SALT TOLERANCE AND CURRENT STATUS OF THE DATE PALMS IN THE UNITED ARAB EMIRATES

By

Mohamed Salman Al Hammadi

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As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Mohamed Salman Al Hammadi

entitled Salt Tolerance and Current Status of the Date Palms in the United Arab Emirates

and recommend that it be accepted as fulfilling the dissertation requirement for the

Degree of: Doctor of Philosophy

____ Date: April 3rd, 2006
Edward P. Glenn

____ Date: April 3rd, 2006
James J. Riley

____ Date: April 3rd, 2006
David Hendricks

____ Date: April 3rd, 2006
James L. Walworth

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

____ Date: April 3rd, 2006
Dissertation Director: Edward P. Glenn

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SIGNED: *Mohamed Salman Al Hammadi*

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DEDICATION

To the late president of the UAE, His Highness Sheikh Zayed Bin Sultan Al Nahyan, who was a great leader with a broad vision. Who made huge agricultural efforts, not only in the UAE, but in other developing countries and who was behind the date palm tree development in the UAE. To his soul I dedicate my work, May Allah the almighty rest his soul in peace and bestow mercy on him

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ABSTRACT

This study aimed to address the current status of the United Arab Emirates date palms. The first chapter focused on the development of the date palm sector in the UAE. A huge increase in the date palm number was achieved in the past few decades. In the same time, there are critical issues facing this development, such as water demand, salinity, and Red Palm Weevil. The second chapter is a greenhouse experiment to test the growth of twelve date palm seeds at four NaCl levels, control, 3000, 6000, and 12000 ppm. Optimal growth found at control and 3000 ppm of NaCl. Relative growth rate (RGR), biomass, and NL decreased significantly by increasing salinity; 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. Na:K ratios were lower in shoots than in roots. Lulu, Fard, Khnaizi, Nabtat Safi, and Razez cultivars showed higher RGR and biomasses whereas Khnaizi, Mesally, and Safri had higher Na:K ratios than other cultivars in the control indicating higher Na^+ 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.

INTRODUCTION

The main source of water for agriculture in the Middle Eastern countries and the UAE is groundwater. The limited precipitation and the huge increase in the area of agricultural land have put pressure on groundwater usage; resulting in increased salinity which poses a serious threat. As a consequence, about 25% of the UAE's land is now influenced by salinity. The salinity of groundwater in most farm wells ranges between 11000-13000 ppm and, in some cases, it has reached 17000 ppm (Dakheel, 2005). Irrigating with this water causes salts to be deposited on the soil surface following water evaporation. This is causing a serious problem with agriculture in the northern and eastern regions of the UAE. If appropriate action is not taken to solve the present water issues, the groundwater shortage and further degradation of its quality, will cause greater problems for the agricultural sector.

Agricultural demand for fresh water in this region is growing. According to Abdullah and Hasbini (2004), agriculture water use increased more than 87% in seven years from 800 million m^3 in 1990 to 1500 million m^3 in 1997, and reached 1,800 million m^3 for the year 2000. Overdrawing of ground water has resulted in the reduction of ground water level and increased salinity. The consequences are that in the most severe cases, farmers have deserted their croplands. The Environmental Research and Wildlife Development Agency of the UAE (ERWDA, 2002) reported that only about 7-8% of the current ground water supply is fresh and the remained is brackish water. An intense water demand that exceeds annual ground water recharge causes seawater intrusion into coastal aquifers and the upward flow of brackish and saline water supplies from lower aquifers

(Abdullah and Hasbini, 2004). This results in an increase in ground water salinity, especially in the eastern region.

The date palm is a halophytic plant that can tolerate high levels of salinity. In the United Arab Emirates (UAE) and most of the Middle Eastern countries, the date palm is the oldest and most widely cultivated tree that is commercially the most important tree in the life of its people and their heritage. The importance of the date palm occurs because the production of other fruit trees is limited in the harsh environment. In fact, it is more salt tolerant than any other fruit crop (FAO, 1982). Furthermore, some varieties can tolerate salinity levels up to 22000 ppm (EC 34 dS m^{-1}). However, their growth and yield productivity are affected (Erskine et al., 2004), where the yield decreased 50% at 11500 ppm and 100% at 20500 ppm (18-32 dS m^{-1}) (Klein and Zaid, 2002).

PRESENT STUDY

The methods, results, and conclusions of this study are presented in the chapters appended to this dissertation. The following is a summary of the most important findings in this document.

I. Summary

Specific objectives and summaries are outlined for the three chapters as follows:

Chapter 1: The Status of Date Palms (*phoenix dactylifera*) in the United Arab Emirates.

The objective is to address the current status of the date palm tree in the United Arab Emirates. This included the impotence of the date palm tree in the life of the UAE's people, its total cultivated area and production in the past few decades, and the efforts made to this sector. Furthermore, this chapter focused on some critical issues facing the date palm, such as water demand, salinity, and Red Palm Weevil. The UAE carries out massive efforts and invested heavily to develop the date palm sector. This is obvious in the sustained growth of the number and varieties of date palm trees every year.

Chapter 2: Effect of Salinity on Growth of Twelve Cultivars of the United Arab Emirates Date Palm (*Phoenix dactylifera*).

The objective is to test the growth ability of twelve cultivars of date palm seeds under four levels of saline water. More information regarding the response of salt tolerant plants to saline environments will be useful for future studies and breeding programs using saline water. Plants that tolerate high salinities are limited in number and economic importance. Little is known regarding the variability of salt tolerance among cultivars of date palms. Interspecies variability in salt tolerance is needed to start a breeding program to improve salt tolerance.

Chapter 3: Detecting Date Palm Trees Health and Vegetation Greenness Change in the Eastern Coast of the United Arab Emirates Using SAVI.

The objective of this study is to: (1) detect the vegetation greenness change during the past two decades in the Eastern Coastal region of the UAE using the SAVI differencing; (2) examine the potential of using remote sensing tools to detect the health of date palm trees, grown in a saline environment, using the SAVI; (3) evaluate the spatial resolution limitations of using TM/ETM+ in studying spectral change in date palm trees.

II. Conclusion

Date palms play a very important role in the life of most people in the UAE and Middle East countries. However, chapter one addressed that more scientific attention is needed regarding the current condition of the date palm trees grown under dry saline environments. In addition, further research is required to identify differences in salinity tolerance between date palm varieties, and thus start new breeding programs. The UAE has made a tremendous investment in the date palm sector and the overall agricultural aspect, including a tissue culture program, desertification control, increasing date palm numbers, and finding fresh water resources for agricultural uses. However, less attention has been paid to the pest infestation of the date palms.

The results of chapter two found that date palm seedlings grew best in the control and with 3000 ppm of NaCl and were most inhibited at 12000 ppm. Plants were able to survive at 12000 ppm of NaCl regardless of their growth performance and some plants did not show signs of nutrient imbalances. In general, salinity can reduce plant growth through osmotic effects, toxicity of ions, nutrient uptake imbalance, or a combination of these factors. The current study indicates that there are differences in salt tolerance between date palm cultivars, which appear to be related to the salt exclusion mechanisms by the root parts (Greenway and Munns 1980), resulting in reduced Na^+ translocation to the shoots. Khnaizi, Lulu, Nabtat Safi, and Razez cultivars showed greatest growth parameters and Na:K ratios that indicates higher sodium discriminations from plant parts than other cultivars. This could make them good candidates for a breeding program. Other cultivars, such as Mesally, Safri and Shishi may have potential for salt tolerance.

The results of chapter three showed that during a period of 13 years from 1987 to 2000, considerable change in vegetation greenness, conditions and health occurred in the eastern region of the UAE due to the salinization of groundwater. Results from SAVI difference images demonstrated that the eastern region of the UAE had experienced serious change to its vegetation cover. Although the official census data show an overall increase in agricultural land areas, the condition and the yield of vegetation generally decreased. An inverse relationship was found between the SAVI values and the date palm health grown in saline environment. It is possible that some factors, such as tree spacing and small vegetation grown under and between date palm trees, are confounding these results, especially when vegetation index measures the integrated signal of the pixel. Future research is required in this regard, where higher spatial resolution remote sensing data can be used to discriminate between the various vegetation types. The observed and measured decreases in the condition of vegetation must become part of a monitoring strategy of the agricultural sector.

REFERENCES

Abdullah, M. and B. A. Hasbini, 2004. Prospects for Biosaline Agriculture in the United Arab Emirates. In: Taha, F. K. et al., Prospects for Saline Agriculture in the Arabian Peninsula. 15-23.

Dakheel, A. 2005. Date Palm tree and biosaline agriculture in the United Arab Emirates. In: The Date Palm: From traditional resource to green wealth. pp. 247-263. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Environmental Research and Wildlife Development Agency (ERWDA). 2002. Technical Developments in Seawater Desalination. Abu Dhabi Water and Electricity Authority. Abu Dhabi, UAE.

Erskine, W., A.T. Moustafa, A.E. Osman, Z. Lashine, A. Nejatian, T. Badawi, and S.M. Ragy. 2004. Date Palm in the GCC countries of the Arabian Peninsula. Regional Workshop on Date Palm Development in the Arabian Peninsula. Abu Dhabi, UAE. 29-31 May 2004.

FAO. 1982. Date production and protection. In: Plant production and protection paper. p. 120. Food and Agriculture Organization of the United Nation. Rome.

Klein, P. and A. Zaid. 2002. Land preparation, planting operation and fertilization requirements. In: Zaid, A. and Arias-Jiménez, E.J. Date palm cultivation. Food and Agricultural Organization of the United Nations, FAO Plant production and protection papers, 156 Rev.1. Rome.

APPENDIX A: THE STATUS OF DATE PALMS (*Phoenix dactylifera*) IN THE UNITED ARAB EMIRATES

I. Introduction

In the United Arab Emirates (UAE) and most of the Middle Eastern countries, the date palm is the oldest and most widely cultivated tree that is commercially the most important tree in the life of its people and their heritage. The importance of the date palm occurs because the production of other fruit trees is limited in the harsh environment. The palm has an extended history in various civilizations from the ancient Indus Valley to Africa and Mesopotamia. In the UAE, the earliest proof of date consumption comes from burnt date stones found on Dalma Island of the Abu Dhabi coast, dating back to more than 7000 years ago. Other historical studies reported that dates were consumed by UAE people during the Bronze Age (3000-1300 BC) (Beech and Shepherd, 2001). The accurate origin of the date palm is unknown (Zaid and de Wet, 2002); however, it is believed that it originated near the Persian Gulf and was particularly abundant between the Nile and Euphrates Rivers in ancient times (Morton, 1987).

II. Climate and Condition

The date palm is grown extensively in the UAE and other Middle Eastern countries because their climate and soil is more suitable than other areas. The climate of the UAE is classified between arid and hyper-arid; annual differences in temperatures and humidity are relatively small along the coastal areas, compared with areas further inland (Boer, 1997). The average humidity in coastal areas ranges between 50%-60%, exceeding 90% in the summer and fall, whereas inland is far less humid (UAE Yearbook, 2002). The average annual rainfall is about 120 mm, and is generally considerably higher in the mountain region (140-200 mm), and the east coast (100-140 mm) in comparison to the gravel plains (100-120 mm). The lowest average records are from the west coast (less than 60 mm) where some years are totally dry, with no rain recorded in some locations for over three years. It is only through the regular formation of dew that vegetation and wildlife can survive.

The date palm requires hot arid regions and has adapted to a climate with long dry summers and mild winters. It must have full sun and can not live in shade. It has a unique feature to succeed in arid environments with long periods of drought and high temperatures (Morton, 1987).

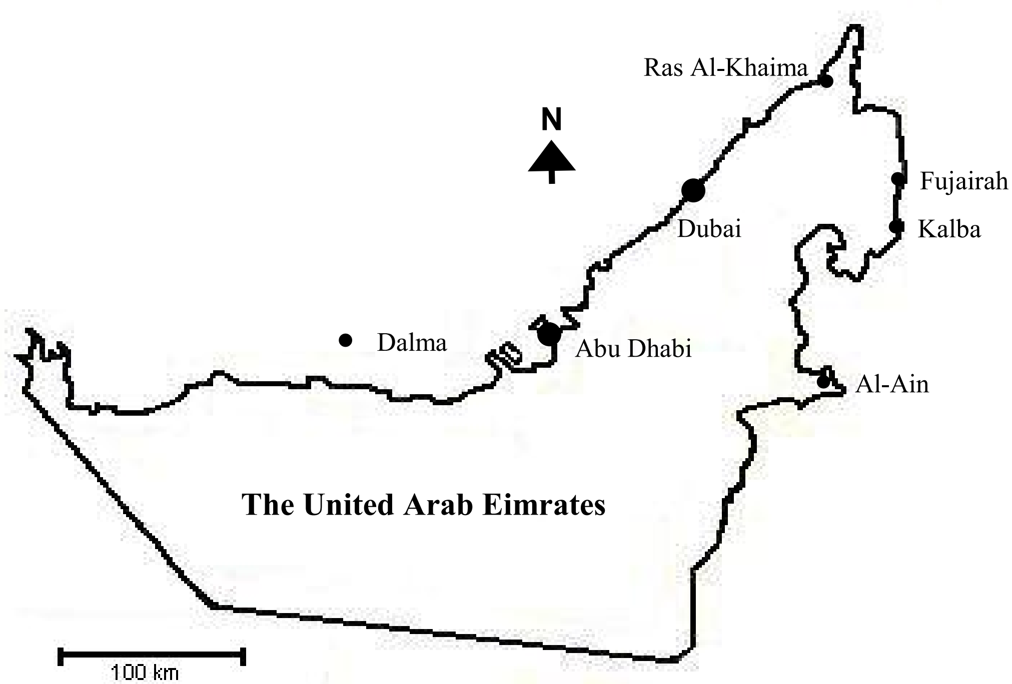

Figure 1: the United Arab Emirates map showing the important areas.

Date palms can grow in various types of soil, such as sandy, sandy loam, clay and other heavy soils in both hot arid and semi-arid regions (Morton, 1987; Klein and Zaid, 2002). However, the best production is found in light deep soils with a good drainage system and where water can penetrate to at least 2 meters (Klein and Zaid, 2002).

III. Date Palm Progress in the UAE

In the UAE, there are over 120 varieties of dates (Dakheel, 2005), many of which originated locally and some others obtained from neighboring countries or as seedlings from North Africa. The UAE carries out massive efforts to develop the date palm sector. This is obvious in the sustained growth of the number and varieties of date palm trees every year. According to Zaid (2005), the UAE has more than 40 million palm trees, most of which have been planted recently. They cover approximately 15% of the total cultivated area and are equal to 20% of the total palm trees planted in the world. Currently, the production of dates in the UAE exceeds 318 thousand tonnes per year (Dakheel, 2005). Table 1 shows the total increase of the date palm cultivated area from less than 0.5 thousand hectare to about 62 thousand hectares in the period from 1961 to 2001. While their production increased from 6 thousand tonnes to 318 thousand tonnes in the same time period. The unusual increase in date palms and their production ranked the country number seven among world countries in 2001 with 6% of the total world production (Table 2).

Table 1: The UAE date palm cultivated area and production for the period from 1961 to 2001

	Cultivated Area (thousand hectares)	Production (thousand tonnes)
1961	0.55	6
1970	0.64	8
1980	5.56	51
1990	22.4	141
2001	62	318

Source: (Dakheel, 2005)

Table 2: Major countries producing dates in 2001

	Production (Thousand tonnes)	Percentage of the world production
Egypt	1102	20.6
Iran	900	16.8
Saudi Arabia	712	13.3
Pakistan	550	10.3
Iraq	400	7.5
Algeria	370	6.9
UAE	318	5.9
Oman	260	4.9
Sudan	177	3.3
Morocco	32	0.6
Others	532	9.9
Total World	5353	

Source: FAOSTAT

Combating Desertification

The date palm is one of the most suitable adapted trees in the world for the arid environment. In addition to its commercial and nutritional value, the date palm tree has a minimum water demand, tolerates harsh weather, and tolerates high levels of salinity (Diallo, 2005). There are very few trees that can tolerate the desert environment, which is characterized by high temperatures, low soil moistures, and high salinity levels. In addition, the palm is rich in sugars, vitamins and other nutrients. Eighty percent of its total weight is sugar and each kilogram of date provides about 3000 calories from (Aljuburi, 2005). Moreover, date palms can live for a long period of time, some for more than 100 years (Dakheel, 2005).

International attention to protect the environment has been increasing in recent decades. For example, the United Nation Conference on Environment and Development (UNCED) that took place in Brazil in 1992 focused on protection from global warmth and desertification, which has affected the ecosystems worldwide. Since then, there have been many efforts among the participant countries to achieve goals outlined at the implementation of conference. In UAE, the date palm tree was believed to be a part of the strategy to control desertification and land reclamation since it needs less investment and effort than other plant species. In addition to its economical and cultural importance, the date palm is thought of as an important means to control desertification and contribute to global protection. The UAE has made great headway in date palm cultivation and has been making strategic progress toward lowering the danger of desertification. Thousands of hectares of date palms have been planted in the UAE's deserts and around oases with government support. This is noticeable from the huge increase of date palm numbers in the country in the last few decades that have reached more than 40 million trees.

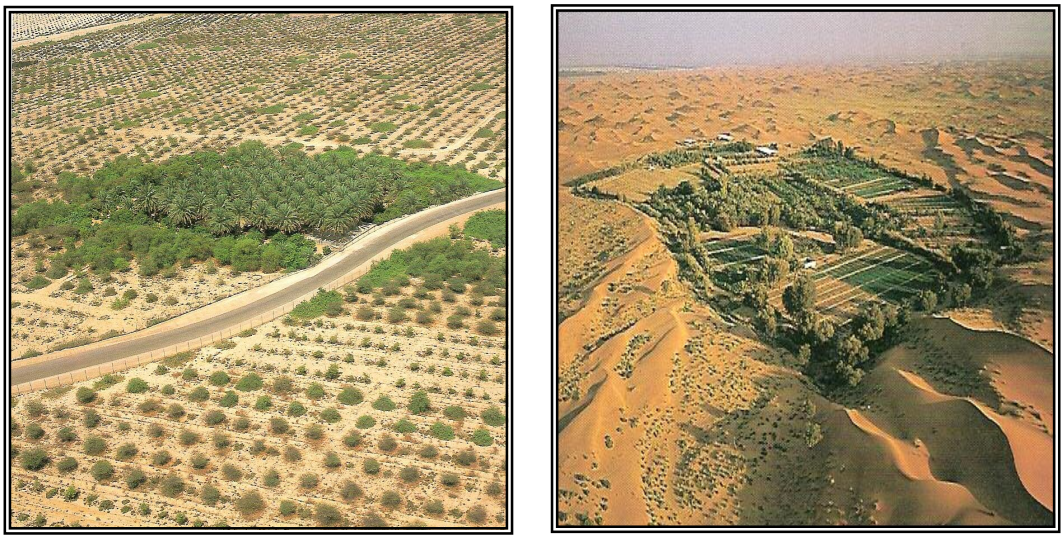

Figure 2: Pictures from the UAE showing its efforts in controlling desertification. In the left, date palm farm surrounded by other trees; in the right, a date palm farm in the heart of the desert (UAE Yearbook, 1996).

Tissue Culture Program

The UAE has invested heavily to improve the date palm sector, including the use of the most modern technology, such as tissue culture that produced 12 new varieties of good quality date palms. In February, 1989, the date palm tissue culture laboratory was established by the UAE University. In 2002, the laboratory became the Date Palm Research and Development Program (DPRDP) and was chosen to be the center of the international network on date palms. It is under the management of the UAE University in cooperation with the United Nation Development Program (UNDP). Its goals are to increase the growth of the date palm industry and to combat desertification. The DPRDP has14 greenhouses and 6 tissue culture growth chambers. It has produced more than

100,000 palms a year and it has plans to reach one million palms by the end of 2006 (Al-Kaabi and Zaid, 2005).

IV. Critical Issues Facing the Date Palm Future

Water Demand

The main source of water for agriculture in the Middle Eastern countries and the UAE is groundwater. The UAE agricultural sector utilizes about 85% of the total water, with 50% of this water used to irrigate forages (Dakheel, 2005). The limited precipitation and the huge increase in the area of agricultural land have put pressure on groundwater usage; resulting in increased salinity which poses a serious threat. The groundwater level in some areas, such as Ras Al-Khaimah has been decreasing sharply. As a consequence, about 25% of the UAE's land is now influenced by salinity. The salinity of groundwater in most farm wells ranges between 11000-13000 ppm and, in some cases, it has reached 17000 ppm (Dakheel, 2005). Irrigating with this water causes salts to be deposited on the soil surface following water evaporation. This is causing a serious problem with agriculture in the northern and eastern regions of the UAE. If appropriate action is not taken to solve the present water issues, the groundwater shortage and further degradation of its quality, will cause greater problems for the agricultural sector. Current water consumption and the shortage of groundwater have increased the dependence on the expensive process of desalination seawater. The UAE is one of the few countries that have taken steps to increase the use of desalinated seawater. The Environmental Research and Wildlife Development Agency (ERWDA, 2002) reported that groundwater contributes about 53% of the available UAE water supplies; desalination water provides 35%; recycled water accounts for 9%; and surface water accounts for 3% of total available water. In addition, the government has built over 130 dams to enhance groundwater recharge, thus improving groundwater quality and reducing seawater intrusion.

A new project is in place in the UAE to solve the shortage of fresh water resources. The government is distributing desalinized water around the country for agricultural uses. The project began in the Abu Dhabi region and covers most of its agricultural areas. In addition to a plant in Abu Dhabi city, a desalination plant built in Fujairah supplies the water to Al-Ain and its surrounding areas. The second phase of this project will provide water to the northern, central, and eastern regions. Optimistically, this expensive project will end the UAE's difficulties with fresh water resources.

Salinity

The date palm is a halophytic plant that can tolerate high levels of salinity. In fact, it is more salt tolerant than any other fruit crop (FAO, 1982). Furr (1975) reported that it is obvious that the date palm is more salt tolerant than barley and may be the most salt tolerant of all crop plants. Barley, one of the most salt-tolerant field crops, is grown in the cool season; in contrast, date palms establish most of their growth in hot weather when salinity has the most adverse influence on plants. Furthermore, some varieties can tolerate salinity levels up to 22000 ppm (EC 34 dS m^{-1}). However, their growth and yield productivity are affected (Erskine et al., 2004), where the yield decreased 50% at 11500 ppm and 100% at 20500 ppm (18-32 dS m^{-1}) (Klein and Zaid, 2002).

The UAE has been struggling with another crisis: growing soil salinity of many agricultural areas caused by increased groundwater salinity. In arid regions, salinity is very common because of the lack of fresh water resources and high evaporation rates. Several areas in the UAE, such as Khatt, Al-Hail, and Al-Fahlain have been seriously affected by salinity. Furthermore, many farmers have abandoned their farms and soon the soil in other areas will not be able to support crops unless a solution is found. In Oman, the neighboring country to the UAE, the Ministry of Agriculture and Fisheries (1993) reported that about 20% of the date palm areas in Oman have been discarded as a consequence of saline groundwater, which reached about 32000 ppm (EC 50 dS m^{-1}) in regions such as Batinah (Al-Ajmi et al., 2002).

Red Palm Weevil (Rhynchophorus ferrugineus Olive.)

There are many pests that intimidate the life of date palm trees and thus their commercial values. Among these pests, the Red Palm Weevil (RPW), observed first in India in 1970 then in the UAE in 1985, is the most dangerous one. Many date trees have been affected by this weevil. The UAE has made extensive efforts to destroy this weevil but, so far, these efforts have been unsuccessful. It is expected that about 100 thousand UAE date palms will be lost in the next 10 years due to the RPW (Zaid, 2005).

V. Conclusion

Date palms play a very important role in the life of most people in the UAE and Middle East countries. However, more scientific attention is needed regarding the current condition of the date palm trees grown under dry saline environments. In addition, further research is required to identify differences in salinity tolerance between date palm varieties, and thus start new breeding programs. The UAE has made a tremendous investment in the date palm sector and the overall agricultural aspect, including a tissue culture program, desertification control, increasing date palm numbers, and finding fresh water resources for agricultural uses. However, less attention has been paid to the pest infestation of the date palms.

VI. References

Al-Ajmi, A., S. Nortcliff, and L.P. Simmonds. 2002. Image: A Physically-based one dimensional irrigation management model for soil salinity control. Soil Use and Management, 18:3: 184-190

Aljuburi, H.J. 2005. Date palm researches and its development in the UAE. In: The Date Palm: From traditional resource to green wealth. pp. 423-440. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Al-Kaabi, H. and A. Zaid. 2005. Plantation of date palm tissue in the UAE. In: The Date Palm: From traditional resource to green wealth. pp. 87-102. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Beech, M. and E. Shepherd. 2001. Archaeobotanical evidence for early date consumption on Dalma Island, United Arab Emirates. Antiquity. 75:83-89.

Boer, B. 1997. An Introduction to the Climate of the United Arab Emirates. Journal of Arid Environments. 35: 3-16

Dakheel, A. 2005. Date Palm tree and biosaline agriculture in the United Arab Emirates. In: The Date Palm: From traditional resource to green wealth. pp. 247-263. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Diallo, H. 2005. The role of date palm in combat desertification. In: The Date Palm: From traditional resource to green wealth. pp. 13-19. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Environmental Research and Wildlife Development Agency (ERWDA). 2002. Technical Developments in Seawater Desalination. Abu Dhabi Water and Electricity Authority. Abu Dhabi, UAE.

Erskine, W., A.T. Moustafa, A.E. Osman, Z. Lashine, A. Nejatian, T. Badawi, and S.M. Ragy. 2004. Date Palm in the GCC countries of the Arabian Peninsula. Regional Workshop on Date Palm Development in the Arabian Peninsula. Abu Dhabi, UAE. 29-31 May 2004.

FAO. 1982. Date production and protection. In: Plant production and protection paper. p. 120. Food and Agriculture Organization of the United Nation. Rome.

Furr, J.R. 1975. Water and salinity problems of Abadan Island date gardens. Date Growers' Inst. Rept. 52:14-17.

Ministry of Agriculture and Fisheries. 1993. South Batinah integrated study. Document No. 4/93/19. Directorate General of Agricultural Research, Ministry of Agriculture and Fisheries, Sultanate of Oman.

Morton, J.F. 1987. Date. In: Fruits of warm climates. pp. 5-11. Miami, FL.

United Arab Emirates Yearbook. 1996. Ministry of Information and Culture.Trident Press Ltd. London. UK.

United Arab Emirates Yearbook. 2002. Ministry of Information and Culture.Trident Press Ltd. London. UK.

Klein, P. and A. Zaid. 2002. Land preparation, planting operation and fertilization requirements. In: Zaid, A. and Arias-Jiménez, E.J. Date palm cultivation. Food and

Agricultural Organization of the United Nations, FAO Plant production and protection papers, 156 Rev.1. Rome.

Zaid, A. and P.F. de Wet. 2002. Origin, geographical distribution and nutritional values of date palm. In: Zaid, A. and Arias-Jiménez, E.J. Date palm cultivation. Food and Agricultural Organization of the United Nations, FAO Plant production and protection papers, 156 Rev.1. Rome.

Zaid, A. 2005. Plantation of date palm in the UAE: current status and future possibilities. In: The Date Palm: From traditional resource to green wealth. pp. 191-210. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

APPENDIX B: EFFECT OF SALINITY ON GROWTH OF TWELVE CULTIVARS OF THE UNITED ARAB EMIRATES DATE PALM (*Phoenix dactylifera*)

Abstract

Fresh water resources in the United Arab Emirates (UAE) are limited. Use of salt water for irrigation of agricultural crops may help decrease the demand for fresh water. Suitable salt tolerant plants, such as date palms, are limited in number and economic importance. To successfully use salt water for crop production and start a breeding program, more information is needed about the response of salt tolerant plants to saline environments. The objective of this experiment was to test the growth of date palm seeds at four NaCl levels, (330) control, 3000, 6000, and 12000 ppm. A greenhouse experiment was conducted at the University of Arizona's Environmental Research Laboratory on twelve cultivars of date palm seeds, which were imported from UAE local farms. Plant height, shoot growth rate (SGR) and number of leaves (NL) were measured every two weeks. Dry biomass and chemical composition for the shoots and roots were measured at the end of the experiment. Optimal growth found at control and 3000 ppm of NaCl. Relative growth rate (RGR), biomass, and NL decreased significantly by increasing salinity; 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. Na:K ratios were lower in shoots than in roots. Lulu, Fard, Khnaizi, Nabtat Safi, and Razez cultivars showed higher RGR and biomasses whereas Khnaizi, Mesally, and Safri had higher Na:K ratios than other cultivars in the control indicating higher Na^{+} discriminations from plant parts.

Key words: Sodium chloride, halophyte, growth rate, Na:K, and cation content.

I. Introduction

Arid and semi-arid regions represent about one-third of the world's land (Archibold, 1995). Lack of fresh water in these regions is one of the most critical problems facing agriculture development. Soil salinity is often associated with the lack of water in arid areas. Halophytic plants that have the ability to survive in these stressful conditions are needed.

Date palm (*Phoenix dactylifera*) accounts for more than 1500 cultivars around the world (FAO, 2002). It has adapted to harsh environments with long dry summers and mild winters. It has the ability to survive in oases and desert environments where the temperature is high and the water table is close to the surface. Date palm is a halophytic plant; in fact, it is more salt tolerant than any other fruit crops (FAO, 1982). Khudairi (1958) cited that the date palm around Baghdad survives in saline soils that have 6% total soluble salts and 0.32% chloride. Furr (1975) reported that date palm is more salt tolerant than barley and may be the most salt tolerant of all crop plants. Barley is usually grown in the cool season; in contrast, date palms grow faster in hot weather when salinity has the most adverse influence on plants. The stages of germination and establishment are critical stages in the life cycle of halophytes (Irwin, 1978). In a laboratory experiment using *Atriplex semibaccata*, Millington, et al. (1951) found that *Atriplex s*. was more sensitive to salinity at the germination stage than at other stages of growth. Generally solutions with salinities above 1% NaCl cause reductions in germination of halophytes. Germination time is delayed (Chapman, 1974) and germination percentages are decreased (Irwin, 1978) with increasing salt concentrations.

Since only a few varieties of date palms have been used in research (Aljuburi, 1992; Furr and Ream, 1968; Hewitt, 1963; Khudairi, 1958; Ramoliya and Pandey, 2003), little information is available about the growth of date palm seedlings in saline environments and the variability in salt tolerance among cultivars is largely unknown. Khudairi (1958) was one of the early scientists to evaluate the behavior of date seeds in saline environment. He used the Zahedi cultivar to examine the seed germination in three concentrations of sodium chloride solutions 0.5, 1.0, and 2.0%. He observed that NaCl suppressed the germinations during the early stages and at 2% NaCl the germination was delayed for 25 days and the maximum germination did not exceed 50%. Ramoliya and Pandey (2003) studied the effect of chlorides and sulfates salts of Na, K, Ca, and Mg on the growth of Rati cultivar of date palm using six different concentrations of salts 4.3, 6.0, 8.2, 10.5, 12.8, and 14.6 dS m^{-1}. They found that the Rati cultivar is salt tolerant at the seed germination stage and it survived and grew up in soil salinity exceeding 12.8 dS m^{-1}. Khudairi (1958) evaluated the effect of sodium chloride solutions ranging between 0.1% (1000 ppm) to 2.5% (25,000 ppm) on germination of Zahidi date palm seeds. He concluded that seeds germination was not affected by solution concentrations up to 0.8% (8000 ppm) and germination continued in solutions up to 2% (20,000 ppm). Furr and Ream (1968) conducted a field experiment to determine the effect of salinity between 520 to 24,000 ppm of salts on growth and salt uptake of Deglet Noor and Medjool varieties of date palms. Their results suggested that the accumulation of sodium and chloride in the plants increased as the salt concentration of the irrigation water increased, but the concentration in the plants was not proportional to the concentration of those ions in the water for each treatment. Furthermore, the average growth rate of leaves was depressed as the salt concentration of the water increased. They also found that the sodium and chloride in the tops of Deglet Noor were slightly higher than in Medjool, but in the roots the reverse was true. They concluded that depression of growth was more related to salinity of irrigation water than to salt content of the plants. Hewitt (1963) tested the effect of various salts and salt concentrations on the germination of Deglet Noor seeds. He used various combinations of NaCl, $CaCl_2$, Na_2SO_4, NaCl+$CaCl_2$, and NaCl+Na_2SO_4 with concentrations from 10,000 to more than 30,000 ppm of salts. The result of his study was that the growth decreased slightly at 10,000 ppm, drastically at 20,000 ppm and was prevented at 30,000 ppm except for 3 seedlings in NaCl+Na_2SO_4 34,000 ppm treatment. Moreover, he found that chloride uptake by the roots was not necessary associated with increased chloride concentration in the tops. Other research done by Aljuburi (1992) evaluated the behavior of four cultivars of date palms, Lulu, Khalas, Boman, and Barhee, using four water salinity concentrations 0, 0.6, 1.2, and 1.8%. He indicated that the cultivar Lulu was highly susceptible to salinity compared to the other cultivars. In addition, Furr and Armstrong (1962) studied the effect of salinity on the growth of mature date palms. They tested the effect of several soil salinities on 17 year old Halawy and Medjool date palms using ECe ranges between 4-24 mmhos cm^{-1} (2,500-15,300 ppm). They found little or no effect on growth rate of leaves, yield, size or quality of fruit, or on chloride content of the leaf pinnae. Fresh water resources in most arid regions such as in the United Arab Emirates are limited. Biosaline agriculture systems could decrease the demand for fresh water. Improved agricultural production using salt water, which is more abundant than fresh water, will help to decrease fresh water demands. In the fruiting stage good water is more important because the quality and quantity of fruits are affected by high salinity (Furr, 1975). Thus good water can be saved for later stages of growth where the good water is more important.

Plants that tolerate high salinities are limited in number and economic importance. Little is known regarding the variability of salt tolerance among cultivars of date palms. Interspecies variability in salt tolerance is needed to start a breeding program to improve salt tolerance. Therefore, the main objective of this experiment was to test the growth ability of twelve cultivars of date palm seeds under four levels of saline water. More information regarding the response of salt tolerant plants to saline environments will be useful for future studies and breeding programs using saline water.

II. Materials and Methods

A greenhouse experiment was conducted at the University of Arizona's Environmental Research Laboratory, Tucson, Arizona, USA. Seed of twelve cultivars of date palm, Fard, Khadri, Khalas, Khnaizi, Lulu, Mesally, Nabtat Safi, Razez, Safri, Sagaai, Shishi, and Mabrowm, imported from the United Arab Emirates local farms. These cultivars were selected based on their fruit quality and the fact that there occurrence is widespread in the county. Seeds were planted in one-gallon plastic pots in a medium of washed sand and peat moss 2:1 (by volume). The seeds were planted in the summer when the average temperature in the greenhouse was 85°F (29°C). The pots were arranged in a randomized complete block design. The seeds were irrigated for 10 weeks with tap water containing 330 ppm salts. Thereafter, the plants were thinned to one plant per pot and irrigated with the designated salinity (NaCl) levels of 330 (control), 3000, 6000, and 12000 ppm. Treatments were replicated three times and the pots were irrigated every three days with a sufficient water to allow drainage to flush out the extra salts. Soil salinities were monitored every two weeks by taking the average salinity of input and output water. Fertilizer (25 ppm N and 0.125 g/l of 20-20-20) was added after week 8 of treatments.

Plant height (PH), shoot growth rate (SGR), and Number of leaves (NL) were recorded every two weeks. SGR data were collected by measuring the length of the leaves in each pot. After 16 weeks of the treatment, plants were washed and shoots and roots were separated and fresh and dry biomasses were measured. The samples were dried at 65°C for three days then ground and analyzed for cations and anions in shoot and root tissues by IAS Laboratories (Phoenix, AZ) using atomic absorption spectrophotometry. Shoot and root biomasses, RGR, and cations were calculated based on total samples, since three replicates were analyzed as one sample in order to maintain a minimum sample weight requirement.

Relative growth rate (RGR) was calculated using the dry biomass and following the method of Chiariello et al. (1989); RGR = [ln(final biomass)-ln(initial biomass)]/(final time-initial time). The results were analyzed with one- and two-way ANOVA (SPSS 13.0). Differences between means were determined using post hoc analyses by the Bonferroni procedure. In cases when data did not meet the requirements for normality (e.g. root:shoot), the Dunnett t-test was used at 0.05 level (one tail test) using a directional hypothesis. Based on the literature reviews (Aljuburi, 1992 and Husein et al, 1993), it has been reported that when salinity increases, the general plant health decreases. Therefore, we used a directional test assuming that increasing salinity leads to decreasing in plant health.

III. Results

Based on harvest data, the variables total plant height (TPH), average shoot growth rate (ASGR), number of leaves (NL), relative growth rate (RGR), shoot and root biomasses, root:shoot (R:S) ratio, and cation contents were determined and analyzed by using one-way ANOVA tests.

Differences between TPH and salinity levels were not significant (Table 1). Significant differences between TPH and cultivars was noted at $P<0.01$. Comparisons between cultivars in each treatment with those in the control were made in order to find differences in TPH among cultivars (Table 2). Most cultivars in 3000 ppm and 6000 ppm of the NaCl had higher TPH than the control. At 12000 ppm, Khnaizi, Lulu, Mesally, Nabtat Safi, Razez, Safri, and Shishi cultivars had TPH higher than the control. The interaction of salinity levels and cultivars on the TPH was noted (Table 3).

No differences were found between salinities and ASGR at various weeks (data not shown), nor between ASGR of all weeks and salinities (Table 1). Significant differences between ASGR and cultivars was noted at $P<0.05$. Differences of ASGR between cultivars relative to control were made (Table 2). Many cultivars at the three salinity levels had higher ASGR than the control. No ASGR interaction of cultivars and salinities was observed (Table 3).

Differences between NL and salinity levels (*P*<0.0001) were noted (Table 1). The result showed an inverse significant relationship between NL and salinities (Table 4). The control had the highest NL and this value decreased with increasing the salinity. There were no differences between the control and 3000 ppm, 3000 and 6000 ppm, or between 6000 and 12000 ppm. No differences were found between NL and cultivars at any salinity level when they were compared with the control (Table 2). The interaction between the salinities and cultivars was not significant (Table 3).

After 16 weeks of treatment, the RGR was significantly (*P*<0.0001) higher in plants grown at control and 3000 ppm of NaCl than in plants grown at higher salinities (Table 1). Some cultivars at 3000 ppm and 6000 ppm NaCl had higher RGR than the control (Table 5). These cultivars are Fard, Khnaizi, Nabtat Safi, Razez, Safri, and Sagaai cultivars at 3000 ppm and Fard and Lulu cultivars at 6000 ppm.

A one-way ANOVA showed a significant effect of salinity on the shoot and root biomasses (*P*<0.0001). Plants grown under control and 3000 ppm had higher shoot and root biomasses and both were higher than plants grown under 6000 and 12000 ppm (Table 1). In addition, the shoot and root biomasses of plants grown under 6000 and 12000 ppm were different. Shoot and root biomasses of plants grown with 12000 ppm were the lowest among the salinities. Many cultivars at 3000 ppm had higher shoot biomasses than the control (Table 6). At 6000 ppm, Fard, Lulu, and Shishi had higher or same shoot biomasses than the control while there were no cultivars at 12000 ppm with greater shoot biomass than the control (Table 6). In addition, Fard, Khadri, Razez, and Safri cultivars at 3000 ppm had higher root biomasses than the control, as did Fard and Lulu at 6000 ppm NaCl.

The R:S ratio was significantly ($P<0.03$) affected by salinities at 0.05 (one tail test) using one-way ANOVA (Table 1). R:S ratio differences were found between plants grown at control versus 3000 ppm and control versus 6000 ppm. Further, differences were found between plants grown at 3000 or 6000 ppm versus 12000 ppm (Table 1). However, there was no difference between plants grown at the control and 12000 ppm, nor between plants grown at 3000 and 6000 ppm. Cultivars Khalas, Mesally, and Mabrowm at 3000 ppm of NaCl had higher R:S ratios than the control. Cultivars Khadri, Mesally, and Razez at 6000 ppm had greater R:S ratios than the control plants. At 12000 ppm, Fard, Khnaizi, Mesally, Nabtat Safi, Razez, and Shishi had higher R:S ratios than the control (Table 6).

The Na^+ content increased in both the shoot and the root with increased salinity. However, the percentage in the root was almost four times higher than that in the shoot. Further, all the cultivars at all salinities had higher Na^+ percentages than the control in both shoots and roots (Table 7). Sagaai cultivar at 12000 ppm NaCl had Na^+ concentrations 22 times higher than the control in the shoots, followed by Mesally and Shishi with 20 and 18 times, respectively, higher than the control (Table 8). On the other hand, the differences between cultivars at different salinities relative to the control were lower in the roots than shoots (Table 9).

The K^+ content in both the shoot and the root decreased with increasing salinity (Table 7). The K^+ content was higher in the shoots than in the roots. The results in both the shoot and the root showed that the differences between the different salinity levels were significant at $P<0.0001$ except the control and the 3000 ppm in the shoots; they were not significant. Shoot K^+ of cultivars at various salinities relative to the control varied among cultivars (Tables 8&9). Many cultivars at 3000 ppm had higher K^+ than the control whereas at 6000 ppm, only Fard and Safri cultivars had higher K^+ concentrations. At 12000 ppm one cultivar, Safri had a K^+ concentration similar to that in the control. On the other hand, root K^+ concentrations did not vary much between cultivars at various salinity treatments relative to the control.

The Na:K ratio was significant ($P<0.0001$) between all salinity levels (Table 7). The Na:K ratio increased with increasing salinity levels in both shoots and roots. Large increases were noted in the roots. All cultivars at 3000 ppm behaved similarly and had Na:K ratios lower than the control (Tables 8&9). This was opposite to cultivars at 6000 ppm and 12000 ppm. Many cultivars had Na:K ratios higher than the control. Of these cultivars Mesally and then Safri cultivars at 12000 ppm had the highest Na:K ratios in the shoots. Khnaizi cultivar at 3000 ppm and 12000 ppm as well as Mabrowm at 6000 ppm had the highest Na:K ratio in the roots.

The Mg^{2+} content in the root was twice as high as in the shoot. The Mg^{2+} content in both shoots and roots decreased with increasing salinity levels. Differences between the control and the three salinity levels and between the 12000 ppm and low salt levels were significant at $P<0.0001$ in both the shoot and in the root (Table 7). However, no significant differences were found between the 3000 and 6000 ppm treatments. There were no shoot or root Mg^{2+} concentrations differences noted between cultivars at various salinities when they were compared with the control (Tables 10&11). Cultivars in the control had the highest Mg^{2+} contents.

The Ca^{2+} content was twice as high in the shoot than in the root. The Ca^{2+} content decreased with higher salinities. The post hoc analyses showed that differences between various salinity levels were significant at ($P<0.0001$) with the exception of differences in the control and 3000 ppm in the shoot and the 3000 and 6000 ppm in the root (Table 7). No differences were found between Ca^{2+} content of shoots among cultivars when they were compared with the control (Tables 10&11). Root Ca^{2+} contents in the control were lowest in all cultivars. Shishi cultivar at all salinity treatments had the higher Ca^{2+} content than the control. It was highest at 6000 ppm, which was 27 times higher than the control. Sagaai and Lulu also had high Ca^{2+} at 12000 ppm relative to the control.

Salinity had an effect ($P<0.0001$) on N and P contents in both shoots and roots (Table 7). In shoots, N was highest with 6000 ppm of NaCl (3.13%) and lowest in the control (2.50%). In roots N increased with increasing NaCl concentrations from 1.48% in the control to 1.73 % at 12000 ppm. P followed the same pattern as N in both shoots and roots. In shoots, it was highest at 3000 and 6000 ppm (0.30%) and lowest in the control (0.23%). In roots P content increased with increasing salinity, from 0.16% at control to 0.20% at 12000 ppm. All cultivars at all treatments had higher N content than the control (Tables 10&11). When cultivars at different salinities were compared with the control, Mabrowm at 3000 ppm and 6000 ppm and Nabtat Safi at 12000 ppm had the highest N values in shoots. In roots, Khnaizi at 3000 ppm and 6000 ppm and Safri at 12000 ppm had the highest N values. P contents for the shoot cultivars were lowest in the control (Tables 12&13). Khadri at 3000 ppm, Khnaizi at 6000 ppm, and Mabrowm at 12000 ppm had highest values than the control. In roots, Khadri at 3000 ppm, Khnaizi at 6000 ppm, and Lulu at 12000 ppm had higher P values than the control.

The cation content for both the roots and shoots are shown in table 7. All the cation contents were affected by salt level (P<0.0001). In general, the total cation concentrations in the shoots were greater than in the roots. The differences in means between the control and various salinities (3000, 6000, and 12000 ppm) were found significant at P<0.0001 for both the shoot and the root with the exception of the total cations between the control and the 12000 ppm in the shoot. The cultivars were also found to differ from one another in total cation contents at different salinities relative to control (Tables 12&13). In shoots, Sagaai at 3000 ppm and 12000 ppm and Shishi at 6000 ppm had the highest total cation content compare to the control. In roots, Shishi cultivar at all salinities levels had the highest total cation contents.

IV. Discussion

The overall results of this work demonstrated that the date palms are a salt tolerant species during the first stage of growth, the most critical stages in the life cycle of halophytes. Data collected for total plant height (TPH), average shoot growth rate (ASGR), number of leaves (NL), and biomass showed that date palms grew best with 3000 ppm or less of NaCl and were most inhibited at 12000 ppm. Plants were able to survive at 12000 ppm of NaCl regardless of their growth performance and some plants did not show signs of nutrient imbalances. The growth response was similar to that found with date palm cultivars in Egypt (Husein et al., 1993); cultivars showed differences in growth parameters with increasing salinity. In general, salinity can reduce plant growth through osmotic effects, toxicity of ions, nutrient uptake imbalance, or a combination of these factors.

Total plant height (TPH) was not affected by salinities. However, variations between cultivars showed differences. Razez and Lulu cultivars showed the highest TPH in 12000 ppm NaCl in comparison with the control.

The effect of salinity on the ASGR was very low and no differences were observed at any NaCl levels, even though there was an increase in ASGR with increasing salinity (Table 1). Furthermore, the ASGR varied between weeks and did not have any constant trend. After two weeks of treatments, the overall ASGR increased and then started to decrease rapidly after week 4 until week 10. Fertilizer was added during week 8 when the date plants were almost two months old. Thereafter, the ASGR increased until the end of the experiment (data not shown). Razez and Safri cultivars had the highest ASGR in 12000 ppm NaCl in comparison with the control (Table 2).

Numbers of leaves were highly affected by salinities. There was an inverse relationship between NL and salinity; as salt concentration increased, NL decreased (Table 1). The same results were observed by Aljuburi (1992). The control had the greatest NL but was not different than plants grown at 3000 ppm. Moreover, the differences between NL at 3000 and 6000 ppm NaCl were not significant, nor were differences between 6000 and 12000 ppm. Plants grown at low NaCl levels were able to produce more leaves. On the other hand, variations in NL of cultivars were not significant at any NaCl levels (Tables 2&3). All cultivars behaved similarly under each treatment. Moreover, there was no NL interaction between any NaCl levels and the cultivars (Table 3).

Low NaCl concentration (3000 ppm) had no significant effect on the RGR of any date palm cultivars. At higher NaCl concentrations (6000 and 12000 ppm) salt reduced RGR were compared to the control and 3000 ppm. The greatest effect was at 12000 ppm of NaCl. Among the cultivars, Fard, Khnaizi, Lulu, Nabtat Safi, and Razez had the greatest RGR relative to control when 12000 ppm NaCl was applied.

Cultivars' dry biomass in the control and at 3000 ppm did not show any differences in shoot and root biomasses. Reductions were noted at higher levels of NaCl (6000 and 12000 ppm) for both shoot and root biomasses. The greatest reductions in the biomasses were observed with 12000 ppm of NaCl. The reductions in shoot biomasses were comparable to these of roots, indicating that shoot and root were equally sensitive to salinity. In all treatments, root biomasses (i.e. growth) were less affected than shoots, thus root:shoot (R:S) ratios increased. R:S ratios were similar between the control and 12000 ppm as well as between 3000 and 6000 ppm of NaCl. Controls and plants grown in 12000 ppm NaCl had higher R:S ratios than other treatments. Aljuburi (1992) reported similar results for Lulu, Boman, Barhee, and Khalas date palm cultivars treated with 0, 6000, 12000, and 18000 ppm of NaCl for 21 weeks. This result could be due to an attempt of plants to decrease water transpiration and/or increase water uptake. Date palm cultivars were observed to change the pattern of dry biomass distribution, favoring root parts, as salt level was increased (Table 1). Shu et al. (1997) reported that plants response to increased their R:S ratios when exposed to harsh environments. Between various cultivars, Lulu showed the highest shoot biomass and Fard had the highest root biomass and R:S ratio at 12000 ppm salinity (Table 6).

In saline environments, cations at high concentrations in the soil solution (e.g. Na^+) are taken up at higher rates, which may result in large accumulations of these cations in the plants' tissues and thus may inhibit biochemical processes (Greenway and Munns, 1980) and protein synthesis in the cytoplasm (Gibson et al., 1984). In response to salinity halophytic plants usually do not accumulate Na^+. In the current study, date palms seemed to adjust cation uptake and retention; hence Na^+ is selectively secreted from leaves and retained in roots, whereas K^+ is taken up and retained in the leaves. Such response occurs with these two cations in order to adjust the osmotic potential. Therefore, the plants may avoid toxicity and buildup of Na^+ in the leaves, whereas other cations such as K^+, Mg^{2+}, and Ca^{2+} could be available for the plant (Khan et al., 2000 and Epstein, 1972). The total content of cations in the tissue increased with increasing NaCl, probably to maintain the osmotic potential and continue water uptake into the plant. The concentration of Na^+ in shoots increased significantly from 0.06 % in the control to 0.88 % in the 12000 ppm treatment. The same pattern was found in roots (0.41% in the control to 2.35% at 12000 ppm). In general, roots had higher Na^+ contents than shoots (Table 7). At 12000 ppm, Sagaai cultivar had the highest shoot Na^+ content while Khalas had the highest Na^+ content in root. On the other hand, K^+ content was different from the Na^+ content. In shoots it was significantly higher than in roots. In both shoots and roots the K^+

content significantly decreased with increasing salinity. The decline in shoots was from 2.44% in the control to 2.04 with 12000 ppm NaCl; corresponding values for roots were from 2.12% to 1.16%. The Na:K ratios were higher in roots than in shoots. In shoots it was 0.03 in the control and increased to 0.44 at 12000 ppm, while in roots it was 0.2 in the control and increased with increasing salinity to 2.05 at 12000 ppm of NaCl. These observations suggest that Na^+ was transported from shoots and retained in roots and K^+ transported from roots and retained in shoots. These results agreed with results found for other halophytes (Greenway, 1968). Mesally and Safri cultivars had the highest shoot Na:K ratios whereas Khnaizi cultivar had highest root Na:K ratio.

The Ca^{2+} was higher in shoots than in roots. This was opposite to the behavior of Mg^{2+}; however, both cations decreased with increasing salinity. Mer et al. (2000) reported that a reduction in internal cation concentrations (e.g. Ca^{2+}) in shoots may be due to the fact that the activity of the ion in the external solutions was reduced and there was disturbance of the translocation of the ion by the main saline cations (Na^+ and K^+). The fact that Ca^{2+} and Mg^{2+} contents were decreased in shoots of date palms grown at high NaCl agrees with results obtained with other halophytes (Glenn and O'Leary, 1984; Ayala and O'Leary, 1995). The accumulation of N and P in shoots was not clearly in response to salinity. However, the results showed that their content in roots increased with increasing salinity level. In general, the concentrations of both cations were higher in roots than in shoots.

V. Conclusion

Suitable salt tolerant plants, such as date palms, are needed in arid countries, which are limited in fresh water resources. More information is needed about the response of salt tolerant plants to saline environments to start breeding programs. The results found that date palm seedlings grew best in the control and with 3000 ppm of NaCl and were most inhibited at 12000 ppm. Plants were able to survive at 12000 ppm of NaCl regardless of their growth performance and some plants did not show signs of nutrient imbalances. In general, salinity can reduce plant growth through osmotic effects, toxicity of ions, nutrient uptake imbalance, or a combination of these factors.

The current study indicates that there are differences in salt tolerance between date palm cultivars, which appear to be related to the salt exclusion mechanisms by the root parts (Greenway and Munns 1980), resulting in reduced Na^+ translocation to the shoots. Khnaizi, Lulu, Nabtat Safi, and Razez cultivars showed greatest growth parameters and Na:K ratios that indicates higher sodium discriminations from plant parts than other cultivars. This could make them good candidates for a breeding program. Other cultivars, such as Mesally, Safri and Shishi may have potential for salt tolerance.

VI. References

Aljuburi, H.J. 1992. Effect of sodium chloride on seedling growth of four date palm varieties. Annals of Arid Zone. 31:4:259-262.

Archibold O.W. 1995. Ecology of world vegetation. Chapman and Hall. London, UK.

Ayala, F. and O'Leary, J.W. 1995. Growth and physiology of *Salicornia bigelovii* Torr. At sub-optimal salinity. International Journal of Plant Science. 156:197-205.

Chapman, V.J. 1974. Salt marshes and salt deserts of the world. pp. 494. Stechert-Macmillan. Pennsauken, New Jersey.

Chiariello, N.R., Mooney, H.A., and Williams, K. 1989. Growth, carbon allocation and cost of plant tissues. p. 257-266. In: R. Pearcy, Ehleringer, J., Mooney, H.A., and Rundel, P.W. (Eds.), Plant physiological ecology. Chapman and Hall, London, UK.

Epstein, E. 1972. Mineral nutrition of plants: principles and perspectives. John Wiley, New York.

FAO. 1982. Plant production and protection paper. Date production and protection. p. 120. Food and Agriculture Organization of the United Nation. Rome.

FAO. 2002. Date Palm Cultivation. FAO plant production and protection papers-156 Rev.1. Food and Agriculture Organization of the United Nation. Rome.

Furr, J.R. 1975. Water and salinity problems of Abadan Island date gardens. Date Growers' Inst. Rept. 52:14-17.

Furr, J.R. and Armstrong, W.W. 1962. A Test of Mature Halawy and Medjool date palms for salt tolerance. Date Growers' Inst. Rept. 39:11-13.

Furr, J.R. and Ream, C.L. 1968. Salinity effects on growth and salt uptake of seedlings of the date, *Phoenix dactylifera* L. Proc. Amer. Soc. Hort. Sci. 92:268-273.

Gibson, T.S., Speirs, J., and Brady, C.J. 1984. Salt tolerance in plants. II. In vitro translation of mRNAs from salt-tolerant and salt-sensitive plants on wheat germ ribosomes. Responses to ions and compatible organic solutes. Plant Cell Environ. 7:579-587.

Glenn, E.P. and O'Leary, J.W. 1984. Relationship between salt accumulation and water content of dicotyledenous halophytes. Plant, Cell and Environment. 7:253-261.

Greenway, H. 1968. Growth of stimulation by high chloride concentrations in halophytes. Israel Journal of Botany. 17:169-177.

Greenway, H., and Munns, R. 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant Physiol. 31:149-190.

Hewitt, A.A. 1963. Effect of different salts and salt concentration on the germination and subsequent growth of Deglet Noor date seeds. Date Growers' Inst. Rept. 40:4-6.

Husein, A.A., El-Desouki, M.I., El-Kased, F.A., Nour, G.M., and Abd El-Hamid, N.G. 1993. Effects of salinity on date palm seeds germination and early seedling growth. Journal of Agriculture Science, Mansoura University. 18:2:458-478.

Irwin, A.U. 1978. Halophyte seed germination. The botanical review. 44:2:233-264.

Khan, M.A., Ungar, I.A. and Showalter, A.M. 2000. Effects of salinity on growth, water relations and ion accumulation of subtropical perennial halophyte, *Atriplex griffithii* var. *stocksii*. Annals of Botany. 85:225-232.

Khudairi, A.K. 1958. Studies on the germination of date-palm seeds. The effect of sodium chloride. Physiol. Plantarum. 11:16-22.

Mer, P.K., Prajith, P.K., Pandya, D.H. and Pandey, A.N. 2000. Effect of Salts on Germination of Seeds and Growth of Young Plants of *Hordeum vulgare*, *Triticum aestivum Cicer arietinum* and *Brassica juncea*. Journal of Agronomy and Crop Science. 185:209-217.

Millington, A.J., Burvill, G.H. and Marsh, B. 1951. Soil salinity investigations. Salt tolerance, germination and growth tests under controlled salinity conditions. J. Agric. West. Australia. 28:198-210

Ramoliya R.J. and Pandey, A.N. 2003. Soil salinity and water status affect growth of *Phoenix dactylifera* seedlings. New Zealand Journal of Crop and Horticultural Science. 31:345-353.

Shu, WS, Zhang, Z.Q. and Lan, C.Y. 1997. Strategies for restoration of mining wastelands in China. Ecological Science, 19:2:24-29

Table 1: Total plant height (TPH), average shoot growth rates (ASGR; in cm per two weeks), and number of leaves (NL), Relative growth rate (RGR; in grams per grams per day), dry biomass weight (in mg), and root:shoot ratio (R:S) for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. The *F* and *P* values from one-way ANOVA are given. Within columns, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test. $N = 36$.

NaCl	TPH	ASGR	NL	RGR	Shoot biomass	Root biomass	R:S
Control	19.02±2.47[a]	0.31±0.21[a]	3.58±0.55[a]	0.026±0.001[a]	0.0030±0.001[a]	0.0054±0.001[a]	1.85±0.20[a]
3,000	19.71±2.40[a]	0.36±0.25[a]	3.28±0.51[ab]	0.026±0.001[a]	0.0030±0.001[a]	0.0052±0.001[a]	1.73±0.23[b]
6,000	20.02±3.00[a]	0.34±0.24[a]	2.97±0.45[bc]	0.025±0.001[b]	0.0026±0.000[b]	0.0045±0.001[b]	1.74±0.24[b]
12,000	19.40±2.32[a]	0.38±0.24[a]	2.72±0.51[c]	0.023±0.001[c]	0.0020±0.000[c]	0.0036±0.001[c]	1.78±0.20[a]
Statistic							
F	1.01	0.52	19.43	47.47	31.58	21.95	2.42
P	0.39	0.67	<0.0001	<0.0001	<0.0001	<0.0001	0.03*

* Dunnett t-test was used (one tail test). Based on the literature reviews, it has been found that when salinity increases, the plant health decreases. Therefore, we used directional hypothesis assuming that increasing salinity leads to decreasing in plant health.

Table 2: Total plant height (TPH), average shoot growth rates (ASGR), number of leaves (NL) and for all treatments in relative control to for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. The *F* and *P* values from two-way ANOVA are given. *N* = 3.

Cultivars	TPH			ASGR			NL		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	1.04±0.08	1.14±0.05	0.89±0.06	0.86±0.39	1.05±0.08	0.44±0.19	1.00±0.00	1.00±0.00	0.89±0.19
Khadri	0.94±0.07	1.06±0.14	0.92±0.08	1.22±0.44	1.46±0.88	0.93±0.47	0.91±0.16	0.82±0.00	0.64±0.16
Khalas	0.93±0.10	0.90±0.16	0.94±0.18	0.95±0.92	0.90±0.45	1.52±0.42	0.82±0.00	0.82±0.00	0.82±0.00
Khnaizi	1.00±0.11	1.12±0.17	1.11±0.24	0.79±0.64	1.63±0.81	1.08±1.23	0.91±0.16	0.73±0.16	0.73±0.16
Lulu	1.27±0.10	1.19±0.13	1.16±0.05	2.39±1.04	1.95±1.44	1.76±0.60	0.82±0.00	0.82±0.00	0.73±0.16
Mesally	1.03±0.09	1.00±0.07	1.00±0.01	1.39±0.29	0.86±0.03	1.31±0.53	0.83±0.14	0.83±0.14	0.67±0.14
Nabtat Safi	1.10±0.03	1.23±0.13	1.11±0.17	0.68±0.40	1.30±0.80	1.18±1.06	1.10±0.17	0.80±0.17	0.80±0.17
Razez	0.96±0.04	1.00±0.21	1.23±0.04	1.49±1.49	1.16±1.03	3.35±1.82	0.91±0.16	0.73±0.16	0.73±0.16
Safri	1.05±0.24	1.12±0.10	1.04±0.18	1.67±2.54	2.27±2.28	3.67±2.90	0.92±0.14	0.67±0.14	0.75±0.00
Sagaai	1.03±0.04	1.02±0.03	0.91±0.06	0.53±0.46	0.56±0.57	0.40±0.31	1.09±0.00	0.91±0.16	0.91±0.16
Shishi	1.18±0.25	1.00±0.21	1.11±0.18	2.04±1.36	0.88±0.72	1.85±1.00	0.80±0.17	1.00±0.17	0.70±0.17
Mabrowm	0.96±0.02	0.90±0.03	0.94±0.10	0.99±0.54	0.24±0.09	0.89±0.67	0.82±0.00	0.82±0.00	0.73±0.16
Statistic									
F	2.11	1.87	2.12	0.83	1.03	2.24	2.24	2.11	0.93
P	0.06	0.10	0.60	0.62	0.45	0.05	0.05	0.06	0.53

Table 3: Effect of NaCl and cultivars on growth of date palm seedlings grown at four concentrations of NaCl (in part per million) for 16 weeks. Numbers represent *F* values from two-way ANOVA. *N* = 36.

Dependent Variable	NaCl	Cultivars	NaCl x Cultivars
TPH	$1.11^{n.s}$	3.32**	$1.13^{n.s}$
ASGR	$0.95^{n.s}$	2.74*	$0.99^{n.s}$
NL	22.76***	$2.02^{n.s}$	$0.88^{n.s}$

* *P* <0.05; ** *P* <0.01 ; *** *P* <0.0001; n.s, non-significant.

Table 4: Correlation coefficients of NaCl with ASGR, TPH, and NL. *N* = 144.

	Significant	Correlation
ASGR	0.28	0.09
TPH	0.65	0.04
NL	<0.0001	-0.53

Table 5: Relative growth rates (RGR) for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

	RGR		
Cultivars	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	1.02	1.02	0.93
Khadri	1.01	0.99	0.87
Khalas	0.97	0.91	0.90
Khnaizi	1.02	0.98	0.93
Lulu	0.97	1.03	0.94
Mesally	0.98	0.95	0.85
Nabtat Safi	1.02	0.92	0.93
Razez	1.01	0.97	0.93
Safri	1.06	0.90	0.89
Sagaai	1.01	0.92	0.87
Shishi	0.93	0.98	0.89
Mabrowm	0.94	0.91	0.86
Mean±SD	0.99 ± 0.037^{a}	0.96 ± 0.044^{a}	0.90 ± 0.032^{b}

Table 6: Shoot, root biomasses and R:S ratio for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	Shoot			Root			R:S		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	1.15	1.15	0.70	1.03	1.03	0.84	0.90	0.88	1.18
Khadri	1.09	0.91	0.59	1.03	0.97	0.58	0.95	1.09	0.96
Khalas	0.77	0.73	0.73	0.94	0.71	0.67	1.22	0.96	0.92
Khnaizi	1.16	0.96	0.76	0.98	0.91	0.78	0.87	0.97	1.02
Lulu	1.09	1.26	0.96	0.83	1.06	0.75	0.80	0.87	0.81
Mesally	0.87	0.77	0.61	0.98	0.91	0.61	1.12	1.19	1.01
Nabtat Safi	1.30	0.81	0.78	0.96	0.71	0.76	0.75	0.87	1.03
Razez	1.12	0.81	0.73	1.00	0.96	0.79	0.88	1.19	1.09
Safri	1.25	0.81	0.81	1.21	0.65	0.59	0.94	0.77	0.71
Sagaai	1.22	0.88	0.72	0.97	0.68	0.57	0.80	0.78	0.80
Shishi	0.77	1.00	0.60	0.74	0.91	0.67	0.96	0.90	1.09
Mabrowm	0.76	0.78	0.59	0.83	0.66	0.56	1.09	0.86	0.99
Mean±SD	1.04 ± 0.20^{a}	0.91 ± 0.16^{a}	0.72 ± 0.11^{b}	0.96 ± 0.12^{a}	0.85 ± 0.15^{a}	0.68 ± 0.10^{b}	0.94 ± 0.14^{a}	0.94 ± 0.14^{a}	0.97 ± 0.14^{a}

Table 7: Cation content (in %; mean ± SD) of shoots and roots for cultivars of date palm seedlings grown at four concentrations of NaCl (in part per million) for 16 weeks. The *F* and *P* values from two-way ANOVA are given. Within columns, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test. $N = 36$.

NaCl	Na	K	Mg	Ca	N	P	Total	Na:K
				Shoot				
Control	0.06±0.02^{a}	2.44±0.25^{a}	0.20±0.03^{a}	0.87±0.07^{a}	2.53±0.19^{a}	0.23±0.03^{a}	6.34±0.36^{a}	0.03±0.01^{a}
3,000	0.34±0.03^{b}	2.48±0.16^{a}	0.23±0.03^{b}	0.87±0.10^{a}	2.96±0.24^{b}	0.30±0.03^{b}	7.18±0.36^{bc}	0.14±0.01^{b}
6,000	0.50±0.06^{c}	2.27±0.23^{b}	0.22±0.03^{b}	0.80±0.13^{b}	3.13±0.22^{c}	0.30±0.04^{b}	7.23±0.31^{b}	0.22±0.04^{c}
12,000	0.88±0.20^{d}	2.04±0.20^{c}	0.18±0.02^{c}	0.62±0.05^{c}	3.01±0.25^{bc}	0.28±0.03^{c}	7.01±0.32^{c}	0.44±0.10^{d}
Statistic								
F	375.16	32.20	20.04	54.22	48.52	47.71	52.83	366.97
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
				Root				
Control	0.41±0.05^{a}	2.12±0.36^{a}	0.54±0.11^{a}	0.65±0.09^{a}	1.48±0.16^{a}	0.16±0.03^{a}	5.36±0.54^{a}	0.20±0.03^{a}
3,000	1.49±0.10^{b}	1.68±0.12^{b}	0.47±0.05^{b}	0.48±0.06^{b}	1.67±0.17^{b}	0.18±0.02^{b}	5.97±0.30^{b}	0.89±0.10^{b}
6,000	1.77±0.17^{c}	1.42±0.13^{c}	0.44±0.06^{b}	0.45±0.05^{b}	1.68±0.13^{b}	0.19±0.03^{c}	5.95±0.37^{b}	1.25±0.13^{c}
12,000	2.35±0.16^{d}	1.16±0.10^{d}	0.38±0.04^{c}	0.36±0.03^{c}	1.73±0.15^{b}	0.20±0.02^{c}	6.17±0.24^{b}	2.05±0.28^{d}
Statistic								
F	1416.72	140.15	32.87	134.44	19.66	21.15	30.82	792.44
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 8: Na, K, and Na:K ratio of the shoots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	Na			K			Na:K		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	3.09	4.09	10.00	0.92	1.08	0.84	0.68	0.77	2.36
Khadri	4.63	6.00	8.75	1.00	0.92	0.92	0.82	1.18	1.71
Khalas	4.00	6.71	13.57	1.04	0.88	0.83	0.52	1.05	2.29
Khnaizi	6.33	8.00	15.50	1.09	0.91	0.78	0.65	1.00	2.26
Lulu	7.40	9.00	15.20	1.04	0.96	0.92	0.70	0.95	1.65
Mesally	5.00	8.00	20.00	0.97	0.87	0.73	0.63	1.16	3.37
Nabtat Safi	6.17	8.67	12.67	1.05	0.86	0.86	0.76	1.29	1.90
Razez	5.00	8.83	11.67	1.00	0.96	0.83	0.68	1.21	1.84
Safri	5.00	6.14	11.29	1.19	1.14	1.00	0.93	1.20	2.53
Sagaai	7.50	11.75	22.00	1.14	0.95	0.81	0.52	0.96	2.08
Shishi	7.20	13.40	18.00	0.89	0.81	0.70	0.75	1.50	2.35
Mabrowm	5.00	7.83	11.83	0.96	0.88	0.84	0.76	1.24	2.00
Mean±SD	5.53 ± 1.40^{a}	8.20 ± 2.51^{a}	14.21 ± 4.07^{b}	1.02 ± 0.09^{a}	0.93 ± 0.09^{a}	0.84 ± 0.08^{b}	0.70 ± 0.12^{a}	1.13 ± 0.19^{b}	2.20 ± 0.46^{c}

Table 9: Na, K, and Na:K ratio of the roots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	Na			K			Na:K		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	3.78	5.14	6.49	1.00	0.82	0.65	1.64	2.72	4.36
Khadri	4.41	5.00	6.47	0.86	0.82	0.55	1.76	2.09	4.07
Khalas	3.95	4.47	6.58	1.00	0.83	0.61	1.63	2.22	4.45
Khnaizi	3.72	3.72	6.05	0.83	0.72	0.56	2.43	2.80	5.91
Lulu	3.66	3.90	5.85	0.80	0.70	0.55	1.96	2.38	4.54
Mesally	3.13	3.96	4.79	0.52	0.48	0.38	1.33	1.81	2.79
Nabtat Safi	3.21	3.21	4.91	0.70	0.57	0.48	1.66	2.05	3.69
Razez	3.59	4.10	5.64	1.00	0.81	0.69	1.40	1.98	3.23
Safri	3.85	4.36	5.38	0.86	0.67	0.62	1.69	2.47	3.31
Sagaai	4.10	4.62	5.90	0.72	0.56	0.52	1.29	1.87	2.57
Shishi	3.68	5.79	6.32	0.77	0.68	0.55	1.67	3.00	4.08
Mabrowm	2.71	3.75	4.58	0.71	0.58	0.54	1.90	3.23	4.23
Mean±SD	3.65±0.46[a]	4.34±0.72[b]	5.75±0.70[c]	0.81±0.14[a]	0.69±0.12[b]	0.56±0.08[c]	1.70±0.31[a]	2.39±0.46[b]	3.94±0.90[c]

Table 10: Mg, Ca, and N of the shoots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	Mg			Ca			N		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	0.22	0.21	0.17	0.080	0.058	0.052	1.12	1.19	1.15
Khadri	0.28	0.22	0.20	0.070	0.061	0.048	1.13	1.22	1.09
Khalas	0.26	0.30	0.22	0.075	0.063	0.052	1.00	1.22	1.19
Khnaizi	0.36	0.27	0.25	0.094	0.076	0.065	1.29	1.25	1.21
Lulu	0.31	0.24	0.18	0.093	0.067	0.051	1.18	1.04	1.04
Mesally	0.26	0.26	0.22	0.057	0.056	0.048	1.16	1.36	1.24
Nabtat Safi	0.26	0.24	0.18	0.069	0.059	0.045	1.32	1.24	1.36
Razez	0.21	0.17	0.22	0.068	0.066	0.057	0.90	1.07	1.07
Safri	0.25	0.28	0.24	0.072	0.111	0.058	1.21	1.25	1.08
Sagaai	0.25	0.25	0.20	0.083	0.069	0.057	1.21	1.50	1.33
Shishi	0.24	0.33	0.20	0.068	0.069	0.054	1.23	1.15	1.19
Mabrowm	0.23	0.25	0.20	0.065	0.070	0.052	1.35	1.43	1.35
Mean±SD	0.26±0.04[a]	0.25±0.04[a]	0.21±0.02[b]	0.07±0.01[a]	0.07±0.01[a]	0.05±0.01[b]	1.18±0.13[a]	1.24±0.13[a]	1.19±0.11[a]

Table 11: Mg, Ca, and N of the roots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	Mg			Ca			N		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	0.95	0.76	0.74	14.50	12.25	10.00	1.20	1.20	1.13
Khadri	0.81	0.70	0.59	16.00	14.00	12.00	1.07	1.14	1.21
Khalas	0.65	0.63	0.57	18.00	14.33	12.67	0.88	1.00	1.12
Khnaizi	0.86	0.66	0.64	15.67	14.00	11.67	1.46	1.31	1.31
Lulu	0.83	0.80	0.61	22.00	22.50	18.00	1.06	0.94	1.13
Mesally	0.53	0.71	0.54	18.00	18.50	16.00	1.14	1.14	1.21
Nabtat Safi	0.74	0.63	0.54	18.00	15.67	12.67	1.00	0.94	1.06
Razez	0.59	0.49	0.45	17.67	13.67	10.00	1.00	1.00	1.13
Safri	0.76	0.62	0.56	16.67	14.00	11.67	1.31	1.23	1.38
Sagaai	0.57	0.62	0.53	23.00	22.00	18.50	1.23	1.54	1.31
Shishi	0.77	0.85	0.58	25.50	27.50	18.50	1.25	1.13	1.19
Mabrowm	0.74	0.81	0.66	19.00	24.50	17.50	1.08	1.23	1.00
Mean±SD	0.73 ± 0.13^{ab}	0.70 ± 0.10^{b}	0.58 ± 0.07^{cb}	18.7 ± 3.25^{ab}	17.7 ± 5.11^{b}	14.1 ± 3.34^{cb}	1.14 ± 0.16^{a}	1.15 ± 0.17^{a}	1.18 ± 0.11^{a}

Table 12: P and total cations of the shoots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test. $N = 3$.

Cultivars	P			Total cations		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	1.26	1.43	1.04	6.69	8.06	13.26
Khadri	1.53	1.37	1.42	8.64	9.79	12.43
Khalas	1.25	1.38	1.21	7.63	10.55	17.07
Khnaizi	1.52	1.48	1.24	10.69	11.98	19.05
Lulu	1.35	1.22	1.22	11.37	12.52	18.60
Mesally	1.29	1.38	1.13	8.73	11.91	23.37
Nabtat Safi	1.28	1.20	1.16	10.15	12.27	16.28
Razez	1.20	1.20	1.32	8.37	12.29	15.17
Safri	1.42	1.32	1.32	9.15	10.24	14.98
Sagaai	1.25	1.32	1.18	11.43	15.84	25.58
Shishi	1.28	1.32	1.16	10.90	17.09	21.31
Mabrowm	1.28	1.44	1.44	8.89	11.91	15.71
Mean±SD	1.32±0.11[a]	1.34±0.09[a]	1.24±0.12[a]	9.39±1.52[a]	12.04±2.46[a]	17.73±4.02[b]

Table 13: P and total cations of the roots for all treatments relative to control for all cultivars of date palm seedlings (means ± SD) grown at four concentrations of NaCl (in part per million) for 16 weeks. Within raw, values followed by different letters are significantly different at $P \leq 0.05$ as separated by Bonferroni test.

Cultivars	P			Total cations		
	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control	3000 ppm/ Control	6000 ppm/ Control	12000 ppm/ Control
Fard	1.27	1.40	1.13	22.70	21.57	20.14
Khadri	1.50	1.64	1.43	24.66	23.31	22.25
Khalas	1.13	1.20	1.20	25.61	22.47	22.75
Khnaizi	1.31	1.77	1.38	23.85	22.18	21.60
Lulu	1.15	1.46	1.69	29.51	30.30	27.83
Mesally	0.86	0.86	1.05	24.17	25.65	23.97
Nabtat Safi	1.00	1.12	1.18	24.65	22.13	20.82
Razez	1.07	1.13	1.33	24.91	21.21	19.24
Safri	1.06	0.88	1.25	24.50	21.75	20.86
Sagaai	0.91	0.86	1.00	30.53	30.19	27.76
Shishi	1.25	1.38	1.38	33.23	37.33	28.50
Mabrowm	1.08	1.58	1.42	25.31	32.46	25.70
Mean±SD	1.13±0.18[a]	1.27±0.31[a]	1.29±0.19[a]	26.13±3.18[a]	25.88±5.36[a]	23.45±3.25[b]

APPENDIX C: DETECTING DATE PALM TREES HEALTH AND VEGETATION GREENNESS CHANGE IN THE EASTERN COAST OF THE UNITED ARAB EMIRATES USING SAVI

Abstract

Due to shortage of fresh water resources, the vegetation of the eastern region of the United Arab Emirates has experienced a series of declines resulting from salinization of groundwater, which is the major source of irrigation. 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. TM and ETM+ 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. This remotely sensed data offered valuable information regarding vegetation health conditions, especially when using greenness indices. However, in open canopies, like date palm trees, soil line indices, such as, SAVI are more robust, since they account for the contribution of the soil background. This research suggest, that in order for the date palm trees of this region to stay productive, considerable attention needs to be placed in managing and monitoring soil salinity conditions and progress. 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.

I. Introduction

The United Arab Emirates (UAE) is located in the southeastern corner of the Arabian Peninsula between 22.5º and 26º N latitude and 51º and 56.25º E longitude, occupying a total area of about 83,600 square kilometers. The country consists of seven emirates and is surrounded by the Persian Gulf to the north, Saudi Arabia to the south and west, and Oman and the Gulf of Oman to the east and Qatar to the northwest. Most of the United Arab Emirates' surface is desert (75% of the surface area) with large, aeolian sand dunes. The eastern region, including Kalba, Fujairah, and Khor Fakkan, has a coast extending more than 90 km in length (Figure 1). This area is the third main agricultural area in the country. It has a sub-humid climate (Boer, 1997) with an average humidity between 50-60%, and exceeding 90% in the summer and fall. The average yearly rainfall of the east coast is about 100-140 mm (UAE Yearbook, 2002).

The current water usage in the UAE far surpasses its renewable resources (Document of the World Bank, 2005). As a consequence of the limited rainfall and high water consumption, ground water is being depleted. Agricultural demand for fresh water in this region is growing. According to Abdullah and Hasbini (2004), agriculture water use increased more than 87% in seven years from 800 million m^3 in 1990 to 1500 million m^3 in 1997, and reached 1,800 million m^3 for the year 2000. Increasing the water supply from ground water and desalination implies a high cost and serious environmental consequences. Overdrawing of ground water has resulted in the reduction of ground water level and increased salinity. The consequences are that in the most severe cases, farmers have deserted their croplands. The Environmental Research and Wildlife

Development Agency of the UAE (ERWDA, 2002) reported that only about 7-8% of the current ground water supply is fresh and the remained is brackish water. An intense water demand that exceeds annual ground water recharge causes seawater intrusion into coastal aquifers and the upward flow of brackish and saline water supplies from lower aquifers (Abdullah and Hasbini, 2004). This results in an increase in ground water salinity, especially in the eastern region. Increased private projects and farms in this region, such as Fujairah National Dairy Farm, which occupies a 0.67 km^2 area near Dibba and extends north to the tip of Musandam has put severe pressures on the ground water resources.

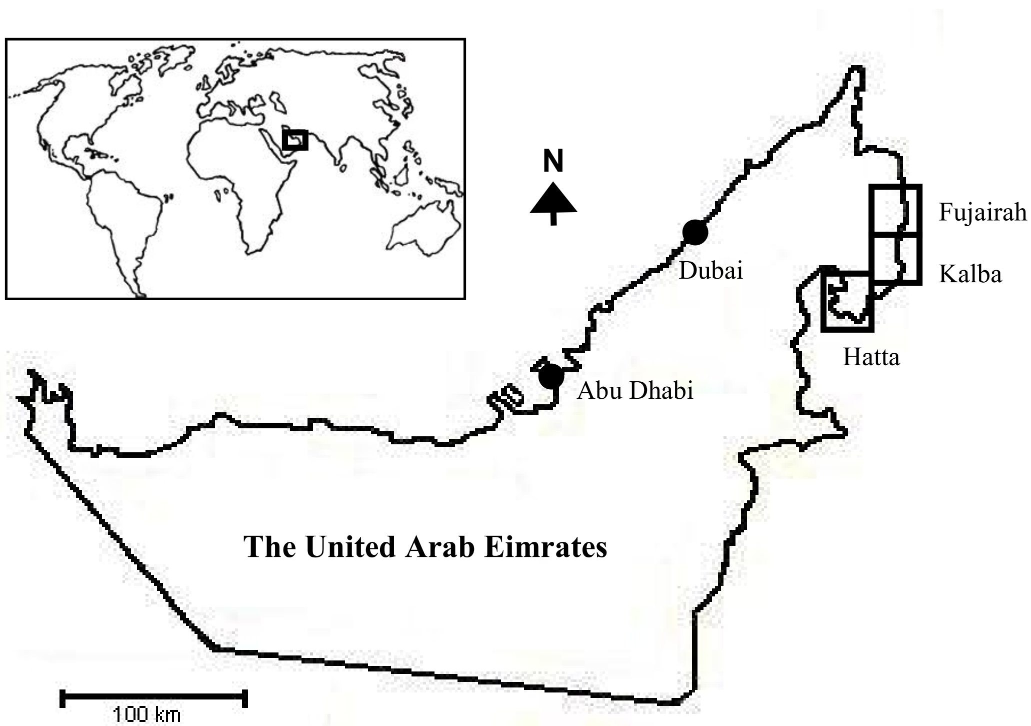

Figure 1: Map of the UAE showing the study areas.

Currently, the eastern region has some of the most saline ground water in the country (Dakheel, 2005). As a result many farms have shifted to new crops that tolerate higher salinity, such as date palms, leaving other crops neglected because of the difficulties in dealing with such situations. Furthermore, some farmers took the drastic and expensive measure of purchasing desalinated water to irrigate their crops.

To study this problem remote sensing tools can be used to monitor changes in vegetation health in salt-affected environments (Howari, 2003; Jackson, 1986; Howell et al., 1984; Myers et al., 1966). Remote sensing is becoming an effective tool in monitoring local, regional, and global environmental issues. Satellite and digital imagery play a significant role in remote sensing, offering much information regarding the land studied. One of the most important uses of satellite imaging is to map the earth's surface and vegetation through change detection. It is used to observe vegetation changes at different time periods. This technique assists in the study of vegetation change quickly and precisely and hence provides useful information for the decision maker (Nelson, 1983).

On the land surface, vegetation is a very active component; a comparison of several images from different periods provides a perspective as to when vegetation changes occurred. Vegetation indices (VI) obtained from multispectral imagery can provide useful data about the vegetation in the area (Tucker, 1979). Vegetation indices combine the low reflectance in the visible region (usually the Red spectral region) of the electromagnetic spectrum with the high reflectance in the near infrared band (NIR) region (Tucker, 1979; Rondeaux et al., 1996). When the VI and the vegetation biomass are correlated, any decline in the vegetation vigor, greenness, or health can be detected by the difference of the index images (Tucker, 1979). Vegetation indices have been widely used to describe the amount of vegetation or biomass production. Vegetation indices use the red band that corresponds to the highest chlorophyll absorption region and the NIR band that corresponds to the highest scattering and reflectance by healthy living vegetation (Tucker and Sellers 1986). The ratio between these two bands was found to correlate with leaf area index (LAI) (Green et al., 1997; Turner et al., 1999; Nordberg and Evertson, 2003). The Normalized Difference Vegetation Index (NDVI) is one of the most commonly used vegetation indices in global vegetation and change detection studies (Townshend et al., 1994; Steven et al., 1990; Wiegand et al., 1991; Malingreau et al., 1989; Townshend and Justice, 1986; Tucker and Sellers, 1986). NDVI has a high correlation with several vegetation properties, such as amount of green cover, biomass, green leaf area, and productivity (Asrar et al., 1984; Sellers, 1985). In arid and semi-arid regions, which are characterized by low vegetation cover, the effect of the soil background reflectance needs to be considered. Huete (1988) suggested using a Soil-Adjusted Vegetation Index (SAVI) that has the ability to minimize the soil background effects, making it less sensitive to soil background than NDVI (Todd and Hoffer, 1998; Huete and Tucker, 1991; Major et al., 1990; Huete et al., 1985). SAVI includes a constant soil adjustment factor “L” in the denominator of the NDVI equation to eliminate the soil background effects on the vegetation signal (Huete, 1988). Jackson et al. (1983) defined the perfect vegetation index as the one most sensitive to vegetation activities, not sensitive to soil background variations, and slightly affected by atmospheric factors. Although indices like SAVI are more effective over low vegetation cover, their use is still very limited (Geneviève et al., 1995).

II. Literature Review

Date palm health

Arid and semi-arid regions usually are characterized by high temperatures, low precipitation, and low vegetation cover. In such environments, salinity is widespread and the plants have adapted to such conditions. The health of vegetation under this harsh environment is highly unstable and hard to quantify. One possible method to detect the vegetation health is to use vegetation indices, such as SAVI, and then compare the results with similar plants response under normal to good conditions. It is suggested that plant responses may provide a more inclusive estimation of its health under saline conditions. When salts reach plant leaves, the plant reacts by excluding them from the cytoplasm and accumulating the salts in the intracellular space outside the cells. Thus, water moves from the cell (low salt) to outside (high salt) to accommodate the ion changes, which in fact dehydrates the cell (Volmar et al., 1998). The NIR reflectance is highly affected by the cellular structure of leaves in plants (Gausman et al, 1978), whereas the short wave infrared (SWIR) region is highly affected by the water content in leaves (Tucker, 1980; Gausman, 1985). In healthy active vegetation, chlorophyll is a strong absorber in the red region, while the cellular structure is a strong reflector in the NIR region. The opposite is true in unhealthy vegetation that has a lower photosynthetic activity, thus an increased reflectance in the red region and a decreased reflectance in the NIR region (Tucker and

Maxwell, 1976; Weiss et al., 2001). Based on this spectral behavior, several studies attempted to link plant health and their spectral characteristics. For example, Peñuelas et al. (1997) found that the canopy reflectance of barley was lower in the NIR and higher in the visible spectrum region as a result of increasing salinity. In addition, several vegetation indices have been used as indirect indicators to correlate remote sensing data with salinity. Cotton was used to study the relations between salinity and NDVI (Wiegand et al., 1992). They found a strong correlation between the yield and plant cover and the vegetation index derived from remote sensing measurements, using either multispectral video images or reflectance data from the SPOT satellite. However, date palm trees have not been well studied with remote sensing mostly because of the natural mixture of the landscape, which makes it difficult to distinguish between the plants. Harris (2003) reported that the difference between date palm trees, variations of tree spacing, and alteration in the understory vegetation is more difficult to sense.

Vegetation change detection

Vegetation indices, which combine the red band to IR band reflectances, are correlated to the amount of green vegetation being sensed (Tucker, 1979). Therefore, comparing these indices between different dates can offer useful information in regard to vegetation change detection. Nelson (1983) conducted a study to detect forest canopy change using Landsat MSS and to test three data transformations, differencing, ratioing, and vegetation index difference (VID). He found that the VID image provided the highest combined change classification accuracy. Lyon et al. (1998) found that the NDVI group, which includes NDVI, SAVI, and TSAVI, was least affected by topographical factors in their study. They also reported that the vegetation index difference technique works well for detecting vegetation change in large regions. On the other hand, Elmore et al. (2000) quantified vegetation change in a semi-arid region using two methods, Spectral Mixture Analysis (SMA) and NDVI differencing. They found that NDVI was less efficient in detecting vegetation changes, when the results were subtracted from each other. They believed the effect was basically due to soil background effects. Sohl (1999) conducted a study in the Abu Dhabi Emirate in the UAE using TM data, to investigate change detection techniques, including vegetation index differencing, using the NDVI. The results show that the NDVI differencing was acceptable but had some difficulties in detecting new agricultural areas and newly planted acacia forests, both of which were not fully grown yet, further indicating problems with soil background affects.

When vegetation density is very low, such as in arid and semi-arid regions, soil becomes a main contributing factor in the reflectance measured by the remote sensing system. Thus, there is a combination between the plant canopy reflectance and the soil variation reflectances (Ray and Murray, 1996). The influence of the soil variations on the spectral reflectance was first noticed by Huete and Jackson (1987). They found that in semi-arid and arid regions, where the vegetation cover is typically less than 30%, the NDVI values were lower at similar vegetation percentages in lighter soil than darker soil. Since SAVI was first introduced by Huete (1988), several studies have been conducted to examine the performance of this index in areas with low vegetation covers (Rondeaux et al., 1996; Huete and Jackson 1987; Pech et al., 1986; Huete et al., 1984, 1985). Rodeaux et al. (1996) used a range of vegetation covers with different soil samples to study several vegetation indices (e.g. NDVI, SAVI) in arid environments where the vegetation cover is usually low. The results showed indices that are related to the soil line, such as the SAVI and the Modified Soil Adjusted Vegetation Index (MSAVI, Qi et al., 1994) were less sensitive to the background contribution and performed better than the NDVI. Later, Gilabert et al. (2002) proposed a new member for the SAVI family. They introduced a generalized soil-adjusted vegetation index (GESAVI) and compared it with other vegetation indices including, the NDVI, Perpendicular Vegetation Index (PVI), SAVI, Transformed Soil Adjusted Vegetation Index (TSAVI etc.). They reported that the GESAVI and then the SAVI and the Optimized Soil Adjusted Vegetation Index (OSAVI) can be classified into the most accurate vegetation indices. Liu and Huete (1995) examined noise sources in several vegetation indices with inconsistent vegetation background materials. They found that the NDVI had the greatest level of noise and error, while the soil noise was partially eliminated at different levels with the SAVI and the MSAVI. Purevdorj et al. (1998) studied the relationships between the NDVI and the SAVI family (SAVI, MSAVI, and TSAVI) with various vegetation cover percentages. They concluded that the TSAVI provided more accurate estimation of vegetation, whereas, at very low densities, the SAVI can be used for estimating vegetation cover and the NDVI is best at detecting a wide range of vegetation densities. Schmidt and Kamieli (2001) studied the sensitivity of seven vegetation indices (NDVI, SAVI, MSAVI, PVI, Weighted Difference Vegetation Index (WDVI), SAVI2, and TSAVI) in a hyper-arid region. The results showed that the SAVI, PVI, AND TSAVI experienced greater correlation indices from brighter backgrounds. Masoud and Koike (2004) successfully detected vegetation change using the SAVI in an extreme arid region, North West Egypt, which has an advanced stage of salinization. The change was detected and quantified using a change detection technique from images acquired from Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (TM/ETM+) satellites for different time periods.

The objective of this study is to: (1) detect the vegetation greenness change during the past two decades in the Eastern Coastal region of the UAE using the SAVI differencing; (2) examine the potential of using remote sensing tools to detect the health of date palm trees, grown in a saline environment, using the SAVI; (3) evaluate the spatial resolution limitations of using TM/ETM+ in studying spectral change in date palm trees.

Date palm trees were selected because of their importance in arid and semi-arid regions such UAE.

III. Methodology

Study area

The study area is located in the upper eastern part of the UAE (Figure 1) and included two sites, Kalba and Fujairah. In the last two decades, this area has been severely influenced by ground water salinity. The average soil salinity of most agricultural areas ranges between 11000 to over 13000 ppm (Dakheel, 2005) and in some cases it exceeds 41000 ppm. These two areas were selected based on ground data availability, the widespread high salinity, and predominance of date palm trees. The third area is located in Hatta, which is located in the lower eastern part of the country (Figure 1). This area with healthier date palms was used to compare results with the more saline areas. The salinity of Hatta's soil is usually lower in comparison to the other study sites.

Soil sampling and analysis

Three soil samples were collected from three different farms each of which represent one study area. An average of three soils were collected from each farm and where analyzed in the Ministry of Environment and Water Laboratory for soil salinity, pH, and macro elements. The latitude and longitude location of each farm was taken using GPS (Magellan eXplorist 300), in addition to other common surface references, including points and major road intersections. Thereafter, these references were used as GPS points and were possible to locate in the images. The chemical measurements and locations of these farms are listed in table 1.

Pre-processing of satellite images

Two cloud free Landsat TM and ETM+ images were acquired from two different dates 22/09/1987 and 31/07/2000 (path 159, row 43). Images from the same sensor were not possible, due to poor quality. These images were from approximately the same time of the year. The Landsat TM and ETM+ sensors provide images with a pixel size of 28.5 m. The two images were selected from the summer to avoid contamination of reflectance from other small vegetations that are highly active in later seasons. Table 2 summarizes the location and the size of the study areas.

Image pre-processing is necessary to improve the image quality and enhance accuracy (Foody et al., 2003). The image pre-processing included geometric and atmospheric corrections, which help reduce and eliminate typical errors associated with remote sensing data (Chen, 2002). Geometric correction was made by using the 1987 image as reference image from which the other image (2000) was rectified through image to image registration. Radiometric correction was performed to standardize the images, and then atmospheric correction was staged to eliminate the atmospheric effects. Both the radiometric and atmospheric corrections were carried out using the COST Model, based on Chavez's (1996) dark object subtraction method. The operations required the sun elevation, sensing time, sun-earth distance, and the raw Digital Number (DN) values for the two images

Vegetation change detection

The vegetation index differencing was based on subtracting 1987 SAVI image from that of 2000 using ERDAS software. Each SAVI image was created using the following equation (Huete, 1988):

$$SAVI = (1 + L)\frac{TM_4 - TM_3}{L + TM_4 + TM_3}$$

Where, TM4 is the NIR band (0.76-0.90 μm), TM3 is the red band (0.63-0.69 μm), and L is a soil adjustment factor, which was set to 0.5 for our study sites (intermediate vegetation density according to Huete, 1988). The L factor differs with vegetation density between 0 for higher densities and 1 for lower densities Huete (1988). The SAVI difference image results in positive, negative, or zero values. Positive values indicate that there is a decrease in the vegetation by time, while negative values indicate an increase in vegetation. A zero value indicates no change in vegetation.

Date palm health

Three date palm farms were selected, Farm-1, Farm-2, and Farm-3, for this part of the study, with different salinity levels (table 1). The health of date palm grown under a saline environment in the eastern region of the two farms in Farm-1 (Fujairah) and Farm-2 (Kalba) were examined using the SAVI. The results then were compared with the SAVI for date palms grown under the lower soil salinity level of the Farm-3. The SAVI images, for 1987 and 2000, created by the change detection technique described above were used to analyze the date palm trees health assessment.

IV. Result and Discussion

Soil Salinity

Results of the soil analysis taken from saturated paste extract solution of the three farms are listed in table 1. The soil texture was sandy loam for the three farms (data not given). The electrical conductivity, a soil salinity measurement, indicated that farm-1 in Fujairah has the highest salinity of about 41000 ppm. Farm-2 in Kalba has intermediate salinity of about 12000 ppm and Farm-3 in Hatta has the lowest salinity level of about 6900 ppm. The pH is slightly alkaline in all farms and ranges between 7.59 and 8.23. On the other hand, the macro elements values indicated that calcium (Ca) and sodium (Na) are high at higher salinity levels. Farm-1 has the highest Na value of 1.30% followed by Farm-2 of 0.35%, while Ca values are 7.79%, 7.99%, and 4.39% for Farm-1, Farm-2, and Farm-3 respectively. Therefore, soil salinity is the driving force for vegetation health decline in this region. This fact is supported by field measurements and observations.

Date Palm Health

Table 1 shows the chemical analysis of soils taken from three date palm farms, representing one study area each. In addition, the table shows the electrical conductivity of the soils (ECe) and the SAVI values of these three farms obtained from the year 2000 imagery. From these data it is evident that SAVI decrease as soil salinity increases. SAVI was at 0.155 at the lowest salinity level (6900 ppm); the value decreased to 0.104 at the very high salinity of 41000 ppm. Moreover, this result supports the fact that the date palms are halophytic plants, and even at high salinity values, the corresponding SAVI values did not decrease a lot. However, these SAVI values for date palms were quite low and not typical of green plants. It is possible that this is due to the natural structure of the date palm leaves. Date palm trees have low density of leaves and branches and subsequently low LAI, which allow more reflectance to pass through the leaf spacing, leading to lower SAVI values. Harris (2003) reported that as the tree spacing increased, the proportion of a Landsat pixel covered by the tree canopy decreased. The spatial resolution of TM/ETM+ did not permit full explorations of the spectral characteristics change of date palm trees, due to the canopy structure of the palm trees and extent of background soil and vegetation contribution. Higher resolution remote sensing data may be needed to accurately account for these issues. There already are sensors with spatial resolution in the 1m range (QuickBird, IKINOS, etc.).

Vegetation change detection

Figures 2-4 represent the false color composition images of the study areas. Many immediate observations can be made about the study sites. First, vegetation condition in the three areas seems to have declined, (from red color to whitish, from 1987 to 2000), which also means a decrease in the vegetation biomass density also. This is more visible in the Kalba than in the Fujairah and Hatta sites. Second, Fujairah and Kalba show a decrease in total vegetated areas, as they are give way to urban areas. Third, the decline in the total vegetated area occurred largely in the southern part of Fujairah, whereas, the decline in Kalba did not have a specific spatial pattern, but was rather random and wide spread.

Figures 5-9 (scatter plots) illustrate the overall vegetation change, which was more noticeable when we plotted the pixels spectral reflectance of the NIR band versus the Red band for the two time periods. The non-vegetated land cover features, urban, water, and stream, usually falls in a straight line in the figure constituting what is called a soil line. On the other hand, vegetated areas lie above the soil line, since they have higher reflectance in NIR band compared to the visible band.

Vegetated areas in the year 1987 were well separated from other features, while the distribution in the year 2000 was poorly discriminated from other features and in some cases were mixed with them. Typically photosynthetically active vegetation spectra is found above the soil line, the more the vegetation activity, the more above the soil line they exist. This result shows that green vegetation reflectances decreased during the time period from 1987 to 2000 in Fujairah and Kalba areas. Vegetation was healthier in the year 1987 than in the year 2000. Although the same trend was found in both sites, the decrease in vegetation condition and biomass was more noticeable in Kalba than in Fujairah. These results were consistently found in the false color composite images.

Table 3 provides the statistical analysis of the SAVI images for the two periods of 1987 and 2000. Although the information acquired from temporal images are influenced by several factors, such as atmospheric, geometric, sensor differences, etc., the data still offer valuable information about the vegetation condition and change. The three central tendency indices Mean, Median, and Mode were not identical for the three areas which indicated that the data sets were not normally distributed in the three areas. The histograms, in figure 10, indicate that the three areas were positively skewed for both years, suggesting the dominance of green vegetation cover compared with other features. The distribution of the histogram for Kalba area in 1987 was totally located in the positive scale, while in the year 2000 the distribution contained slightly negative values. This indicated that the green vegetation in the year 1987 is healthier than that in 2000. The standard deviation statistic showed less variability in the year 2000 than in 1987. This indicates less dispersion, which is related to the decrease in the vegetation on average. Furthermore, the statistical analyses show a decrease in the mean SAVI values in all study areas. The greatest decrease was observed in Kalba, which exhibited the most vegetation change that was noticeable in the false color images in figure 3. It is then clear that vegetation biomass decreased during the two decades in the eastern region of the UAE.

SAVI difference images were analyzed for two levels of threshold of changes, 10% and 20%. Tables 4 and 5 represent the 10% and 20% vegetation changes, respectively, in the study areas between 1987 and 2000 using the SAVI images. Figure 11 illustrates the spatial change associated with these levels. Decrease in vegetation was represented by gray colors; increase was represented in white colors, and areas with no significant change were represented by black colors. Both tables 4-5 and figure 11 show a change in vegetation cover from 1987 to 2000 being the greatest in the Kalba site than Fujairah and Hatta. Table 4 shows that 33.2% of the Kalba area corresponds to a 10% decrease in SAVI, with 24.8% of Hatta and 18.4% of the Fujairah area at the 10% SAVI. The 10% SAVI increase corresponded to 7.3%, 12.7% and 16.3 for Fujairah, Kalba and Hatta respectively, far lower than the decrease rate. These SAVI change values are related to a decrease in vegetation biomass, which suggest that the salinization rate had negatively impacted the area and had accelerated in the past decade. The percent areas with unchanged SAVI indicate that Fujairah appeared to be the least affected with the most stable vegetation (74.3% unchanged). With these decline rates in the condition of vegetation immediate attention is required in order to stabilize the salinity problem and bring it under control. Table 5 summarizes the SAVI image difference between 1987 and 2000 at 20% change in vegetation, which is equivalent to one fifth of the total vegetation biomass. More than 20% of the total study area in Kalba lost about one fifth of its vegetation greenness, whereas in Hatta the loss was about 10.8%. The 20% increase in vegetation biomass corresponded to 8.8% in Hatta, 5.6% in Kalba, and 2.5% in Fujairah, again far lower than the decrease percentages. This change in vegetation greenness between 1987 and 2000 was mostly caused by salinity, which is directly related to the salinization of groundwater. The observed increase could, in fact, be the result of some farmers irrigating their land with purchased desalinized water, as well as using crops that are more tolerant to salinity.

Agricultural changes in UAE

In the past few decades and after the oil boom, UAE has completed enormous development projects in all sectors. Agriculture benefited from this development, resulting in an increase of the vegetated areas, although there is an acute shortage of fresh water resources. It is worth noting the results of this study in the context of theses changes. Tables 6 and 7 summarize the agricultural sector change in the UAE between 1996 and 2000. The overall number of farms increased in all regions with different percentages. This increase was associated with an increase of the total area cultivated in the four regions. Abu Dhabi region had the highest increase in the total number of farms, 8866 farms in 1996 to 20706 in 2000 (Table 6), with a total cultivated area of 476.96 km^2 in 1996 to more than 2351 km^2 in 2000 (Table 7). The percentage of increase is more than 130% in the total number of farms and was more than 390% in the total cultivated area. This huge increase in the number of farms and total cultivated area were primarily because of the large support that the government is providing to farmers, such as providing land, water, and seeds. While the percentage of increase in the total number of farms was lower in the other regions, 7%, 8%, and 6% for the central, northern, and eastern regions respectively. Moreover, the percentage of increase in the total cultivated area was 16% for each region, the central and the northern and 30% in the eastern region. These numbers also show that all regions had an increase in both total number of farms and total cultivated areas regardless of neither the shortage of fresh water resources nor considering the vegetation conditions. A possible explanation is that seawater desalination was the main source of fresh water especially in the Abu Dhabi region. The daily water production of the UAE desalination plant was about 446 million m^3 in 1997, which represented about 13% of the world production of desalinated water (Abdullah and Hasbini, 2004). The central, northern, and eastern regions of the UAE were not a part of this tremendous growth because of problems related to salinization of groundwater that is the major fresh water source in these regions. Another explanation is that the total cultivated areas and thus the vegetation areas increased but in the same time the health of this vegetation (e.g. date palm) has decreased. An example of palm health decreasing is listed in table 8. According to the table values, the total cultivated area of date palm in the UAE increased tremendously 113 times during the period from 1961 to 2001 however, the date palm production (kg per hectare) decreased during the same period. The magnitude of change, -58.26%, clearly indicates the decrease of the date palm health.

V. Conclusion

The agricultural sector is the most valuable resource for societies. During a period of 13 years from 1987 to 2000, considerable change in vegetation greenness, conditions and health occurred in the eastern region of the UAE due to the salinization of groundwater. Results from SAVI difference images demonstrated that the eastern region of the UAE had experienced serious change to its vegetation cover. The major change was the loss of vegetation health, particularly in the Kalba area. Although the official census data show an overall increase in agricultural land areas, the condition and the yield of vegetation generally decreased. An inverse relationship was found between the SAVI values and the date palm health grown in saline environment. It is possible that some factors, such as tree spacing and small vegetation grown under and between date palm trees, are confounding these results, especially when vegetation index measures the integrated signal of the pixel. Future research is required in this regard, where higher spatial resolution remote sensing data can be used to discriminate between the various vegetation types. The observed and measured decreases in the condition of vegetation must become part of a monitoring strategy of the agricultural sector.

Remote sensing data and techniques, particularly Landsat TM/ETM+ imagery, offered a fast and practical tool to study the vegetation conditions of the area using vegetation indices. The spatial and temporal change rates were quantified using this data and enabled large scale vegetation health assessment. Useful information about the locations and rates of change was collected. Nonetheless, in arid regions, especially where the vegetation canopy is very open a soil line index, such as SAVI, is more suitable. Standardization of the images, through radiometric calibration and atmosphere correction, is a very crucial step in studying temporal change to distinguish real vegetation change from other sources.

VI. References

Abdullah, M. and B. A. Hasbini, 2004. Prospects for Biosaline Agriculture in the United Arab Emirates. In: Taha, F. K. et al., Prospects for Saline Agriculture in the Arabian Peninsula. 15-23.

Asrar, G., M. Fuchs, E.T. Kanemasu, and J.L. Hatfield. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. J. 76:300-306.

Chavez, P.S., jr. 1996. Image-based atmospheric corrections-revisited and improved. Photogrammetric Engineering and Remote Sensing. 62:1025-1036.

Chen, X. 2002. Using remote sensing and GIS to analyse land cover change and its impacts on regional sustainable development. Int. J. Remote Sensing. 23:1:107-124.

Dakheel, A. 2005. Date Palm tree and biosaline agriculture in the United Arab Emirates. In: The Date Palm: From traditional resource to green wealth. pp. 247-263. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Document of the World Bank. 2005. A water sector assessment report on the countries of the cooperation council of the Arab Sates of the gulf. Water, Environment, Social and Rural Development Department. Report No. 32539-MNA

Elmore, A.J., J.F. Mustard, S.J. Manning, and D.B. Lobell. 2000. Quantifying vegetation change in semiarid environments: precision and accuracy of spectral mixture analysis and the normalized difference vegetation index. Remote Sens. Environ. 73:87-102.

Environmental Research and Wildlife Development Agency (ERWDA). 2002. Technical Developments in Seawater Desalination. Abu Dhabi Water and Electricity Authority. Abu Dhabi, UAE.

Foody, G.M., D.S. Boyd, and M.E.J. Cutler. 2003. Predictive relations of tropical forest biomass from Landsat TM data and their transferability between regions. Remote Sensing of Environment. 85:463-474.

Gausman, H.W. 1985. Plant leaf optical properties in visible and nearinfrared light. p. 78. Graduate Studies, Texas Tech University (No. 29). Lubbock, Texas: Texas Tech Press.

Gausman H.W., D.E. Escobar, J.H. Everutt, A.J. Richardson and R.R. Rodriguez. 1978. Distinguishing succulent plants from crop and woody plants. Phot. Eng. Rem. Sens. 44:487-491.

Gilabert, M.A., J. González-Piqueras, F.J. García-Haro, and J. Meliá. 2002. A generalized soil-adjusted vegetation index. Remote Sensing of Environment. 82:303-310

Green, E.P., P.J. Mumby, A.J. Edwards, C.D. Clark, and A.C. Ellis. 1997. Estimating leaf area index of mangroves from satellite data. Aquatic Botany. 58:11-19.

Harris R. 2001. Remote sensing of agriculture change in Oman. International Journal of Remote Sensing. 24:23:4835-4852.

Howari, F.M. 2003. The use of remote sensing data to extract information from agricultural land with emphasis on soil salinity. Australian Journal of Soil Research. 41:1243-1253.

Howell, T.A., J.L. Hatfield, J.D. Rhoades, and M. Meron, 1984. Response of cotton water stress indicators to soil salinity. Irrig. Sci. 5:25-36

Huete, A.R. 1988. A soil adjusted vegetation index (SAVI). Remote Sens. Environ. 25:295-309.

Huete, A.R. and C. Tucker. 1991. Investigation of soil influences in AVHRR red and near-infrared vegetation index imagery. Int. J. of Remote Sens. 12:1223-1242.

Huete, A.R. and R.D. Jackson. 1987. Suitability of spectral indices for evaluating vegetation characteristics on arid rangelands. Remote Sens. Environ. 23:213-232.

Huete, A.R., D.F. Post, and R.D. Jackson. 1984, Soil spectral effects on 4-space vegetation discrimination. Remote Sens. Environ. 15:155-165.

Huete, A.R., R.D. Jackson, and D.F. Post. 1985. Spectral response of a plant canopy with different soil backgrounds. Remote Sensing of Environment. 17:37-53.

Jackson, R.D. 1986. Remote sensing of biotic and abiotic plant stress. Annual Review of Phytopathology. 24:265-287.

Jackson, R., P. Slater, and P. Printer. 1983. Discrimination of growth and water stress in wheat by various vegetation indices through clear and turbid atmospheres. Remote Sensing of Environment. 13:187-208.

Liu, H.Q. and A. Huete. 1995, A feedback based modification of the NDVI to minimize canopy background and atmospheric noise. IEEE Transactions on Geoscience and Remote Sensing. 33:457-465.

Lyon, J.G., D. Yuan, R.S. Lunetta, and C.D. Elvidge. 1998. A change detection experiment using vegetation indices. Photogrammetric Engineering & Remote Sensing. 64:2:143-150.

Malingreau, J. P., C.J. Tucker, and N. Laporte. 1989, AVHRR for monitoring global tropical deforestation. International Journal of Remote Sensing.10:855-867.

Major, D. J., F. Baret, and G. Guyot. 1990. A ratio vegetation index adjusted for soil brightness. Int. J. Remote Sens. 11:727-740.

Masoud, A.A. and K. Koike. 2004. Soil salinity induced land cover change detection and analysis in Siwa Region, NW Egypt. International Symposium of Geoinformatics for Spatial Infrastructure Development in Earth and Allied Science. September 16-18, 2004. Available online: http://gisws.media.osaka-cu.ac.jp/gisideas04/viewpaper.php?id=65

Myers, V.I., D.L. Carter, and W.J. Rippert. 1966. Remote sensing for estimating soil salinity. J. Irrig. Drain. Div. Am. Soc. Civil Eng. 92:59-68.

Nelson, R.F. 1983. Detecting forest canopy change due to insect activity using Landsat MSS. Photogrammetric Engineering and Remote Sensing. 49:9:1303-1314.

Nordberg, M. and J. Evertson. 2003. Monitoring Change in Mountainous Dry-heath Vegetation at a Regional Scale Using Multitemporal Landsat TM Data. AMBIO: 32:8: 502–509.

Pech, R.P., A.W. Davis, R.R. Lamacraft, and R.D. Graetz. 1986. Calibration of Landsat data for sparsely vegetated semi-arid rangelands. International Journal of Remote Sensing, 7:1729-1750.

Peñuelas, J., R. Isla, I. Filella, and J.L. Araus. 1997. Visible and near-infrared reflectance assessment of salinity effects on barley. Crop Science. 37:198-202.

Purevdorj, Ts., R. Tateishi, T. Ishiyama, and Y. Honda. 1998. Relationships between percent vegetation cover and vegetation indices. Int. J. Remote Sensing. 19:18:3519-3535.

Qi, J., A. Chehbouni, A.R. Huete, Y.H. Kerr, and S. Sorooshian. 1994. A modified soil adjusted vegetation index (MSAVI). Remote Sens. Environ. 48:119-126.

Ray, T.W. and B.C. Murray. 1996. Nonlinear spectral mixing in desert vegetation. Remote Sensing of Environment. 55:59-64.

Rondeaux, G., M. Steven, and F. Baret. 1996. Optimization of soil-adjusted vegetation indices. Remote Sensing of Environment, 55:95-107.

Schmidt, H. and A. Karnieli. 2001. Sensitivity of vegetation indices to substrate brightness in hyper-arid environment: The Makhtesh Ramon Crater (Israel) case study: Int. J. Remote Sens. 22 3503-3520.

Sellers, P.J. 1985. Canopy reflectance, photosynthesis and transpiration. Int. J. Remote Sens. 6:1335-1372.

Sohl, T.L. 1999. Change analysis in the United Arab Emirates: an investigation of techniques. Photogrammetric Engineering and Remote Sensing. 65:4:475-484.

Steven, M.D., T.J. Malthus, T.H. Demetriades-Shah, F.M. Danson, and J.A. Clark. 1990. High-spectral resolution indices for crop stress. In: Steven M.D. and J.A. Clark. Applications of Remote Sensing in Agriculture. pp. 209-227. Butterworths: London.

Todd, S.W. and R.M Hoffer. 1998. Responses to spectral indices to variations in vegetation cover and soil background. Photogramm. Eng. Remote Sens. 64:915-921.

Townshend, J.R.G. and C.O. Justice. 1986. Analysis of dynamics of African vegetation using the NDVI. International Journal of Remote Sensing. 7:1224-1242.

Townshend, J.R.G., C.O. Justice, D. Skole., J-P. Malingreau, J. Cihlar, P.M. Teillet, F. Sadowski, and S. Ruttenberg. 1994. The 1 km resolution global data set: needs of the International Geosphere Biosphere Programme. International Journal of Remote Sensing. 15:3417-3441.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote sensing of the environment. 8:2:127-150.

Tucker, C.J. 1980. Remote sensing of leaf water content in the near infrared. Remote Sensing of Environment. 10:23-32.

Tucker, C.J. and E.L. Maxwell. 1976. Sensor Design for monitoring vegetation canopies. Photogrammetric Engineering and Remote Sensing. 42:11:1399-1410.

Tucker, C.J., and P. J. Sellers. 1986. Satellite remote sensing of primary productivity. International Journal of Remote Sensing. 7:1395-1416.

Turner, D.P., W.B. Cohen, R.E. Kennedy, K.S. Fassnacht, and J.M. Briggs. 1999. Relationships between leaf area index and Landsat TM Spectral Vegetation Indices across three temperate zone sites. Remote Sensing of Environment. 70:52-68.

United Arab Emirates Statistical Book. 2000. Ministry of Environment and Water. UAE.

United Arab Emirates Yearbook. 2002. Ministry of Information and Culture. pp. 33-35.Trident Press Ltd. London. UK.

Volmar, K.M., Y. Hu, and H. Steppuhn. 1998. Physiological responses of plants to salinity: a review. Can. J. Plant Sci. 78:19-27.

Weiss, E., S.E. Marsh, and E.S. Pfirman. 2001. Application of NOAA-AVHRR NDVI time-series data to assess change in Saudi Arabia's rangelands. Int. J. Remote Sensing. 22:6:1005-1027.

Wiegand, C.L., A.J. Richardson, D.E. Escobar, and A.H. Gerbermann. 1991. Vegetation indices in crop assessments. Remote Sensing of Environment. 35:105-119.

Wiegand, C.L., J.H. Everitt, and A.J. Richardson. 1992. Comparison of multispectral video and SPOT-1 HRV observations for cotton affected by soil salinity. International Journal of Remote Sensing. 13:1511-1525.

Zaid, A. 2005. Plantation of date palm in the UAE: current status and future possibilities. In: The Date Palm: From traditional resource to green wealth. pp. 191-210. UAE Center of Studies and Strategy Researches. Abu Dhabi, UAE.

Table 1: Average of chemical measurements of three soil samples (from saturated paste extract solution) taken from date palm farms in the three study areas and SAVI average values of these farms that obtained from the 2000 image.

Sample	Location	ECe (ppm)	pH	Macro Elements (%)						SAVI
				Ca	Mg	K	P	Na	S	
Farm-1 Fujairah	25º 06 58.06 N 56º 21 17.53 E	41000	7.59	6.79	6.34	0.46	0.04	1.20	0.01	0.104
Farm-2 Kalba	25º 02 42.87 N 56º 20 31.95 E	12000	8.10	7.99	2.40	0.99	0.01	0.35	0.06	0.111
Farm-3 Hatta	24º 48 49.13 N 56º 08 04.31 E	6900	8.23	4.39	6.70	0.49	0.06	0.05	0.02	0.155

Table 2: Location and size of the study areas.

Study area	Center of Image location	Size (km^2)
Fujairah	25º 07 28.15 N, 56º 20 36.98 E	15.92
Kalba	25º 04 44.29 N, 56º 20 28.41 E	15.33
Hatta	24º 48 06.71 N, 56º 07.30.02 E	7.72

Table 3: SAVI statistical data for the three study areas obtained from images 1987 and 2000.

Date	22 Sept. 1987			31 July 2000		
	Fujairah	Kalba	Hatta	Fujairah	Kalba	Hatta
Minimum	- 0.119	0.018	- 0.058	- 0.071	- 0.004	- 0.003
Maximum	0.575	0.590	0.483	0.602	0.501	0.563
Range	0.694	0.572	0.541	0.673	0.505	0.566
Mean	0.111	0.158	0.100	0.096	0.119	0.090
Median	0.076	0.130	0.077	0.068	0.103	0.068
Mode	0.052	0.056	0.071	0.050	0.061	0.057
Std. Dev.	0.085	0.098	0.069	0.068	0.063	0.058

Table 4: 10% threshold vegetation change for the average areas of Fujairah, Kalba, and Hatta in the period between 1987 and 2000.

Study area	10% decreased		10% increased		Unchanged	
	km^2	%	km^2	%	km^2	%
Fujairah	2.93	18.4	1.17	7.3	11.82	74.3
Kalba	5.09	33.2	1.94	12.7	8.30	54.1
Hatta	0.47	24.8	0.31	16.3	1.11	59.0

Table 5: 20% threshold vegetation change for the average areas of Fujairah, Kalba, and Hatta in the period between 1987 and 2000.

Study area	20% decreased		20% increased		Unchanged	
	km^2	%	Km^2	%	km^2	%
Fujairah	1.26	7.9	0.40	2.5	14.26	89.6
Kalba	3.12	20.3	0.85	5.6	11.36	74.1
Hatta	0.20	10.8	0.17	8.8	1.51	80.1

Table 6: Change in the total number of farms in the UAE between 1996 and 2000. (UAE Statistical Book, 2000)

Region	1996		2000		% increase
	Number	%	Number	%	
Abu Dhabi	8866	39	20706	58	134
Central	5333	23	5718	16	7
Northern	3024	13	3253	9	8
Eastern	5574	25	5907	17	6

Table 7: Change in total cultivated area in the UAE between 1996 and 2000. (UAE Statistical Book, 2000).

Region	1996		2000		% increase
	Km^2	%	Km^2	%	
Abu Dhabi	476.96	59.70	2351.04	86.01	393
Central	166.14	20.79	192.99	7.06	16
Northern	97.51	12.20	113.40	4.15	16
Eastern	58.36	7.30	75.89	2.78	30

Table 8: Date palm cultivated area and production in the last four decades (Zaid, 2005).

	1961	1970	1980	1990	2001	% change (1961-2001)
Cultivated area (hectare)	550	640	5564	22368	62000	11172.73
Production (kg $hectare^{-1}$)	120000	125000	91943	63849	51290	-58.26

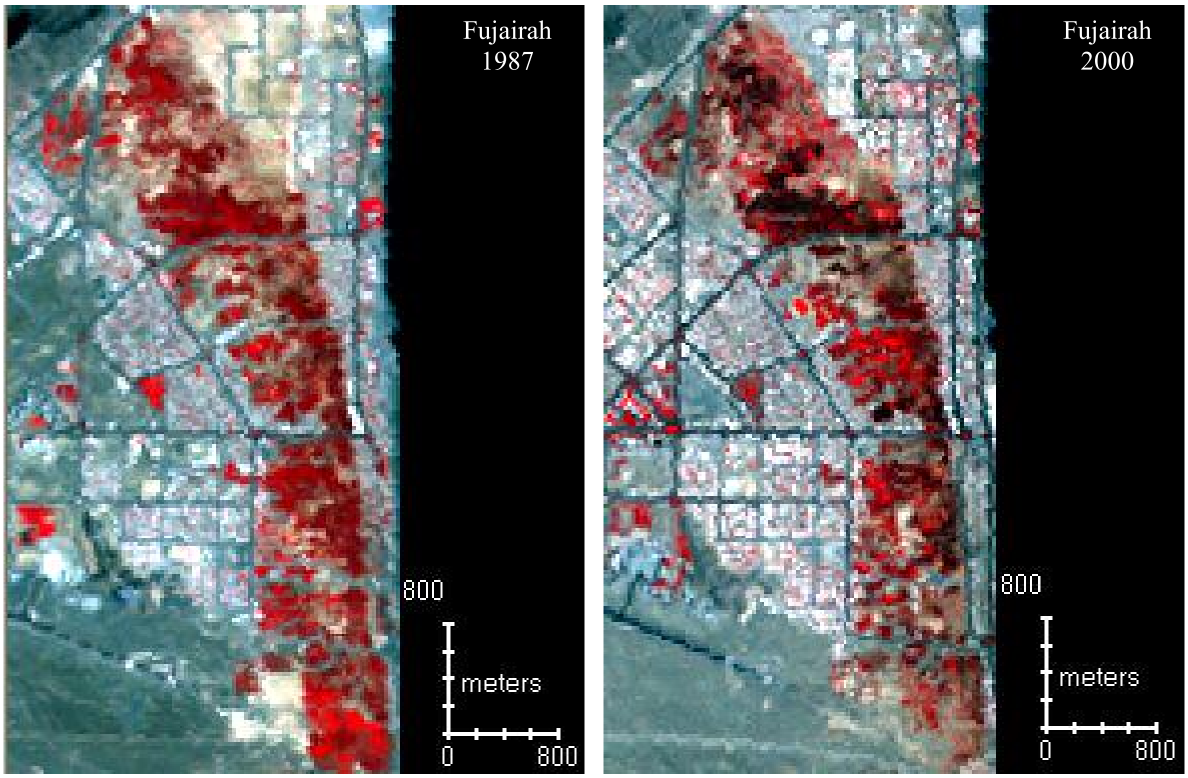

Figure 2: False color composite images (Red=layer 4, Green=layer 3, Blue=layer 2) for Fujairah area in the two years 1987 and 2000. Red colors represent vegetation.

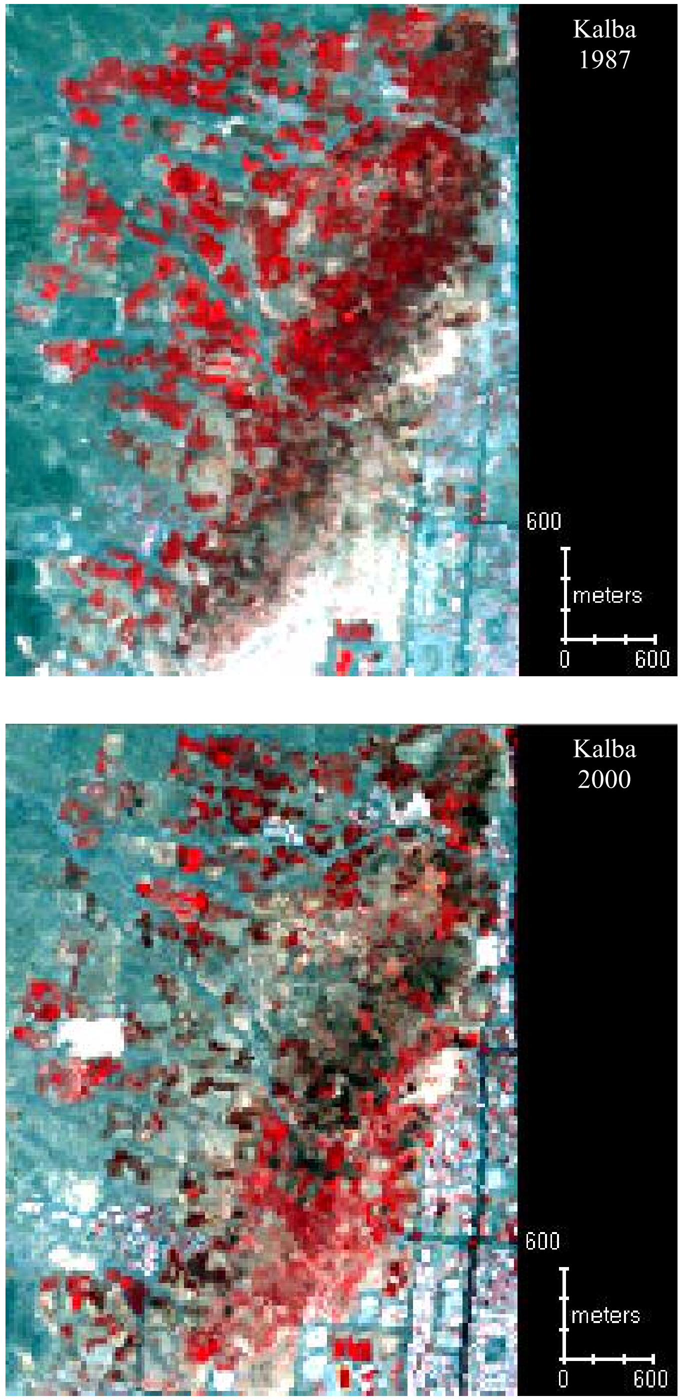

Figure 3: False color composite images (Red=layer 4, Green=layer 3, Blue=layer 2) for Kalba area in the two years 1987 and 2000. Red colors represent vegetation.

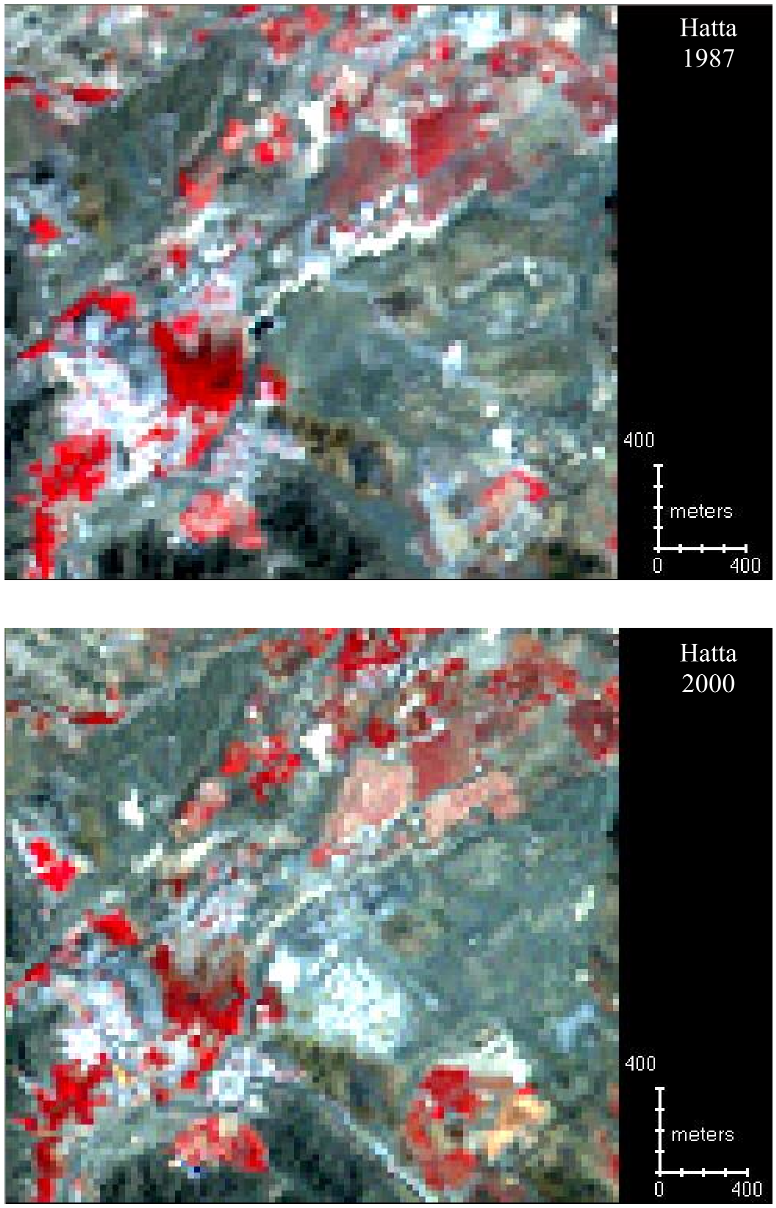

Figure 4: False color composite images (Red=layer 4, Green=layer 3, Blue=layer 2) for Hatta area in the two years 1987 and 2000. Red colors represent vegetation.

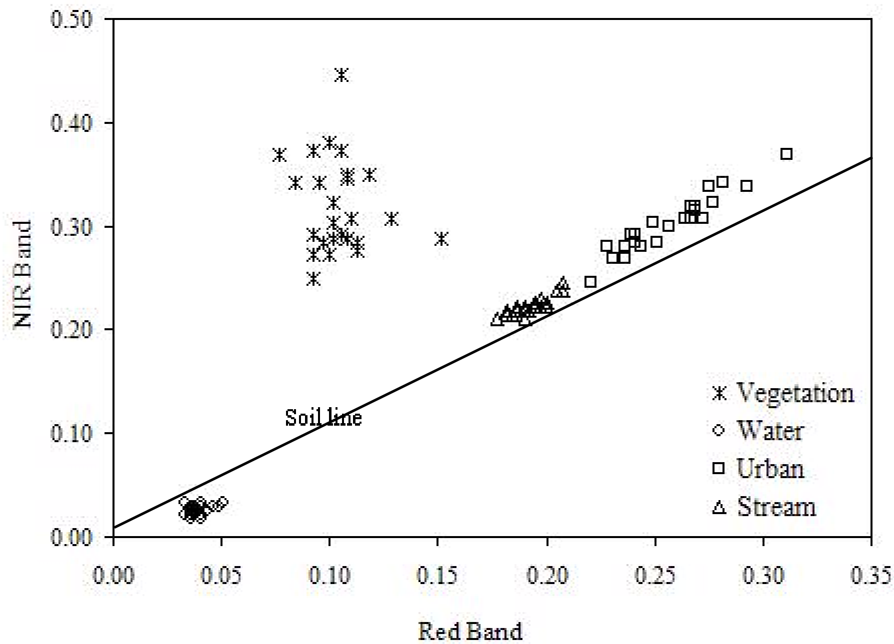

Figure 5: Spectral reflectances distribution of four land features in Fujairah area in year 1987.

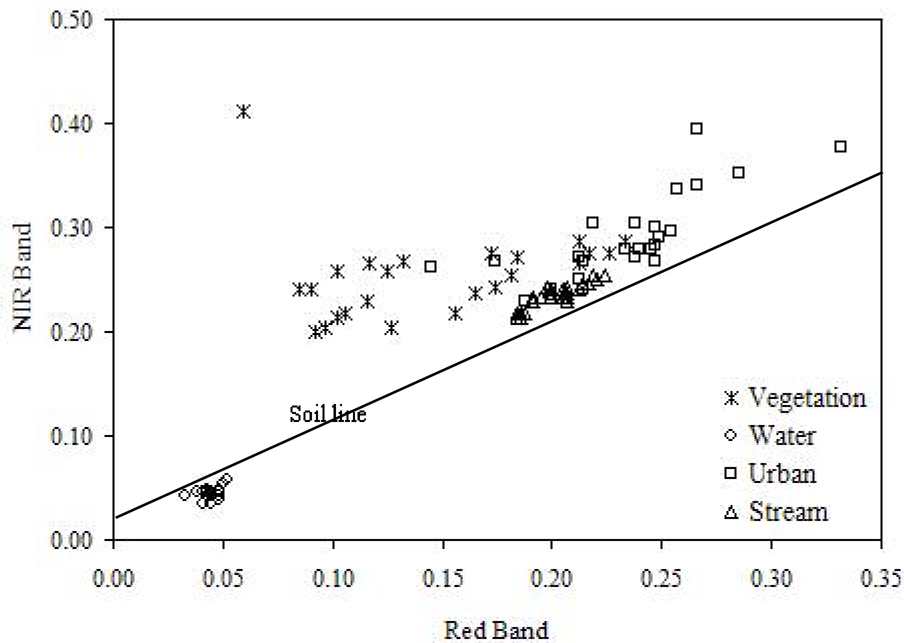

Figure 6: Spectral reflectances distribution of four land features in Fujairah area in year 2000.

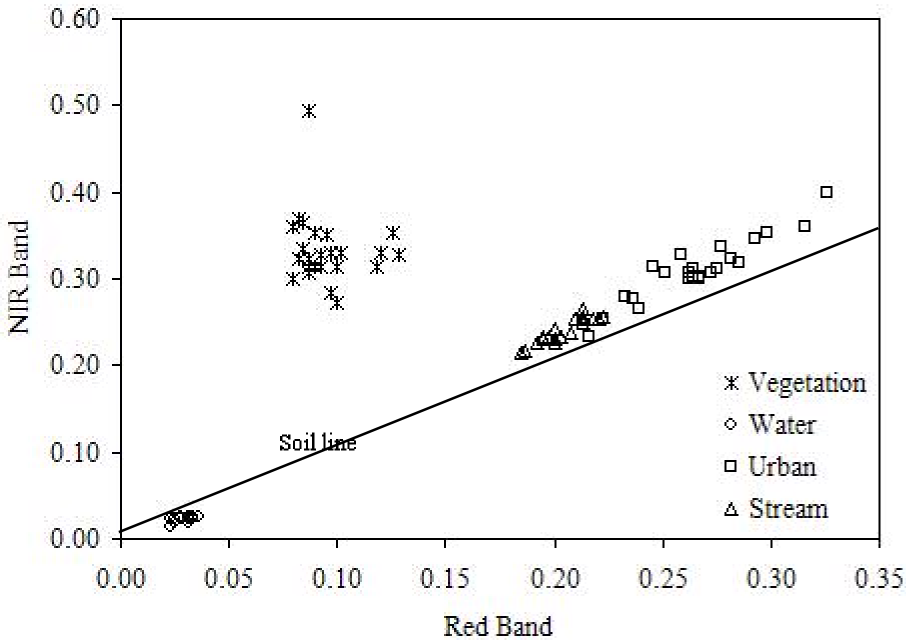

Figure 7: Spectral reflectances distribution of four land features in Kalba area in year 1987.

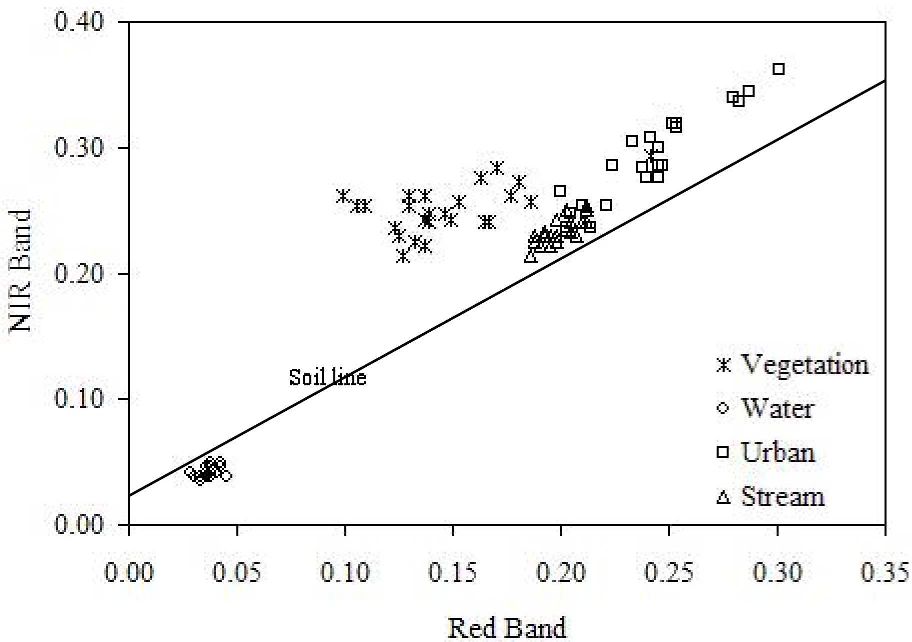

Figure 8: Spectral reflectances distribution of four land features in Kalba area in year 2000.

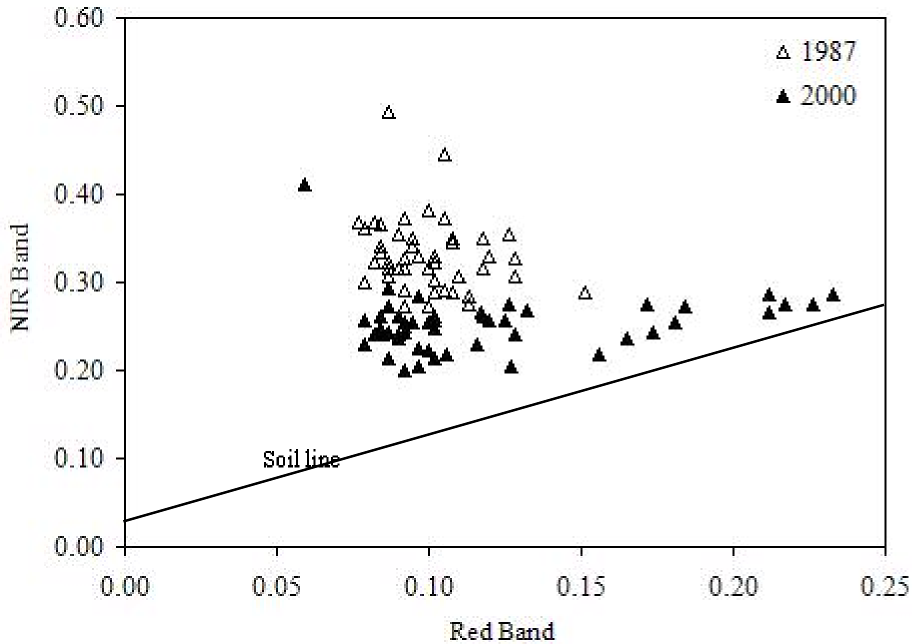

Figure 9: Distribution of vegetation reflectances of several sites for Fujairah and Kalba in the two periods, 1987 and 2000.

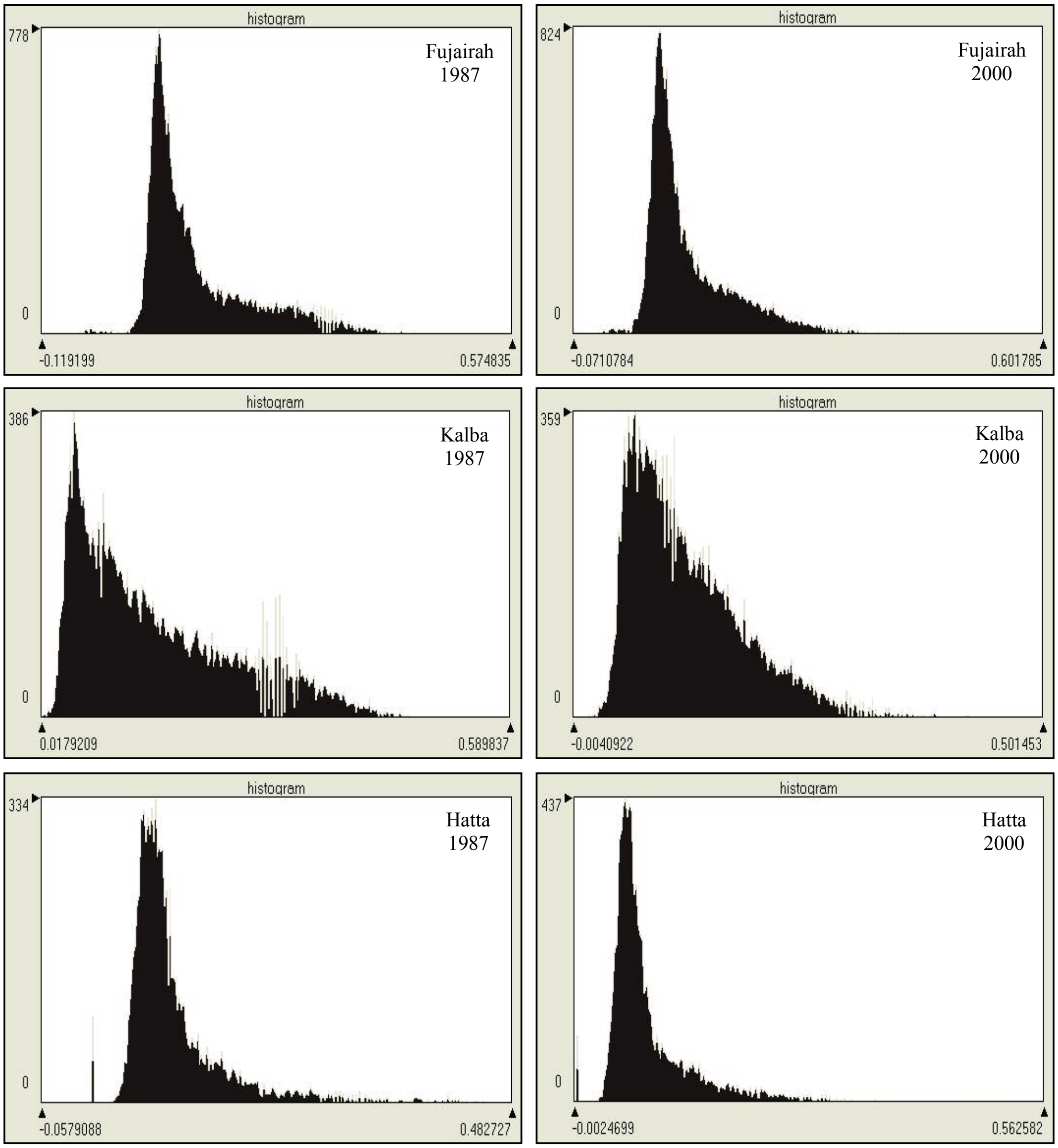

Figure 10: Histograms of the image describe the statistical distribution of the pixels for the three study areas in 1987 and 2000.

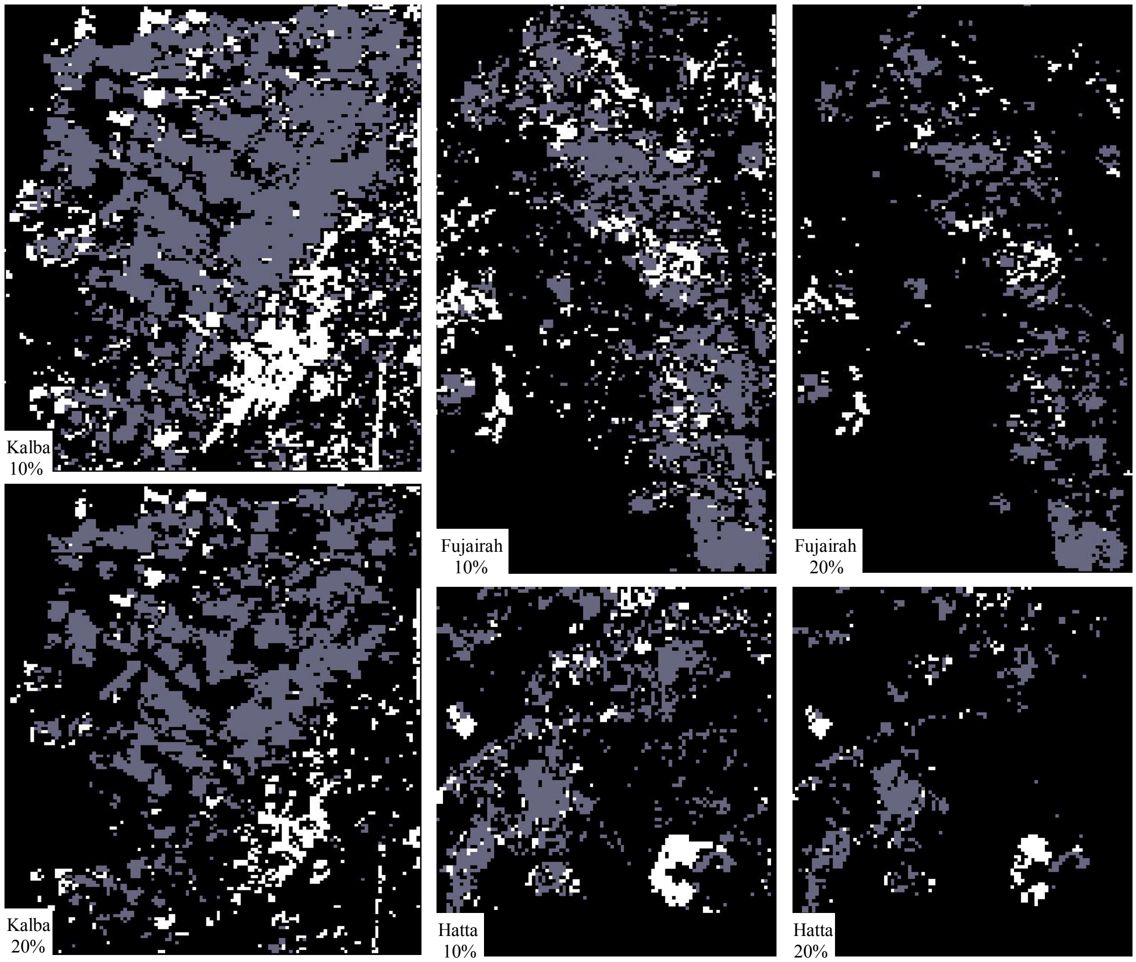

Figure 11: 10% and 20% rate of SAVI change for the three study areas, Fujairah, Kalba, and Hatta. White colors represent an increase in vegetation, gray colors represent a decrease in vegetation, and black colors represent no change in vegetation at considered percentage.