6-2014

Growth and Nutrient Uptake of Young Date Palms in Response to Deficit Irrigation and Partial Rootzone Drying.

Noura Mubarak Al Ameri

Follow this and additional works at: https://scholarworks.uaeu.ac.ae/all_theses
Part of the Horticulture Commons

Recommended Citation
https://scholarworks.uaeu.ac.ae/all_theses/256

This Thesis is brought to you for free and open access by the Electronic Theses and Dissertations at Scholarworks@UAEU. It has been accepted for inclusion in Theses by an authorized administrator of Scholarworks@UAEU. For more information, please contact fadl.musa@uaeu.ac.ae.
United Arab Emirates University
Faculty of Food and Agriculture
Masters Program in Horticulture Sciences

THESIS TITLE

GROWTH AND NUTRIENT UPTAKE OF YOUNG DATE PALMS IN RESPONSE TO DEFICIT IRRIGATION AND PARTIAL ROOTZONE DRYING

By

Noura Mubarak Al Ameri

This dissertation is submitted in partial fulfillment of the requirements for the Degree of M.Sc. in Horticultural Sciences

Under the supervision of Dr. Elke Neumann

June 2014
Declaration

I am Noura Mubarak Al Ameri the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of the thesis/dissertation titled “Growth and Nutrient Uptake of Young Date Palms in Response to Deficit Irrigation and Partial Rootzone Drying”, hereby solemnly declare that this thesis/dissertation is an original work done and prepared by me under the guidance of Dr. Elke Neumann, in the College of Food and Agriculture at UAEU. This work has not been previously formed as the basis for the award of any degree, diploma or similar title at this or any other university. The materials borrowed from other sources and included in my thesis/dissertation have been properly acknowledged.

Student’s Signature ........................................ Date ..................................................
Advisory Committee:

1) Advisor: Dr. Elke Neumann
   Title: Assistant Professor and Chair
   Department: Aridland Agriculture
   Institution: UAE University
   Signature .................................. Date 26.03.2015

2) Member: Dr. Shyam S. Kurup
   Title: Associate Professor
   Department: Aridland Agriculture
   Institution: UAE University
   Signature .................................. Date 26.03.2015

3) Member: Dr. Kenneth B. Marcum
   Title: Assistant Professor
   Department: Aridland Agriculture
   Institution: UAE University
   Signature .................................. Date ...

4) Member: Dr. Mohamed Salem
   Title: Assistant Dean for Student Affairs
   Department: Aridland Agriculture
   Institution: UAE University
   Signature .................................. Date .........
Thesis Examination Committee:

5) Advisor: Dr. Elke Neumann
Title: Assistant Professor and Chair
Department: Aridland Agriculture
Institution: UAE University
Signature .................................. Date ...........................................

1) Member Dr. Kenneth B. Marcum
Title: Assistant Professor
Department: Aridland Agriculture
Institution: UAE University
Signature .................................. Date ...........................................

6) Member Dr. Mohamed Salem
Title: Assistant Dean for Student Affairs
Department: Aridland Agriculture
Institution: UAE University
Signature .................................. Date ...........................................

2) External Examiner
Title ................................ Dr. Mohamed Badawi
Department: Microbiology
Institution: SUEF Agric Res. Center, Egypt
Signature .................................. Date ...........................................
Accepted by

Master’s Program Director: Dr. Ibrahim Belal

Signature .................................. Date ..................................

Dean of the College: Dr. Aisha Abushelaibi

Signature .................................. Date ..................................
Abstract

In this study young clonal date palm plants were transferred into horizontal split-root pots filled with compost-amended soil of the UAE. The pots were constructed from two adjacent plastic containers, fastened together by adhesive tape. Once the plants had established new roots in the containers, the soil moisture level was measured every two to four days in all soil compartments. In the control treatment, the soil moisture level was brought to 30 % w/w after every soil moisture recording. Deficit irrigation treatments received exactly 60 % of the average amount of water supplied to the pots of the control treatment. In the homogeneous deficit irrigation treatment, irrigation water was distributed over the two adjacent root compartments of each pot in a way that the soil moisture level was kept the same between the two parts of the plant root system. In partial rootzone drying (PRD) treatments, irrigation water was supplied only to one of the two adjacent pots. The PRD treatments were shifted every 2, 4 or 6 weeks, in a way that the formerly dry soil part of each split root pot was irrigated, and the moist part fell dry. In the ‘permanent PRD’ treatment, water supply was not shifted, and only one compartment was irrigated throughout the experiment. The irrigation treatments were maintained for 240 days. By the end of this period, no visual differences could be detected between palms of the different irrigation treatments. Leaf elongation measurements did not reveal an effect of deficit irrigation on leaf growth. Though leaves of the control treatment grew faster during the first phase of development, they grew slower compared with the other treatments during later stages, so that in the end no significant differences in leaf length were detected. There were no differences in the nutritional status between plants of the different irrigation treatments, suggesting that date palms are very well able to take up nutritional elements from dry soil.

The results of this study indicate that date palms respond to high amounts of irrigation water supply with a severe reduction in water use efficiency. Since PRD and
homogeneous deficit irrigation yielded the same results in terms of plant growth and nutrient uptake, homogeneous deficit irrigation is recommended for date palm production, as it does not require the expansion of the existing irrigation system.
ملخص

في هذه التجربة تم دراسة مدى استجابة فسائل النخيل للري الجزيئي للجذور وتقليص كمية المياه من حيث النمو والمواد الغذائية، حيث تم نقل فسائل مستنسخة بعد تسميم الجذور إلى قسمين متساويين إلى أوانى والتي تم تعبيرها بتبني زراعية من الأمارات. شهدت الأولى من حاويتين من البلاستيك تم تثبيتها بشرط ل nhắc. تم قياس رطوبة النبئ كل يومين إلى 4 أيام في مقصورات النبئ بعد أن تبين وجود نمطات جديدة في الجذور. تم رفع مستوى الرطوبة في العلاج الافتراضي إلى 30% أو بعد كل قراءة. أما بالنسبة إلى العلاجات التي تخص إلى التجفيف الجزيئي للجذور، فقد تم تخفيض نسبة الرطوبة إلى 60% من رطوبة النبئ الكلية للعلاج الافتراضي. في علاج تخفيض الرري المتجانس، تم توزيع مياه الري بالتساوي على الحاويتين بحيث تكون نسبة رطوبة النبئ متساوية. تم رفع إحدى الحاويات في علاجات التجفيف الجزيئي للجذور، بحيث يتم ري الحاويات الأخرى كل (2 أو 4 أو 6) أسابيع لكل علاج. في العلاج الدائم، لم يتم استبدال الري بين الحاويتين، وتم فقط رري حاوية واحدة طول فترة التجربة. استغرقت التجربة مدة 240 يوم. مع انتهاء التجربة، لم يتم ملاحظة أي اختلاف ظاهري في أي من الفسائيل بمختلف العلاجات. لم يتم ملاحظة أي اختلاف في استطالة الأوراق، على الرغم من أن أوراق العلاج الافتراضي قد استطالت بصورة صغيرة مقارنة بالعلاجات الأخرى. إلا أن مع نهاية التجربة، نمت الأوراق بشكل أبطأ من العلاجات الأخرى. أما بالنسبة للعناصر الغذائية، فلم يتم ملاحظة أي تأثير بين جميع العلاجات، مما يدل على أن الفسائيل لم تجد أي صعوبة في استخراج تلك العناصر من النبتة.

أشارت نتائج الدراسة إلى أن زيادة نسبة مياه الري أدت إلى انخفاض نسبة (استخدام كفاءة المياه). بما أن نتيجة التجفيف الجزيئي للجذور والتقليل نسبة المياه كانت متساوية من حيث النمو واستخراج العناصر الغذائية، فنصيح مزاولة تخفيض مياه الري المتجانس في انتاج النخيل حيث لا ينطوي أي توسيع في نظام الري.
ACKNOWLEDGEMENT

My biggest gratitude goes to my creator for none of this would happen except if Allah will. I'm thankful for the support of my instructors and their patient. My thanks goes also to my supportive friends, colleagues and family, for being there and encourage me in all times. Also, I would like to thank the chair and all members of the Department of food and agriculture at UAE University for assisting me all over my studies and research.

Finally a Special gratitude goes to Dr. Elkie for accepting me as her master student and not just being a very helpful and understanding but a great inspiring instructor.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>I</td>
</tr>
<tr>
<td>DECLARATION OF ORIGINAL WORK PAGE</td>
<td>II</td>
</tr>
<tr>
<td>COPYRIGHT PAGE</td>
<td>III</td>
</tr>
<tr>
<td>SIGNATURE PAGE</td>
<td>IV</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>VII</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>IX</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>X</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>XI</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>XII</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>MATERIAL AND METHODS</td>
<td>8</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>17</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>38</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>40</td>
</tr>
</tbody>
</table>
List of Tables

Table 1: The table below the figure shows the results of phosphorus in Two Way ANOVA performed on data obtained for PRD treatments. P-values indicative of a significant (< 0.05) effect of either the shifting interval or age of the leaf, or an interaction between both factors are printed in bold.

Table 2: Results of the Two Way ANOVA performed on values obtained for PRD treatments of cations (Mg, K, Na, Ca)

Table 3: Results of the Two Way ANOVA performed on values obtained for PRD treatments of micronutrients (Fe, Cu, Zn)
List of Figures

Figure 1: Split-root planting pots used in this study

Figure 2: Filling of the split-root pots with soil

Figure 3: Cover the base of the date palm trunk with soil, a small plastic planting pot was fixed around the palms, and filled with soil

Figure 4: Experimental plants after transfer to the split-root pots

Figure 5: Illustration of the irrigation treatments of this experiment

Figure 6: Average soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for control treatments during the first 180 days of the deficit irrigation treatment period.

Figure 7: Average soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for homogeneous deficit irrigation (HDI) treatments during the first 180 days of the deficit irrigation treatment period.

Figure 8: Soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for the partial rootzone drying treatments where irrigation was shifted between the two compartments of each pots after either two

Figure 9: Soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for the partial rootzone drying treatments where irrigation was not shifted between compartment A and B.

Figure 10: Average daily evapotranspiration in ml per plant.

Figure 11: Total evapotranspiration over the first 180 days of the deficit irrigation period in L per plant.

Figure 12: Visual appearance of the control plants, and PRD treatments where irrigation water supply was shifted between the two root compartments.

Figure 13: The length measured for leaf 1 and leaf 2 as described in the Materials and Methods section in cm per palm.

Figure 14: Leaf elongation rates over the seven (leaf 1) or four (leaf 2) measurement intervals in mm per day

Figure 15: Leaf length measured on the final day of measurements in cm per plant
Figure 16: Phosphorus concentrations in mg per g dry weight in primordial, young and old leaves by the end of the experiment.

Figure 17: Cation concentrations in mg per g dry weight primordial, young and old leaves by the end of the experiment.

Figure 18: Sodium concentrations in mg per g dry weight in primordial, young and old leaves by the end of the experiment.

Figure 19: Micronutrient concentrations in primordial, young and old leaves by the end of the experiment.
1. Introduction

1.1. Date palms and their cultivation in the United Arab Emirates

The date palm (Phoenix dactylifera) is a monocotyledonous plant of the genus *Coryphoeidae*, and belongs to the family of the Palmae. The date palm is native to the Gulf Region, and occurs in the wild mainly in areas where the groundwater table is shallow, and allows for its roots to have access (Chao and Krueger, 2007). Iraq is most likely the evolutionary center of the date palm, but spread to other parts of the Middle Eastern and North African drylands occurred more than 8000 years back. More recently breeding programs have evolved cultivars that can be grown under cooler climate, allowing for the spread of date palm cultivation to South America, South Africa, Australia, India and even the United States (Alhaider et al., 2014).

The date palm is a dioecious feather palm, which forms new leaves from one growing point at the top of the trunk (Barreveld, 1993). The female plants start producing fruits when between six and eight years old, but, depending on the cultivar and the environmental conditions, they may take up to 15 year to reach full productivity (Chao and Krueger, 2007). Under intensive production, annual fruit yields of around 100 kg can be achieved, while only around 20 kg are common when no input other than irrigation water is provided (Nixon and Carpenter, 1978).

Date palms constitute the most commonly grown agricultural plant of the Gulf Region. In the UAE date palm plantations occupy around 60 % of the total agricultural land. Since the government banned the production of fodder grasses in 2011 (Malek, 2011), many farmers are replacing former pastures by date palm plantation, and the relative importance of date production for the agricultural sector of the UAE is expected to increase. While in the UAE date production contributes less than 1 % to the GDP, and
is nowadays not needed for food sufficiency anymore, farmers in several poorer countries of arid lands rely on the fruits for survival. Date plantations are considered to be among the most sustainable agro-ecosystems of arid lands (Jain, 2011). However, the irrigation water requirements of these plants are not little. A common traditional saying among date palm growers of the Gulf Region is that the date palm grows ‘with its head in the fire and its feet in the water’. Though date palms are able to withstand periods of reduced water supply well, they cannot be grown in fully arid areas without irrigation, unless their roots have access to groundwater. The actual irrigation water demand of date palms has rarely been assessed. Date palms used in urban landscapes of the UAE are commonly irrigated with between 200 and 250 L of water per day during the summer months (Al Ain Municipality representatives, personal communication). While some authors estimated similar values for the water requirements of date palms under hot, arid conditions (Sellami and Sifaoui, 2003), other estimates are higher, stating that between 300 and 700 L would be required (Carr, 2013).

The response of date palms to different irrigation regimes or practices has rarely been investigated, but there are some hints that reasonable yields can be achieved at reduced water supply levels. Al-Amoud et al. (2000) estimated that the optimal water use efficiency for date palms grown in Central Saudi Arabia could be achieved at annual water supply of 108 m³ per palm. Given an average planting density of 220 palms per ha, this would result in an average annual application rate of 2.37 m³ per m². This would be lower than what is currently commonly applied by local farmers of the Gulf Region. In a later study the same authors (Al-Amoud et al. 2012) estimated the actual annual water use of date palm plantations to be between 2140 and 2830 mm in different locations in Saudi Arabia.
Salam and Mazrooei (2007) estimated the annual irrigation requirement of date palm plantations in Kuwait to be around 2600 mm.

Traditionally date palms are grown in square irrigation basins that are flooded regularly. Animal fodder, vegetables and fruit trees are sometimes grown beneath the palms. Particularly in the countries of the Gulf Region, modern irrigation technology is nowadays more commonly used than the traditional basin irrigation system (Abdul-Baki et al., 2002). The most commonly used irrigation practice for date palms in the UAE is water supply through bubblers. The palms are grown with round irrigation basins around their stem, which are flooded at regular intervals.

1.2. The need for water conservation in the Gulf Region

Agricultural and landscaping activities account for 82% of the total annual water consumption of the UAE, while contributing only 2% to the GDP (FAO, 2009). Strategic plans of the government thus aim at significantly reducing the water consumption for agriculture in order to save non-renewable water resources for future generations (MOEW, 2010). However, the UAE also strives to maintain national food security, and aims at supporting agricultural activities that look back onto a long tradition, such as date palm production, which may have been practiced in the country since more than 7000 years (Beech, 2003). To achieve this, water-saving irrigation technologies and practices are required.

In the UAE, most date palms are grown on small-scale farms that are between 2 and 6 ha in size. These farms are owned by local people and managed by expatriate labors, often from Bangladesh or Pakistan, who have little experience with date cultivation until they come to the UAE. Groundwater is most commonly used for date palm irrigation on small-scale farms. However, the quality and availability of groundwater
has declined over the last decades in many places. Where groundwater is still readily available and of reasonable quality, the farm labors are striving to maximize the yield per palm. However, when water needs to be desalinated or brought in from other places, it is no longer available for free, and it can be expected that in the future, it will become more and more important to maximize the crop yield per unit of water applied, than maximizing the yield per plant. Knowledge on strategies by which the water use efficiency of date palms could be improved, would be required to do this. However, almost nothing is known about strategies by which date palm water use efficiency could be improved.

1.3. Effect of water availability on water use efficiency in plants

Plants adapted to warm fully arid ecosystems have to deal with a wide range of adverse environmental conditions. Particularly perennial plants that remain physiologically active throughout the whole year have evolved various adaptive strategies that allow them to cope with scarcity of resources (Oliver et al. 2000). Date palms, for example, are known to exploit the soil efficiently through forming a root system that reaches horizontally up to 25 m away from the trunk, and vertically more than 6 m deep (Oihabi, 1991; Munier, 1973).

Particularly plants native to areas where the availability of water and nutritional elements in the soil is low, are also able to internally use available water and nutrients efficiently for the formation of biomass. The extent, by which such adaptive strategies are expressed, depends on the genotype of the plant, as well as on the environmental conditions it is exposed to. When plants are grown under conditions where nutrients and water are available without limitation, they will use these resources less efficiently, and exhibit a state known as ‘luxury consumption’ (van Wijk et al., 2003).
Roots continuously sense their water supply status and respond with the production of the phytohormone abscisic acid (ABA) when water influx rates fall below a certain threshold (Dodd et al. 2008). Abscisic acid induces a full set of water saving mechanisms in the shoot, including stomata closure, a reduction in leaf expansion and synthesis of organic osmolytes. Under water deficiency, plants frequently suffer from an increased production of reactive oxygen species within their tissues that may lead to necrosis and loss of leaves (Mittler, 2002). The synthesis of antioxidants and protective metabolites such as catalase, superoxide dismutase and proline has also been shown to be triggered by ABA (Argawal et al. 2005). The hormone also leads to increased primary root elongation in many plant species, which may facilitate the exploitation of deeper soil layers for water (Spollen et al. 2000). Interestingly, the ABA signal is produced by roots exposed to dry soil, irrespectively of the overall water status of the plant. In split-root experiments where plants are grown with half of their root system in moist and the other half in dry soil, stomata closure and a decreased rate of leaf elongation are commonly observed, even when the roots in the moist soil part are well able to supply the shoot with sufficient amounts of nutrients and water for optimal growth (Jackson, 1997).

Though most people consider water scarcity first when thinking of arid environments, a low soil moisture level may also severely impair the availability of nutrients. When soil falls dry, the flux of nutritional elements from the soil matrix to the root surface by diffusion and massflow is impaired (Gahoonia et al. 1994; Hebbar et al. 1994).

1.4. Deficit irrigation and partial rootzone drying

Deficit irrigation techniques make use of the ability of plants to adapt to a reduced water availability by restricting the water supply. This restriction may either apply to
the whole rooting zone, or only to a part of it. A technique where water supply is restricted to one part of the root system only is called ‘partial rootzone drying’, PRD (Davies et al. 2002; Loveys et al. 2004). Plants irrigated by the PRD technique will be supplied with water only to half of their root system, whereas the other half falls dry (Snoar and Loveys, 2007). Roots in moist soil have access to water, while roots in the dry soil part will produce the ABA signal that triggers water saving mechanisms in the shoot. Irrigation is shifted between the two the formerly dry soil part will become moist, and the formerly irrigated soil part will fall dry. Deficit irrigation usually implies that annual amounts of irrigation water supplied by are between 30 to 50 % lower compared with conventional irrigation (Fereres and Soriano, 2007). Deficit irrigation has been shown to lead to a reduction in plant vegetative growth, and to reduce the yield. However the water productivity (amount of yield produced per unit of irrigation water) in annual as well as perennial crops has been shown to increase considerably (Zwaart and Bastiaanssen, 2004). Studies comparing PRD with homogeneous deficit irrigation have yielded controversial results. While some studies showed no difference in water productivity between the two systems (Melgar et al., 2010), other demonstrated the superiority of PRD over homogeneous deficit irrigation (Egea et al. 2010). Almost nothing is known about how date palms would respond to deficit irrigation, even though these irrigation strategies might have a particularly high potential to save water in plants adapted to warm, fully arid agroecosystems.

1.5. Objectives of this study

The first objective of this study was to test how young date palms would respond to deficit irrigation in terms of nutrient uptake and leaf expansion.
The second aim of this study was to investigate whether date palm responses to deficit irrigation would differ depending on whether a restriction in water supply would affect the whole root system equally, or only a part of it (PRD).

The third objective was to identify the most suitable interval length at which irrigation should be shifted between the two rootzone parts in partial rootzone drying.
2. Materials and Methods

2.1 Plant material

To achieve homogeneity, 24 clonal date palms of the cultivar ‘Khadrawy’ were obtained from the UAE University Date Palm Tissue Culture Laboratory in Al-Foah, United Arab Emirates. The plants were all approximately 30 cm high, and 27 months old. They had 4-5 healthy fully developed leaves. They had been cultivated in round black plastic bags in a shaded, air-conditioned greenhouse prior to their use in the experiment. The young date palms had been transplanted three times during this cultivation period, at the age of 12, 13 and 26 months. A 3:1 (vol/vol) mixture of dune sand from the area around the farm, and compost was used for cultivating the plants. When the date palms were obtained from the tissue culture laboratory, they grew in 4 L of substrate. Prior to their transfer to the experimental pots the date palms were kept in a shadehouse at the UAE University Campus in Al Jimi / Al Ain for one month. Each planting bag was supplied daily with 250 ml of deionized water every day during this time.

2.2 Experimental planting pots

The plants were transferred to split-root pots that consisted of two adjacent soil compartments (Figure 1). The soil compartments were constructed from bottles made out of transparent plastic. Their openings were widened by cutting out a piece of the upper part of each bottle neck using a soldering iron. Six holes were stitched into the bottom of each bottle, to allow for aeration and drainage of excessive amounts of irrigation water. Two bottles were fixed together using tape and silicon glue. A layer of aluminum foil was fixed around the adjacent root compartments in order to protect roots and soil from exposure to light.
2.3 Soil preparation and transplanting

At the time of transplanting, on the 17. and 18.05. 2011, the bags in which the plants grew were cut open, and the roots were carefully separated from the soil. The soil obtained from all planting bags was spread on plastic sheets under the open air for drying. Substrate obtained from all pots was thoroughly mixed, and stones or other larger particles were removed manually.

After removal of soil, the date palm roots were kept between sheets of moist paper towels until they were transferred to the experimental pots. The root system of each plant was split into two parts of approximately equal size. Each root part was placed in one of the two adjacent plastic bottles (Fig. 2).
The root system was split into two parts of approximately equal size and embedded into air-dried growth substrate.

The homogenized soil was used for the filling of the split root pots, where each plastic bottle was filled with 1200 ml of air-dried soil (1500 g). To make sure that a homogeneous soil density was achieved, the bottles were filled by layers of 400 ml (500 g). The growth substrate was carefully spread around the plant roots and compacted to the desired bulk density of 1.25 g cm\(^{-3}\).

In order to keep the shoot base and upper roots covered with soil, an additional small, round plastic planting pot was cut open and fixed around the lower part of the shoot (Fig. 3). A hole of 2 cm diameter was cut into the center of the bottom of the small planting pots to allow roots to grow out. All other drainage holes were covered by adhesive tape. After placing around the base of the stem the cute was sealed with two layers of adhesive tape. To keep soil from failing out of the pot, pieces of fleece were placed around the stem and over the bottom of each pot. Then the small pot was filled with 150g dry, non-fertilized sandy soil from a sand dune in Al Foah. 30 ml of water
were added to keep roots and stem base moist. 350 ml of deionized water were added to each root compartment after planting was completed (Fig.4).

Figure 3: To cover the base of the date palm trunk with soil, a small plastic planting pot was fixed around the palms, and filled with soil.

Figure 4: Experimental plants after transfer to the split-root pots. The pots were wrapped with aluminous foil prior to their transfer to the greenhouse, in order to protect roots from exposure to light.
one particular compartment was maintained for either two, four or six weeks (= 2, 4 or 6 wk), before it was shifted in a way that the formerly watered compartment fell dry, and the formerly dry compartment received most of the irrigation water (Fig. 5). In a non-shifted (= Perm.) PRD treatment, water was mainly supplied only to one of the two root compartments throughout the whole experimental period. Four replicates were prepared of each treatment. The irrigation treatments were maintained for eight months, from January until August 2012.

Figure 5: Illustration of the irrigation treatments of this experiment. The letters ‘A’ and ‘B’ represent the two root compartments of the split-root pots. PRD means ‘Partial rootzone drying’ with shifts in water supply between the two compartments at either two, four or six weeks (wk). In the ‘Perm’ treatment water is supplied mainly to one half of the root system throughout the whole experimental period.
2.6 Soil moisture measurements and water supply

Prior to water supply to the plants, the soil moisture level was measured using the soil moisture meter FieldScout TDR 100 with 12 cm rods. The TDR rods were stitched into the soil from the surface. Soil moisture measurements were done before each irrigation event in all root compartments. The moisture level after water supply was calculated from the amount of water that was calculated under the assumption that the decline in moisture between two irrigation events was linear.

The water loss from the control pots was estimated gravimetrically and replaced with deionized water. Sixty percent of the average water loss from the control split-root pots was supplied to each plant under deficit irrigation. To maintain a homogeneous soil moisture level over both root compartments of each HDI treatment, the irrigation water way that after irrigation, the soil moisture level in both pots was equal. In the PRD treatments water was moisture level in the dry compartment fell below 5% w/w, amounts of irrigation water sufficient to raise the moisture level to 5% w/w again were also supplied to this compartment.

2.7 Leaf elongation measurements

To measure the effect of the treatments on the elongation rate of leaves, a line was drawn horizontally from the base of the oldest living leaf to the primordial leaf when it first appeared. As the youngest leaf elongated while the oldest one did not change in length, the part of the line on the primordial leaf would move higher, while the line part on the old leaf would not change in place. The distance between the two line
parts was measured at regular intervals. At the time of labeling the visible length of
the primordial leaf was between 1 and 3 cm. The primordial leaf that was
was termed 'leaf 1'. Once the next leaf (= leaf 2) had appeared in all plants by a
visible length of at least 1 cm, its elongation was measured in the same way as for leaf
1. The elongation rates in mm per day were calculated by dividing the length
increment between tw
s
y
s
between the length of leaf 2 at the time of labeling was between 1 and 5
cm in all plants.

2.8 Leaf sampling and element analysis
At 160 days after set up of the different irrigation treatments (26. June 2012), three
leaf samples were taken from each plant. The first comprised of around 40 % of the
area of the oldest still living leaf. The second consisted of three leaflets cut from the
middle of the youngest fully developed leaf, and the third of two to three leaflets cut
from the youngest not yet fully developed (= primordial) leaf. These leaflets were not
yet green.

The samples were washed with deionized water, and then bagged and oven dried at
65° C for 3 days in a drying oven. Samples were chopped into pieces of
approximately 0.5 cm length with scissors. Subsamples of around 300 mg of the
chopped samples were then weighed into ceramic crucibles, and ashed at 550 °C. The
ash was further oxidized with 5 ml 1:2 diluted HNO₃, and then taken up into 25 ml of
1:30 diluted HCl. The samples were boiled for 2 min to cleave orthophosphates,
before being filtered through Blue Ribbon Filter paper. Every third sample was
prepared in duplicate.
The concentrations of P, Mg, K, Na, Ca, Fe, Cu and Zn in the liquid samples were measured using inductively coupled plasma optical emission spectrometry (ICP-OES, Thermo Scientific, USA).

2.9 Statistical Analysis

All statistical analyses were calculated using the SigmaStat 3.5 program (SYSTAT, USA). Error bars shown in figures always represent the standard deviation. Mean values obtained for the total evapotranspiration over the first 180 days of the deficit irrigation period were compared between all irrigation treatments by a One Way ANOVA (Tukey's multiple comparison). Differences were considered significant when P was below 0.05. Mean values obtained for the total leaf expansion and the leaf expansion rates were compared between the different irrigation treatments in the same way.

For the element concentrations, a Two Way ANOVA was performed on values obtained for primordial, young and old leaves of the PRD treatments. P-values lower than 0.05 were considered indicative of a significant effect of either the soil moisture shifting interval (factor 1) leaf age (factor 2), or an interaction between both factors.
3. Results and Discussion

3.1. Soil moisture level in the planting pots measured over the first 180 days of the irrigation treatment period

In the control treatments, the moisture level in both root compartments was very similar, and fluctuated between around 15 and 25 % w/w (Fig 6). During the first two weeks the average soil moisture level decreased from 35 % to around 20 %. Throughout the rest of the treatment period the average soil moisture level fluctuated around the same level.

![Figure 6: Average soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for control treatments during the first 180 days of the deficit irrigation treatment period. Shown are the mean values obtained for all ‘A’ and all ‘B’ compartments.](image)

In the control treatments, the moisture level of the soil was brought to 30 % w/w with each irrigation event. The water holding capacity of the growth substrate was reached at around 35 % w/w (observation during the experiment). Between two irrigation intervals the moisture level of the soil of control treatments rarely dropped below 10 % (data not shown). Since plants of the deficit irrigation treatments seemed readily
able to extract water from soil that had a moisture level even below 10 % w/w, it can be assumed that the control treatments did not experience limitation in water supply, and that water uptake in these plants would represent the maximal or ‘ad libitum’ consumption under the given environmental conditions.

The reason for the decrease in average soil moisture during the first two weeks lay in a higher level of water supply before the set up of the irrigation treatments, and an increase in the greenhouse temperature during this time (data not shown).

Similar with the control treatments, the average soil moisture level in the HDI compartments decreased from around 25-30 % w/w to between 10-17 % w/w during the first three weeks (Fig.7). As intended by the irrigation procedures applied, there was no difference in soil moisture between the two root compartments. The average soil moisture never exceeded 20 % and never dropped below 10 %. However, the soil moisture measured before irrigation was often below 5 % (data not shown), indicating that the plants might have experienced water shortage.

![Figure 7: Average soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for homogeneous deficit irrigation (HDI) treatments](image-url)
during the first 180 days of the deficit irrigation treatment period. Shown are the mean values obtained for all ‘A’ and all ‘B’ compartments.

In the PRD 2wk treatment, the average soil moisture in the well watered compartments was around 25 % by the time perdominant water supply shifted to the respective other compartment (Fig. 8). It then dropped gradually to around 5 %.

The water supply was shifted ten times between the two root compartments. The length of each interval was in a range between one and three weeks.

In the PRD 4wk treatment the soil moisture level decreased in the compartments that were not watered to around 5 %. Upon re-supply of water, the moisture level increased up to 25 to 30 %. In this treatment, the water supply was shifted five times between the two root compartments during the growth period. Each interval was between four and five weeks long. Similar with the other PRD treatments, the average moisture level in the 6wk pots rose to a range of 25 to 30 % in well watered compartments, and decreased to 5% in the compartment that received restricted water supply. The first shift was done after approximately six weeks, the second one after another five weeks, and the third one after ten weeks.

Across all PRD treatments where irrigation was shifted between two compartments, the speed by which the average moisture level declined when irrigation was switched from one compartment to the other, was always approximately the same, indicating that the roots did not die or lose their ability to take up water when exposed to dry soil for up to ten weeks.

For the treatments where PRD was applied without any shift of irrigation between the two root compartments, moisture level in compartment B decreased from 37% to 21% in the first week, and thereafter fluctuated between 25 and 15% throughout the first 180 days of treatment (Fig. 9). Compartment A started with a moisture level of 11% to reach 8% in the first week and 5% by week 2. Moisture level in the compartment
Figure 8: Soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for the partial rootzone drying treatments where irrigation was shifted between compartment A and B. Shown are the mean values.

Figure 9: Soil moisture (in % w/w) in the two root compartments (A and B) of each split root pot, measured for the partial rootzone drying treatments where irrigation was not shifted between compartments A and B. Shown are the mean values.

Receiving restricted water supply remained between 5 and 7% throughout the growth period. Interestingly, the average moisture level in the well-watered compartments did not differ much between the PRD treatment and the well-watered control. Since the PRD treatments received only 60% of the water supplied to the controls, one might expect that the plants under deficit irrigation would lower the soil moisture in well-watered compartments to a greater extent between the irrigation events, resulting in a lower average soil moisture level. Since plants of all PRD treatments managed to lower the moisture level in the non-irrigated compartments quickly to below 5% when water supply was withheld, the reason for this effect might not lie in the inability of the plants to take up water from soil that has a low moisture regime. It cannot be excluded that ABA signals produced by roots in the adjacent compartment induced...
3.2. Evapotranspiration during the first 180 days of the deficit irrigation period

During the first 180 days of the deficit irrigation period, the average daily evapotranspiration was around 50 ml per plant for all deficit irrigation treatments (Fig. 10). The well watered control plants had average daily evapotranspiration around 90 ml per day. Thereafter, the average daily evapotranspiration increased in all treatments and fluctuated from 70-200 ml during the remaining four months in the well watered control and between 40 and 140 ml for the deficit irrigation treatments.

Figure 10: Average daily evapotranspiration in ml per plant. Shown are the mean values. Since there was no significant difference between mean values for the different deficit irrigation treatments, the corresponding curves are shown in the same color. The values for the well watered control were significantly higher compared with deficit irrigation treatments starting from day 15 of the deficit irrigation period (exceptions: 90, 162, 175 days).

There was no significant difference in daily evapotranspiration between the different deficit irrigation treatments (Tukey’s multiple comparison, P < 0.005, data not shown). The total amounts of water lost from planting pots under deficit irrigation...
3.3. Plant appearance and leaf elongation rates throughout the deficit irrigation period.

Figure 11: Total evapotranspiration over the first 180 days of the deficit irrigation period in L per plant. Shown are the mean values ± standard deviation. There was no significant difference between the mean values obtained for the different deficit irrigation treatments (P < 0.05; Tukey’s multiple comparison). The control had a significantly higher evapotranspiration compared with all other treatments.

3.3. Plant appearance and leaf elongation rates throughout the deficit irrigation period.
Day 210. All plants had grown considerably at the time of transplanting. The size of the PRD 2 plant appeared to be slightly larger compared to the control and PRD 6 plant. However, such growth difference could not be measured in terms of leaf number or height of the plant above the ground level (data not shown).

Figure 12: Visual appearance of the control plants and PRD treatments where irrigation water supply was shifted between the two root compartments. The two treatments that are not shown (homogeneous deficit irrigation and PRD without shifting) could visually not be distinguished from the plants on the photograph.

The length growth of leaves appeared to be faster for control compared with the deficit irrigation treatments during the first part of leaf emergence (Figs. 13 and 14). During later stages of leaf formation, the elongation rates decreased for the control treatments, and on the last measurement date, when leaf 1 was completely expanded, there was no difference in the total leaf length between the treatments (Fig. 15). Leaf 2 visually appeared at approximately the same time in all treatments. This could be an
indicating that the speed of leaf formation was not affected by the deficit irrigation treatment. Similar with leaf elongation, the leaf length occurred at a higher rate for the control treatment compared with the deficit irrigation treatment during the first three months of observation. Thereafter, the deficit irrigation treatments seemed to catch up and reach the same length on the last date of measurement.

Figure 13: G% T(12 %) & S 'T' $T+$ . T ! T+ . cT $T$ (G/SVO(Tv T)%T (G#-3T ! T 9 /%T&/ #! Tm / T) $T W, H% T+ . T+ ! 2 %@ $T. Wv (Tb V ! T # . $T - SV 2T% $T 210 'Z6' Qs $a #! T) ($# 'T' $T+ . T!'. T'- $T+ . T!'. T'- $T+ . T+T23 'W6' Qs $L W#! T) ($# 'T' $T . P%@/ T $T% $T . T!'. T + $T

Control HDI PRD 2 Wk PRD 4 Wk PRD 6 Wk PRD Perm

<table>
<thead>
<tr>
<th>Days after labeling of the first leaf</th>
<th>Days after labeling of the first leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf length in cm</td>
<td>Leaf length in cm</td>
</tr>
<tr>
<td>0 30 60 90 120 150 180 210</td>
<td>0 30 60 90 120 150 180 210</td>
</tr>
<tr>
<td>Control</td>
<td>Control</td>
</tr>
<tr>
<td>HDI</td>
<td>HDI</td>
</tr>
<tr>
<td>PRD 2 Wk</td>
<td>PRD 2 Wk</td>
</tr>
<tr>
<td>PRD 4 Wk</td>
<td>PRD 4 Wk</td>
</tr>
<tr>
<td>PRD 6 Wk</td>
<td>PRD 6 Wk</td>
</tr>
<tr>
<td>PRD Perm</td>
<td>PRD Perm</td>
</tr>
</tbody>
</table>
Figure 14: Leaf elongation rates over the seven (leaf 1) or four (leaf 2) measurement intervals in mm per day. Shown are the mean values ± standard deviation. For each interval mean values were compared by Tukey’s multiple comparison. Mean values followed by the same letter are not significantly different (P < 0.05).
Figure 15: Leaf length measured on the final day of measurements in cm per plant. Shown are the mean values ± standard deviation. Mean values obtained for leaf 1 and for leaf two were compared between the treatments by Tukey’s multiple comparison (P < 0.05), but no significant differences were detected.

The results obtained here are in contradiction with a number of other studies, where a reduction in leaf expansion and an overall smaller leaf size was observed (Jackson, 1997; Keller, 2005). In response to deficit irrigation, our results rather suggest that in response to deficit irrigation, leaf expansion rates are smaller only during early stages of leaf development. However, we did not measure the length of the leaflets or the weight of the leaves. Thus an unequivocal conclusion on leaf growth in response to deficit irrigation cannot yet be made based on the present findings. However, since there was no apparent delay in leaf formation in response to deficit irrigation in this experiment, it can be concluded that a reduction in irrigation water supply to young date palms by 40% compared with the maximum consumption does apparently not lead to major growth retardations. Reasons for this remain speculative. It is possible that date palms can well
To regulate transpiration from their leaves through mechanisms other than leaf area, date palms, for example, can contract their leaflets under water deficiency, in order to reduce the leaf surface area. Previous studies on deficit irrigation were done on plants that are not native to arid land (Cotta et al., 2007).

The different deficit irrigation treatments also had no effect on the leaf elongation rate, suggesting that the partial distribution of soil moisture does not affect the growth of date palms much. It could be that date palms are well adapted to a heterogeneous soil moisture level in their rooting zone. In plants that grow in the wild, the lower part of the root system may be well watered as it lies in the moist subsoil. Roots in the topsoil may be exposed to dry soil.

3.4. Macronutrient concentrations in leaves of different age at 160 days after the beginning of the deficit irrigation treatment

3.4.1 Phosphorus

Phosphorus concentrations in plants' leaves were measured in primordial, young and old leaves (Fig. 16). Concentrations ranged from 1.5 to 2.4 mg per g OW, but there was no difference depending on the age of the leaf or the water supply treatment. Standard values for indicating a minimum and maximum range for optimal growth of plants are available for a large number of cultivated plants (Bergmann et al., 1992), but to date they have not yet been published for date palms. Ibrahim et al. (2013) reported P concentrations in field-grown date palms receiving additional PK fertilizer of 1.3 mg per g dry weight. Silva and Uchida (2000) give P concentrations of between 1.1 and 2.4 mg per g dry weight as optimal values for a range of ornamental plants, and Van Uexkull (2007) states that...
P concentrations of 1.9 mg per g dry weight as optimal for oil palm. Comparing the values obtained for plants of our study, it is thus very likely that the date palms of this experiment were well supplied.

Figure 16: Phosphorus concentrations in mg per g dry weight in primordial, young and old leaves by the end of the experiment. Shown are mean values ± standard deviations. Numbers below bars of the partial rootzone drying (PRD) treatments represent the shifting intervals in weeks. The P stands for PRD treatments where irrigation was not shifted between the root parts. Mean values were compared within each type of leaf by Tukey's multiple comparison, but no significant (p < 0.05) differences were detected. The table below the figure shows the results of the Two Way ANOVA performed on data obtained for PRD treatments. P-values indicative of a significant (< 0.05) effect of either the shifting interval or age of the leaf, or an interaction between both factors are printed in bold.

Results of the Two Way ANOVA:

<table>
<thead>
<tr>
<th></th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD shifting intervals</td>
<td>0.097</td>
</tr>
<tr>
<td>Age of the leaf</td>
<td>0.079</td>
</tr>
<tr>
<td>Interactions</td>
<td>0.514</td>
</tr>
</tbody>
</table>
with P, and that their growth was not limited by deficiency of this experiment. The relatively small difference in P concentrations between primordial and old leaves supports this assumption. Since P is very well mobile in the plant, it is usually preferentially transferred to primordial tissues under deficiency, resulting in much lower element concentrations in older compared with younger plant parts.

In the plant P is involved in the energy metabolism. It is also part of the DNA and the biomembranes. The concentrations of P in the soil solution are very low, particularly on slightly alkaline soils of the UAE. When the soil falls dry, plant P acquisition can be severely hampered. (Neumann et al., 2009). It is thus surprising that deficit irrigation did not result in lower P concentrations of date palm leaves. Whether date palm plants of this experiment were assisted by arbuscular mycorrhizal fungi (Neumann and George, 2004), long root hairs or other P acquisition strategies that helped them to overcome poor P availability in dry soil, deserves further investigation.

3.4.2 Magnesium, Potassium and Calcium

Magnesium concentration in primordial, young and old leaves were between 2 and 3 mg/g DW. Concentrations were highest in young leaves, possibly because Mg is required for the formation of chlorophyll, which is not yet present in primordial leaves. Mg is mobile in the plant, and thus younger plant parts generally are supplied with this element by priority. Bergmann (1992) stated Mg levels of above 2.3 mg per g dry weight as optimal for coconut palms. Similarly, Van Uexkull (2007) stated 2.5 mg per g dry weight as optimal for oil palm. For some ornamental palms Silva and Uchida (2000) stated
values between 2 and 3.4 as optimal. According to these values, it is likely that plants of all treatments were well supplied with Mg in the present study.

Different from Mg, Ca is not mobile in the plant body and can thus not be relocated from older leaves into younger plant parts or fruits. As Ca is transported only through the xylem, the Ca concentrations in leaves commonly increase with increasing leaf age. There are so far no reports in the literature on Ca concentrations in primordial palm leaves. For adult leaves of palms concentrations between 5 and 10 mg per g dry weight are commonly stated (Broschat, 1997; Silva and Uchida, 2000; Krueger 2007). Compared with these values, it can be concluded that the plants of our study were most likely sufficiently supplied with Ca. Calcium in plants is responsible for the stability of the cell wall and biomembranes. Since Ca is transported only with the transpirational pull and the root pressure, Ca uptake is facilitated by sufficient water supply and high levels of transpiration. In our study, however, the concentrations of Ca were not lower for plants that grew under deficit irrigation, suggesting that in date palms, Ca uptake and transpiration are not that tightly coupled.

Potassium is highly mobile in the plant, and can thus be transferred from older into younger leaves easily. Potassium is also very mobile in the soil, and thus its uptake does not depend as much on the soil moisture level as that several other nutrients. The K levels in leaves of date palms of our study were in agreement with optimal values for palms stated by Bergmann (1992), Krueger (2007) and Silva and Uchida (2000), suggesting that the plants of the present study were all well supplied with this element. Again, there were no differences in the K nutritional status, depending on the irrigation treatment.
Homogeneous Partial rootzone drying

Control (100 %) Deficit irrigation (60 %)
**Figure 17:** Cation concentrations in mg per g dry weight primordial, young and old leaves by the end of the experiment. Shown are mean values ± standard deviations. For further explanations and statistics see Fig. 16. Mean values were compared by Tukey’s multiple comparison, but no differences were detected.

Results of the Two Way ANOVA performed on values obtained for PRD treatments:

<table>
<thead>
<tr>
<th>P-value</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD shifting intervals</td>
<td>0.320</td>
<td>0.695</td>
<td>0.807</td>
<td>0.660</td>
</tr>
<tr>
<td>Age of the leaf</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Interactions</td>
<td>0.648</td>
<td>0.732</td>
<td>0.096</td>
<td>0.931</td>
</tr>
</tbody>
</table>

### 3.4.3 Sodium

Date palms are known as salt tolerant plants (Maas, 1993) that can produce a reasonable yield even on saline soils. The plants of this study, however, were planted in non-saline soil and irrigated with deionized water, so that elevated levels of Na or Cl in the leaf tissues can not be expected. A negative effect of Na on the growth of date palms can most likely only be expected at concentration above 5 mg per kg, and a Na/K of above one. Concentrations of Na measured in leaves of the plants of this study (Fig. 18) might be rather in a beneficial than a detrimental range. It has been shown that date palms benefit from low amounts of Na supplied to the growth medium.
Figure 18: Sodium concentrations in mg per g dry weight in primordial, young and old leaves by the end of the experiment. Shown are mean values ± standard deviations. For further explanations and statistics see Fig. 16. Mean values were compared by Tukey’s multiple comparison, but no differences were detected.

3.4.4. Micronutrients

Most studies where iron concentrations in palm leaves were measured have reported values between 140 and 240 μg per g dry weight (Broschat, 1997; Krueger 2007, Saleh, 2008). However, Silva and Uchida stated minimum values for optimal growth of 50 – 80 μg per g dry weight for ornamental palms, suggesting that the date palms of the present study were sufficiently supplied with iron. Slightly lower concentrations of Fe were observed in younger compared with older leaves, which is related to the fact that iron can not easily be remobilized from older leaves. Concentrations of Cu have rarely been measured in palms in previous studies. Krueger (2007) found Cu concentrations of 10 μg per g dry weight in leaflets from lower leaves. Values normally found in optimally supplied vegetable and ornamental crops are in a range of between 5 and 15 10 μg per g.
dry weight. Thus, it can be conclude that the supply level of the date palms of the present study with Cu was also sufficient.

Optimum levels of Zn given for ornamental palms are in a range of 20 to 50 μg per g dry weight, according to Silva and Uchida (2000). Broschat (1997) measured Zn concentrations of 29 μg per g dry weight in Phoenix canariensis plants. The results obtained for Zn concentrations in the present study are in accordance with these values, suggesting that Zn deficiency did not play a role in plants of the present study. There was no effect of the irrigation treatment on micronutrient acquisition.
Figure 19: Micronutrient concentrations in primordial, young and old leaves by the end of the experiment. Shown are mean values ± standard deviations. For further explanations and statistics see Fig. 16. Mean values were compared by Tukey's multiple comparison, but no differences were detected.
Results of the Two Way ANOVA performed on values obtained for PRD treatments:

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD shifting intervals</td>
<td>0.507</td>
<td>0.493</td>
<td>0.057</td>
</tr>
<tr>
<td>Age of the leaf</td>
<td><strong>0.012</strong></td>
<td>0.172</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Interactions</td>
<td>0.535</td>
<td>0.943</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Note: The values in bold indicate significant differences at the p < 0.05 level.
4. Conclusions

In the present study young date palms supplied with only 60% of the irrigation water quantities consumed by palms exposed to unlimited water availability, did not appear to bear any disadvantages compared with these well watered controls in terms of visual appearance, growth and nutrient uptake. These results suggest that date palms, when maintained under high levels of irrigation water supply, respond with a considerable decrease in water use efficiency. Since no visual symptoms of water deficiency, such as browning or leaf loss were observed in plants under deficit irrigation of the present study, restricted supply of water might be particularly feasible for palms of urban landscapes. Further studies on older date palms will still need to elucidate whether deficit irrigation has an effect on the quantity or quality of the yield. Since, according to our study, apparently no reduction in leaf growth occurs in response to a reduced water supply, palms may still be able to support a high yield by appropriate overall photosynthetic capacity.

Even after prolonged exposure to dry soil, date roots do not seem to die or become inactive, making date palms particularly suitable plants for PRD systems. On the other hand, results of our study also show that PRD is of no advantage compared with a homogeneously reduced water supply to the soil. Since PRD in the field requires a more sophisticated irrigation system compared with conventional water supply to the whole root system, it might not be a feasible option for date palms, after all.

The ability of date palms to take up nutrients from a slightly alkaline sandy dune soil of the UAE, did not decrease in response to a reduction in the total amount of irrigation water supplied. The mechanisms behind this remarkable ability of the date palm to take
up nutrients from dry soil need further investigation. Associations with symbiotic microorganisms cannot be ruled out. It is also possible that the plants in this study found a reservoir of nutrients and water in the compost particles that were mixed with the experimental soil, even at low soil moisture regimes. Thus, this experiment might need to be repeated on an agricultural soil of the UAE that does not contain compost.
5. References

Abdul-Baki A, Aslan S, Linderman R, Cobb S, Davis A 2002 Soil, water, and nutritional management of date orchards in the Coachella Valley and Bard. 2nd Ed. California Date Commission, Indio, CA.


Broschat T K 1997 Nutrient distribution, dynamics and sampling in coconut and canary island date palms. Journal of the American Society of Horticultural Sciences 122, 884-890


Carr M K 2013 The water relations and irrigation requirements of the date palm. Experimental Agriculture 49, 91-113


Davis W J, Wilkinson S, Loveys B 2002 Stomatal control by chemical signaling and the exploitation of this mechanism to increase water use efficiency in agriculture. New Phytologist 153: 449-460
Dodd I C, Egea G, Davies W J 2008 Accounting for sap flow from different parts of the root system improves the prediction of xylem ABA concentration in plants grown with heterogeneous soil moisture. Journal of Experimental Botany 59, 4083-4093

FAO 2009 Irrigation in the Middle Eastern Region in Figures. AQUASTAT survey-2008: FAO Water Report No. 34. FAO, Rome, Italy.


Gahoonia T S, Raza S, Nielsen NE 1994 Phosphorus depletion in the rhizosphere as influenced by soil moisture. Plant and Soil 159, 213 – 218


Jackson M 1997 Hormones from roots as signals for the shoots of stressed plants. Trends in Plant Science 2, 22-28


JICA 1996 The Master Plan Study on the Groundwater Resources Development for Agriculture in the vicinity of Al Dhayd in the United Arab Emirates. Final Report, Japanese International Cooperation Agency (JICA) and the Ministry of Agriculture and Fisheries of the UAE.


Krueger R R 2007 Nutritional Dynamics of Date Palm (Phoenix dactylifera L.) Acta Horticulturae 736, 177-186


Malek C 2011 Water use for agriculture to be cut by 40 per cent by 2013. The National Sept. 14, 2011


Munier P 1973 Le Palmier-dattier—Techniques agricoles et productions tropicales; Maison Neuve et Larose, 217pp; Paris

Neumann E, George E 2004 Colonization with the arbuscular mycorrhizal fungus Glomus mosseae (Nicol. & Gerd.) enhanced phosphorus uptake from dry soil in Sorghum bicolor (L.) Plant and Soil 261, 245-255 Impact factor: 2.773; Times cited: 34

Neumann E, Schmid B, Roemheld V, George E 2009 Extraradical development and contribution to plant performance of an arbuscular mycorrhizal symbiosis exposed to complete and partial rootzone drying. Mycorrhiza 20, 13-23


Ramoliya P J, Pandey A N Soil salinity and water status affect growth of Phoenix dactylifera seedlings. New Zealand Journal of Crop and Horticultural Science 3, 345-353

Salam M A, Mazrooei S 2007 Crop water and irrigation water requirements of date palm (Phoenix dactylifera) in the loamy sands of Kuwait. Acta Horticulturae 736, 309-315

Saleh J 2008 Yield and chemical composition of ‘Piarom’ date palm as affected by levels and methods of iron fertilization. International Journal of Plant Production 2, 207-214


Zwaart S J, Bastiaanssen W G M 2004 Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management 69, 115-134.


Zwaart S J, Bastiaanssen W G M 2004 Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management 69, 115-134