# INTEGRATION OF GROUNDWATER RESOURCES IN WATER MANAGEMENT FOR BETTER SUSTAINABILITY OF THE OASIS ECOSYSTEMS - CASE STUDY OF TAFILALET PLAIN, MOROCCO

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## ABSTRACT

Oases have always existed in a complex environment characterized by an arid climate. Despite the severity of the physical conditions, farmers have ensured palm groves sustainability by practicing irrigation and settling along the rivers and groundwater table. Currently, oases are threatened. In addition to the constraining space in which the oasis regions are located, they are under intense pressure on natural resources, both physical and human. This degradation has been amplified by the succession of drought periods, desertification, the effect of climate change and above all the overexploitation of groundwater resources in or near the oases. The preservation of oases requires a good understanding of the interactions between water and palm, which is the framework of the oasis agroecosystem. This relationship is generally studied based on the surface water irrigation. However, the palm is also fed by the groundwater table. The objective of this paper is to study the interaction between the groundwater table and the palm plantation as well as the quantification of the direct groundwater uptake by the root system. This work highlights the importance of groundwater resources in the conservation and revitalization of the oasis system. The study took place in the plain of Tafilalet which is one of the largest palm groves in Morocco. The methodology adopted is based on surveys and field investigations coupled with an experiment. The results obtained led to the conclusion that groundwater table is the basic resource for the survival of palm trees in these sub-desertic zones. In less than 40 years, the thickness of the groundwater table has dropped by 50% and the piezometric levels have decreased; at the same time, a 50% reduction in the number of the date palm was observed. However, areas with higher groundwater table levels were the least affected by the downsizing. Indeed, this invisible resource is not only the main resource that supplies irrigation water, but it also contributes to the direct feeding of crops, especially the date palm. The present work also showed that the presence of a groundwater table strongly affects the development of the root system. Indeed, in a situation of water stress, the roots of the date palm develop in depth until reaching the level of the groundwater table to satisfy the water needs. The results of the experiments show that the date palm is not a major consumer of water, compared with the context in which it is located, its annual transpiration was estimated at 42m$^3$ and constitutes 49% of the total evapotranspiration. In addition, the groundwater table can contribute to 50% in this transpiration even for a depth that exceeds 4m. Taking this participation into account when determining water requirements could reduce water supply and save up to 50% of irrigation water, which is very scarce and very costly to mobilize in these environments. The integration of this parameter in the establishment of water balances would also help to better understanding the dynamics of groundwater resources and thus to ensure a more rational and controlled management of water.

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## 1. INTRODUCTION

Oases is a complex and fragile agro-ecosystem that characterizes arid areas (Elkhoumsi *et al.,* 2014). The structure of this landscape depends mainly on the structure of desert-oases-water components (yang et al., 2010). The existence of the palm grove had always been related to the existence of water because they grew along streams and water tables (Zella et Smadhi, 2006, Grenade, 2013). In fact, in arid regions, the contribution of groundwater to satisfy crop water requirements can be very high (Wallender et al., 1979; Yang et al., 2000).

In Morocco, the sustainability of oases systems is increasingly threatened. During the last century, the oases system has deteriorated markedly. From the 15 million palm trees which inhabited the south Atlas oases, there remains only 4 million trees (Haddouch M., 1996). This degradation is caused by multiple factors interacting on each other. These oases are under increasing pressure from human activities on natural resources already depleted by effects of long periods of drought, climate changes, 'Fusarium' disease, etc. The severity of the aforementioned factors varies from one oasis to another depending on each one's specific criteria. However, the common cause of the observed decline in all palm groves is the degradation of water resources, which is essential to the survival of these oases. In arid areas, groundwater is the safest water resources given the scarce rainfall and the dry climate. In Morocco, surface water that feeds oases come from mountains; thus, the scarcity of rainfall causes the decrease of surface waters (Elkhoumsi et al, 2014,2016). Water levels decline in rivers and impellent farmers to use groundwater (Messouli et al., 2009). Thus, it is supposed that groundwater is the one that contributed to the persistence of palm groves and ensured their durability until now, in spite of weather conditions severity and physical/human characteristics.

Within oases agro systems, interactions between groundwater and existing crops, particularly the date palm (Phoenix dactylifera) are very important (El Khoumsi et al., 2016). Research in California and Texas has shown that salinity-tolerant crops are able to extract significant amounts of water from the water table, even when saline (Ayars and Schoneman, 1986; et al., 2003). In fact, the water table can satisfy up to 50% of the water needs of the crop (Ayars et al., 1999, 2006, Hutmacher et al., 1996) and this figure can reach 70% in arid conditions, depending on salt tolerance, quality and depth of the groundwater table (Grismer and Gates, 1988).

Understanding the interaction between groundwater and date palm development is essential to improve water use and ensure the sustainability of the oases system (El Khoumsi et al., 2014). Indeed, the quantification of the participation of the water table appears as an important term of the water budget, in order to ensure a rational management of the water resources through the limitation of the contributions in irrigation water and volumes of water to evacuate by drainage (Grismer and Gates, 1988), especially when water is very scarce and expensive to mobilize. However, this requires prior knowledge of a set of terms that are involved in this relationship, namely the transpiration of the date palm and the distribution of its root system.

Work that has studied groundwater participation in the water supply of date palm remains very limited and relatively recent (Ben Aïssa et al., 2009, Zeineldin and Aldakheel, 2010). In addition, the majority of these works dealt only with surface water tables with a depth of not more than 2 m or young date palms. The study conducted by Zeineldin and Aldakheel (2010) in Saudi Arabia in the palm grove of Al-Hassa on young palms, grown in lysimeters, shows that there is indeed a contribution of the surface water in the water supply date palm when reducing irrigation water supply.

Understanding the interaction between groundwater and date palm development is essential to improve water use and ensure the sustainability of the oases system, which is increasingly confronted with water scarcity problems. (El Khoumsi et al., 2014). Indeed, the quantification of the participation of the water table appears as an important term of the water budget, in order to ensure a rational management of the water resources through the limitation of the contributions in irrigation water and volumes of water to evacuate by drainage (Grismer and Gates, 1988), especially when water is very scarce and expensive to mobilize. However, this requires prior knowledge of a set of terms that are involved in this relationship, namely the transpiration of the date palm and the distribution of its root system. The aim of this paper is to study the interaction between the groundwater table and the palm plantation as well as the quantification of the direct groundwater uptake by the root system.

## 2. METHODS

### 2.1 Physical Characteristics of The Study Area

The Tafilalet oases is one of the largest palm groves in Morocco. It is located in the southeast of the Kingdom, in the pre-Saharan zone, covers an area estimated at 700 $km^2$ and represents 29% of the Moroccan phoenicultural heritage. The cultivated area is of 21,300 of which 19,290 ha is irrigated by Ziz and Ghriss wadis who ensure also groundwater table recharge (Margat, 1962).

In Tafilalet, the climate is desert with very low rainfall and a great spatiotemporal irregularity with a small number of rainy days per year (10 to 15 days/year). The annual average temperature is around 20°C with high amplitudes going up to 50°C in summer and -2°C in winter. Average potential evaporation amounts to 2500mm/year; however, the existence of palm trees creates a microclimate, which soothes the harsh climatic conditions and consequently reduces the potential evapotranspiration to 1200 mm/yr (Bouhlassa and Paré, 2006).

The low rainfall and potential evapotranspiration ratio require use of irrigation (Guimimi, 1991). Direct rainfalls on the plain are of little use for agriculture, wadis and infiltration. They allow a contribution of less than 4% of the surface water resources (Margat, 2001). So, faced with water scarcity, groundwater becomes the most exploitable and safest resource. In fact, the geological structure of the region, which prevents the existence of deep aquifers, has facilitated the creation of an extensive water table over the entire plain (Margat, 1962), thus representing the only groundwater resource available in the Tafilalet oases.The applied agricultural system includes two to three layers: date palm trees, fruit trees and surface cropping which are generally cereals, legumes, fodder and vegetables. The number of layers depends on the availability of water. Similarly, intercropped agriculture depends on the water quality (Renovot et al., 2010). In this area, the most spread irrigation system is flood irrigation system. Drip irrigation is practiced on a very small area (Keddal, 2006).

## 3. METHODOLOGY

To understand the various interactions between date palm development and groundwater evolution, we have adopted two complementary approaches. The first approach was based on collecting and synthesizing data supplemented by field surveys. The second approach focused on conducting experiments to support the results and assumptions derived from the first approach.

### 3.1 Data collection and field surveys

To better understand the relationship between the evolution of the palm grove and groundwater resources, several data were collected concerning various components of the oases system such as climate, plant, irrigation practices, etc. Collected information was supported by surveys and field measurements. These surveys were conducted on a sample of 200 farms in different parts of the plain to take into account the specific relationships between production systems and local groundwater conditions.

## 1. Experimental apparatus

Experiment aimed to measure the date palm transpiration and to study the distribution of its root system in the presence of groundwater table. The experiment was conducted on a 50-hectare farm in the Tafilalet plain (longitude 04 ° 20’43.2” West, latitude 31 ° 27’17.3” North) (Figure 1). The depth of the groundwater table is 5m with an average salinity of 5 g/l. Experiment was conducted on adult Majhoul palm trees (30 years old) with a spacing of 7m x 7m and an average density of 224 palms per ha using a drip irrigation system. The climatic data used were collected from a weather station located 10 km from the farm.

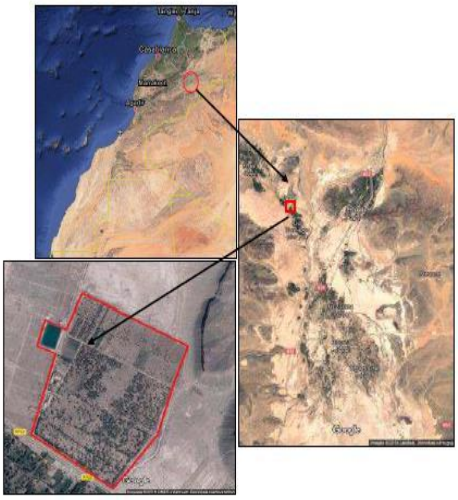


**Figure 1.** Expérimental site location map

## 2. Mapping date palm root system

To characterize the spatial distribution of the date palm root system on the experimental site, the method of the profile wall was used. A profile with 5 m long and 4 m deep was made near a palm tree, in the form of a wall. A square grid (1 x1 m) with a 10 cm mesh was installed at this level to count the number of roots per mesh (Figure 2). The addition of the roots observed by horizon allowed us to create root density profiles. These data were converted to a root density map by interpolation of the results obtained.

**Figure 2:** Roots profile

### 3.2 Date palm transpiration measurement

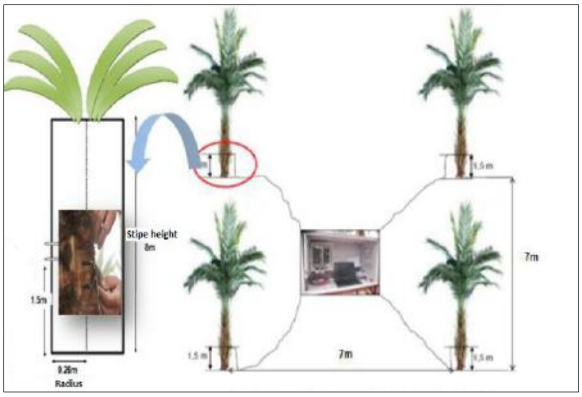
The monitoring of direct transpiration was carried out according to the heat dissipation method proposed by Granier (1985, 1987). The sap flow sensors have been installed in a height of 1.5 m from the bottom of the stipe (figure 3). Each sensor consists of two probeshaving a length of 100mm each, inserted radially in the stipe. Data was recorded in a central data acquisition each 30 min.The Granier method is based on the principle of convection cooling, due to the circulation of the sap flow, from a heated probe to a constant power. Indeed, when the speed of the sap flow circulation is zero or minimal, the temperature difference between the two sensors is maximum (DTmax); The decrease in temperature difference between the two probes is related to the flux density by the following formulas:

$$\boldsymbol{V = 119,10^{-6} * K^{1,231}\ m/s}$$

$$\boldsymbol{VK = \frac{DTmax - DT}{DT}}$$

$$\boldsymbol{Fs = SC * V * 3600\ (m^3/h)}$$

1. The Transpiration is calculated using the formula with N: number of trees per Ha:




$$\boldsymbol{TP = \sum_1^{24h} Fs * N * 10^{-5}}$$

**Figure 3.** Schematic representation of the experimental device adopted for the installation of the sap flow sensors

3. Estimation of groundwater contribution in date palm water requirement

4. In order to quantify the date palm root extraction from the groundwater table, we have adopted an approach that consists on measuring transpiration while suspending the irrigation for 15 days. Irrigation shutdown was scheduled during the period of high climatic demand where water requirements are maximized.

## 4. RESULTS AND DISCUSSION

### 4.1 Comparative Evolution of the Tafilalet Palm Grove and Groundwater Table

In the Tafilalet, crop irrigation is ensured through the mobilization of several water resources at a time. The limitation of surface water makes the use of groundwater a primary necessity. In fact, the contributions of wadis in addition to the restitution of the Hassan Addakhil dam satisfy only 38% of the water requirement; also, these superficial contributions remain very variable and uncertain according to the years. Thus, the majority of the water needs are ensured by the groundwater which covers almost 62% of these needs and is the safest. The combined use of surface water and groundwater is a very common practice in Tafilalet. In general, surface resources are used for the leaching the soil due to the high salinity ratio and for the recharge of the water table.

The groundwater table not only provides a supply of irrigation water to the palm grove (pumping, kettaras ...), but it also allows a direct supply to the date palm through the roots water uptake. In fact, during the long consecutive periods of drought, thousands of palms have been able to survive thanks to the presence of the groundwater table which supplies them with water. Indeed, in arid conditions, as it is the case of Tafilalet, the shallow water table can contribute by 60% to 70% of crop water requirements (Grismer and Gates, 1988). This has been confirmed by farmers who have ensured that drought does not kill palms because they can reach water from the groundwater even when it's deep. A farmer reported that "We do not need to irrigate the palm tree because they are able to take water directly from the water table."

According to Margat (1962) and Ammary (2007), this contribution, translated in the form of evapotranspiration, constitutes the great part of the groundwater table outflows (3/4 of the water balance) The same observation was made by Boualamat et al. (2016) who found that the water table outflow form of evapotranspiration is significantly higher than the pumped water, which is explained by the special conditions of Tafilalet which is characterized by a high rate of evapotranspiration. The comparison of the groundwater table evolution and that of the number of date palm trees in Tafilalet shows the existence of a strong interaction between the two (figure 4). The degradation of the groundwater table has strongly affected the state of palm groves. In fact, the drop in water table levels has led to the drying up of several wells and kettaras, which has limited the availability of irrigation water. Also, the accelerated falls in groundwater levels caused the decline of a large number of palms that were fed directly from the water table. The degradation of the oases has also impacted the state of the water table. Indeed, this degradation has increased the percentage of bare land which has intensified the discharge of the water table by evaporation. Also, the development of new date palm extensions in monoculture increased the withdrawals from the water table levels and accelerated its decline.

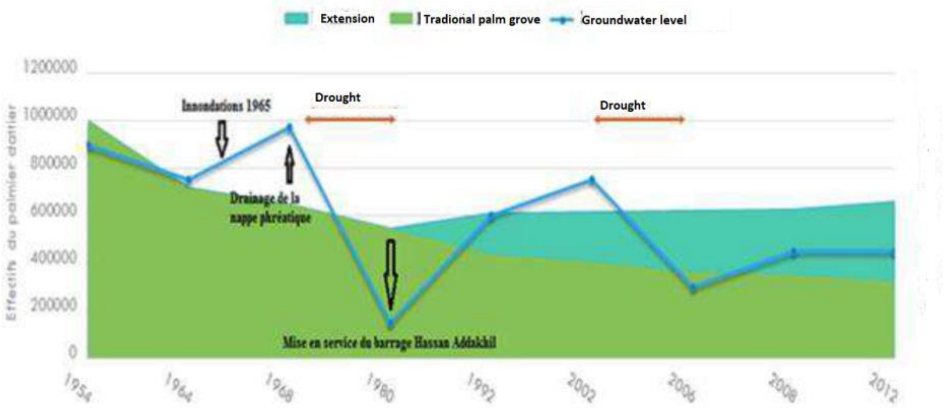



**Figure 4:** Interaction between the palm grove dynamic and groundwater table evolution

### 4.2 Distribution of the date palm root system in the presence of a groundwater table

The architecture of the root system plays an important role in drought resistance, thanks to the mobilization of water and mineral salts. In our case study, the results obtained show that 80% of the roots are concentrated in the first 1.5m with a maximum roots density of 7 roots per $dm^2$ (Figure 5). Above 3m, it is rather the absorption roots that develop to reach deep water and allow the anchoring of the trees. The gallery created under the palm tree allowed us to examine the deep roots starting directly from the stipe beyond 4m. These pivoting roots have a significant density, which can be up to 4 roots per $dm^2$ with large diameters. On one of the observations, where the water table was 9m deep, we identified roots that reached the groundwater table. The results show that the date palm roots system grows until reaching the water table in order to cover their water requirement; in other words, the deeper the water table is, the more the root system is developed.

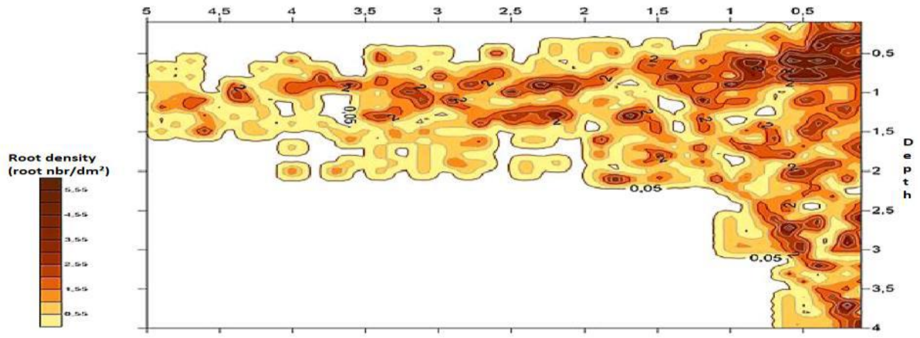



**Figure 5:** Mapping of the distribution of the date palm root system in the presence of a 5m shallow water table (case of an adult palm).

Our results confirm those of Sedra (2003) and Peyron (2000) who claim that most of the date palm roots are concentrated on the first 2 meters. Authors such as Al-Bakr (1972), Munier (1973) and Oihabi (1991) report that the root system can spread over an area of up to $167m^2$. They also found that the roots of a solitary palm tree can take water at more than 8m, and sometimes up to 15m deep. The diversity of the results obtained is explained by the influence of a certain factors like age, the soil characteristics, irrigation practices and of course the depth of the groundwater table.

### 4.3 Contribution of the water table in the water supply of the date palm

The results obtained showed that even in the absence of irrigation (Figure 6) date palms continue to transpirate. The combination of these results with those obtained during the characterization of the root system distribution confirms our hypothesis that the quantities of transpired water come mainly from the groundwater table. Indeed, under water stress, the water table contributes significantly to the transpiration of the date palm and can cover up to 65% of water requirements (Figure 7). However, this contribution varies depending on climate demand and biological activity.In the period of vegetative rest that coincides with the winter period, the contribution of the groundwater table can reach 65% against 50% during the period of maturity of the dates that occurs during the summer period. During the spring period, which represents the start of vegetation, this contribution is of the order of 45%. Thus, on an annual scale, the aquifer can cover almost 50% of the water requirements of the date palm, which would reduce the inflow of irrigation water and thus save up to 50% of water, ie the equivalent of 21 m3 / year / tree, even for a groundwater table with a depth of 5 m.

In the total absence of irrigation, the contribution of the groundwater table ensures the survival of the palm tree, however, the question of production remains raised. Thus and in order to ensure a stable production, a water supply is necessary to complete the water uptake from the aquifer. These results complement those found by Sabri et al. (2016) about the application of deficit irrigation strategy. Indeed, they found that even providing 60% of the maximal evapotranspiration the plant parameters and the state of the palm were not affected, which we explain by the fact that the palm tree compensates the water deficit by uptaking directly from the groundwater table. By combining these two results, it can be seen that taking into account the contribution of the groundwater table to irrigation strategies is very important whether it is as much as a main resource or as a complementary resource. During the vegetative rest period, the reservoir of the aquifer could be used to cover the needs of the palm tree without the need to bring surface irrigations. Indeed, during this period, the needs of the palm are minimal so that the groundwater table alone can fill them. However, during the growing and maturing phase, the groundwater table is only a supplement and a superficial supply of irrigation water is needed to ensure stable production. During these phases, the groundwater table can cover up to 50% of the water needs of the palm tree, but an external water supply remains necessary to ensure good production. Of course, these results are debatable depending on the depth of the groundwater table and the degree of development of the root system.

Some research has tried to highlight the contribution of the groundwater in covering the date palm water requirements (Benaissa et al., 2009, Zeineldin and Aldakheel, 2010). However, the results found vary considerably depending on the physical context. For example, the results obtained by Zeineldin and Aldakheel (2010) in Saudi Arabia in the AL-Hassa palm grove showed that groundwater table can contribute to the date palm water uptake by 22 % when reducing irrigation by 50%. These values are too low compared to our results especially that the depth of the water table does not exceed 1.5 m. This is because their experiment was conducted on young (3-year-old) palms grown in lysimeters, which limited the development of the root system. Also, the variation of the climatic context and the physical characteristics of the soil can strongly influence the contribution of the groundwater table in the water requirements of the date palm in oasis.

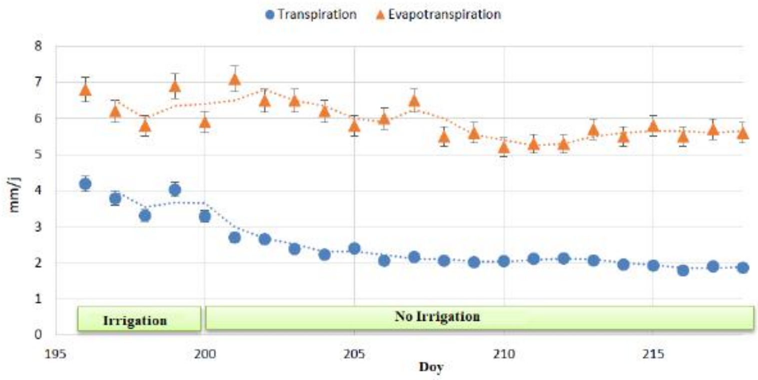



**Figure 6:** Variation of date palm transpiration during a period of high climatic demand with and without an irrigation supply

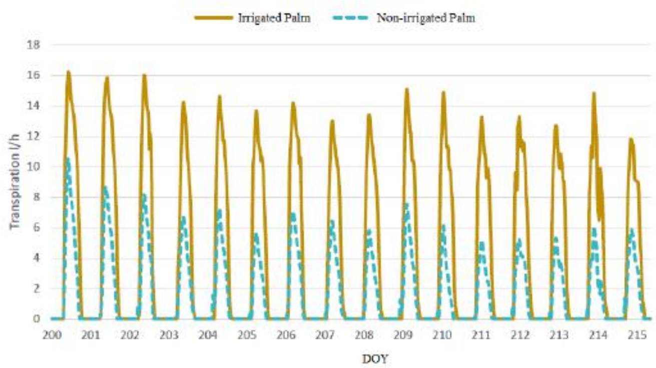



**Figure 7:** Comparison of the daily flow variation for two neigh boring palms (irrigated palm and non-irrigated palm) during a period of high climatic demand

## 5. CONCLUSIONS

Groundwater is the basic resources for survival in arid areas. This invisible resource is not only one that provides water for irrigation, it is also a resource that feeds directly the date palm, symbol of oases system. As a result, the sustainability of this system depends entirely on the groundwater resources. However, water tables are subjected to global, local and regional drastic changes. In recent years, the balance between supply and demand for water has become more difficult. Indeed, in response to climate change affecting the region, the extracted water volumes are constantly increasing.The new extension dynamics of the oases and the government vision for the development on phoenicicol sector raises higher demands opposite to a threatened, very limited and very sensitive resource to any change in the physical or social order (Elkhoumsi et al, 2014, 2016). This requires a review of adopted policies by integrating a global vision that takes into account all the components of the oasis system and more specifically the groundwater resource as the first factor of production.

Taking into account the contribution of the water table in the water supply of the date palm when determining its water needs could reduce the volumes of water to be supplied; this would save up to 50% of irrigation water, which is very rare and whose mobilization is very expensive in arid environments. Integrating this parameter into water balance assessments would also provide a better understanding of the dynamics of groundwater resources and thus provide for more rational and controlled management of water. In addition, it is important to emphasize the importance of maintaining the water table at a level that allows the date palm to draw water during periods of high water stress.

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