.10 C**	**0.16 A**	**0.13 B**	**0.11 B**	**0.14 A**	**-**	**0.14**	**0.12**

B. **After two years (2008)**

Leaching Uj8mFractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.15	0.13	0.16	0.14	0.14	0.15	**0.15 A**	0.16	0.13
0.15 (L_1)	0.14	0.12	0.14	0.14	0.13	0.14	**0.13 B**	0.14	0.13
0.22 (L_2)	0.13	0.11	0.14	0.13	0.12	0.13	**0.12 B**	0.14	0.12
Means	**0.14 B**	**0.12 C**	**0.15 A**	**0.14 B**	**0.13B**	**0.14 A**	**-**	**0.15 A**	**0.13 B**

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.24: Effect of water salinity management techniques on leaf K (%) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.86	1.97	1.85	1.71	1.91	1.78	**1.85 NS**	1.85	1.84
0.15 (L_1)	1.82	1.86	1.85	1.84	1.84	1.84	**1.84**	1.83	1.85
0.22 (L_2)	1.83	1.91	1.76	1.79	1.87	1.77	**1.82**	1.79	1.85
Means	**1.84 NS**	**1.91**	**1.82**	**1.78**	**1.87**	**1.80**	**-**	**1.83 NS**	**1.85**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.41	1.41	1.41	1.51	1.41	1.46	1.43 NS	1.41	1.46
0.15 (L_1)	1.39	1.45	1.49	1.42	1.42	1.45	1.44	1.44	1.43
0.22 (L_2)	1.41	1.39	1.49	1.41	1.40	1.45	1.43	1.45	1.40
Means	**1.40 NS**	**1.42**	**1.46**	**1.45**	**1.41**	**1.45**	**-**	**1.43**	**1.43**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.25: Effect of water salinity management techniques on leaf Ca (%) of date palm (Exp.2)

A. **After one year (2007)**

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.27	0.27	0.32	0.32	0.27	0.32	**0.29 NS**	0.29	0.29
0.15 (L_1)	0.27	0.35	0.29	0.24	0.31	0.27	**0.29**	0.28	0.29
0.22 (L_2)	0.27	0.27	0.37	0.29	0.27	0.33	**0.30**	0.32	0.28
Means	**0.27 NS**	**0.29**	**0.33**	**0.28**	**0.28 NS**	**0.31**	**-**	**0.30 NS**	**0.29**

B. **After two years (2008)**

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.40	0.29	0.32	0.32	0.36	0.31	**0.33 NS**	0.36	0.31
0.15 (L_1)	0.33	0.35	0.32	0.35	0.33	0.35	**0.34**	0.33	0.35
0.22 (L_2)	0.35	0.29	0.36	0.32	0.35	0.31	**0.33**	0.35	0.31
Means	**0.36 NS**	**0.31**	**0.33**	**0.33**	**0.34NS**	**o.33**	**-**	**0.35 NS**	**0.32**

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.26: Effect of water salinity management techniques on leaf Mg (%) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.35	0.35	0.38	0.48	0.35bc	0.43b	**0.39 NS**	0.37	0.41
0.15 (L_1)	0.37	0.37	0.30	0.40	0.37bc	0.35bc	**0.36**	0.34	0.39
0.22 (L_2)	0.30	0.32	0.46	0.61	0.31c	0.54a	**0.42**	0.38	0.47
Means	**0.34 NS**	**0.35**	**0.38**	**0.50**	**0.34 B**	**0.44 A**	**-**	**0.36 NS**	**0.42**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.19	0.29	0.40	0.41	0.24	0.40	**0.32 NS**	0.30	0.35
0.15 (L_1)	0.23	0.35	0.41	0.38	0.29	0.40	**0.34**	0.32	0.37
0.22 (L_2)	0.24	0.34	0.31	0.43	0.29	0.37	**0.33**	0.28	0.38
Means	**0.22 C**	**0.37 AB**	**0.33 B**	**0.41 A**	**0.27 B**	**0.39 A**	**-**	**0.30 B**	**0.37 A**

Values are mean of four replications

Values sharing same letters are non-significant at 5 % level of significance

Table 4.27: Effect of water salinity management techniques on leaf Cl (%) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.07	1.13	1.24	1.13	1.10	1.19	**1.18 NS**	1.16	1.13
0.15 (L_1)	1.36	1.07	1.07	1.18	1.21	1.13	**1.17**	1.22	1.13
0.22 (L_2)	1.24	1.07	1.24	1.18	1.16	1.12	**1.18**	1.24	1.13
Means	**1.22 A**	**1.09 B**	**1.19 AB**	**1.16 AB**	**1.16 NS**	**1.17**	**-**	**1.21 A**	**1.13 B**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.15	1.20	1.20	1.21	1.17	1.20	**1.19 NS**	1.17	1.20
0.15 (L_1)	1.15	1.10	1.21	1.18	1.12	1.19	**1.16**	1.18	1.14
0.22 (L_2)	1.15	1.10	1.18	1.15	1.12	1.17	**1.10**	1.16	1.12
Means	**1.18 NS**	**1.13**	**1.20**	**1.15**	**1.14 NS**	**1.19**	**-**	**1.17NS**	**1.15**

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.28: Effect of water salinity management techniques on leaf N (%) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.32b	1.38b	1.26b	1.35b	1.35	1.31	**1.33 NS**	1.29	1.37
0.15 (L_1)	1.41b	1.40b	1.39b	1.35b	1.41	1.37	**1.39**	1.40	1.38
0.22 (L_2)	1.29b	1.60a	1.26b	1.40b	1.45	1.33	**1.39**	1.27	1.50
Means	**1.34 B**	**1.46 A**	**1.30 B**	**1.37 AB**	**1.40 NS**	**1.33**	**-**	**1.32 NS**	**1.42**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	1.48	1.63	1.34	1.42	1.55	1.38	**1.46 NS**	1.41	1.53
0.15 (L_1)	1.58	1.51	1.33	1.44	1.55	1.38	**1.47**	1.45	1.48
0.22 (L_2)	1.44	1.72	1.41	1.36	1.58	1.38	**1.48**	1.42	1.50
Means	**1.50 B**	**1.62 A**	**1.36 C**	**1.40 C**	**1.56 A**	**1.38 B**	**-**	**1.43 B**	**1.50 A**

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.29: Effect of water salinity management techniques on leaf P (%) of date palm (Exp.2)

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.03	0.05	0.03	0.03	0.04	0.03	**0.05 NS**	0.03	0.04
0.15 (L_1)	0.04	0.04	0.05	0.05	0.04	0.05	**0.04**	0.04	0.05
0.22 (L_2)	0.05	0.06	0.03	0.05	0.06	0.04	**0.05**	0.04	0.06
Means	**0.04 B**	**0.05 A**	**0.04 B**	**0.04 B**	**0.05 A**	**0.04 B**	**-**	**0.04 B**	**0.05 A**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	0.07	0.05	0.06	0.06	0.06	0.06	**0.06 NS**	0.06	0.06
0.15 (L_1)	0.04	0.07	0.07	0.06	0.05	0.06	**0.06**	0.05	0.07
0.22 (L_2)	0.07	0.07	0.06	0.08	0.07	0.07	**0.07**	0.06	0.07
Means	**0.06NS**	**0.06**	**0.06**	**0.07**	**0.07 NS**	**0.07**	**-**	**0.06 B**	**0.07 A**

Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.30: Effect of water salinity management techniques on soil EC (dS/m) at the end of Experiment -2

A. After one year (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	8.76b	7.24b	10.77a	8.14b	8.00 b	9.45a	**8.72 A**	9.76a	7.69b
0.15 (L_1)	6.07cd	5.75de	7.04bc	6.99c	5.91 de	7.01bc	**6.46 B**	6.55c	6.37cd
0.22 (L_2)	5.07de	4.91e	6.98c	5.83de	4.99 e	6.41cd	**5.7 B**	6.02cd	5.37d
Means	**6.63 BC**	**5.97 C**	**8.26 A**	**6.99 B**	**6.30 B**	**7.62 A**	**-**	**7.44 A**	**6.48 B**

B. After two years (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	10.72	9.70	11.55	10.42	10.21ab	10.98a	**10.59 A**	11.13a	10.06a
0.15 (L_1)	7.73	7.27	9.67	9.24	7.50d	9.45bc	**8.47 B**	8.70b	8.25b
0.22 (L_2)	6.27	5.63	9.29	7.90	5.95e	8.59cd	**7.27 B**	7.78bc	6.76c
Means	**8.24 B**	**7.53 C**	**10.17 A**	**9.19 B**	**7.89 B**	**9.67 A**	**-**	**9.20 A**	**8.36 B**

Original EC of the composite soil sample= 3.3 dS/m
Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.31: Effect of water salinity management techniques on soil pH at the end of Experiment -2 (2007)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} 9 dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	8.04	7.99	7.87	7.86	8.02	7.86	7.94 NS	7.95	7.92
0.15 (L_1)	7.90	7.90	7.83	7.76	7.90	7.79	7.85	7.86	7.83
0.22 (L_2)	7.89	7.69	7.80	7.78	7.79	7.78	7.79	7.84	7.73
Means	**7.94 NS**	**7.86**	**7.84**	**7.80**	**7.90 NS**	**7.81**	**-**	**7.88 NS**	**7.83**

Original pH of the composite soil sample= 7.6
Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.32: Effect of water salinity management techniques on soil pH at the end of Experiment -2 (2008)

Leaching Fractions	Leaching X Organic matter X irrigation water salinity (iw)				Means for EC_{iw} 6 dS m^{-1}	Means for EC_{iw} 9 dS m^{-1}	Overall leaching Means	Organic matter X overall leaching	
	EC_{iw} 6 dS m^{-1}		EC_{iw} dS m^{-1}						
	(O_0)	(O_1)	(O_0)	(O_1)				O_0	O_1
0 (L_0)	8.26	8.02	8.28	8.12	8.14	8.20	8.17 NS	8.27	8.07
0.15 (L_1)	8.34	8.19	8.21	8.09	8.26	8.15	8.20	8.27	8.14
0.22 (L_2)	8.31	8.25	8.31	8.23	8.28	8.27	8.27	8.31	8.24
Means	**8.30 NS**	**8.15**	**8.27**	**8.15**	**8.23 NS**	**8.21**	**-**	**8.28 NS**	**8.15**

Original pH of the composite soil sample= 7.6
Values are mean of four replications

Experiment 3

Table 4.35: Effect of N application on increase of trunk height (cm) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	Increase after one year (February 2007)			Increase after two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	29.3	21.0	25.2 NS	46.0	40.7	43.3 NS
2) 0.125	26.3	17.9	22.1	40.7	45.8	43.3
3) 0. 250	24.7	25.7	25.2	45.3	44.2	44.8
4) 0. 375	21.8	18.7	20.3	44.0	46.0	45.0
5) 0.500	22.0	22.0	22.0	42.3	45.8	44.1
Mean	24.8 NS	21.1	-	43.7 NS	44.5	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications

Table 4.36: Effect of N application on increase in number of fronds of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	Increase after one year (February 2007)			Increase after two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	16.3	14.7	15.5 NS	25.0	27.0	25.5 B
2) 0.125	15.3	14.7	15.0	27.3	28.7	27.8 A
3) 0. 250	14.3	14.7	14.5	28.7	27.7	28.2 A
4) 0. 375	14.3	14.3	14.3	28.0	26.0	28.4 A
5) 0.500	14.3	15.0	14.8	28.0	28.0	28.5 A
Mean	15.0 NS	14.8	-	27.4 NS	27.5	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.37: Effect of N application on increase in leaf length (cm) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	80.9	76.0	78.5 NS	165.6	163.7	164.6 NS
2) 0.125	78.2	68.1	73.2	168.5	154.0	161.3
3) 0. 250	69.7	73.7	71.7	161.8	167.6	164.7
4) 0. 375	70.1	69.0	69.6	156.7	156.7	156.7
5) 0.500	70.1	64.3	72.2	157.3	160.5	158.9
Mean	73.8 NS	72.2	-	162.0NS	160.5	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications

Table 4.38: Effect of N application on increase in trunk girth (cm) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	11.9	10.9	11.37NS	30.1	28.7	29.40 C
2) 0.125	12.7	10.3	11.50	30.5	28.7	29.58 BC
3) 0. 250	11.2	11.1	11.15	32.2	29.8	31.00AB
4) 0. 375	11.1	11.1	11.12	29.8	32.5	31.17 A
5) 0.500	10.9	10.9	10.92	28.6	28.2	28.42 C
Mean	11.56 NS	10.88	-	30.25 NS	29.58	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.39: Effect of N application on leaf Na (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control.	0.07	0.06	0.07 NS	0.06	0.08	0.07 NS
2) 0.125	0.08	0.06	0.07	0.07	0.08	0.08
3) 0. 250	0.06	0.07	0.08	0.06	0.07	0.06
4) 0. 375	0.06	0.07	0.07	0.08	0.07	0.08
5) 0.500	0.06	0.07	0.06	0.08	0.08	0.08
Mean	0.07 NS	0.07	-	0.07 B	0.08 A	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications

Table 4.40: Effect of N application on leaf K (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control.	1.4	1.5	1.5 NS	1.6	1.6	1.6 NS
2) 0.125	1.0	1.5	1.5	1.5	1.7	1.6
3) 0. 250	1.5	1.6	1.5	1.7	1.5	1.5
4) 0. 375	1.4	1.4	1.4	1.7	1.6	1.7
5) 0.500	1.4	1.4	1.4	1.7	1.6	1.6
Mean	1.4 NS	1.5	-	1.6 NS	1.6	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications

Table 4.41: Effect of N application on leaf Na/ K of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control.	NS 0.12	0.093	NS 0.107	NS 0.1	0.097	0.098
2) 0.125	0.113	0.12	0.117	0.107	0.097	0.102
3) 0. 250	0.10	0.107	0.13	0.123	0.103	0.113
4) 0. 375	0.137	0.143	0.14	0.113	0.1	0.107
5) 0.500	0.14	0.107	0.123	0.103	0.117	0.110
Mean	NS 0.122	0.114	-	0.109 NS	0.103	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.42: Effect of N application on leaf Ca (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	0.29	0.26	0.28 NS	0.25	0.29	0.27 NS
2) 0.125	0.27	0.24	0.25	0.35	0.27	0.31
3) 0. 250	0.29	0.30	0.29	0.32	0.28	0.30
4) 0. 375	0.29	0.31	0.30	0.32	0.21	0.27
5) 0.500	0.27	0.27	0.27	0.32	0.24	0.28
Mean	0.28 NS	0.27	-	0.31 A	0.26 B	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.43: Effect of N application on leaf Mg (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg $plant^{-1}$ $year^{-1}$	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	0.44	0.41	0.42 NS	0.46	0.29	0.37 AB
2) 0.125	0.43	0.46	0.44	0.40	0.31	0.35 B
3) 0. 250	0.57	0.56	0.59	0.51	0.40	0.46 A
4) 0. 375	0.36	0.43	0.40	0.36	0.30	0.33 B
5) 0.500	0.43	0.56	0.43	0.54	0.37	0.33 B
Mean	0.47 NS	0.46	-	0.46 A	0.33 B	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.44: Effect of N application on leaf Cl (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg $plant^{-1}$ $year^{-1}$	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	1.1	0.95	1.0 NS	1.21	1.21	1.21 NS
2) 0.125	0.95	1.00	0.98	1.24	1.21	1.23
3) 0. 250	0.98	1.00	0.99	1.15	1.21	1.18
4) 0. 375	0.89	1.00	0.95	1.18	1.21	1.20
5) 0.500	0.98	0.95	0.96	1.10	1.3	1.20
Mean	0.97 NS	0.98	-	1.18 B	1.23 A	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.45: Effect of N application on leaf N (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	1.2	1.1	1.2 B	1.1	1.1	1.0 B
2) 0.125	1.1	1.5	1.3 AB	1.3	1.2	1.2 A
3) 0. 250	1.2	1.5	1.4 AB	1.3	1.3	1.3 A
4) 0. 375	1.5	1.5	1.5 A	1.3	1.3	1.3 A
5) 0.500	1.4	1.5	1.5 A	1.3	1.4	1.3 A
Mean	1.3 NS	1.4	-	1.2 NS	1.3	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values sharing same letters are non-significant at 5 % level of significance

Table 4.46: Effect of N application on leaf P (%) of date palm plants when irrigated with saline water (Exp. 3)

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	0.04	0.04	0.03 NS	0.02	0.02	0.02 C
2) 0.125	0.03	0.04	0.04	0.03	0.02	0.025 C
3) 0. 250	0.03	0.05	0.04	0.04	0.03	0.04 B
4) 0. 375	0.03	0.04	0.04	0.04	0.06	0.05 A
5) 0.500	0.05	0.05	0.05	0.04	0.06	0.05 A
Mean	0.03 NS	0.05	-	0.04 NS	0.04	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.47: Effect of N application on soil EC (dS/m) at the end of Experiment-3

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	3.3	7.2	5.3 NS	5.8	9.9	7.8 NS
2) 0.125	3.5	8.2	5.8	6.2	7.8	7.0
3) 0. 250	3.4	6.7	5.1	6.9	8.4	7.6
4) 0. 375	3.8	5.5	4.6	5.8	8.3	7.1
5) 0.500	4.2	6.5	5.3	6.9	8.4	7.6
Mean	3.6 B	6.8 A	-	6.3 B	8.5 A	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
EC of original composite soil sample= 3.5 dS/m
Values are mean of four replications
Values with different letters are significant at 5 % level of significance

Table 4.48: Effect of N application on soil pH at the end of Experiment-3

Nitrogen Levels Kg plant^{-1} year^{-1}	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control	7.7	8.2	8.0 NS	7.7	8.0	7.8 NS
2) 0.125	7.8	8.1	7.9	8.1	8.1	8.1
3) 0. 250	8.2	8.1	8.1	7.9	7.9	7.9
4) 0. 375	8.1	8.2	8.2 A	8.0	7.8	7.9
5) 0.500	8.1	8.2	8.1	7.6f	7.8	7.7
Mean	7.9 NS	8.2	-	7.9 NS	7.9	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
pH of original composite soil sample= 7.6
Values are mean of four replications

Table 4.49: Effect of N application on soil N at the end of Experiment-3

Nitrogen Levels (Kg plant^{-1} year^{-1})	After one year (February 2007)			After two years (February 2008)		
	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean	EC 3 dS m^{-1}	EC 6 dS m^{-1}	Mean
1) Control.	0.032	0.026	0.029 NS	0.033	0.028	0.031 B
2) 0.125	0.035	0.025	0.030	0.036	0.027	0.032 B
3) 0. 250	0.026	0.034	0.030	0.027	0.036	0.032 B
4) 0. 375	0.036	0.034	0.035	0.037	0.036	0.037 A
5) 0.500	0.032	0.042	0.037	0.033	0.044	0.039 A
Mean	0.032 NS	0.032	-	0.033 NS	0.034	-

A basal uniform dose of PK = 0.20-0.30 Kg per plant per year was also applied
N of original composite soil sample= 0.03%
Values are mean of four replications

CHAPTER 5

Summary, conclusions and recommendations

5.1 Summary

The Sultanate of Oman is located in the South East corner of the Arabian Peninsula. . The country has a coastal line of almost 1700 km, looking three seas: the Persian Gulf, the Gulf of Oman and the Arabian Sea. The climate is hot and humid during summer in the coastal areas and hot and dry in the interior regions while it is moderate in the winter. The highest degrees of temperature range between 35 to 50°C and the lowest vary from 7 to 31°C. It is an arid country where annual rainfall ranges between 50mm to 300mm with an annual mean of less than 100mm. Rainfalls occur scarcely and randomly. Groundwater is the main water resource of the country. The net annual natural recharge has been estimated around 1260 million cubic meters (MCM). The total water demand is around 1650 MCM of which 90% is used for agriculture. The annual deficit of 390 MCM is drawn from the groundwater reserves. The cultivable area has been estimated as 2.2 million ha, which is 7% of the total area of the country. Over half of the agricultural area is located in the Batinah Plain in the north where Mean Annual Temperature is 28.6^{o}C and Relative Humidity is 58%. Rainfall is very irregular from year to year and most of the months around the year can be totally dry. The Batinah Plain is comprised of very thick alluvial, marine and Aeolian sediments. Agriculture has been one of the important sources of income of Oman. It not only provides food and shelter but also employs a bigger portion of its rural population. Some of the agricultural commodities are exported to Arab and overseas Countries. About 141,000 people are employed in this national sector that also shares 26.5% in non-oil exports.

Fifty percent of the agricultural area in the South Batinah is affected from salinity (EC_e of > 4 dS m^{-1}). Date palm is the overwhelming crop of the country. Other major crops grown in this area include lime, alfalfa, vegetables, fruits, Rhodes grass and other fodder crops. Water salinity is one of the biggest problems of agriculture in Oman. Water EC is more than 3.0 dS m^{-1} at many of the agricultural farms and even may reach 40.0 dS m^{-1} at certain places in the coastal belt. The categorization of groundwater was found to be 53, 18, 15, 6, 4, 3 and 1% that were having EC of 2, 2-3, 3-5, 5-7, 7-10, 10-15 and more than 15 dS m^{-1} respectively. The very high concentration of salts in the ground water is increasing further due to more motorized pumping and extension in agriculture. There have been sea water intrusions as well. Resultantly, not only the plant growth and yields are being affected negatively, but also secondary soil salinity is increasing at an accelerated rate. The loss due to salinity has been estimated as 7.311-13.966 million OR per annum.

Date palm trees are grown in Oman since centuries long. According to estimates, there are about 7.8 million plants growing at present. The area of date palm plantations has been estimated as 97059ha. Naturally, this plant has high tolerance against salinity. Nevertheless, at very high EC of water the plant can be affected negatively. The plants may totally dry out when irrigated continuously with very saline water otherwise their yields may decrease significantly to bring them below the economic level. The date palm production and yield have been cut short in recent years. Many big and small date palm farms have been abandoned now due to increasing impact of salinity. The causes of low yield or abandoning of date palm orchards are; increased soil and water salinity level slowly and gradually beyond the tolerance potential of the date palm/ inter- crops practiced with date palm, non-adoption of any management practices for using saline water, very low or imbalanced use of fertilizer to meet the good plant nutrition and miscellaneous factors like pests and diseases.

Therefore, this Ph.D. research work was conducted to investigate some of these important components. Hence the objectives of this study were:

1. Evaluation of the water salinity tolerance levels of important date palm varieties grown in Oman.
2. Assessment of some management techniques for safe utilization of saline water under soil and climatic conditions of Oman.
3. Standardization of the N fertilizer levels that may prove effective under saline water irrigation for date palm seedlings.
4. Formulation of recommendations for majority of the farming community who are growing date palm trees and vastly using saline water for irrigation.

The Ph. D. study comprised of three field experiments. Growth rate of seedlings of date palm was studied for two years coupled with soil and plant analysis.

1. **Screening of date palm varieties for tolerance to water salinity**
2. **Managing saline water for growing date palm**
3. **Nitrogen fertilizer requirements of date palm seedlings at early stage when irrigated with saline water**

The research work was undertaken at Agricultural Research Center (ARC), Rumais (latitude 23^{o}, 68' N, and longitude 58^{o} , 01' E), Sultanate of Oman during the years 2006-08. The details of treatments and methodologies of each experiment are as under.

Experiment No. 1: Screening of date palm varieties for water salinity tolerance

Treatments:

A) Categories of irrigation water: EC_{iw} 3 (Control), 6, 9, 12, 15 & 18 dS m^{-1}

B) Date palm varieties; Three (Khalas Adhahirah (subsequently designated as only Khalas), Khunaizy and Abunarenjeh)

Statistical design was split plot with four replications. A low ECe soil was selected, leveled and prepared for transplantation of seedlings. Soil samples were collected just before transplantation and twice subsequently with one year interval. These samples were analyzed for ECe and pH. The required levels of EC of water (EC_{iw}) were synthesized through mixing of fresh water (EC 1.0 dS m^{-1}) and the saline water (EC 35-40 dS m^{-1}) in appropriate ratios. Three meter buffer plot was left fallow in between two treatment plots to protect and keep separate the effect of different irrigation regimes. After the first year, trenches of 115cm deep were made to separate each treatment. The blocks were separated by thick polythene black color sheets to make sure that no interference occurs between the treatments. Plants were maintained through proper irrigation, weeding and protection. Growth data (Plant height, plant girth, number of new fronds (leaves) and length of fronds) were recorded annually. The leaf samples were analyzed for N, P, K, Na, Ca, Mg and Cl.

Experiment No. 2: Managing saline water for growing date palm

The objective of this experiment was to standardize some management practices that are effective to minimize the deleterious effects of saline groundwater. Duration of the field experiment was two years with following treatments.

Treatments:

A) Categories of irrigation water: EC 6 & 9 dS m^{-1}

B) Management practices

7. Control (No leaching fraction and no organic matter)
8. Application of irrigation water including leaching fractions of 0.15
9. Application of irrigation water including leaching fractions of 0.22
10. Application of organic matter (crop residues) 10 kg $plant^{-1}$
11. Leaching fraction 0.15 + Organic matter (Treatments 1 + 3)
12. Leaching fraction 0.22 + Organic matter (Treatments 2 + 3)

Statistical design of the experiment was two factorial split plot with four replications. Seedlings of Khalas variety of date palm were transplanted. Irrigation category was kept in main plots while management techniques were placed in sub-plots. Volume of irrigation water was fulfilled to meet the treatment requirements by adjusting opening time of drippers. A uniform quantity of fertilizer (NPK at the rate of 0.375 – 0.20 – 0.30 kg $plant^{-1}$ $year^{-1}$) was applied to fulfill the major nutrient requirements of the crop. Other methodologies and recording of data were the same as described under experiment 1.

Experiment No. 3: Nitrogen fertilizer requirements of date palm seedlings at early stage when irrigated with saline water

Standardization of the N doses for date palm during seedling establishment and early stages of growth when irrigated with saline groundwater was the main objective of this experiment and it consisted of the following treatments.

Treatments

A) Categories of irrigation water: EC 3 (Control) & 6 d S m^{-1}

B) Fertilizer doses.

1. Control (NPK 0.0-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$)
2. NPK = 0.125-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$

3. NPK = 0.250-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
4. NPK = 0.375-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$
5. NPK = 0.500-0.20-0.30 Kg $plant^{-1}$ $year^{-1}$

Statistical design of this experiment was two factorial (Factor A= Categories of water Factor B= Fertilizer doses) Split Plot with four replications and 60 total number of plants (3 x 5 x 4 = 60). Seedlings of Khalas variety of date palm were transplanted. A uniform quantity of irrigation water was applied to fulfill the requirement of the crop. Irrigation category was kept in main plots while fertilizer doses were placed in sub-plots. Whole of P and half of K was applied in the month of February. Remaining half of K was applied in the month of September. Urea (as nitrogen source) was applied weekly in equal split doses. Other methodologies and recording of data was that of experiment 1 and 2.

Experimental soil

A coarse textured soil with good drainage was selected for the study because it represented the major soils of the country of Oman. It was a non-saline soil (EC 2.77- 3.5) with alkaline pH (7.6-7.7). Generally, fertility of the soil was low with comparatively lesser values of organic carbon and total N whereas available P indicted moderate values.

Irrigation water and system

Special irrigation system comprising of tanks, pumps, distribution pipes, drippers and separate supply lines of good quality (EC 1.0 dS m^{-1}) and ground saline water (EC 35.0 – 45.0 dS m^{-1}) were set up. Uniform quantity of water was applied to all the plants in the field except experiment 2 in which different volumes of water were applied to meet requirements of various treatments (leaching fractions, LF). Waters of different qualities required in various treatments of the experiment were synthesized by mixing calculated volumes of saline and desalinized water. The tanks were refilled by remixing both types of water when these became empty.

Selection of varieties

The selection of date palm varieties for was based upon future trend and demand of farmers. Variety Khalas Adhahirah is very famous all over the Arab world for its quality and good yields and therefore, grown on larger areas in Oman. This variety is now being propagated through tissue culture techniques besides suckers. The other famous varieties in Oman are Khunaizy and Abunarenjeh. Hence, these three varieties were selected for the present studies so that results can be recommended to the farmers for adoption.

5.2 Salient results

Following salient results were obtained on the basis of data recorded in the present investigations.

1. The consistent irrigation for two years with water of various salinities (6, 9, 12, 15 & 18 dS m^{-1}) checked growth of date palm seedlings (all the three varieties; Khalas, Khunaizy and Abunarenjeh) and quantum of growth parameters like trunk height, plant girth, Number of new fronds (leaves) and leaf length decreased significantly when compared with water of EC 3 dS m^{-1}.
2. Deleterious effects increased with time and increasing level of water salinity because the salts being added through irrigation water kept concentrating gradually and increased soil ECe significantly. Therefore, the magnitudes of percentage decrease in various growth characters when compared with control (EC_{iw} 3 dS m^{-1}) were lesser at the end of first year than the second year. More decrease due to lower levels (6 & 9 dS m^{-1}) occurred in the second year. The higher levels of EC_{iw} 15 and 18 dS m^{-1} proved more detrimental in both years for all the varieties.
3. The overall respective decrease values for trunk height were 14, 21, 31, 47 and 50% for water salinity levels of 6, 9, 12, 15 & 18 dS m^{-1} at the end of first year while these were 18, 28, 36, 46 and 53% at the end of second year, although the salinity effect was diluted a little in the second year because salts were removed partially in the middle of the year by a natural cyclone ‘Gonu’.
4. The curtailment in number of fronds $plant^{-1}$ was 8, 11, 21, 29 and 39% during first year and 12, 27, 32, 39 and 48% in the second year with EC_{iw} of 6, 9, 12, 15 and 18 dS m^{-1} respectively.
5. Overall mean leaf length was a little bit different in behavior and indicted decrease of 10, 19, 27, 32 and 41% in the second year for the above mentioned respective water salinity levels.
6. Decreases in trunk girth were 11, 17, 28, 40 and 46% in the second year as against 4, 10, 15, 24 and 38% for EC_{iw} 6, 9, 12, 15 and 18 dS m^{-1} respectively during first year of observations.

7. The EC_{iw} of 18 dS m^{-1} proved the water salinity level that caused nearly 50% decrease of various plant parameters of date palm during seedling stage when planted in coarse textured soils (sandy loam, loamy sand and sand that are dominated in Oman) with very good drainage. Of course losses were lesser with water having EC lower than 18 dS m^{-1}.
8. Differences between varieties were significant only after second year of study. Overall mean reductions due to water salinity for trunk height, number of fronds, length of leaves and trunk girth for Khalas were 47, 36, 33 and 25% respectively at the end of second year while respective values for Abunarenjeh were 37, 31, 24 and 25%. The values for same characters of Khunaizy were respectively 36, 30, 28 and 28%.
9. Khunaizy was having a little edge over other two varieties as regards salt tolerance potential but differences were not much wider between three varieties.
10. The interaction of varieties and water salinity levels was found to be significant only in case of plant height during first year and plant height as well as number of fronds during the second year.
11. Consistent irrigation with saline water of different EC levels affected the plants in two ways; direct effect of saline water (osmotic effect, specific ion effect of Na and nutritional imbalance) and gradual accumulation of salts in the soil profile that ultimately increased soil EC.
12. In general uptake of Na, Mg and P increased significantly while that of K decreased whereas Ca, N and Cl remained non-significant. Despite check on entry of Na, as revealed by lower levels of EC_{iw} (differences with control non-significant), there was more uptake of Na by the plants that accumulated in leaves of date palm, in particular at the higher water salinity levels (15 and 18 dS m^{-1}). The correlation of EC_{iw} and leaf Na was also found to be highly significant and positive. Similarly, Mg uptake by plant roots also increased in accordance with its concentration in the soil solution as result of continuous irrigations with high Mg water.
13. Although date palm plants exercised preferred uptake of K but very high concentrations of Na in the rhizosephere shattered this potential of the plant and K ion uptake decreased resultantly.
14. The plants indicated very strict control on Cl uptake and its concentration in the leaves did not increase significantly. Hence plants were saved from severe toxic effects of Cl.

The computation of correlation between plant Cl and EC of irrigation water also indicted non-significant values.

15. Soil EC_e increased significantly with each level of water salinity as compared with control when either observed after one year or two years (Table 4.15). Nevertheless, EC_{iw} 6 dS m^{-1} was found to be similar with 9 dS m^{-1} while 12 dS m^{-1} was alike with 15 dS m^{-1} during second year. The reason was that Gonu cyclone removed salts partially in the middle of the second year due to excessive and unusual rainfall (cm).
16. The experimental soil was slightly alkaline with a pH of 7.7. The irrigation with saline water for two years indicated a significant increase in this important soil characteristic and made it more alkaline.
17. Date palm plants were able to maintain Na/ K ratio when irrigated with water of EC up to 12 dS m^{-1}. This indicated that maintaining Na/ K ratio may be regarded as the major salt tolerance mechanism in date palm. The Khunaizy variety was having the least values of this parameter in both the years therefore can be regarded as more salt tolerant than Khalas and Abunarenjeh.
18. Surprisingly amounts of Cl determined in the plant leaves were very low and treatment effect was found to be non-significant although irrigation water contained lot of this ion. The correlation of leaf chloride was also determined to be non-significant. Therefore, it can be concluded that date palm exercises a strict control on Cl uptake as another salt tolerance mechanism.
19. Usefulness of leaching fractions (LF) to manage effects of saline water was found to be partial. The effectiveness of LF was not so pronounced in case of water with higher EC of 9 dS m^{-1} because during the first year, LF of 0.15 and 0.22 kept the plant parameters (Trunk height, girth and number of fronds) at significantly higher magnitude but during the second year differences between leaching fractions and control (No LF) became non-significant in case of water EC 9 dS m^{-1}.
20. The salt addition and accumulation through irrigations exceeded salt removal through leaching fractions. Thus, there was an ultimate increase in salt EC that restricted date palm growth. The lesser end vales of soil EC after two years in LF treatments revealed its usefulness. The numerical values of soil EC remained within the salt tolerance potential

of date palm in the present that could be claimed as safe with lesser losses to plant growth.

21. The Na content in plant leaves were also restricted by LF indicating a positive sign as well. Higher LF (0.22) was more effective when water EC was 9 dS m^{-1}. However, supplementation of organic matter improved effectiveness and usefulness of LF further.
22. Various LF were found to be positively correlated with No. of fronds, height of trunk and trunk girth while leaf Na was negatively and significantly correlated.
23. Application of organic matter (10Kg per plant per year) also proved effective to remove deleterious effects of saline water because determined soil EC after irrigation of two consistent years with water EC of 9 dS m^{-1} was significantly lesser in the organic matter applied treatment. The increase in soil pH was also controlled. Such types of result were through controlling transpiration that resulted in less concentration of salts. This effect was translated into better growth of date palm seedlings because magnitude of all the growth parameters was higher in organic applied treatments.
24. The correlation of organic matter application was found to be positive and significant with leaf Ca and Mg while it was negative with Na and Cl indicting favorable combination that was conducive for better growth of plants.
25. Surprisingly effect of N application was found only slightly increasing plant growth but there was not a clear significant response. The computation of correlation coefficient also indicated that only leaf length significantly correlated with N application. The reason may be high salt tolerance of date palm that did not permitted major nutrient disturbances under water salinity up to 6 dS m^{-1} as well as low N requirement of N by date palm seedlings in early age of two years.
26. Leaf analysis indicated the significant effect of N application only in case of N, P and Mg while all the other ions were not affected significantly. The relationship between applied N and leaf content of N, P and K were found significant and positive as well.
27. There was no statistical effect on soil EC, pH and N due to application of N at any level. The increase in soil N was just slight and could not be assessed as significant. The reason may be that texture of the soil was light and drainage was very good which were conducive for high leaching losses of this nutrient although N was in highly split doses that added before each irrigation.

5.3 Conclusions

1. The growth of all the three date palm varieties (Khalas, Khunaizy and Abunarenjeh) was decreased significantly during irrigation for two consistent years with saline water (6-18 dS m^{-1}) when compared with 3 dS m^{-1} even in sandy soil with good drainage. However, 50 % decline was recorded only at water EC 18 dS m^{-1}. Therefore, date palm could be regarded as highly salt tolerant.
2. Much difference between salt tolerance potential of three varieties was not recorded, only Khunaizy showed a little edge over the other two.
3. Leaf ionic concentration of date palm changed with saline water irrigation. There was a significant increase in Na, decrease in K while Cl remained unchanged.
4. The physiological basis of salt tolerance in date palm was a strict control on Na and Cl concentration in leaves and keeping up the K content with narrow Na/ K ratio.
5. Applying more water in the form of Leaching Fractions (LF 0.15 and 0.22) proved partially useful because its effectiveness decreased at water EC of 9 dS m^{-1}, especially in the second year. Similar was the usefulness of organic matter (10Kg per plant per year). However, coupling of both proved more effective.
6. Application of nitrogen fertilizer beyond 0.125 Kg $plant^{-1}$ $year^{-1}$ did not indicate any material gain in growth of date palm seedlings.

5.4 Recommendations

1. Date palm plants (seedlings during vegetative growth) can be irrigated with saline water when good quality water is not available. However, significant decline in growth will be expected when the EC of irrigation water exceeds 9 dS m^{-1} that may reach up to 50% in case of EC 18 dS m^{-1} used on sandy soil with very good drainage.
2. Three varieties; Khalas, Khunaizy and Abunarenjeh revealed a good salt tolerance potential and can be grown with saline water of EC up to 18 dS m^{-1}.

3. In the absence of any other option LF can be regarded useful technique to check deleterious effects during irrigation with saline water but may not be adopted blindly. This technique can usefully be used when water EC is not too high (Exceeds 9 dS m^{-1}) and texture is light with good soil drainage.
4. Application of organic matter (10 kg per plant per year) is another useful management practice to mitigate deleterious effects of saline water. Its combination with LF can prove more effective provided that EC of water is not beyond 9 dS m^{-1}.
5. Application of nitrogen fertilizer beyond 0.125 Kg $plant^{-1}$ $year^{-1}$ will not be required for date palm in early growth of initial two years.

5.5 Future research in this field

This initial research has opened new horizons in the water salinity field, especially fruit plants and deemed necessary to be continued under prevailing conditions of Oman as well as other places with similar conditions. Following will be a few future options but these may not encompass all.

1. The investigations on irrigation with saline water will be required on later stages of growing date palm; the reproductive, fruit setting and maturity stages.
2. Data have to be generated under medium and heavy soil textures with relatively restricted drainage.
3. The percentage losses for the whole life cycle of date palm have yet to be finalized through long-term studies (5- 10 years).
4. Some more management techniques have to be brought out through different investigations so that negative effects on plants and soil can be avoided and minimized.
5. Studies on fertilizer application including P, K and micronutrients during irrigation with saline water at later stages of plant growth will be required.
6. Experimentation on some more varieties can be undertaken to prepare a long list of salt tolerant cultivars of date palm.

KAPITEL 5

Zusammenfassung, Schlussbemerkungen und Empfehlungen

5.1. Zusammenfassung,

Das Sultanat Oman befindet sich in der südöstlichen Ecke der Arabischen Halbinsel. Das Land hat eine Küstenlinie von mehr als 1.700 km und liegt an drei Meeren: dem Persischen Golf, dem Golf von Oman und der Arabischen See. Das Klima ist während des Sommers an den Küstenregionen heiß und humid und heiß und trocken in den inneren Regionen des Landes, während es im Winter moderat ist. Die höchsten Temperaturen schwanken zwischen 35-50° C und die niedrigsten zwischen 7-31° C. Es ist ein arides Land mit jährlichen Regenmengen von 50 mm bis 300 mm und einem Durchschnitt von weniger als 100 mm. Regen fällt selten und zufällig. Grundwasser ist die Hauptwasserreserve des Landes. Die jährliche Nettoerneuerung wird auf 1.260 Mill. m^3 (MCM) geschätzt. Die gesamte Wassernachfrage beträgt um 1.650 MCM, wovon 90% für die Landwirtschaft benötigt wird. Das jährliche Defizit von 390 MCM wird von den Grundwasserreserven beansprucht. Die kultivierbare Fläche beträgt 2,2 Mill. ha und somit 7% der Gesamtfläche des Landes. Über die Hälfte der landwirtschaftlichen Nutzfläche befindet sich in der Batinah Ebene im Norden, in der die jährliche Durchschnittstemperatur 28,6° C und die relative Luftfeuchtigkeit 58% beträgt. Regen fällt von Jahr zu Jahr sehr unregelmäßig und die meisten Monate des Jahres können völlig trocken sein. Die Batinah Ebene umfasst sehr mächtige alluviale, marine und äolische Sedimente. Landwirtschaft ist eine wichtige Einkommensquelle des Oman. Sie liefert nicht nur Nahrung und Unterkunft, sondern auch Beschäftigung für einen großen Teil der ländliche Bevölkerung. Einige der landwirtschaftlichen Produkte werden in die arabischen und überseeischen Länder exportiert. Über 141.000 Menschen sind in diesem nationalen Bereich beschäftigt, der 26.5% der Nicht-Öl-Exporte beträgt.

50% der landwirtschaftlichen Fläche der südlichen Batinah Ebene sind von einer Versalzung beeinflusst (EC_e-Leitfähigkeit > 4dS m^{-1}). Die Hauptfrucht im Land ist die Dattelpalme. Andere wichtige Feldfrüchte sind in dieser Gegend Limonen, Luzerne, Gemüse, Früchte, Rhodes-Gras und andere Futterpflanzen. Der Salzgehalt des Wassers ist eines der größten landwirtschaftlichen

Probleme des Omans. Die Leitfähigkeit des Wassers ist auf vielen Farmen größer als 3.0 dS m^{-1} und kann an verschiedenen küstennahen Plätzen sogar 40 dS m^{-1} erreichen. Das Grundwasser wird mit 53, 18, 15, 6, 4, 3 und 1% kategorisiert, das Leitfähigkeiten von 2, 2-3, 3-5, 5-7, 7-10, 10-15 und mehr als 15 dS m^{-1} aufweist. Die besonders hohen Salzkonzentrationen im Grundwasser steigen weiterhin durch Nutzung von Motorpumpen und Ausdehnung der Landwirtschaft an. Außerdem findet ein Eindringen von Meerwasser statt. Als Resultat wird nicht nur das Pflanzenwachstum und der Ertrag negativ beeinflusst, sondern sekundär beschleunigt sich auch die Bodenversalzung. Der Schaden durch Versalzung wird jährlich auf 7.311 – 13.966 Mill. omanische Rial geschätzt.

Dattelpalmen wachsen im Oman seit Jahrhunderten. Nach Schätzungen gedeihen hier zurzeit 7,8 Mill. Pflanzen. Die Fläche mit Palm-Plantagen wird auf 97.059 ha geschätzt Von Natur aus hat die Pflanze eine hohe Toleranz gegenüber einer Versalzung. Dennoch wird sie bei sehr hohen Leitfähigkeiten des Wassers negativ beeinflusst. Die Pflanze kann völlig austrocknen, wenn sie kontinuierlich mit salzhaltigem Wasser bewässert wird bzw. der Ertrag verringert sich derartig signifikant, so dass der Anbau unwirtschaftlich wird. Die Produktion von Datteln und die Erträge sind in den letzten Jahren zurückgegangen. Viele Farmer großer und kleiner Farmen haben wegen des ansteigenden Salzgehaltes aufgegeben. Die Gründe für die geringen Erträge und die Aufgabe von Dattelpalm- Gärten sind der Anstieg der Boden- und Wassersalzgehalte, der Zwischenfruchtanbau unter Dattelpalmen ohne eine Anpassung der Arbeitstechniken zur Nutzung salzhaltigen Wassers, sehr geringer oder nicht ausgewogener Einsatz von Dünger für eine gute Pflanzenernährung und viele weitere Faktoren wie Schädlingsbefall und Krankheiten.

Deshalb wurde diese Dissertation durchgeführt, um einige dieser wichtigen Aspekte zu untersuchen. Inhalt der Studie waren:

1. Ermittlung der Salzwassertoleranz wichtiger Dattelpalm-Sorten, die im Oman wachsen
2. Beurteilung einiger Einsatztechniken für die vorsichtige Nutzung von Salzwasser unter den Boden- und Klimabedingungen des Oman
3. Festlegung effektiver N- Düngermengen für die Bewässerung von Dattelpalm- Setzlingen mit salzhaltigem Wasser
4. Formulierung von Empfehlungen für die Mehrzahl von Farmern, die Datteln anbauen und Salzwasser für die Bewässerung nutzen.

Die Dissertation beinhaltet drei Feldexperimente. Die Zuwachsrate von Dattelpalm- Setzlingen wurde zwei Jahre lang, in Verbindung mit Boden- und Pflanzenanalysen, untersucht.

1. Auswahl von Dattelpalm- Sorten für eine Toleranz gegenüber Salzwasser
2. Verwendung von Salzwasser zum Wuchs von Dattelpalmen
3. Erforderlicher Stickstoffdünger für Dattelpalm- Setzlinge bei Bewässerung mit Salzwasser im jungen Stadium

Die Untersuchungen wurden im landwirtschaftlichen Forschungszentrum (ARC), Rumais (Breitengrad 23°, 68'N und Längengrad 58°, 01'E) im Sultanat Oman während der Jahre 2006 - 08 durchgeführt. Die Einzelheiten der Behandlung und Methoden jeden Experiments sind:

Experiment Nr. 1: Auswahl von Dattelpalm- Sorten für eine Salzwasser- Toleranz

Behandlungen:

A) Kategorie des Bewässerungswassers: Leitfähigkeit (EC_{iw}) Kontrolle 3,6,9,12,15 u. 18 dS m^{-1}

B) Dattelpalm- Sorten: Drei (Khalas Adnahirah (weiterhin als Khalas bezeichnet), Khunaizy und Abunarenjeh.

Die Versuche wurden randomiesiert mit vierfacher Wiederholung durchgeführt. Für die Pflanzung der Setzlinge wurde ein Boden mit geringer Leitfähigkeit ausgewählt. Vor der Bepflanzung wurden Bodenproben entnommen und ein Jahr später ein zweites Mal. Diese Proben wurden auf Leitfähigkeit (EC_e) und pH-Wert analysiert. Die gewünschte Leitfähigkeit des Wassers (EC_{iw}) wurde durch Mischung von Frischwasser (EC 1.0 dS m^{-1}) und Salzwasser (EC 35-40 dS m^{-1}) in entsprechender Menge erreicht. Eine drei Meter breite Pufferzone bleib zwischen den Versuchsparzellen brach liegen, um die einzelnen Behandlungen nicht zu beeinflussen. Nach einem Jahr wurden 115 cm tiefe Gräben gezogen, um die Parzellen voneinander zu trennen. Die Versuchsblöcke trennte man durch dicke schwarze Kunststofffolien, um sicher zu gehen, dass es nicht zu einer gegenseitigen Beeinflussung kommt. Die Pflege der Pflanzen erfolgte durch ständige Bewässerung, Unkrautbekämpfung und Pflanzenschutz. Wuchsparameter (Pflanzenhöhe, Pflanzenumfang, Anzahl neuer Wedel und Länge der Wedel /Blätter) wurden jährlich erfasst. Von den Blattproben gab es Analysen hinsichtlich N, P, K, Na, Mg und Cl.

Experiment 2: Verwendung von Salzwasser zum Wuchs von Dattelpalmen

Bei diesem Experiment ging es darum, einige Praktiken zu standardisieren (verbessern), um die schädlichen Auswirkungen auf das salzhaltige Grundwasser zu minimieren. Die Dauer der Feldexperimente mit den folgenden Behandlungen betrug zwei Jahre.

Behandlungen:

A) Kategorien des Bewässerungswassers: EC 6 u. 9 dS m^{-1}

B) Bearbeitungsmaßnahmen

1 Kontrolle (keine Durchsickerung, kein organisches Material)

2 Zugabe einer Bewässerung mit 0,15% Salzfracht

3 Zugabe einer Bewässerung mit 0,22% Salzfracht

4 Zugabe von organ. Material (Ernterückstände/ 10 kg Pflanze)

5 Salzwasser 0,15 + organ. Material (Behandlungen 1 + 3)

6 Salzwasser 0,22 + organ. Material (Behandlungen 2 + 3)

Der Versuchsaufbau war randomisiert mit vier Wiederholungen. Setzlinge der Dattelpalmsorte Khalas wurden gepflanzt. Die Bewässerungskategorien wurden in Blöcken und die Bearbeitungsmaßnahmen in Parzellen durchgeführt. Den Umfang der Bewässerung erreichte man entsprechend der gewünschten Behandlung durch die Öffnungszeiten der Tropfer. Eine einheitliche Menge des Düngers (NPK in der Zusammensetzung von 0,375 - 0,20 - 0,30 kg pro Pflanze und Jahr) gab man zur Befriedigung der Hauptnähransprüche der Pflanzen auf die Fläche. Weitere Methoden und die Erfassung von Daten erfolgten wie im ersten Experiment.

Experiment 3: Erforderlicher Stickstoffdünger für Dattelpalm- Setzlinge bei Bewässerung mit Salzwasser im jungen Stadium

Die Standardisierung von Stickstoffgaben in der Setzlingsphase und frühen Stadien des Wachstums von Dattelpalmen bei Bewässerung mit salzhaltigem Grundwasser war das Hauptanliegen dieses Experiments mit folgenden Behandlungen:

Behandlungen:

A) Kategorien des Bewässerungswassers: EC 3 (Kontrolle) u. 6 dS m^{-1}

B) Düngermenge

1. Kontrolle (NPK 0.0 – 0.20 – 0.30 kg/Pflanze/Jahr)
2. NPK = 0,125 – 0,20 – 0,30 kg/Pflanze/Jahr)

3. NPK = 0,250 – 0,20 – 0,30 kg/Pflanze/Jahr)
4. NPK = 0,375 – 0,20 – 0,30 kg/Pflanze/Jahr)
5. NPK = 0,500 – 0,20 – 0,30 kg/Pflanze/Jahr).

Der statistische Aufbau des Experiments war zwei-faktoriell (Faktor A = Wasserkategorie, Faktor B = Düngermenge), randomisiert und mit vier Wiederholungen (insgesamt 60 Pflanzen – 3 x 5 x 4 = 60). Verwendet wurden Setzlinge der Sorte Khalas Adahirah. Die Pflanzen erhielten eine einheitliche und ausreichende Bewässerungsmenge. Die Bewässerungen wurden in Hauptblöcken und Düngungsmaßnahmen in Parzellen durchgeführt. Die Applikation der Gesamtmenge P und der halben Menge an K erfolgte im Februar. Die verbleibende Hälfte des K kam im September auf die Fläche. Urea (als Stickstoffquelle) verabreichte man aufgeteilt in gleichen Mengen wöchentlich. Die anderen Methoden und Datenerfassungen waren wie in den beiden ersten Experimenten

Der Boden im Experiment

Ein grob strukturierter Boden mit guter Drainage stellte die Auswahl für den Versuch dar, weil dieser die meisten Böden des Omans repräsentiert. Es handelt sich um einen nicht salzhaltigen Boden (EC 2,77 – 3,5) mit einem basischen pH-Wert (7,6 – 7,7). Insgesamt lag eine geringe Nährstoffversorgung mit vergleichsweise niedrigen Werten des organischen Kohlenstoffs und N gesamt, jedoch moderatem Gehalt an verfügbarem P vor.

Bewässerungswasser und -system

Ein spezielles Bewässerungssystem bestehend aus Tanks, Pumpen, Verteilungsleitungen, Tropfern und separaten Zuleitungen für Frischwasser (EC 1.0 dS m^{-1}) und salzhaltigem Grundwasser (EC 35.0 – 45 dS m^{-1}) wurde aufgebaut. Alle Pflanzen im Feldversuch erhielten die gleichen Wassermengen bei Ausnahme des 2. Versuchs mit unterschiedlichen Wassermengen zur Einstellung verschiedener Behandlungen (Durchsickerungsmengen, L.F.). Das für die Experimente benötigte Wasser unterschiedlicher Qualität (Salzgehalt) entstand durch Mischung von salzhaltigem und entsalzenem Wasser.

Auswahl der Sorten

Die Auswahl der Dattelpalm-Sorten basierte auf zukünftigen Trends und der Nachfrage von Farmern. Die Sorte Khalas Adhahirah ist in der gesamten arabischen Welt wegen der Qualität und der guten Erträge sehr bekannt und deshalb in großen Flächen im Oman angepflanzt. Die anderen bekannten Sorten im Oman sind Khunaizy und Abunarenjeh. Deshalb kamen diese drei Sorten in die Auswahl für die jetzigen Untersuchungen, damit die Ergebnisse von den Farmern übernommen werden können.

5.2 Herausragende Ergebnisse

Folgende herausragende Ergebnisse resultieren aus den ausgewerteten Daten der derzeitigen Untersuchungen:

1. Die dauerhafte Bewässerung von 2 Jahren mit Wasser verschiedener Salzgehalte (6,9,12,15 und 18 dS m^{-1}) beeinträchtigt den Wuchs von Dattelpalm- Setzlingen (alle drei Sorten: Khalas, Khunaizy und Abunarenjeh) und das der Wuchsparameter wie Stammhöhe, Pflanzenumfang, Anzahl der neuen Wedel (Blätter) und Länge der Wedel; diese nehmen signifikant ab, wenn sie mit Wasser über 3 dS/m^{-1} Leitfähigkeit versehen werden
2. Die nachteiligen Auswirkungen erhöhen sich mit der Zeit und dem ansteigenden Salzgehalt des Wassers und dieser führt zu einer signifikanten Erhöhung der Leitfähigkeit im Boden. Deshalb waren die Größenordnungen der prozentualen Abnahme bei verschiedenen Wuchsparametern im Vergleich zur Kontrolle (EC_{iw} 3dS m^{-1}) am Ende des ersten Jahres geringer als nach dem zweiten Jahr. Ein größerer Verlust trat bei den niedrigen Salzgehalten (6 u. 9 dS m^{-1}) im zweiten Jahr auf. Die höheren Leitfähigkeiten (15 u. 18 dS m^{-1}) wirkten sich noch schädlicher auf alle Sorten in beiden Jahren aus.
3. Die durchgängige Abnahme der Stammhöhe betrug 14, 21, 31, 47 und 50% bei Leitfähigkeiten von 6, 9, 12, 15 und 18 dS m^{-1} am Ende des ersten Jahres und 18, 28, 36, 46 und 58% am Ende des zweiten Jahres, obwohl der Salzeffekt in der Mitte des zweiten Jahres ein wenig durch den Zyklon „Gonu“ geschwächt wurde (Salzverlagerung).

4. Die Reduzierung der Wedel (Blätter) pro Pflanze betrug beachtliche 8, 11, 21, 29 und 39% während des ersten Jahres und 12, 27, 32, 39 und 48% im zweiten Jahr bei den Leitfähigkeiten (EC_{iw}) von 6, 9, 12, 15 und 18 dS m^{-1}.
5. Die Hauptblattlänge war ein bisschen differenzierter in der Ausbildung und der zu beklagende Rückgang betrug 10, 19, 27, 32 und 41% bei den zuvor genannten Leitfähigkeiten.
6. Der Rückgang beim Stammumfang betrug 11, 17, 28, 40 und 46% im zweiten Jahr gegenüber 4, 10, 15, 24 und 38% im ersten Jahr (Leitfähigkeiten wie oben).
7. Die Leitfähigkeit (EC_{iw}) von 18 dS m^{-1} verursacht einen Rückgang von nahezu 50% innerhalb verschiedener Pflanzenparameter bei Dattelpalmen, während des Setzlingsstadiums in grob strukturierten Böden (sandiger Lehm, lehmiger Sand und Sand dominieren im Oman) mit sehr guter Drainage. Natürlich waren die Verluste geringer mit Wasser, das weniger als 18 dS m^{-1} hatte.
8. Unterschiede zwischen den Sorten waren erst nach dem zweiten Jahr signifikant. Die Hauptreduzierungen in Verbindung mit dem Salzgehalt des Wassers waren für die Stammhöhe, Anzahl der Wedel, Länge der Blätter und Stammumfang bei der Sorte Khalas 47, 36, 33 und 25% am Ende des zweiten Jahres, während die jeweiligen Werte für Abunarenjeh 37, 31, 24 und 25% betrugen. Die Werte für dieselben Parameter bei Khunaizy lagen bei 36, 30, 28 und 28% (ECiw 15, 12, 9 und 6 dS m^{-1}).
9. Khunaizy wies gegenüber den beiden anderen Sorten eine leicht erhöhte Salztoleranz auf, aber die Abweichungen waren nicht viel größer als zwischen allen drei Sorten.
10. Die Beziehung zwischen den Sorten und dem Salzgehalt des Wassers war bei den Pflanzenhöhen im ersten Jahr und den Pflanzenhöhen sowie der Anzahl der Wedel im zweiten Jahr signifikant.
11. Dauerhafte Bewässerung mit Wasser verschiedener Salzgehalte beeinflusst die Pflanzen auf zwei Wegen: direkter Einfluss des Salzwassers (osmotischer Effekt, spezieller Effekt des Natrium-Ions und ernährungsmäßige Unausgewogenheit) und eine graduelle Anreicherung von Salzen im Bodenprofil, die die Leitfähigkeit des Bodens erhöht.
12. Im Allgemeinen steigt die Aufnahme von Na, Mg und P signifikant , während die von K fällt und Ca, N und Cl bleiben nicht signifikant. Abgesehen von Kontrollen über die Aufnahme von Natrium bei geringeren Salzgehalten (Differenzen zur Kontrolle waren

nicht signifikant) bestand eine höhere Na- Aufnahme bei Dattelpalmen mit einer Anreicherung in den Blättern insbesondere bei den höheren Leitfähigkeitswerten (15 u. 18 dS m^{-1}). Die Korrelation zwischen EC_{iw} und Na in den Blättern war hoch signifikant und positiv. Entsprechend steigt die Mg- Aufnahme in Pflanzenwurzeln in Übereinstimmung mit der Konzentration in der Bodenlösung als Ergebnis kontinuierlicher Beregnung mit Mg- reichem Wasser.

13. Obwohl Dattelpalmen bevorzugt K aufnehmen, wird dieses Potenzial durch sehr hohe Na- Konzentration in der Rhizosphäre zerstört und als Resultat fällt die Aufnahme des K-Ions ab.
14. Die Pflanzen üben eine strikte Kontrolle über die Aufnahme von Cl aus und die Konzentration steigt nicht signifikant in den Blättern an. Deshalb werden die Pflanzen vor verschiedenen toxischen Einflüssen des Cl bewahrt. Die Berechnung der Korrelation zwischen Cl und Leitfähigkeit des Wassers ergibt ebenfalls keine signifikanten Werte.
15. Die Boden- Leitfähigkeit steigt signifikant mit jeder Stufe des Wasser- Salzgehaltes im Vergleich zur Kontrolle nach einem bzw. zwei Jahren an (Tab. 4.15). Trotzdem stellte sich heraus, dass die EC_{iw} mit 6 dS m^{-1} ähnlich wie die mit 9 dS m^{-1} war, während die mit 12 dS m^{-1}der mit 15 dS m^{-1} im zweiten Jahr gleich war. Der Grund bestand darin, dass der Zykon „Gonu“ in der Mitte des zweiten Jahres mit seinen exzessiven und ungewöhnlichen Regenfällen das Salz teilweise ausgewaschen hatte.
16. Der Boden aus den Experimenten war leicht basisch mit eine pH-Wert von 7.7. Die zweijährige Bewässerung mit salzigem Wasser führte zu einem signifikanten Anstieg der Alkalität des Bodens.
17. Dattelpalmen sind in der Lage, ihr K/Na- Verhältnis aufrecht zu erhalten, selbst wenn mit Wasser gegossen wird, dass Leitfähigkeiten (EC) bis 12 dS m^{-1} aufweist. Die Erhaltung des K/Na- Verhältnisses dürfte als der wichtigste Salztoleranz- Mechanismus der Dattelpalme angesehen werden. Die Sorte Khunaizy wies in beiden Jahren das kleinste Verhältnis dieses Parameters auf und kann deshalb als salztoleranter als die Sorten Khalas und Abunarenjah angesehen werden.
18. Überraschenderweise waren die analysierten Cl- Gehalte in den Blättern sehr gering und der Behandlungseffekt nicht signifikant, obwohl das Wasser eine Menge diese Ions enthielt. Die Korrelation zum Cl- Gehalt in den Blättern war nicht signifikant. Deshalb

kann angenommen werden, dass die Dattelpalme eine strenge Kontrolle über die Aufnahme von Cl ausübt, die größer ist als andere Salztoleranz- Mechanismen.

19. Die Nützlichkeit einer Auslaugung (leaching fraction LF) zur Regelung des Salzgehaltes ist unterschiedlich. Die Effektivität der LF ist nicht besonders bei Verwendung von Wasser mit hoher EC von 9 dS m^{-1}. Im ersten Jahr blieben die Pflanzenparameter (Stammhöhe, -umfang und Anzahl der Wedel) bei den LF von 0,15 und 0,22 in einer signifikanten höheren Größenordnung, aber während des zweiten Jahres waren die Unterschiede zwischen LF und Kontrolle (keine LF) bei Wasser mit einer EC von 9 dS m^{-1} nicht mehr signifikant.
20. Die Salz- Zugabe und Akkumulation durch Bewässerung überschreitet die Salzauswaschung durch leaching. Deshalb findet ein ultimativer Anstieg in der Leitfähigkeit statt, der das Wachstum der Pflanzen behindert. Die geringeren Gehalte der Boden- EC nach zweijähriger leaching- Behandlung zeigt deren Nützlichkeit. Die numerischen Werte der Boden- EC blieben im Salztoleranz- Potenzial der Dattelpalmen.
21. Der Na- Gehalt in den Pflanzenblättern wurde ebenfalls durch das LF- Verfahren beschränkt und ist somit ebenfalls positiv zu bewerten. Höhere LF (0,22) war effektiver, wenn die Wasser- EC 9 dS m^{-1} betrug. Die Zugabe von organischem Material erhöhte die Effektivität und Nützlichkeit der LF noch weiter.
22. Verschiedene LF wirkten sich positiv auf die Anzahl der Wedel, Höhe des Stammes und Stammumfang aus, wohingegen der Natrium- Gehalt der Blätter negativ und signifikant korriliert war.
23. Die Zugabe von organischem Material (10 kg pro Pflanze im Jahr) wirkte sich ebenfalls positiv auf den verheerenden Einfluss des Salzwassers aus. Nach zweijähriger andauernder Bewässerung mit Wasser von EC 9 dS m^{-1} war die EC des Bodens signifikant geringer. Der Anstieg des pH-Wertes im Boden ging kontrollierter voran. Diese Ergebnisse hatten Einfluss auf die Transpiration durch die geringere Salzkonzentration. Diese wiederum bewirkten einen besseren Wuchs der Dattelpalm-Setzlinge in allen Wuchsparametern bei Zugabe von organischem Material.
24. Die Applikation von organischem Material ergab eine positive und signifikante Korrelation zu Ca und Mg in den Blättern, aber eine negative zu Na und Cl, womit eine günstige Kombination für ein besseres Wachstum der Pflanzen erreicht wurde.

25. Erstaunlicherweise wirkte sich eine Zugabe von N nur gering auf das Pflanzenwachstum aus und ohne eine deutliche Signifikanz. Die Berechnung der Korrelationskoeffizienten ergab, dass nur die Blattlänge mit der N- Zugabe korrelierte. Der Grund kann die hohe Salztoleranz der Dattelpalme sein, die zu keinen Störungen bei der Aufnahme von Hauptnährelementen unter salzhaltigen Bedingungen (Wasser mit EC bis 6 dS m^{-1}) führt, und das gilt auch für geringen N- Anspruch von Dattelpalm- Setzlingen in den ersten zwei Jahren.
26. Eine Blattanalyse der Ionen- Konzentration ergab einen signifikanten Einfluss bei Zugabe von N nur im Fall von N, P und Mg, während alle anderen Ionen nicht signifikant betroffen waren. Die Beziehungen zwischen appliziertem N und dem Gehalt von N, P und K in den Blättern war ebenfalls positiv und signifikant.
27. Es gab keinen statistisch zu sichernden Einfluss auf Boden EC, pH-Wert und N durch Zugabe von Stickstoff in jeder Aufwandmenge. Der Anstieg des Boden- N war gering und konnte als nicht signifikant eingeschätzt werden. Der Grund dafür kann in der leichten Durchlässigkeit des Bodens und seiner guten Dränbarkeit liegen, die zu großen Auswaschungsverlusten dieses Nährstoffs führten, obwohl N in großen Teilmengen vor jeder Bewässerung ausgebracht wurde.

Schlussbemerkung

1. Das Wachstum aller drei Dattelpalmsorten (Khalas, Khunaizy und Abunarenjeh) verringerte sich signifikant während der durchgängigen Bewässerung von 2 Jahren mit Salzwasser (6 - 18 dS m^{-1}) gemischt mit 3 dS m^{-1} sogar in sandigen Böden mit guter Drainage. Allerdings waren 50% des Verlustes nur bei dem Wasser mit EC 18 dS m^{-1}. Deshalb können Dattelpalmen als hoch salztolerant angesehen werden.
2. Ein großer Unterschied im Potenzial der Salztoleranz konnte bei allen drei Sorten nicht verzeichnet werden, nur die Sorte Khunaizy lag etwas höher.
3. Die Ionen- Konzentration in den Blättern von Dattelpalmen ändert sich mit der Bewässerung von Salzwasser. Es gibt eine signifikante Erhöhung von Na, eine Verminderung von K, während Cl unverändert verbleibt.

4. Die physiologische Basis für die Salztoleranz der Dattelpalme liegt in einer strikten Kontrolle der Na- und Cl-Konzentration in den Blättern und einer Erhöhung des K-Gehaltes zu einem engen K/Na- Verhältnis.
5. Die Zugabe von Wasser in Form von Leaching- Fraktionen (LF 0.15% und 0.22%) erweist sich nur teilweise als brauchbar, weil die Effektivität bei Wasser mit EC 9 dS m^{-1} abnimmt, besonders im zweiten Jahr. Ähnlich war der Nutzeffekt durch organisches Material (10 kg/Pflanze/Jahr). Die Verbindung beider Maßnahmen erwies sich als noch effektiver.
6. Die Zugabe von Stickstoffdünger hatte nirgendwo Einfluss auf das Wachstum von Dattelpalm- Setzlingen.

5.4. Empfehlungen

1. Dattelpalmpflanzen (Setzlinge während des vegetativen Wachstums) können mit salz-haltigem Wasser bewässert werden, wenn kein qualitativ besseres Wasser vorhanden ist. Ein signifikanter Wuchsverlust tritt bei Bewässerungswasser über 9 dS m^{-1} ein. Der Verlust kann sich bei EC 18 dS m^{-1} auf 50% erhöhen in sandigem Boden mit guter Drainage.
2. Die drei Sorten Khalas, Khunaizy und Abunarenjah verfügen über eine gute Salztoleranz und können mit Salzwasser bis zu EC 18 dS m^{-1} wachsen.
3. Bestehen keine weiteren Möglichkeiten, können Leaching - Fraktionen (LF) als nutzbare Technik zur Verhinderung verheerender Einflüsse bei der Bewässerung mit salzigem Wasser verwendet werden, aber nicht blindlings. Diese Technik kann verwendet werden, wenn die EC nicht zu hoch (unter 9 dS m^{-1}) und eine gute Durchlässigkeit und Drainage des Bodens vorhanden ist.
4. Die Zugabe von organischem Material (10 kg/Pflanze/Jahr) ist eine weitere praktische Möglichkeit, um die schädliche Wirkung des Salzwassers zu lindern. Die Kombination mit LF (leaching fracting) kann sich als effektiver erweisen, vorausgesetzt das Wasser hat eine EC unter 9 dS m^{-1}.
5. Die Zugabe von Stickstoffdünger ist für Dattelpalmen in den beiden ersten Wuchsjahren nicht erforderlich.

5.5. Zukünftige Untersuchungen auf diesem Gebiet

Diese Anfangsuntersuchung hat neue Horizonte auf dem Gebiet der Bewässerung mit Salzwasser insbesondere bei Obstpflanzen erbracht und es wird als notwendig erachtet, eine Fortführung unter den vorherrschenden Bedingungen des Omans und anderer Gegenden mit gleichen Verhältnissen anzustreben. Nachfolgend einige zukünftige Optionen:

1. Es wird erforderlich sein, die Untersuchungen mit salzhaltigem Wasser auf spätere Wachstumsphasen der Dattelpalmen, wie der Blüte, Fruchtansatz und dem Reifestadium auszudehnen.
2. Daten müssen von mittleren und schweren Böden mit relativ eingeschränkter Durchlässigkeit erhoben werden.
3. Der prozentuale Verlust der gesamten Lebensdauer von Dattelpalmen muss jetzt durch Langzeitstudien (5-10 Jahre) erfasst werden.
4. Es müssen einige weitere Arbeitstechniken erprobt werden, um negative Einflüsse auf Pflanzen und Böden zu vermeiden oder zu minimieren
5. Untersuchungen über Dünger, die P, K und Mikronährstoffe einschließen, sind bei älteren Wuchsstadien mit Bewässerung von Salzwasser erforderlich.
6. Zur Vorbereitung einer langen Liste salztoleranter Sorten von Dattelpalmen müssen mit weiteren Varietäten Experimente durchgeführt werden.

Literature Cited

- ABDEL-RAHMAN, H. A. and I.S. ABDEL-MAJID. 1993. Water Conservation in Oman, Water Int. 18: 95-102.
- AHMED, M., H. ESECHIE and A. AL-AJMI. 2004. Biosaline Agriculture: Perspectives from Oman. Presented at a workshop on Biosaline Agriculture, 27-30 June 2004, Wageiningen, Netherlands.
- AL-BUSAIDI, A., T. YAMAMOTO, M., INOUE, M., IRSHAD, Y., MORI, Y. and T. SATOSHI. 2007. Effects of seawater salinity on salt accumulation and barley (Hordeum vulgare L.). Growth under different metrological conditions. J. Food, Agri. and Environ. 5 (2): 270 – 279.
- AL-DAWWEY, G.M. 1998. Tolerance of Balady Mandarin and Manfalouty pomegranate seedlings to salinity. Ast. J. Agric. Sci. 29 (3): 123-133.
- Al DINAR, H.M., G. EBERT and P. LUDDERS. 1998. Biomass production and partitioning of guava (Psidium guajava L.) in response to salinity and nitrogen nutrition. Angewandte-Botanik. 72 (1-2): 56-60`
- ALi-DINAR, H.M., G. EBERT and P. LUDDERS 1999. Growth, chlorophyll content, photosynthesis and water relations in guava (Psidium guajava L.) under salinity and different nitrogen supply. Gartenbauwissenschaft. 64 (2): 54-59.
- Al-GHAMIDI, A.A., A.A. HLAL and M.H. ALWHAIBI. 1999. Nitrogen source and growth of date palm seedlings. Pak. J. Biol. Sci. 2(4): 1207-1210.
- AL-HAMMADI, M. S. 2006. Salt tolerance and current status of the date palms in the United Arab Emirates. Ph.D. Dissertation. Arizona, USA. The University of Arizona, Publication Number: AAT 3207858.
- AL-KHAYRI, J. M. 2002. Growth, proline accumulation and ion content in sodium chloride-stressed callus of date palm. In Vitro Cell Dev. Biol. Plant. 38: 79-82.
- AL-MANSOORI, T. A. 2001. Salt tolerance in date palm (Phoenix dactylifera L.). Ph.D. Dissertation, University of Reading, Reading, 52-17406 (BL: DXN061960).
- ALNADI, A.M.H. 2001. Extension guide of water requirements for crops in Sultanate of Oman. Soil and Water Lab. Plant Protection Research Center. Ministry of Agriculture and Fisheries, Sultanate of Oman. p.36.

- AL-RIYAMI, A. A. 2005. Oman's steady progress in agriculture and fisheries. Spotlight, 35th National Day. Oman Daily Observer, November 23, 2005.
- AL-WAHAIBI, N.S., E. A. ELAMINE and O. REHMAN. 2007. Alternate use of good quality and saline irrigation water for tomato production. Sci. Int.19 (1): 69-73.
- AL-WAHAIBI, N.S., N. HUSSAIN and S. A. AL-RAWAHI. 2007. Mulching for sustainable use of saline water to grow tomato in Sultanate of Oman. Sci. Int. 19 (1): 79-81.
- AL-YAHYAI, R and S. AL-KHANJARI. 2008. Biodiversity of Date palm in the Sultanate of Oman. African J. Agri. Res. 3 (6): 389-395. Available online at http://www.academicjournals.org/AJAR.
- ANONYMOUS. 2005. Study of brackish water in the Sultanate of Oman. Consultancy Report. Parasons International & Co. LLC, Wadi Kabir. Ministry of Regional Muncipalties, Environment and Water Resources, Sultanate of Oman.
- ANONYMOUS. 2009. Managing climate variability. Climag Jan. 2009, Australia.
- ASEMOTA, O., C.R. EKE and J.O. ODEWALE. 2007. Date palm (Phoenix dactylifera L.) in vitro morphogenesis in response to growth regulators, sucrose and nitrogen. African J. Biotech. 6 (20): 2353-2357.
- ASHRAF, M.Y., K. AKHTAR, G. SARWAR and M. ASHRAF. 2002. Evaluation of arid and semi arid ecotypes of guar (Cyamopsis tetragonoloba L.) for salinity (NaCl) tolerance. J. Arid Environ. 52: 473-482.
- ASLAM M., R.H. QURESHI and S. MUHAMMAD 1989 Salinity tolerance in rice (Oryza sativa L.). Morphological studies Pak J. Agri. Sci. 26: 92-98.
- ASLAM, M., R.H. QURESHI and N.AHMAD. 1993. Mechanism of salinity tolerance in rice (Oryza sativa L.). In: Towards the rational use of high salinity tolerant plants [Lieth, H. and A.A.A Massoum (editors)] Kluwer Acad. Publ. Dordreacht 2: 135-138.
- ASLAM, M., R.H. QURESHI, N. AHMAD and M.A. KAUSAR. 1991. Relative growth rate and ion transport in rice under saline environment Pak J. Bot. 23: 3-10.
- ASRAF, M., and P.J.C. HARRIS. 2004. Potential indicators of salinity tolerance in plants. Plant Sci. 166: 3-16.

- ATTALLA, A.M. and F.M. HARRAZ. 1996. Chemical composition of the pits of selected date palm cultivars grown in the Qassim Region, Saudi Arabia Arab. Gulf J. Scient. Res. 14 (3): 629-639.
- AWAD, M.A., A.A. SOAUD and S.M. El-KONAISSI. 2006. Effect of exogenous application of anti-stress substances and elemental sulfur on growth and stress tolerance of tissue culture derived plantlets of date palm (Phoenix dactylifera L.) c.v. 'Khalas' during acclimatization, J. Appli. Hort. 8: 129–134.
- AWASTHI, O.P. and R.K. PATHA. 1999. Effect of salinity levels on survival and anatomy of four scion cultivars budded on Indian jujube. Hort. J. 12 (2): 53-59.
- AYERS, R.S. and D.W. WESTCOT. 1985. Water quality for agriculture. Irrig. Drainage Paper 29, FAO, Rome, Italy.
- AYSHA, M. K. AND T.H.A.E. ATTA. 2008. The effect of Gonu cyclone on recharging groundwater aquifers- Sultanate of Oman. Abstracts of the First International Conference, Water Resources and Climate Change in the MENA Region. Nov. 2-4, 2008, Muscat-Sultanate of Oman. p.14.
- BADI, D.A. 2000. Straw management effects on organic matter mineralization and salinity in semiarid agricultural soils. Arid Soil Res. and Rehabilitation. 14: 193-203.
- BERNSTEIN, N.L. 1965. Salt tolerance of fruit crops. U.S Dept. Agric. Int. Bull. p. 292-98.
- BROSCHAT, T.K. 1997. Nutrient distribution, dynamics, and sampling in coconut and Canary Island date palms. J. American Soc. Hort. Sci. 122 (6): 884-890.
- BUERKERT, A., M. NAGIEB, S., SIEBERT, I., KHAN and A. AL-MASKRI. 2005. Nutrient cycling and field-based partial nutrient balances in two mountain oases of Oman. Field Crops Res. 94 (2-3): 149-164.
- COOKSON, P. and A. LEPIECE. 2001. Could date palms ever disappear from the Batinah? Salination of a coastal plain in the Sultanate of Oman. Water in the Arabian Peninsula: 221-235.
- COOPER, W. C., N. MAXWELLl, G. Oley. 1957. Salt tolerance and cold hardiness tests on avocado trees. Rio Grande vol. Hort. Soc. J. 11: 67-74.

- DARWISH, T., T. ATALLAH, M. EL-MOUJABBER and N. KHATIB. 2005. Salinity evolution and crop response to secondary soil salinity in two agro-climatic zones in Lebanon. Agri. Water Management. 78 (1-2): 152-164.
- DJIBRIL, S., O. K. MOHAMED, D. DIAGA, D. DIÉGANE, B. F. ABAYE, S. MAURICE and B. ALAIN. 2005. Growth and development of date palm (Phoenix dactylifera L.) seedlings under drought and salinity stresses. African J. Biotech. 4 (9): 968-972.
- EL-BABLY, A.Z. 2002. Advanced and integrated approaches for crop tolerance to poor quality irrigation water in Egypt. Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt. Options Mediterranean's, Série A n.50:363-378.
- ESECHIE, H. A. and V. RODRIGUEZ. 1998. Ion compartmentation in salinity stressed alfalfa seedlings growing under different temperature regimes. Commun. Soil Sci. Plant Anal. 29: 2607 – 2618.
- ESECHIE, H. A. and V. RODRIGUEZ. 1999. Does salinity inhibit alfalfa leaf growth by reducing tissue concentration of essential nutrients? J. Agron. Crop Sci. 182: 273 -278.
- ESECHIE, H. A., B. AL-BAHRI, S. AL-GHEITY and S. AL-KHANJARI. 2002. Root and shoot growth in salinity stressed alfalfa in response to nitrogen source. J. Plant Nutr. 23: 2559 – 2569.
- ESECHIE, H. A., V. RODRIGUEZ and H.S. AL-ASMI. 2002. Effect of sodium chloride salinity on cation equilibra in alfalfa (Medicago sativa L.). Crop Res. 23: 253 – 258.
- ESKARINE, W., T. AHMED, M. AHMED, E. OSMAN, Z. LASHINE, A. NEJATIAN, T. BADAWI AND S.M. RAGY. 2004. Date palm in the GCC countries of the Arabian Peninsula. Proc. of Regional Workshop on date palm development in the Arabian Peninsula. May 29-31, 2004, Abu Dhabi, UAE. http://www.icarda.org/APRP/Datepalm/Fo&Ac/foreword.htm
- FAO. 2005. Global network on integrated soil management for sustainable use of salt affected soils. Food and Agriculture Organization, land and Plant Nutrition Management Services, Rome Italy.
- FLOWERS, T.J. 1988. Chloride as a nutrient and as an osmoticum. In. Advances in Plant Nutrition. [B. Tinker and A. Lauchli (editors)]. Praeger, New York 3: 55-78.

- FLOWERS, T.J. and A. LAUCHLI. 1983. Sodium verses potassium substitution and compartmentation p.651-681. In. A. Lauchli and Pirson (eds.), Inorganic plant Nutrition. Encyclopedia of plant physiology, New Series, Kol 15b Springer-Verlag, Berlin.
- FLOWERS, T.J., M.A. HAJIBAGHERI and A.R. YEO. 1991. Ion accumulation in the cell walls of rice plants growing under saline conditions, evidence for the Oertli hypothesis. Plant Cell Environ. 14: 319-325.
- FLOWERS, T.J., P.F. TROKE and A.R. YEO. 1977. The mechanisms of salt tolerance in halophytes Ann. Rev. Plant Physiol. 28: 89-121.
- GARCIA-LIDON, A., J. M.ORTIZ, M.F.GARCIA-LEGAZ and A. CEDRA. 1998. Role of rootstock and scion on root and leaf ion accumulation in lemon trees grown under saline conditions. Fruits. 53 (2): 89-97.
- GHADIRI, H., I. DORDIPOUR, M. BYBORDI and M. J. MALAKOURTI. 2005. Potential use of Caspian Sea for supplementary irrigation in North Iran. Agri.Water Manag. 79: 209 – 224.
- GHAFOOR, A.G., M. QADIR and G. MURTAZA. 2004. Salt affected soils: Principles of management. Institute of Soil and Environmental Sciences. University of Agriculture, Faisalabad, Pakistan. p. 110-111.
- GLYAN΄KO A.K., L.E. MAKAROVA, G.G. VASILEVA and N.V. MORONOVA. 2005. Possible involvement of hydrogen peroxide and salicylic acid in the legume – Rhizobium symbiosis. Biol. Bollet. 32: 245-249.
- GREENWAY, H and R. MUNNS. 1980. Mechanisms of salt tolerance in non-halophytes. Ann. Rev. Plant Physiol. 31: 149-190.
- HAGGAG, L.F and M.A. MAKSOUD. 1996. Effect of salinity of irrigation water on some properties of guava fruits. Egyp. J. Hort. 23 (2): 203-209.
- HASSAN, M. M., S. A. SEIFAND M. M. MORSI. 2000. Salt tolerance of olive trees. Egyptian. J. Hort. 27 (1): 105-116.
- HASSAN, M.M., IAA. EL-KHALIK and AIA. AZAYEM. 2001. Salt tolerance of apricot trees. Egyptian J. Hort. 28 (1): 91-99.
- HOMER, D. C. AND F. P. PARKER. 1961. Methods of analysis for soils, plants, and waters. Riverside, University of California. p. 309.

- HUSSAIN, N. 2005. Strategic plan for combating soil and water salinity in Sultanate of Oman. P.117.
- HUSSAIN, N., AL-RAWAHY, S.A., RABEE, J. and AL-AMRI, M., 2006a. Causes, origin, genesis and extent of soil salinity in the Sultanate of Oman. Pak. J. Agri. Sci. 43 (1-2): 1-6.
- HUSSAIN, N., N. S. AL-WEHAIBI, S. S. A. AL-HABSI and A. AL-BAKRI. 2006b. Hydro-Economical localization of Oman Agriculture. International Conference on Economic Incentives & Water Demand Management, Sultan Qaboos University, College of Agricultural and Marine Sciences (CAMS) held at Sultanate of Oman, 18-22 March, 2006. P. 188-197.
- KARLBERG, L., J. ROCKSTROM, J. G. ANNANDALE and J. M. STEYN. 2007. Low-cost drip irrigation- A suitable technology for Southern Africa? An example with tomatoes using saline irrigation water. Agri. Water Managt. 89: 59–70.
- KEFU Z, H., Z., SAN Z and S. JIE. 2003. Study on the salt and drought tolerance of Suaeda salsa and Kalanchoe claigremontiana under isoosmotic salt and water stress. Plant Sci. 165: 837-844.
- KLEINERMAN, Y.A.Z. 1958. Soils maritime regions of the Ukrainian SSRR and their use in growing fruit crops. Pochven. Inst in v.v. dokuchaeva. Trudy, Vol. 54, P. 275-301.
- KATERJI, N., J.W. VAN HOORN, AL HAMDY and M. MASTRORILLI. 2002. Salinity effect on crop development and yield. Analysis of salt tolerance according to several classification methods. Agri. Water Managt. 62: 37–66.
- Khadri, M., N.A. Tejera and C. Lluch. 2006. Alleviation of salt stress in common bean (Phaseolus vulgaris) by exogenous abscisic acid supply. Journal of Plant Growth Regulation, 25:110-119.
- KOLSI-BENZINA, N. and B. ZOUGARI. 2008. Mineral composition of the palms leaflets of the date palm. J. Plant Nut. 31 (3): 583-591.
- KURDALI, F. and F. AL-AIN. 2002. Effect of different water salinity levels on growth, nodulation, and nitrogen fixation by Dhaincha and on growth of sunflower using 15N tracer technique. J. Plant Nut. 25 (11): 2483-2498.

- LATIF, M, and G. NABI. 2003. Utilization of different quality drainage waters for silviculture and agriculture purpose. PP: 12. Center of Excellence in Water Resources. Univ. Engg. Technol., Lahore.
- LEVITT, J. 1980 Response of plants to environmental stresses. Vol. II. 2nd ed. Water, radiation, salt and other stresses Academic Press, New York.
- LEVY, Y., D. COLUMBUS, D. SADAN and J. LIFSHITZ. 1998. Trickle linear gradient for assessment of the salt tolerance of citrus rootstocks in the orchard. Irri. Sci. 18 (4): 181-184.
- LIU, X. N. 1998. Effects of NaCl treatment on free radical metabolism of fig (Ficus carica). Advances in Hort. (2): 235-241.
- LONE, M. L. 1988. Ionic relations of barley embryos response to equisomolar salts. Managing Soil Resources: Proc. of First Nat. Cong. Soil Sci. Lahore, Oct. 1985. p. 364.
- LOPEZ, M., J. A. HERRERA-CERVERA, C. IRIBARNE, N.A. TEJERA and C. LLUCH. 2007. Growth and nitrogen fixation in Lotus japonicus and Medicago truncatula under NaCl stress: nodule carbon metabolism. J. Plant Physi. 165 (6): 641-650.
- MAAS, E.V. 1986. Salt tolerance of plants Appl. Agric. Res. 1 (1): 12-26.
- MAAS, E.V. and R.H. NIEMAN. 1978. Physiology of plant tolerance to salinity. 13: 277-299. In: G.A. Jung (eds.), Crop Tolerance to Suboptimal Land Conditions. Soil Sci. Soc. Am. Spec. Pub. Madison, USA.
- MAHMOOD, K. 2007. Salinity/ sodicity tolerance of *Acacia ampliceps* and identification of techniques useful to avoid early stage salt stress. Ph.D. Dissertation, Faculty of Organic Sciences, University of Kassel, Witzenhausen, Germany.
- MARCAR, N., D. CRAWFORD, P. LEPPART, T. JOVANVIC, R. FLOYL and R. FARROW. 1995. Trees for Saltland: A guide to select native species for Australia. CSRIO, East Melbourne, Vic. p.72.
- MARCHNER, H. 1995. Adaptation of plants to adverse chemical soil conditions. In: Mineral Nutrition of Higher Plants 2nd ed. Academic Press Itd. P. 596-680.
- MINISTRY OF ARICULTURE AND FISHERIES. 1990. General soil map of Sultanate of Oman. Ministry of Agriculture and Fisheries, Sultanate of Oman.
- MINISTRY OF ARICULTURE AND FISHERIES. 1992. Salalah Integrated Study. Ministry of Agriculture and Fisheries, Sultanate of Oman.

- MINISTRY OF ARICULTURE AND FISHERIES. 1993. South Batinah Integrated Study. Directorate General of Agricultural Research, Ministry of Agriculture and Fisheries, Sultanate of Oman.
- MINISTRY OF ARICULTURE AND FISHERIES. 1997. Integrated Study of North Batinah. Ministry of Agriculture and Fisheries, Sultanate of Oman.
- MINISTRY OF ARICULTURE AND FISHERIES. 2004. Year Book of Agriculture. Ministry of Agriculture and Fisheries, Sultanate of Oman.
- MINISTRY OF ARICULTURE AND FISHERIES. 2005. Annual Report of 2005, Directorate General of Agriculture & Livestock Research, Ministry of Agriculture & Fisheries, Sultanate of Oman.
- MINISTRY OF WATER RESOURCES. 1993. Water Resources Master Plan. Ministry of Water Resources, Muscat, Sultanate of Oman.
- MIYAMOTO, S. and A. CHACON. 2006. Soil salinity of urban turf areas irrigated with saline water: II. Soil factors. Landscape and Urban Planning. 77 (1-2): 28-38.
- MOODIE, C.D., H.W. SMITH and R.A. McCREERY. 1959. Laboratory manual for soil fertility. Dept .Agron. State College of Washigton, Pullman. p. 31-39.
- MUNNS, R. 2002. Comparative physiology of salt and water stress. Plant, Cell Environ. 25: 239–250.
- MUNNS, R. 2005. Genes and salt tolerance: bringing them together. New Phytologist. 167: 645-663.
- NAVARRO, A., S. BAÑON, E. OLMOS and M.J. SÁNCHEZ-BLANCO. 2007. Effects of sodium chloride on water potential components, hydraulic conductivity, gas exchange and leaf ultra structure of Arbutus unedo plants. Plant Sci. 172: 473-480.
- OKUBO, M., Y., FURUKAWA and T. SAKURATANI. 2000. Growth, flowering and leaf properties of pear cultivars grafted on two Asian pear rootstock seedlings under NaCl irrigation. Scientia Horticulturae. 85 (1-2): 91-101.
- ORON, G., Y. DEMALACH, L. GILLERMAN, I. DAVID and S. LURIE. 2002. Effect of water salinity and irrigation technology on yield and quality of pears. Biosystems Engg. 81:237-247.
- PANDY, S. D., R.K. PATHAN and O.P.AWASTHI. 1993. Note on effect of salinity levels on nutrient status in BER. Indian J. HORT. 50 (1): 46-48.

- PARIDAA, A.K. and A.B. DAS. 2005. Salt tolerance and salinity effects on plants: A review. Ecotoxicology and Environmental Safety. 60: 324–349.
- PESSARAKLI, M. 1999. Handbook of plant and crop stress. CRC, USA.
- PESSINGHAM, J. 1986. Selection for a better quanndong. Aust. Hort. 84(2): 55-59. PASTERNAK, D. 1987. salt tolerance and crop production. A comprehensive approach. Annual Review, Phytopathlogoy .25: 271-291.
- PRATHAPAR, S.A. 2000. Water Shortages in the 21st century. In: Cadman.H.ed. . The Food and Environment Tiyhtrope.Australian Centtre for International Agric. Res. Canberra. p. 125-133.
- QUERSHI, R. H. and M. RASHID. 1988. Research on management and reclamation of salt affected soils of Pakistan. Present Status. Proceedings of 1st. National Congress of Soil Science, Lahore, October 1985. p. 173-184.
- QUERSHI., R. H. BARRETT- LENNARD, E.G. 1998. Saline Agriculture for Irrigated Lands in Pakistan: A Hand Book. ACIAR, Canberra, Australia.
- QURESHI, R. H., 1995. Final Report of visit of Prof. Riaz Hussain Qureshi, Salinity Expert at ARC, Rumais, August 1, 1994 to Jan. 31, 1995. Faisalabad, Pakistan.
- RAJAK, D., M.V. MANJUNATHA, G.R. RAJKUMAR, M. HEBBARA and P.S. MINHAS. 2006. Comparative effects of drip and furrow irrigation on the yield and water productivity of cotton (Gossypium hirsutum L.) in a saline and waterlogged vertisol. Agri. Water Mangt. 83 (1-2): 30-36.
- RAO, D.L.N., K.E. GILLER, A.R. YEO and T.J. FLOWER. 2002. The effect of salinity and sodicity upon nodulation and nitrogen fixation in chickpea (Cicer arietinum). Annals of Bot. 89: 563-570.
- RAO, G.G. and M.K. KHANDELWAL. 2001. Performance of Ber (Zizyphus mauritiana) and pomegranate (Punica granatum) on sandy loam saline and saline black soils. Ind. J. Soil Cons. 29 (1): 59-64.
- REJILI, M., A.M. VADEL, A. GUETET and M. NEFFATTI. 2007. Effect of NaCl on the growth and the ionic balance Na^+/K^+ of two populations of Liotus creticus L. (Papilionaceae). South African J. Bot. 73: 623-631.
- RENGASAMY, P. 2006. World salinization with emphasis on Australia. J. Exptal Bot. Salinity Special Issue. P. 1-7.

- SAIRAM, R.K. and D.C. SAXENA. 2000. Oxidative stress and antioxidants in wheat genotypes: possible mechanism of water stress tolerance, J. Agron. Crop Sci. 184: 55–61.
- SAMENI, A.M. and A. MORSHEDI. 2000. Hydraulic conductivity of calcareous soils as affected by salinity and sodicity. II. Effect of gypsum application and flow rate of leaching solution carbohydrate pol. Soil Sci. Plant Anal. 31: 69-80.
- SHANI, U., L.M. DUDLEY. 2001. Field studies of crop response to water and salt stress. Soil Sci. Soc. Am. J. 65: 1522 – 1528.
- SHARMA, S.K. 1986. Mechanism of tolerance in rice varieties differing in sodicity tolerance. Plant and Soil. 93: 141-145.
- Sifola, M.I. and L. Postiglione. 2002. The Effect of increasing NaCl in irrigation water on growth, gas exchange and yield of tobacco Burley type. Field Crops Res. 74 (1): 81-91.
- SINGH G., J.K. BHIST, N. T.SINGH, J.C. DAGAR and G. SINGH. 1998. Evaluation of fruit plants for sodicity tolerance. Range Management and Agro-Forestry. 19 (1): 87-91.
- SINGH, A.K and R.K. PATHAK. 1992. Sodicity and salinity effects on guava (Psidium guajava). Ind. J. Agric. Sci. 62 (3): 220-223.
- SINGH, A.K and R.K. PATHAK. 1994. Effect of salinity levels on nutrient status and chlorophyll content in guava leaves. Orissa J. Hort. 22 (1-2): 31-35.
- SINGH, G., J.C. DOGAR and N.T.SINGH.1997. Growing fruit trees in highly alkali soils - A case study. Land Degradation and Development. 8 (3): 257-268.
- SREENIVASULU, N., B. GRIMM, U. WOBUS and W. WESCHKE. 2000. Differential response of antioxidant compounds to salinity stress in salt-tolerant and salt-sensitive seedlings of foxtail millet (Setaria italica). Physiol. Plant 109: 435–444.
- STANGER, G. 1985. Coastal salinization: A case history from Oman. Agric Water Manage. 9: 269-286.
- STEWART, E. A., H.M. GRIMSHAW and A. JOHN. 1974. Chemical analysis of ecological materials. Allen Parkinson and Christopher Quarmby. Edited by Stewart, E. A. Black Well Scientific Publications. p.565.
- TEJERA, N.A., M.SOUSSI and C. LLUCH. 2006. Physiological and nutritional indicators of tolerance to salinity in chickpea plants growing under symbiotic conditions. Env. Exptal Bot. 58: 17-24.

- TRIPLER, E., A. BEN-GAL and U. SHANI. 2007. Consequence of salinity and excess boron on growth, evapotranspiration and ion uptake in date palm (Phoenix dactylifera L., cv. Medjool). Plant Soil. 297: 147-155.
- U.S. SALINITY LAB. STAFF. 1954. Diagnosis and improvement of saline and alkali soils. USDA Hand Book No. 60, US Govt. Printing Office, Washington, D.C.
- UDVARI, M.K., K KAKAR, M. WANDREY, O. MONTANARI, J. MURRAY, A. ANDRIANKAJA, J.Y. ZHANG, V. BENEDITO, J.M.I. HOFER., F. CHUENG and C.D. TOWN. 2007. Legume Transcription Factors: Global Regulators of Plant Development and Response to the Env. Plant Phys. 144: 538-549.
- VAN HOORN, J.W., N. KATERJI, A HAMDY and M. MASTRORILLI. 2001. Effect of salinity on yield and nitrogen uptake of four grain legumes and on biological nitrogen contribution from the soil. Agri. Water Mangt.51: 87-98.
- VERMA, L.P., S. ROOM and P.N. DWIVEDI. 1994. Changes in properties of the salt affected soils under different fruit species. J. Ind. Soc. Soil Sci. 42 (1): 141-142.
- WANG, L., Y. LIU, K. MA, J. WANG, X. LIU, L.J. WANG, Y.L. LIU,K. MA, J.Z. WANG and X.N. LIU. 1998. Effects of NaCl treatment on free radical metabolism of fig (Ficus carica) Adv. Hort. (2): 235-241.
- WANG, L., Y. LIU, K. MA, J. WANG, X. LIU, L. J. WANG, Y. L. LIU, K. MA, J. Z. WANG and XIE, Z.K., Y. WAN and F. M. LI. 2005. Effect of plastic mulching on soil and water use and spring wheat yield in arid region of North West China. Agri. Water Mangt. 75: 71–83.
- YOUNIS, M.E. and D.M.A. EL-BIALY. 2008. Plant growth, metabolism and adaptation in relation to stress conditions: Further studies supporting nullification of harmful effects of salinity in lettuce plants by urea treatment. Plant Soil Env. 54 (3): 123 –131.
- YOUSSEF, T. and M.A. AWAD. 2008. Mechanisms of enhancing photosynthetic gas exchange in date palm seedlings (Phoenix dactylifera L.) under salinity stress by a 5-aminolevulinic acid-based fertilizer, J. Plant Growth Regul. 27: 1–9.

APPENDICES TO DATA TABLES: ANALYSIS OF VARIANCE TABLES

Experiment 1: Screening of date palm varieties for tolerance to water salinity

Two Factorial Completely Randomized Block Design
Replication (Variable 1: Replications 4)
Factor A (Variable 2: EC of irrigation water 6 levels)
Factor B (Variable 3: Varieties 3)

Appendix to table 4.1: Effect of water salinity on increase of trunk height (cm) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	991.0413	198.2088	115.3212	0.000
Factor B	2	101.3538	50.6775	29.4848	0.000
AB	10	216.7713	21.6775	12.6122	0.003
Error	47	99	1.78475		
Total	71	1432.916			

Coefficient of Variation: 12.49%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	3065.139	613.0275	119.5612	0.000
Factor B	2	869.41	434.705	84.7822	0.000
AB	10	259.2013	25.92	5.0554	0.0202
Error	47	295.333	5.324396		
Total	71	295.333			

Coefficient of Variation: 9.86%

Appendix to table 4.2: Water salinity effect on increasing number of fronds (Per plant) of date palm (Expt. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	259.445	51.88875	66.9134	0.000
Factor B	2	2.63875	1.32	1.7014	
AB	10	26.25	2.625	3.385	0.1206
Error	47	44.667	0.805409		
Total	71	344.1663			

Coefficient of Variation: 10.55%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	1218.889	243.7775	198.7018	0.000
Factor B	2	23.88875	11.945	9.7358	0.0135
AB	10	76.38875	7.63875	6.2264	0.0059
Error	47	70.667	1.273987		
Total	71	1407.5			

Coefficient of Variation: 6.67%

Appendix to table 4.3: Effect of water salinity on leaf length (cm) of date palm (Expt. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	5621.764	1124.353	35.6488	0
Factor B	2	327.835	163.9175	5.1972	0.0883
AB	10	378.86	37.88625	1.2012	
Error	47	1816.687	32.75114		
Total	71	8599.318			

Coefficient of Variation: 15.76%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	13738.42	2747.684	11.2538	0.0006
Factor B	2	4699.128	2349.564	9.6232	0.0141
AB	10	7628.28	762.8275	3.1244	0.1581
Error	47	14063.43	253.5325		
Total	71	43645.11			

Coefficient of Variation: 16.03%

Appendix to tale 4.4: Effect of water salinity on increase of trunk girth (cm) of date palm

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	143.3538	28.67125	35.2366	0.000
Factor B	2	6.72125	3.36	4.1302	0.1416
AB	10	29.54125	2.95375	3.6308	0.0931
Error	47	46.867	0.844998		
Total	71	238.2			

Coefficient of Variation: 12.11%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Probability
Factor A	5	13738.42	2747.684	11.2538	0.0006
Factor B	2	4699.128	2349.564	9.6232	0.0141
AB	10	7628.28	762.8275	3.1244	0.1581
Error	47	14063.43	253.5325		
Total	71	43645.11			

Coefficient of Variation: 9.34%

Appendix to table 4.7: Effect of water salinity on leaf Na (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.41375	0.0825	31.2266	0.000
Factor B	2	0.03875	0.01875	2.2286	0.371
AB	10	0.04375	0.005	1.658	
Error	47	0.153	0.002596		
Total	71	0.6875			

Coefficient of Variation: 20.89%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.04	0.0075	14.799	0.0001
Factor B	2	0.00125	0.00125	1.396	
AB	10	0.025	0.0025	2.6406	0.3015
Error	47	0.031	0.000649		
Total	71	0.105			

Coefficient of Variation: 10.73%

Appendix to table 4.8: Effect of water salinity on leaf K (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.2225	0.045	4.2726	0.0833
Factor B	2	0.1375	0.06875	6.5944	0.0484
AB	10	0.10875	0.01125	1.0468	
Error	47	0.598	0.011033		
Total	71	1.21625			

Coefficient of Variation: 6.97%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.23	0.04625	5.0228	0.0475
Factor B	2	0.24625	0.12375	13.4684	0.0033
AB	10	0.27375	0.0275	2.9874	0.1819
Error	47	0.527	0.009735		
Total	71	1.4075			

Coefficient of Variation: 7.39%

Appendix to table 4.9: Effect of water salinity on leaf Ca (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.073	0.015	3.1994	0.0458
Factor B	2	0.015	0.007	1.1046	0.3423
AB	10	0.039	0.004	0.5836	
Error	47	0.238	0.007		
Total	71	0.365			

Coefficient of Variation: 20.17

Year (2008)

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.02625	0.005	1.925	
Factor B	2	0.01125	0.00625	2.0924	0.3617
AB	10	0.10625	0.01125	3.9	0.0699
Error	47	0.157	0.002596		
Total	71	0.34125			

Coefficient of Variation: 19.02%

Appendix to table 4.10: Effect of water salinity on leaf Mg (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.23375	0.04625	3.6932	0.1284
Factor B	2	0	0	0.0032	
AB	10	0.34625	0.035	2.7388	0.2335
Error	47	0.728	0.01298		
Total	71	1.4875			

Coefficient of Variation: 17.54%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.1	0.02	16.1798	0.000
Factor B	2	0.0775	0.03875	31.163	0.000
AB	10	0.05625	0.005	4.5472	0.0349
Error	47	0.071	0.001298		
Total	71	0.3225			

Coefficient of Variation: 16.07%

Appendix to table 4.11: Effect of water salinity on leaf N (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.29375	0.05875	6.1216	0.0211
Factor B	2	0.3475	0.17375	18.0472	0.0007
AB	10	0.275	0.0275	2.8638	0.2061
Error	47	0.554	0.009735		
Total	71	1.60875			

Coefficient of Variation: 8.75%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.1375	0.0275	2.7264	0.261
Factor B	2	0.19125	0.095	9.4712	0.0149
AB	10	0.22875	0.0225	2.2712	0.3642
Error	47	0.58	0.010384		
Total	71	1.28125			

Coefficient of Variation: 8.51%

Appendix to table 4.12: Effect of water salinity on leaf P (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.00103	0.00125	1.3658	0.4601
Factor B	2	0	0	2.3902	0.3144
AB	10	0.00125	0	2.039	0.4468
Error	47	0.003	0		
Total	71	0.01125			

Coefficient of Variation: 19.21%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.005	0.00125	8.6924	0.0034
Factor B	2	0.00125	0	2.8528	0.2534
AB	10	0	0	0.3468	
Error	47	0.007	0		
Total	71	0.015			

Coefficient of Variation: 16.16%

Appendix to table 4.13: Effect of water salinity on leaf Cl (%) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.2	0.04	1.458	
Factor B	2	0.08	0.04	1.4656	
AB	10	0.27	0.0275	0.9834	
Error	47	1.58	0.028556		
Total	71	2.525			

Coefficient of Variation: 9.21%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.07125	0.01375	1.8535	0.2137
Factor B	2	0.01625	0.00875	3.6466	0.1761
AB	10	0.30125	0.03	3.0292	0.13
Error	47	0.133	0.002596		
Total	71	0.555			

Coefficient of Variation: 7.91%

Appendix to table 4.15: Effect of water salinity on soil EC (dS m^{-1}) (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	325.745	63.34875	19.342	0.000
Factor B	2	34.445	14.7225	4.6996	0.1463
AB	10	63.66625	5.43219	2.4824	0.31290
Error	47	142.366	2.746568		
Total	71	604.3125			

Coefficient of Variation 9.12%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	316.745	63.03426	23.9484	0.000
Factor B	2	35.445	17.7225	3.06354	0.1143
AB	10	65.66625	6.56625	1.9912	0.2993
Error	47	152.366	1.82193		
Total	71	608.3125			

Coefficient of Variation 7.02%

Appendix to table 4.16: Effect of water salinity on soil pH (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.019	0.00375	27.0674	0.000
Factor B	2	0	0	3.9288	0.05378
AB	10	0.004931	0.00125	0.7409	
Error	47	0.009	0		
Total	71	0.032931			

Coefficient of Variation: 1.41%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	9.89875	1.18	173.405	0.000
Factor B	2	0.0175	0.00752	0.9137	
AB	10	0.1625	0.02001	2.1037	0.19329
Error	47	0.421	0.007612		
Total	71	11.611			

Coefficient of Variation: 2.73%

Appendix to table 4.18: Effect of water salinity on leaf Na/ K (ratio) of date palm (Exp. 1)

Year 2007

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.02	0.004183	33.0674	0.000
Factor B	2	0	0	5.9288	0.0423
AB	10	0.00625	0.00112	0.6142	
Error	47	0.01	0		
Total	71	0.03875			

Coefficient of Variation: 11.02%

Year 2008

Source	Degrees of Freedom	Sum of Square	Mean Square	F Value	Prob.
Factor A	5	0.019	0.00375	27.0674	0.000
Factor B	2	0	0	3.9288	0.04378
AB	10	0.004931	0.00125	0.7409	
Error	47	0.009	0		
Total	71	0.032931			

Coefficient of Variation: 9.74%

Experiment No. 2: Managing saline water for growing date palm

Three Factorial Completely Randomized Block Design
Replication (Variable 1: Replications 4)
Factor A (Variable 2: EC of irrigation water 2 levels)
Factor B (Variable 3: Leaching fractions 3 levels)
Factor C (Variable 4: Organic matter 2 levels)

Table 4.19: Effect of water salinity management techniques on trunk height of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	90.3125	90.3125	19.7046	0.0014
4	Factor B	2	30.955	15.4775	3.37695	0.127
6	AB	2	95.0525	47.52625	10.36935	0.0043
8	Factor C	1	300.3125	300.3125	65.5227	0.000
10	AC	1	5.8675	5.8675	1.28025	
12	BC	2	12.5525	6.27625	1.36935	
14	ABC	2	8.66375	4.33125	0.94515	
15-	Error	36	132	3.3	-	
	Total	47	708.715	-	-	

Coefficient of Variation: 0.0824

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	52.8125	52.8125	53.05815	0.00
4	Factor B	2	61.945	30.9725	31.1163	0.00
6	AB	2	85.83375	42.91625	43.1163	0.00
8	Factor C	1	5.8675	5.8675	5.8953	0.059
10	AC	1	10.035	10.035	10.08135	0.016
12	BC	2	63.61125	31.805	31.95345	0.00
14	ABC	2	63.61125	31.805	31.95345	0.00
-15	Error	36	28.667	0.7164		
	Total	47	379.5488			

Appendix to table 4.20: Effect of water salinity management techniques on number of fronds (per plant) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.035	0.035	0.03495	
4	Factor B	2	3.4025	1.70125	1.70925	0.3367
6	AB	2	8.82	4.41	4.43025	0.0713
8	Factor C	1	4.20125	4.20125	4.221	0.1064
10	AC	1	4.20125	4.20125	4.221	0.1064
12	BC	2	0.48625	0.2425	0.2442	
14	ABC	2	5.07	2.535	2.54655	0.2044
15	Error	36	28.667	0.7164		
	Total	47	62.04875			

Coefficient of Variation: 0.0888

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	23.4725	23.4725	53.36835	0.00
4	Factor B	2	15.07	7.535	17.13165	0.0003
6	AB	2	15.48625	7.7425	17.6052	0.0003
8	Factor C	1	27.2225	27.2225	61.8948	0.00
10	AC	1	0.555	0.555	1.26315	
12	BC	2	19.23625	9.6175	21.86835	0.0001
14	ABC	2	19.6525	9.82625	22.34205	0.0001
-15	Error	36	12.667	0.3168		
	Total	47	136.5275			

Coefficient of Variation: 0.0306

Appendix to table 4.21: Effect of water salinity management techniques on trunk girth (cm) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	5.77875	5.77875	15.7884	0.0034
4	Factor B	2	4.60875	2.30375	6.29595	0.0273
6	AB	2	2.50875	1.25375	3.4269	0.1235
8	Factor C	1	3.975	3.975	10.8624	0.0128
10	AC	1	0.9025	0.9025	2.4678	0.2119
12	BC	2	6.01125	3.005	8.2125	0.011
14	ABC	2	4.825	2.4125	6.59205	0.0236
15-	Error	36	10.54	0.2634		
	Total	47	41.785			

Coefficient of Variation: 0.0658

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	32.3	32.3	52.3593	0.00
4	Factor B	2	20.31125	10.155	16.46235	0.0004
6	AB	2	31.38625	15.6925	25.43865	0.00
8	Factor C	1	60.37875	60.37875	97.87365	0.00
10	AC	1	1.05	1.05	1.70265	0.2973
12	BC	2	12.10875	6.05375	9.8139	0.0054
14	ABC	2	18.7525	9.37625	15.1992	0.0006
-15	Error	36	17.767	0.444		
	Total	47	198.495			

Coefficient of Variation: 0.0338

Appendix to table 4.22: Effect of water salinity management techniques on leaf length (cm) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	99.57125	49.78625	1.67835	0.1181
4	Factor B	2	264.5463	132.2738	4.4592	0.0702
6	AB	2	177.9338	88.9675	2.99925	0.1573
8	Factor C	1	445.725	445.725	15.0264	0.0042
10	AC	1	342.3788	342.3788	11.54235	0.0105
12	BC	2	370.5175	370.5175	11.49095	0.03431
14	ABC	2	44.69	22.345	0.7533	
15-	Error	36	854.287	21.357		
	Total	47	2813.221			

Coefficient of Variation: 0.1025

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	1.55875	1.55875	0.19785	
4	Factor B	2	69.59625	34.79875	4.4187	0.0718
6	AB	2	48.68	24.34	3.09075	0.1493
8	Factor C	1	387.9338	387.9338	49.26	0.0001
10	AC	1	334.1525	334.1525	42.43095	0.0070
12	BC	2	45.68	21.34	3.08165	0.11060
14	ABC	2	2.815	1.4075	0.17865	
-15	Error	36	226.807	5.67		
	Total	47	1117.223			

Coefficient of Variation: 0.0212

Appendix to table 4.23: Effect of water salinity management techniques on leaf Na (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.04375	0.04375	12.6963	0.0077
4	Factor B	2	0.01	0.005	1.50105	0.3825
6	AB	2	0.03	0.015	4.30065	0.0765
8	Factor C	1	0	0	0.0648	
10	AC	1	0.00375	0.00375	6.91095	0.03256
12	BC	2	0.0075	0.00375	1.10625	
14	ABC	2	0.0025	0.00125	0.4038	
15-	Error	36	0.099	0.0024		
	Total	47	0.22			

Coefficient of Variation: 0.2431

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.04375	0.04375	12.6963	0.0077
4	Factor B	2	0.04185	0.04185	10.6963	0.03125
6	AB	2	0.03	0.015	4.30065	0.0765
8	Factor C	1	0.04125	0.04125	10.6963	0.0107
10	AC	1	0.00375	0.00375	6.91095	0.03256
12	BC	2	0.0075	0.00375	1.10625	
14	ABC	2	0.0025	0.00125	0.4038	
15-	Error	36	0.099	0.0024		
	Total	47	0.22			

Coefficient of Variation: 0.2151

Appendix to table 4.24: Effect of water salinity management techniques on leaf K (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.065	0.065	3.4658	0.0953
4	Factor B	2	0.005	0.0025	0.25335	
6	AB	2	0.03875	0.02	2.22	0.2477
8	Factor C	1	0.00375	0.00375	0.4872	
10	AC	1	0.03875	0.03875	4.3854	0.1002
12	BC	2	0.01	0.005	0.6066	
14	ABC	2	0.02375	0.0125	1.36395	
-15	Error	36	0.251	0.006		
	Total	47	0.47			

Coefficient of Variation: 0.0557

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	0.85875	
4	Factor B	2	0	0	0.1068	
6	AB	2	0.0125	0.00625	6.77865	0.09216
8	Factor C	1	0.00375	0.00375	3.66795	0.131
10	AC	1	0.04125	0.04125	5.34725	0.091
12	BC	2	0.0075	0.00375	4.3206	0.0756
14	ABC	2	0.0075	0.00375	4.09155	0.0856
-15	Error	36	0.026	0.0005		
	Total	47	0.07375			

Coefficient of Variation: 0.085

Appendix to table 4.25: Effect of water salinity management techniques on leaf Ca (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	0.1476	
4	Factor B	2	0.01625	0.00875	0.6699	
6	AB	2	0.04625	0.0225	1.8519	0.3088
8	Factor C	1	0.05125	0.05125	4.0851	0.1119
10	AC	1	0.02	0.02	1.65435	0.3041
12	BC	2	0.01625	0.0075	0.6465	
14	ABC	2	0.00625	0.0025	0.2481	
15-	Error	36	0.358	0.009		
	Total	47	0.60625			

Coefficient of Variation: 0.3247

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0	0	0.19995	
4	Factor B	2	0	0	0.15	
6	AB	2	0.00375	0.0025	1.84995	0.3091
8	Factor C	1	0.0075	0.0075	2.7	0.3842
10	AC	1	0.005	0.005	4.99995	0.0804
12	BC	2	0.0125	0.00625	4.935	0.0998
14	ABC	2	0.005	0.0025	2.44995	0.2162
-15	Error	36	0.032	0.0006		
	Total	47	0.07625			

Coefficient of Variation: 0.1095

Appendix to table 4.26: Effect of water salinity management techniques on leaf Mg (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.33	0.33	12.969	0.0071
4	Factor B	2	0.1025	0.05125	2.00655	0.2813
6	AB	2	0.36875	0.18375	7.25535	0.0172
8	Factor C	1	0.0975	0.0975	3.8586	0.1218
10	AC	1	0.02625	0.02625	1.01115	
12	BC	2	0.04375	0.02125	0.84945	
14	ABC	2	0.06	0.03	1.1838	
15-	Error	36	0.731	0.018		
	Total	47	1.94125			

Coefficient of Variation: 0.3904

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.15375	0.15375	68.90625	0.0001
4	Factor B	2	0.00375	0.00125	0.80625	
6	AB	2	0.0125	0.00625	2.925	0.1642
8	Factor C	1	0.055	0.055	24.80625	0.0004
10	AC	1	0.015	0.015	6.80625	0.0436
12	BC	2	0.0075	0.00375	1.70625	0.3373
14	ABC	2	0.01375	0.00625	3.05625	0.1523
-15	Error	36	0.064	0.032		
	Total	47	0.34125			

Coefficient of Variation: 0.57%

Appendix to table 4.27: Effect of water salinity management techniques on leaf Cl (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00375	0.00375	0.3855	
4	Factor B	2	0.015	0.0075	0.7467	
6	AB	2	0.06625	0.0325	3.34875	0.1291
8	Factor C	1	0.15625	0.0775	7.94685	0.0124
10	AC	1	0.06875	0.06875	7.0383	0.0405
12	BC	2	0.03625	0.03625	3.75585	0.1267
14	ABC	2	0.015	0.0075	0.7467	
-15	Error	36	0.282	0.006		
	Total	47	0.71375			

Coefficient of Variation: 9.31%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00375	0.00375	2.06505	0.2522
4	Factor B	2	0.015	0.0075	3.9993	0.09
6	AB	2	0.01375	0.00625	3.5898	0.1128
8	Factor C	1	0.025	0.025	3.201	0.1005
10	AC	1	0	0	0.0474	
12	BC	2	0.00375	0.00125	0.969	
14	ABC	2	0.0025	0.00125	0.58215	
-15	Error	36	0.053	0.0012		
	Total	47	0.12875			

Coefficient of Variation: 11.01%

Appendix to table 4.28: Effect of water salinity management techniques on leaf N (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.05	0.05	5.04795	0.079
4	Factor B	2	0.03375	0.0175	1.71765	0.335
6	AB	2	0.01375	0.0075	0.71085	
8	Factor C	1	0.01	0.01	1.02225	
10	AC	1	0.0975	0.0975	9.89385	0.0169
12	BC	2	0.02	0.01	0.9969	
14	ABC	2	0.1225	0.06125	6.18795	0.0288
15-	Error	36	0.285	0.0072		
	Total	47	0.705			

Coefficient of Variation: 0.0797

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.3575	0.3575	57.54345	0.00
4	Factor B	2	0.00375	0.00125	0.2619	
6	AB	2	0.0025	0.00125	0.15585	
8	Factor C	1	0.0125	0.0125	9.944	0.02662
10	AC	1	0.0725	0.0725	11.7414	0.01618
12	BC	2	0.1175	0.05875	2.43275	0.2564
14	ABC	2	0.02125	0.01	1.66245	0.3464
-15	Error	36	0.179	0.0042		
	Total	47	0.81			

Coefficient of Variation: 0.0588

Appendix to table 4.29: Effect of water salinity management techniques on leaf P (%) of date palm plants (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.0025	0.0025	30.1539	0.0002
4	Factor B	2	0	0	2.4231	0.2197
6	AB	2	0.0025	0.00125	3.57685	0.2908
8	Factor C	1	0.00125	0.00125	9.84615	0.0171
10	AC	1	0.0025	0.0025	25.99995	0.0003
12	BC	2	0.0025	0.00125	1.8077	0.1900
14	ABC	2	0.00125	0.00125	2.49995	0.3062
15-	Error	36	0.003	0		
	Total	47	0.01625			

Coefficient of Variation: 0.2153

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0	0	1.5639	0.13174
4	Factor B	2	0.00125	0	3.28725	0.1336
6	AB	2	0	0	0.9894	
8	Factor C	1	0	0	5.5851	0.02017
10	AC	1	0	0	0.28725	
12	BC	2	0.00125	0	3.7341	0.1041
14	ABC	2	0.0025	0.00125	2.71275	0.30088
-15	Error	36	0.003	0		
	Total	47	0.0075			

Coefficient of Variation: 0.1796

Appendix to table 4.30: Effect of water salinity management techniques on soil ECe (dS/m) (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	10.375	10.375	6.8682	0.0213
4	Factor B	1	25.32875	25.32875	5.78145	0.0535
6	AB	1	4.275	4.275	5.4759	0.03
16	Factor C	2	7.05875	3.52875	8.30565	0.01541
18	AC	2	7.03875	3.51875	12.80325	0.0041
20	BC	2	128.8325	64.41625	14.70375	0.0002
22	ABC	2	6.7025	8.85125	11.47695	0.009319
31	Error	36	378.514	2.6285		
	Total	47	568.1253			

Coefficient of Variation: 20.07%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	10.375	10.375	6.8682	0.0213
4	Factor B	1	25.32875	25.32875	5.78145	0.0535
6	AB	1	4.275	4.275	5.4759	0.03
16	Factor C	2	7.05875	3.52875	8.30565	0.01541
18	AC	2	7.03875	3.51875	12.80325	0.0041
20	BC	2	128.8325	64.41625	14.70375	0.0002
22	ABC	2	2.7025	2.85125	3.47695	0.1319
-31	Error	36	378.514	2.6285		
	Total	47	557.7538			

Coefficient of Variation: 12.07%

Appendix to table 4.31: Effect of water salinity management techniques on soil pH (Exp. 2)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	4.66875	4.66875	2.09069	0.14213
4	Factor B	1	11.39794	11.39794	2.901653	0.21535
6	AB	1	1.92375	1.92375	2.764155	0.19324
16	Factor C	2	3.176438	1.587938	3.037543	0.12541
18	AC	2	3.167438	1.583438	5.216146	0.0741
20	BC	2	57.97463	28.98731	6.616688	0.1102
22	ABC	2	2.7123	1.283063	1.325628	0.1319
-31	Error	36	170.3313			
	Total	47	255.3525			

Coefficient of Variation: 3.07%

Appendix to table 4.32: Effect of water salinity on soil pH at the end of Experiment -2 (2008)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	3.86563	4.66875	3.09069	0.1213
4	Factor B	1	9.36384	11.39794	2.601653	0.1535
6	AB	1	1.72875	1.92375	2.464155	0.093
16	Factor C	2	2.91365	1.587938	3.737543	0.12541
18	AC	2	3.20158	1.583438	5.761463	0.0741
20	BC	2	54.8746	28.98731	6.616688	0.1102
22	ABC	2	2.52932	1.283063	1.564628	0.1319
-31	Error	36	168.361			
	Total	47	246.8384			

Coefficient of Variation: 4.03%

Experiment No. 3: Nitrogen fertilizer requirements of date palm at early stage when irrigated with saline water

Two Factorial Completely Randomized Block Design
Replications (Variable 1: Replications 4)
Factor A (Variable 2: EC of irrigation water 2 levels)
Factor B (Variable 3: N fertilizer levels 5)

Appendix to table 4.35: Effect of N application on increase of trunk height (cm) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	33.48125	20.98125	4.164	0.3219
4	Factor B	4	41.03125	22.7575	2.2596	0.6035
6	AB	4	24.96375	12.49125	4.75785	0.0901
-7	Error	30	53.693	1.611		
	Total	39	166.5925			

Coefficient of Variation: 7.14%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	FactorA	1	6.51	6.51	0.82605	
4	FactorB	4	19.0625	4.76625	0.60465	
6	AB	4	129.8963	32.47375	2.62005	0.087
-7	Error	30	189.167	5.6748		
	Total	39	391.9275			

Coefficient of Variation: 6.98%

Appendix to table 4.36: Effect of N application on increase in number of fronds of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	1.04125	1.04125	1.56255	0.3196
4	Factor B	4	6.25	1.5625	2.34375	0.2229
6	AB	4	5.41625	1.35375	2.0313	0.285
-7	Error	30	16	0.48		
	Total	39	32.7075			

Coefficient of Variation: 6.03%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.04125	0.04125	0.02205	
4	Factor B	4	41.66625	10.41625	5.51475	0.0212
6	AB	4	11	2.75	1.4559	
-7	Error	30	45.333	1.3602		
	Total	39	109.3738			

Coefficient of Variation: 5.47%

Appendix to table 4.37: Effect of N application on increase in leaf length (cm) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	23.20625	23.20625	0.95985	
4	Factor B	4	331.7025	82.925	3.4296	0.0958
6	AB	4	277.8138	69.45375	2.8725	0.1473
-7	Error	30	580.3	17.409		
	Total	39	1358.098			

Coefficient of Variation: 7.38%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	20.72	20.72	0.6897	
4	Factor B	4	372.9188	93.23	3.1035	0.1231
6	AB	4	462.7813	115.695	3.85125	0.0696
-7	Error	30	720.973	21.6294		
	Total	39	1757.636			

Coefficient of Variation: 3.72%

Appendix to table 4.38: Effect of N application on increase in trunk girth (cm) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	4.25	4.25	6.0648	0.068
4	Factor B	4	1.5525	0.38875	0.5538	
6	AB	4	8.43125	2.1075	3.0075	0.1326
-7	Error	30	16.82	0.5046		
	Total	39	35.25875			

Coefficient of Variation: 8.18%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	3.75	7.75	5.0648	0.0736
4	Factor B	4	1.5525	0.38875	8.5538	0.0151
6	AB	4	7.4575	1.1921	2.3275	0.1326
-7	Error	30	17.72	0.5046		
	Total	39	30.48			

Coefficient of Variation: 8.18%

Appendix to table 4.39: Effect of N application on leaf Na (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0	0	0.5193	
4	Factor B	4	0	0	0.63465	
6	AB	4	0.00125	0	2.13465	0.275
-7	Error	30	0.002	0		
	Total	39	0.00375			

Coefficient of Variation: 14.03%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0	0	2.5851	0.2041
4	Factor B	4	0.625125	0.375	5.4255	0.0209
6	AB	4	0.00125	0	1.46805	
-7	Error	30	0.003	0		
	Total	39	0.630125			

Coefficient of Variation: 17.15%

Appendix to table 4.40: Effect of N application on leaf K (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.015	0.015	1.4211	
4	Factor B	4	0.0775	0.02	1.83555	0.3322
6	AB	4	0.03125	0.0075	0.7302	
-7	Error	30	0.253	0.0078		
	Total	39	0.44			

Coefficient of Variation: 7.71%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00625	0.00625	0.9771	
4	Factor B	4	0.0475	0.01125	1.81095	0.3387
6	AB	4	0.06875	0.0175	2.628	0.1783
-7	Error	30	0.156	0.0048		
	Total	39	0.3175			

Coefficient of Variation: 5.51%

Appendix to table 4.41: Effect of N application on leaf Na/ K of date palm plants when irrigated with saline water (Exp. 3)

Year (2007)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	FactorA	1	0	0	0.6729	
4	FactorB	4	0.00625	0.00125	1.80375	0.3406
6	AB	4	0.0025	0.00125	0.8598	
-7	Error	30	0.021	0.0006		
	Total	39	0.035			

Coefficient of Variation: 17.72%

Appendix to table 4.42: Effect of N application on leaf Ca (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	0.17625	
4	Factor B	4	0.01125	0.0025	0.6264	
6	AB	4	0.00375	0.00125	0.2055	
-7	Error	30	0.111	0.0036		
	Total	39	0.155			

Coefficient of Variation: 16.89%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.02625	0.02625	20.68965	0.0014
4	Factor B	4	0.00875	0.0025	1.7328	0.3599
6	AB	4	0.025	0.00625	1.78455	0.4352
-7	Error	30	0.031	0.0012		
	Total	39	0.09875			

Coefficient of Variation: 14.9%

Appendix to table 4.43: Effect of N application on leaf Mg (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.26	0.26	8.5714	0.12432
4	Factor B	4	0.05875	0.015	3.0971	0.30463
6	AB	4	0.005	0.00125	0.91425	
-7	Error	30	0.035	0.0012		
	Total	39	0.3675			

Coefficient of Variation: 17.9%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.26	0.26	178.5714	0.000
4	Factor B	4	0.05875	0.015	10.0971	0.0013
6	AB	4	0.005	0.00125	0.91425	
-7	Error	30	0.035	0.0012		
	Total	39	0.3675			

Coefficient of Variation: 19.3%

Appendix to table 4.44: Effect of N application on leaf Cl (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	0.2022	
4	Factor B	4	0.01625	0.00375	0.62505	
6	AB	4	0.06125	0.015	2.3244	0.2263
-7	Error	30	0.157	0.0048		
	Total	39	0.275			

Coefficient of Variation: 5.08%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.02625	0.02625	8.38095	0.0283
4	Factor B	4	0.00875	0.0025	0.6882	
6	AB	4	0.06125	0.015	1.96665	0.331
-7	Error	30	0.074	0.0024		
	Total	39	0.18875			

Coefficient of Variation: 5.08%

Appendix to table 4.45: Effect of N application on leaf N (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Valu	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.17875	0.17875	4.78545	0.0892
4	Factor B	4	0.61	0.1525	4.08975	0.0533
6	AB	4	0.2775	0.07	1.8627	0.3252
-7	Error	30	0.895	0.027		
	Total	39	2.185			

Coefficient of Variation: 15.57%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.04125	0.04125	3.12495	0.1644
4	Factor B	4	0.56	0.14	10.5	0.0011
6	AB	4	0.14125	0.035	2.6562	0.1744
-7	Error	30	0.32	0.0096		
	Total	39	1.1425			

Coefficient of Variation: 10.09%

Appendix to table 4.46: Effect of N application on leaf P (%) of date palm plants when irrigated with saline water (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	5.84745	0.0787
4	Factor B	4	0.00125	0	1.99575	0.293
6	AB	4	0	0	0.6738	
-7	Error	30	0.004	0		
	Total	39	0.0075			

Coefficient of Variation: 15.35%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0	0	0.4341	
4	Factor B	4	0.00625	0.00125	24.2352	0
6	AB	4	0.00125	0	2.85285	0.1168
-7	Error	30	0.002	0		
	Total	39	0.01			

Coefficient of Variation: 14.83%

Appendix to table 4.47: Effect of N application on soil EC (dS/m) (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	11.06125	2.765	1.36665	
8	Factor B	4	186.63	186.63	92.2308	0
10	AB	4	20.6975	5.175	2.5572	0.168
-15	Error	30	97.129	1.4568		
	Total	39	339.8			

Coefficient of Variation: 19.87%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	11.7375	2.935	0.9207	
8	Factor C	4	140.17	140.17	43.9809	0
10	AC	4	26.09375	6.52375	2.0469	0.257
-15	Error	30	229.468	2.2944		
	Total	39	464.8363			

Coefficient of Variation: 16.32%

Appendix to table 4.48: Effect of N application on soil pH at the end of (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.0475	0.01875	2.74845	0.2109
8	Factor B	4	0.08	0.08675	3.04575	0.12
10	AB	4	0.02	0.005	3.1527	0.103
-15	Error	30	1.093	0.0162		
	Total	39	1.51375			

Coefficient of Variation: 2.05%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.5875	0.45875	2.15835	0.2021
8	Factor B	4	0.10875	0.10875	5.1354	0.0692
10	AB	4	0.03125	0.051325	1.76535	0.1004
-15	Error	30	1.527	0.015		
	Total	39	2.63625			

Coefficient of Variation: 2.02%

Appendix to table 4.49: Effect of N application on soil N (Exp. 3)

Year 2007

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0	1.53165	0.4082
8	Factor B	4	0	0	0.01695	
10	AB	4	0.00125	0	2.26275	0.218
-15	Error	30	0.006	0		
	Total	39	0.01			

Coefficient of Variation: 17.68%

Year 2008

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
2	Factor A	1	0.00125	0.00125	0.1029	
4	Factor B	4	0.33875	0.085	10.6794	0.001
6	AB	4	0.01625	0.00375	0.4929	
-7	Error	30	0.19	0.006		
	Total	39	0.59375			

Coefficient of Variation: 7.79%

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