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Water saving in arid irrigated lands: a comparison between different irrigation techniques adopted under date palms in the Tunisian Oasis

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ABSTRACT

Water irrigation resources scarcity combined with the problem of poor quality of most of these resources known by their high salinity, present a great threat for the oasis agriculture sustainability. Hence, improvement of water saving technologies is imperative to ensure the better oasis productivity. The main objective of this work is to identify the efficiency of the irrigation technique for date palm trees through the assessment of irrigation technologies newly introduced by a few farmers in some of the Tunisian oasien regions. The three irrigation techniques, which were evaluated by applying the same volume of water irrigation under date palm trees, are the bubbler, the mini diffuser and the subsurface drip irrigation systems. The irrigation assessment showed that the uniformity in water irrigation distribution of the soil after irrigation is around 90% for the three techniques. The water irrigation losses after irrigation were 42, 63 and 72 mm, respectively, by bubbler, by mini diffuser and by subsurface drip irrigation. The irrigation water application efficiency is the best for the bubbler irrigation (62%). The water use productivity is also the highest for the bubbler (0.66 kg/m^3); in addition to the desalination efficiency which was 63% . The results of this study showed that the bubbler irrigation system is the most efficient technique which will be the best technology practice under date palm trees in the Tunisian Oasis conditions.

Keywords: Tunisian Oasis; Date palm; Bubbler irrigation; Mini diffuser; Subsurface irrigation

1. Introduction

The agricultural sector consumes from 70% to 72% of the total world water resources (Ahmed et al., 2012). In arid and semi-arid regions, the consumption of these resources is the biggest. In some countries, it could account for more than 80% of the total annual water consumption (Alamoud, 2012; Mumtaz Khan et al., 2012). In this current situation, the challenge is to find the ways to ensure the food security in these regions. In this context, it is necessary to improve irrigation and water use efficiencies in order to get higher crop productivity and agricultural sustainability.

Date palm trees are crops which can provide food and nutrition for people and they have been the major agricultural crop in the oases of Algeria, Egypt, Iran, Libya, Morocco, Oman, Saudi Arabia, Tunisia, United Arab Emirates and Yamen which are largely arid countries. These fruit trees cope in an excellent way with the arid climate but they are dependent on irrigation because they need enough amounts of water to sustain growth through keeping all metabolic processes intact, and produce marketable fruit (MKV carr 2012; Mumtaz Khan et al., 2012). Deglet Nour date palm cultivar is one of the most high quality commercial and popular dates in Tunisia (third place of food products nationally) and in the world but in this decade the fruit quality is endangered by the effects of the climate change and the absence of adaptation strategies.

The Tunisian oases are located in four main regions: Tozeur, Kebili, Gabes and Gafsa. These oases are in the Sahara Mediterranean bioclimatic floor, on top floor, varying mild winter. This climate is characterized by low and erratic rainfall, contrasting temperatures and climate rather than irregular winds. The average annual rainfall is less than 100 mm in Tozeur and Kebili and it exceeds 150 mm in Gafsa and Gabes. The highest temperatures are recorded in continental regions, highly influenced by the Sahara. The average maximum temperatures recorded in the regions of Tozeur, Kebili and Gafsa are, respectively, about 40.4°C, 42.2°C and 38°C. As for the region of Gabes, the maximum average temperatures are, respectively, around 32.7°C and 36.8°C.

Evaluating the water resources in the oasis zones, we can say that they reach a total of 551,700,000 m^3/year against an estimated operating 645.88 Mm^3/year, or 117% over-exploitation. All aquifers are over-exploited with different degrees. The sheet of terminal complex (TC) is the most over-exploited with a rate of 129%. The oasis of Kebili

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region recorded the highest rate of exploitation with 157% and 172%, respectively, for the TC and CI (continental inter-calary). So the main problem of oases agriculture is water scarcity and its worsening quality. In addition to that, the distribution of water irrigation done according to the system of the water rotation to different farmers has been conducted according to pre-established areas and has not been conducted according to the real water needs of crops. On each antenna, there are series of irrigation terminals each irrigates a set of plots (3–4 ha). The irrigation period lasts from 10 to 14 h/ha, irrigation rate of 90 to 120 mm/rev water. This irrigation method practice can reduce and damage the irrigated land productivity (Tyagi et al. 2005). So we are facing a serious oasis ecological problem. That is why, in order to ensure the oasis sustainability, it is necessary to develop irrigation systems under date palms. The flood irrigation system which is the most widespread in traditional production oasis is not efficient compared with the modern one such as, surface drip irrigation, bubbler and subsurface one (Alamoud, 2012; Dhaouadi et al., 2015). In 2014, Bourziza Rquia et al. showed that subsurface drip irrigation (SDI) is an efficient technique, which allows the sustainable irrigation under date palm in arid areas. Al-Subaiee et al. in 2013 demonstrated that bubbler irrigation method has been proved as a very efficient one judging by producing higher vegetative growth. In Tunisian oases, the use of the SDI and the bubblers under date palms is limited in spite of both the evolution of palm date areas and the absence of the irrigation scheduling programs caused by water scarcity conditions.

Several oasian farmers have been aware of the necessity to modernize their irrigation methods in order to ensure their future income sources and their food security.

The aim of this work is to identify the best efficient irrigation system under the date palm. It consists mainly of an evaluation of the different irrigation techniques that are currently applied under date palms in the Tunisian oases, namely irrigation by mini diffuser, by bubbling and by drip subsurface irrigation.

2. Materials and methods

The experiments were carried out in oasis plot which is located in the slope of Chott El Jerid in the north-west of the ancient oasis of Déguache (33° 59′28.27′′N, 8° 14′16.44′′E) knowing that El Jerid is located in the south-west of Tunisia. Our study area belongs to the Saharan domain that is characterized by a fairly flat relief except in its eastern part where the North chain chotts are situated. This region has the highest summer humidity rate and the nature of the soil is favorable to the plantation of the date palm (Namsi, 2008)

The experimental plot has an area of 4 ha irrigated with different water qualities (well water, water association) for many years by basin irrigation system (5 L/s). Starting from 2012, a gravitational irrigation was implemented under palms for a surface of 1 ha where the bubbler has been adopted (360 L/h), and the water irrigation has been uniquely from the well (12 L/s). This water has been drawn from well of filling a basin. Irrigation, by these three different irrigation systems (bubbler, mini diffuser and subsurface drip irrigation) was assessed.

The experiments focused on the following aspects:

- Physico-chemical characterization of irrigation water.
- Hydrodynamic characterization of the soil of the study plot.
- Study of the root distribution of date palms.
- Monitoring the moisture soils for different irrigation systems.

2.1. Irrigation water quality

Water samples were taken from irrigation drilling. Temperature, pH and electrical conductivity of these samples were measured using portable devices. The major elements were measured in the laboratory using standard methods such as volumetric method for bicarbonate ions, total hardness, calcium, magnesium and chloride. The colorimetric method was used for sulfates and nitrates. The sodium adsorption ratio (SAR), which measures the risk of sodisation complex adsorbent, was calculated using the following formula in which concentrations are expressed in (meq/L; Hanson et al., 2006):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{+} - \mathrm{Mg}^{2+}}{2}}} \quad (1)$$

2.2. Soil texture

The samples, which have suffered the particle size analysis, were taken from four horizons (0–30, 30–60, 60–90 and 90–120 cm). It was limited to five sampling profiles: four at the vertices and one at the middle of the study plot. The results were used to identify the soil texture by the mean of the USDA chart (United states Department of Agriculture; De Forges et al., 2008).

2.3. Bulk density

Soil samples verifications were carried out from a pit (1.2 m × 1.2 m) in slices 0–30, 30–60, 60–90 and 90–120 cm; these undisturbed samples were transported to the laboratory with the aid of the cylinders of a non-disturbed auger. Knowing the constant dry weight of the samples to 105°C and the capacity of cylinders, we measured the soil bulk density of the experimental plot.

2.4. Infiltration

The experimental study of water infiltration into the ground at the field scale was performed by double-ring infiltrometer. The result of cumulative infiltration test over time allowed the determination of water infiltration law for the experimental plot soil by Philip equation (1966):

$$i(t) = \frac{1}{2} s t^{-0.5} + A \quad (3)$$

$$\mathrm{A} = \frac{\gamma s_2}{r} + \frac{(2-b)}{3} \times k(h_0) \quad (4)$$

$$K(h_0) = q(h_0) - \frac{4bs_2}{\pi r} \quad (5)$$

q (h_0): infiltration flow in steady state (from infiltration curve), s: sorptivity, r: radius of the inner ring 30 cm, b = 0.55, $\gamma = 4b/\pi = 0.7$.

The experimental infiltration study allowed to identify the hydraulic conductivity at saturation K_s.

2.5. Soil water content characteristics

The objective is to identify the function of the water retention curve which is described according to Van Genuchten (1980) as:

$$\theta(h) = \theta_r + \frac{(\theta_s - \theta_r)}{\left(1 + |\alpha h|^n\right)^m} \quad (2)$$

where $\theta(h)$ is the water content at pressure head h, θ_r is a residual water content which is usually fitted to measured data, θ_s is the water content at saturation which is usually not fitted but taken as the measured total porosity. α, n and m are parameters without physical meaning describing the shape of the function; m is usually fixed as $m = 1–1/n$.

In this work, the Richards Pots were used (Set PF-meter ceramic plate, basic standard set) to determine θ_{cc} the water content at field capacity and θ_{pf} the water content in the permanent wilting point. Using these parameters by the Hydrus-1D; θ_r, θ_s, α, n and m were easily evaluated.

This experimental study allowed to predict the hydraulic conductivity function (Mualem, 1976; Van Genuchten, 1980):

$$K(h) = K_s S_e^{\lambda} \left[1 - \left(\left(1 - S_e^{\frac{1}{n}}\right)^m\right)\right]^2 \quad (3)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (4)$$

λ is the connectivity parameter 0.5 and S_e is the effective saturation.

2.6. Root profile

It is evident that knowing where roots are located and their concentrations on the soil layers increases the production system efficiency when cultural practices are wisely applied under-tree area such as irrigation and fertilization (Bauer et al., 2003).

The root distribution at the experimental site was studied on soil profiles 0.5 m, on 1 m and on 2 m radium from the tree. Soil and root-samples have been taken every 0.20 m layer until 1.20 m depth.

2.7. Assessment of irrigation

To analyze the distribution of water in the soil before and after irrigation, we adopted the following steps: experiments had begun in the experimental plot with a first irrigation, the duration of which was about 5 h for bubbler, subsurface and mini diffuser and basin system; these durations are practiced by farmers in the study area. Monitoring soil moisture was observed before and after irrigation for four successive irrigations every 10 d. The monitoring of moisture and water stocks in the study plot was performed by gravimetric method.

Two other durations have been tested for the case of bubbler irrigation technique, namely 9 and 4.5 h with monitoring the soil moisture before and after every irrigation. Using an auger, soil samples have been taken from different depths ranging from 20 to 120 cm for multiple profiles following the irrigation technique and the tested duration. All these measures have allowed us to determine both the irrigation performance indicators:

Uniformity Christiansen CU (Heermann et al. 1990):

$$\mathrm{CU}(\%) = 100 \times \left(1 - \frac{\sum|\theta_i - \theta\mathrm{moy}|}{\sum\theta_i}\right) \quad (5)$$

Irrigation efficiency (Burt et al. 1997):

$$\mathrm{IE} = \frac{\text{vol. irrig. water beneficially used}}{\text{vol. irrig. water applied-a storage of irrig. Water}} \times 100\% \quad (6)$$

3. Results and discussion

3.1. Zone characterization

3.1.1. Irrigation water quality

The analysis in Table 1 presents the water irrigation quality in the experimental field. The SAR value that was evaluated by Eq. (1) is 6.37. This value is less than 10 so the risk of sodium accumulation in the soil is minimal (N'DIAYE et al. 2010).

Table 1
Physical and chemical composition of water irrigation for experimental plot

	Water drilling		
T (°C)	25.3		
pH	7.46		
Electrical conductivity (ms/cm)	3.38		
Dry residue (mg/L)	1.91		
Ion concentration	mg/L	Mmol/L	Meq/L
Calcium	152.8	3.82	7.64
Magnesium	78.04	3.21	6.42
Sodium	3.89	16.91	16.91
Potassium	23	0.58	0.58
Bicarbonate	352	5.77	5.77
Sulfate	427	4.44	8.89
Chlorure	568	16	16
Nitrate	8.7	0.14	0.14

Fig. 1. Localisation of the study plot. (A): the study area. (B): the experimental plot.

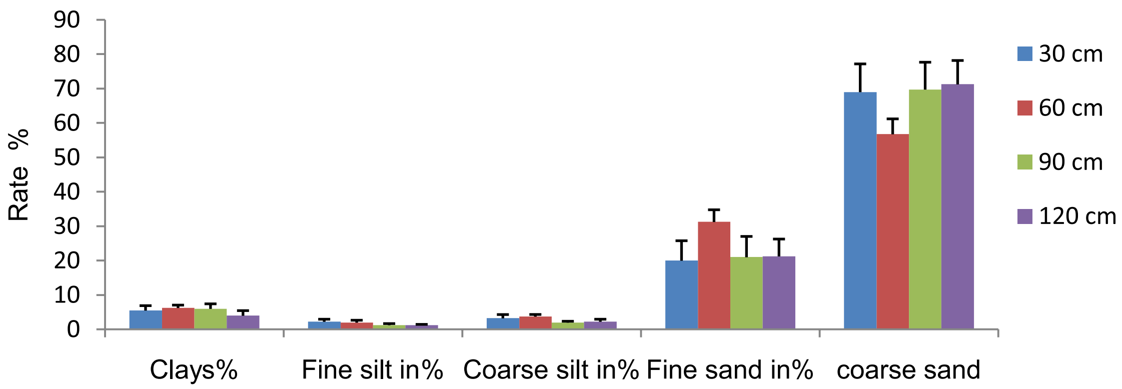

Fig. 2. Soil texture of the study plot per depth.

3.1.2. Soil texture

3.1.3. Bulk density

The curve of Fig. 3 shows that the bulk density is slightly varying depending on the depth. The maximum value is about 1.46 g/cm^3 for the depth of 90 cm. The average is in order to 1.44 g/cm^3.

3.1.4. Infiltration

According to Philip's Eq. (2) and the following figure, the infiltration law of the experimental plot soil is as follows:

$$i(t) = 0.17t^{-0.5} + 27 \quad (5)$$

And K_s = 1, 9.10^{-3}cm/s.

3.1.5. Soil water content characteristics

The results in Table 2 were used to establish Eqs. (2)–(4) characterizing the soil of the experimental plot:

The water retention curve function:

$$\theta(h) = 0.04 + \frac{0.4}{\left(1 + |0.062 \times h|^{1.679}\right)^{0.404}} \quad (6)$$

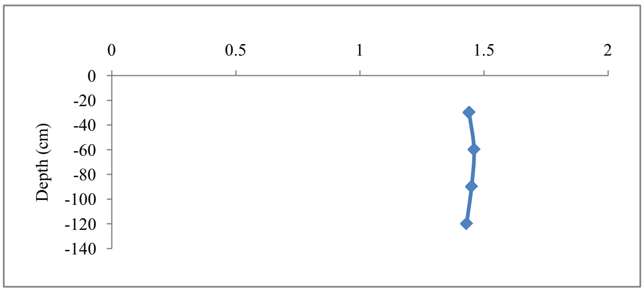

Fig. 3. Soil bulk density of experimental plot.

The hydraulic conductivity function:

$$K(h) = 6.8 S_e^{\lambda}\left[1 - \left(\left(1 - S_e^{0.595}\right)^{0.404}\right)\right]^2 \quad (7)$$

where:

$$S_e = \frac{\theta - 0.04}{0.4} \quad (8)$$

3.1.6. Root date palm distribution

The expérimental study of root distribution showed that the majority of the roots (approximately 90%) were located between 0.4 and 1.2 m. knowing that Leyron in 2000 (Jrad, 2012) showed that the region between 0.9 and 1.5 m is occupied by the nutrition roots which present the high proportion of root system.

Fig. 5 presents the spatial distribution of roots in the soil depending on the depths and distances from the palm trunk. Root equal percentage curves in the soil was drawn by the software SURFER 9.

4. Monitoring soil water content

4.1. Drip subsurface irrigation

The irrigation duration, which was about 2.7 h of irrigation, adopted this technique that lasts 2.7 h. The initial average water content was about 7%. It oscillates between 6% and 9%; values slightly above θ_{pf}, which is higher than the water content θ_{pf} (6%). At the end of irrigation, the maximum water content is 20%; in the average it was 17%. Soil moisture gradually decreases over time to reach 14% 48 h after the end of irrigation. It is an average grade value that is greater than the average moisture content at the field capacity θ_{cc} (11%). The moistened radius at the end of the irrigation was about 120 cm whereas the average water contents were 9% and 18%, respectively, for the whole profile and around the point of emission. The average water content is 9%, and the average water content next to the emitter is 18%.

4.2. Mini irrigation diffusers

The irrigation practiced by this technique lasted 3 h. The initial average water content was slightly higher (7%)

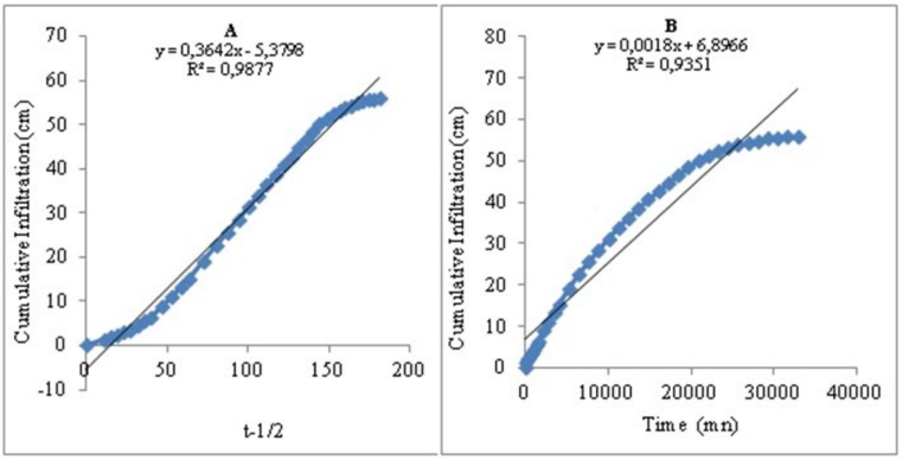

Fig. 4. (A): Sorptivity, (B): hydraulic conductivity at saturation K_s.

Table 2
Adjustment parameters of the relation θ (*h*) according to van Genuchten Model (1980)

Depth cm	θ_{cc} (cm³/cm³)	θ_{pf} (cm³/cm³)	θ_s (cm³/cm³)	θ_r (cm³/cm³)	*A* cm⁻¹	*n*	*m*
0–30	0.12	0.07	0.41	0.04	0.0602	1.600	0.375
30–60	0.11	0.06	0.41	0.04	0.0612	1.608	0.378
60–90	0.07	0.04	0.40	0.04	0.0585	2.009	0.502
60–120	0.08	0.05	0.41	0.04	0.0574	2.003	0.501
0–120 cm	0.10	0.06	0.41	0.04	0.062	1.679	0.404

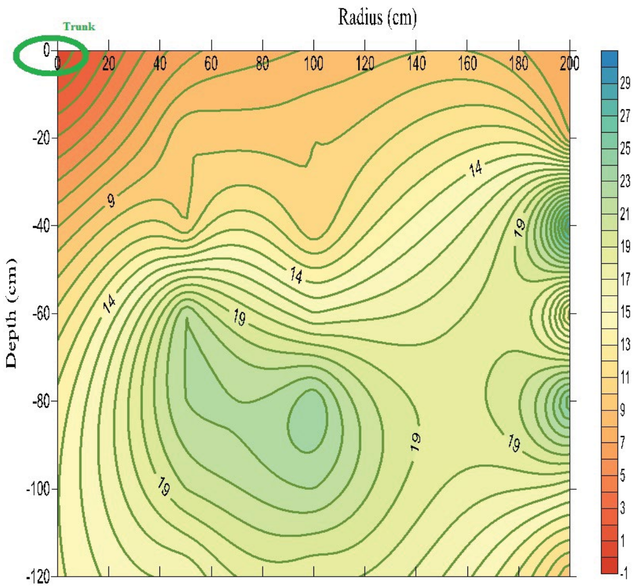

Fig. 5. Space distribution of date palm roots in the soil.

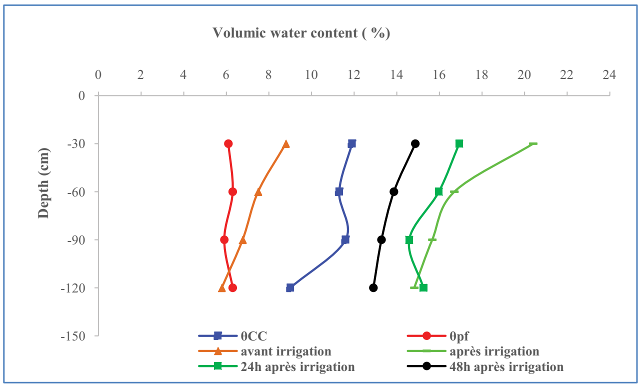

Fig. 6. Water profile in the soil after irrigation by drip subsurface system.

than the water content θ_{pf} (6%). The maximum value (9%) was recorded at the 0–30 cm horizon (Fig. 7). Just at the end of the irrigation, the soil moisture varies between 15% and 17% depending on the depth. Over time, the decrease in moisture content was regular and remarkable over the entire root depth. After 48 h, the minimum average water content is about 13%, which is higher than the average moisture content at the field capacity θ_{cc} (11%). At the end of irrigation, the water content, compared with the mini-diffuser emitter, is 17% knowing that the radius of the wet front is 110 cm whereas the average value of the soil moisture is 14% in all the root depth.

The water stock, immediately after irrigation, was greater (about 194 mm) than its field capacity value (132 mm). So the losses were 62 mm.

4.3. Bubbler irrigation system

With this technique, the irrigation lasted 5 h. The initial average water content did not exceed 7%. Just after

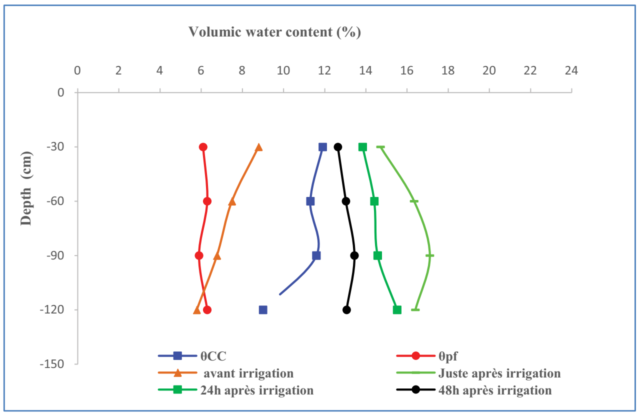

Fig. 7. Water profile in the soil after irrigation by mini-diffuser system.

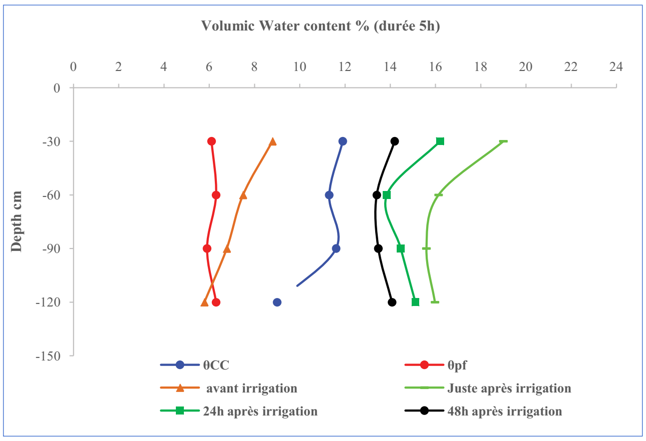

Fig. 8. Water profile in the soil after irrigation by bubbler system.

irrigation, the minimum humidity was about 16%; value greater than θ_{cc}. At the end of irrigation, the moistened ray was 170 cm. Average water content was 19% close to the bubbler but decreased to 14% at mid-distance between bubblers. The distribution of moisture in the root zone is homogeneous and decreases steadily with time. Indeed, before irrigation, it does not exceed 7%. On the other hand, just after irrigation, it reached 21% (60 cm from the bubbler) but it did not exceed 10% at the edge of the wetting front (at 140 cm from the bubbler). On the scale of the root profile, it reached 17%. After 48 h, this decrease was more remarkable (14%) although it remains higher than θ_{cc}. Just after irrigation, the moistened ray on the soil surface was greater (140 cm) than the spacing between the two dabblers of the same palm.

4.3.1. Efficiency of water irrigation application

The efficiency of water application for the various techniques adopted varied among 57%, 36% and 30%, obtained, respectively, for drip irrigation, drip subsurface irrigation and by mini diffusers. These low efficiencies obtained, values can be explained by the low soil water retention capacity and the relatively high doses of the low soil water

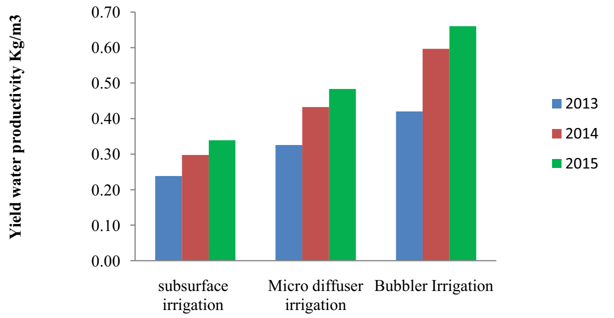

Fig. 9. Yield productivity of the three irrigation systems.

reserves, which has resulted in the excessive loss of water percolation.

4.3.2. Yield water productivity

The analysis results showed that for the year 2013, the average yields per palm tree were not significantly different and did not differ significantly between the three irrigation techniques adopted. 42 kg/tree were obtained. In 2015, production increased to 63, 59 and 66 kg/palm in irrigation by mini diffusers, subsurface and bubblers, respectively. During the years 2014 and 2015, the irrigation technique that gave the best yield is bubbler irrigation. In 2011, Talat Farid Ahmed proved that localized surface irrigation was more cost-effective than underground localized irrigation in an Al-Gassim palm grove (Saudi Arabia). This result did not agree with the work that was done by Al-Amoud (2006), on the drip subsurface irrigation under date palm in the same region (Al-Gassim, Saudi Arabia), which recommended that the technique of drip subsurface irrigation applied by farmers can promote better production compared with other localized surface techniques and the increase in production can reach 50% compared with the other localized techniques.

5. Conclusion

The main objective of this work is to identify the efficient irrigation system under palm date in Tunisian oasis conditions. Following tentative conclusions can be drawn:

- Good uniformity was observed. It exceeds 85% for the three techniques adopted in this test.
- Measurements of soil moisture after the irrigation test using the three localized irrigation techniques show that bubbler water application efficiency is 57% while it is 36% and 30%, respectively, for drip subsurface and mini-diffuser techniques.
- During the years 2014 and 2015, the bubbler irrigation technique gave the best yield, an average of 62 kg/palm. During 2015, the efficiency of the lowest water use is obtained by underground irrigation, that is, 0.34 kg/m^3. The most important efficiency is that recorded by bubbler which is of 0.66 kg/m^3.
- Improvement of bubbler irrigation system uses under date palm will be necessary and the key to save irrigation water resources in Tunisian oasis.

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