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Response of drip-irrigated chufa (*Cyperus esculentus* L. var. *sativus* Boeck.) to different planting configurations: yield and irrigation water-use efficiency

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Abstract

A two-year study was conducted to analyse the yield and irrigation water-use efficiency of chufa crop in response to planting configuration and drip irrigation scheduling as a function of the volumetric soil water content. The planting configurations were: beds with three plant rows and three driplines (B3), beds with three plant rows and two driplines (B2), beds with two plant rows and two driplines (b), and ridges (R). The yield was affected by the planting configuration; greater yields were obtained in beds (on average 2.36 kg m^{-2}) than in R (2.14 kg m^{-2}). Considerably less irrigation water was applied in R and in B2 than in beds B3 and b. The irrigation water-use efficiency was affected by the planting configuration in the same line that the irrigation water was applied, with greater values being obtained in B2 (7.58 kg m^{-3}) than in the R (6.63 kg m^{-3}), which in turn was higher than B3 (5.92 kg m^{-3}) and b (5.69 kg m^{-3}). These values of the irrigation water-use efficiency were considerably higher than those obtained in previous experiments (based on the volumetric soil water content in the ridges). Neither the yield nor the average tuber weight were affected by the position of the different planting rows in the bed.

Keywords

Chufa yield; Automatic drip irrigation; Planting method

1. Introduction

Chufa, also known as tiger nut, is the botanical variety *sativus* of *Cyperus esculentus* L. Chufa is a typical crop from the Huerta Norte area of the Valencia Region in Spain, where approximately 500 ha is dedicated to the chufa crop (MAGRAMA, 2014), with 6.5×10^6 kg of tubers grown annually at a value of 4 million Euros. Chufa is cultivated for its tubers, which are mainly used to produce "*horchata*", which is a popular, refreshing, and wholesome drink in Spain, although fresh chufa tubers can also be consumed on their own after soaking. Approximately 46×10^6 L of "*horchata*" is produced annually, representing a retail market value of 32 million Euros (INE, 2014). Due to the current interest in this crop, the Regional Administration of the Valencian Community has developed specific legislation regarding chufa quality parameters (CAPA, 2010). Increasing interest in chufa cultivation, primarily for food technology and biodiesel production, has also been reported in Brazil, Cameroon, China, Egypt, Ghana, Hungary, the Republic of Korea, Poland, Turkey, and the USA (Abdel-Nabey, 2001; Coskuner et al., 2002; Djomdi et al., 2007; Matos et al., 2008; Asante et al., 2014).

In Spain, chufa is cultivated in rotation with other crops, such as potato, onion, lettuce, escarole, and red cabbage. Chufa is grown in ridges, and irrigation is only performed by gravity systems, using water that is delivered by open channels, whose flow before has not been previously measured or controlled. In the chufa cultivation area, water is readily available and inexpensive; however, due to extended periods of drought and the shift of water to other applications, the use of irrigation water may soon become subject to regulation, increasing its cost (Pascual-Seva et al., 2013a), thus water productivity should be increased. Molden et al. (2003) reported two strategies for improving water productivity: increasing the productivity per unit of water consumed (obtaining higher yields) and lowering non-beneficial depletion (diminishing irrecoverable deep percolation and surface runoff). Within this context, a line of research was initiated to identify the best practices for the management of the irrigation of chufa. The effect of furrow irrigation on chufa yield has been addressed in previous research (Pascual-Seva et al., 2013a, 2013b). In these studies, irrigation was optimised through the development and validation of an empirical function that estimated the optimum irrigation time as a function of flow discharge, and among other indices, the irrigation water-use efficiency (IWUE) was determined. The IWUE is an indicator to assess the efficient use of irrigation water in crop production (Tolk and Howell, 2003). The term, as introduced by Boss (1980), refers to the increase in yield under irrigated production compared to that under dryland production in relation to the mass of the irrigation water that is furnished to the field. But also the IWUE is also currently used to relate the yield to the volume of irrigation water ($I_{applied}$; Tolk and Howell, 2003). The last definition is the one applied in the present study, as the chufa crop is not cultivated under dryland conditions in Spain. Drip irrigation is an alternative to surface irrigation, especially in areas where water is scarce. When properly designed, installed and managed, drip irrigation systems usually result in high uniformities and application efficiencies (Evans et al., 2007); furthermore, the wetted area is smaller, as water is localised near the plant, thus decreasing soil evaporation in the early stages of the plant (Allen et al., 1998) and conserving water compared to other irrigation methods. The first studies of this irrigation method performed in chufa demonstrated that it could be an alternative to the traditional irrigation (Pascual-Seva et al., 2015). Different refill points (soil moisture levels before the start of each irrigation event) in ridges were compared; the two drip irrigation refill points that maintained higher levels of soil moisture [80% and 90% of field capacity (FC)] resulted in a higher yield (2.40 kg m^{-2} and 2.80 kg m^{-2}, respectively) than the traditional furrow irrigation (2.14 kg m^{-2}) and resulted in a higher IWUE (4.22 kg m^{-3} on average for drip irrigation; 2.09 kg m^{-3} for furrow irrigation; Pascual-Seva et al., 2015).

Leskovar et al. (2012) stated that it is questionable whether conventional cultivation in ridges results in maximum yield, being the optimization of plant density of great importance in maximizing yield, particularly for root and tuber crops, such as chufa. Although other planting systems are not common, most likely because of the special, locally made ridge forming and harvesting machines that are used for its cultivation, slight changes in these machines would allow chufa to be grown in flat raised beds, as discussed by Pascual-Seva et al. (2012). The study, conducted in furrow irrigation, with beds with three and two planting rows and ridges were irrigated simultaneously and an identical application time, resulted in higher yields and IWUE in flat raised beds (2.67 kg m^{-2} and 3.96 kg m^{-3}, respectively) than in ridges (2.47 kg m^{-2} and 2.22 kg m^{-3}, respectively).

Considering that both planting in flat raised beds and drip irrigation studies resulted in increased yield, and especially in increased IWUE, the authors decided to analyse the productive response and the IWUE in flat raised beds in relation to ridges, with furrow and drip irrigation systems (Pascual-Seva et al., 2014). Irrigation management was conducted as a function of the volumetric soil water content (VSWC) in the ridges, with the beds and ridges irrigated simultaneously and with identical application time. The ridges produced a lower yield (on average 2.09 kg m^{-2}) than the beds with two plant rows (2.30 kg m^{-2}), and the yields with drip irrigation (2.33 kg m^{-2}) were higher than those obtained using furrow irrigation (2.07 kg m^{-2}). Ridges led to the greatest IWUE (4.88 kg m^{-3}) with drip irrigation and to the lowest (1.91 kg m^{-3}) with furrow irrigation.

Therefore, the herein presented study was designed to improve the IWUE obtained in drip irrigated flat raised beds.

The goals of this work were to study the effect of drip irrigation on the productive response and IWUE of chufa cultivated under different planting configurations and irrigation layouts, with irrigation schedules based on the VSWC in each type of planting configuration, and to compare the yield and average tuber weight in the different planting rows.

2. Materials and methods

2.1. Cultivation methods

This two-year study was conducted in an experimental plot with a total area of approximately 500 m^2 on the campus of the Universitat Politècnica de València, Spain (39º38´N, 0º22´W), which lies within the primary chufa-producing area. According to Papadakis's agro-climatic classification (MOPT, 1992), the climate is subtropical Mediterranean (Su, Me), with hot, dry summers and an average annual rainfall of approximately 450 mm that is distributed irregularly throughout the year, with approximately 40% falling in autumn. Figure 1 shows the most significant meteorological data for the two experimental years expressed as monthly values, i.e., temperature and precipitation registered in the experimental plot, and the reference evapotranspiration (ETo) as calculated by the Penman-Monteith equation considering the weather information obtained from an automated meteorological station located near the experimental plot.

To avoid soil replant disorders resulting from serial chufa cropping, the experiments were conducted in two non-consecutive years (2011 and 2013). The soils are deep with a sandy texture (Table 1) and classified as anthropic torrifluvent according to the USDA

Soil Taxonomy (Soil Survey Staff, 2010). The soil was uniform in the top 0.25 m depth, since it suffers a sieving when the tubers are harvested (in previous seasons), in conjunction with seedbed preparation, which entails two crossed passes with a rotary tiller. An analysis conducted from a homogenised sample from the top 0.25 m of soil indicated that the soil had a moderately alkaline pH (8.2), was not saline [EC (1:5) 0.24-0.27 dS m^{-1}] and was fertile (Table 1). The average soil bulk density was 1680 kg m^{-3}, and its porosity was 36.6 %.

The planting configurations (Figure 2) were: beds with three plant rows and three driplines (B3); beds with three plant rows and two driplines (B2); beds with two plant rows and two driplines (b); and ridges (R).

Standard cultivation practices were followed during the crop period, as described by Pascual et al. (1997). The dates corresponding to planting, straw burning, and tuber harvesting were 15 April and 5 and 10 December 2011 and 10 April and 5 and 12 December 2013. The plots were furrowed at the time of planting with precision mechanical planters. Tubers were planted at a depth of 0.1 m and spaced 0.1 m apart within rows that, in turn, were spaced 0.3 m apart in beds. The ridges and beds were made using a disk plough and a plough, coupled with the planters. The bed width in B3 and B2 was adapted to the existing harvesters; the flat raised part of the bed was 0.9 m wide (the distance from bed centre-to-centre was 1.2 m). The distance from bed centre-to-centre in b was 0.8 m, and R were spaced 0.6 m apart. The corresponding planting densities were 180 kg ha^{-1} (b, B2, and B3; in all cases 250,000 plants ha^{-1}) and 120 kg ha^{-1} (R; 167,000 plants ha^{-1}). The beds and ridges were oriented lengthwise from west to east. The furrow length was 30 m, and the average slope was approximately 0.1%.

Fertilization management was in accordance with local practices. Basal dressing, which was applied on the day before planting, consisted of 2 kg m^{-2} sheep manure [572 g kg^{-1}

dry weight; 609 g kg^{-1} organic matter dry weight] and 90 g m^{-2} 15:15:15 (N: P_2O_5: K_2O). The top dressing was based on Hoagland's No. 2 nutrient solution (Maynard and Hochmuth, 1997) [EC: 2.31 dS m^{-1}; pH adjusted to 6.1; macronutrient concentrations (all in mM): NO_3^-, 14.0; $H_2PO_4^-$, 1.0; SO_4^{2-}, 2.45; K^+, 6.0; Ca^{2+}, 4.0; and Mg^{2+}, 2.0; micronutrient concentrations (all in μM): Fe^{2+}, 15; Mn^{2+}, 10; Zn^{2+}, 5; B^{3+}, 30; Cu^{2+}, 0.75; and Mo^{6+}, 0.5], applied up to 3.12 g m^{-2} N, fractionated in two alternate irrigation events during the first two weeks of July through the irrigation system.

2.2. Irrigation management

Plants were irrigated using turbulent flow surface driplines with emitters (2.2 L h^{-1}) spaced 0.25 m apart. The groundwater used for irrigation displayed no restrictions in terms of salinity for non-sensitive crops, such as chufa, or permeability (EC = 1.6 dS m^{-1}, $SAR_{(adjusted)}$ = 2.9, pH = 7.4; Ayers and Westcot, 1994). The VSWC was continuously monitored with a multi-depth capacitance probe (Cprobe; Agrilink Inc. Ltd., Adelaide, Australia) in the central line of one ridge or bed of each planting configuration, located at half the length of the plot (15 m from the upper head) of the ridge and beds. The multi-depth capacitance probe had sensors at depths of 0.1, 0.2 and 0.3 m that were connected to a radio telemetry unit, which read the value of each sensor every 5 min and stored the average value for 15 min, as reported in Mounzer et al. (2008). Stored raw data were sent by radio through a relay station and then to a gateway connected to a computer for data analysis with the addVANTAGE software (ADCON telemetry GMbH; Vienna, Austria; Vera et al., 2009). Before installation in the field, each sensor (of the multi-depth capacitance probe) inside its PVC access tube was normalised by taking voltage readings that were exposed to air (Va) and water (Vw) at ≈ 22ºC. The scaled voltage is defined as (Va - Vs) / (Va - Vw), where Vs is the voltage in the soil

(Abrisqueta et al., 2012). Then, the scaled voltage values were converted to VSWC using local calibration equations (Vera et al., 2009). The total rainfall and the emitter flow rate (measured in one emitter per treatment) were recorded using automatic tipping bucket gauges that were connected to the radio telemetry unit.

Variations in VSWC in each planting configuration were used to determine in situ the corresponding FC values [defined as the amount of water held in the soil after excess water has drained away and the rate of the downward movement of water has materially decreased (Veihmeyer and Hendrickson, 1931), and that coincided with the VSWC when its change approached to zero over the elapsed time]. This agrees with Fares and Alva (2000), who stated that given that the soil-water dynamics can not be assessed in the laboratory, it would be desirably to measure FC in the field.

Irrigation scheduling was managed by initiating each irrigation event when VSWC values at a soil depth of 0.1 m decreased to 85% of FC. This value was suggested such that the soil never becomes dry enough to limit plant growth and yield, as stated by Evett et al. (2007). The 0.1-m depth was selected given that this depth corresponds to the maximum root density and water uptake by chufa plants (Pascual-Seva, 2011). The irrigation time was set at 40 min (1.5 L emitter^{-1}), considering the results obtained in previous experiments (Pascual-Seva et al., 2014; unpublished experiments carried out in 2009). Given that all irrigation events lasted 40 min, the $I_{applied}$ per event in each configuration depended on the number of emitters per area, which was higher in B3 and b (10 emitter m^{-2}), than in B2 and R (6.7 emitter m^{-2}), so that the $I_{applied}$ per event corresponded to 14.67 mm in B3 and b and 9.83 mm in B2 and R. In 2013, the first irrigation event lasted as long as in 2011, 40 min, but given that the soil was dry, 40 min was not enough to increase VSWC up to the FC level; therefore, it was decided to increase the irrigation duration to 120 min for the second irrigation event (and the third one in R).

2.3. Vegetative and productive parameters

Periodically, 10 plants, corresponding to 1 m of each plant row, were sampled from each individual plot. The plant height was measured, and plants were divided into their parts and analysed separately: (i) shoots and all of their leaves (hereinafter referred to as 'leaves') and (ii) tubers. After washing, each sampled plant part (leaves or tubers) was weighed, and after being dried at 65ºC in a forced-air oven (Model 297; JP Selecta, Barcelona, Spain) for four days to obtain the dry weight and the harvest index, the ratio of tuber to total biomass was calculated on a dry matter basis (Van der Veeken and Lommen, 2009). At harvest, the fresh average tuber weight was determined by counting and weighing tubers from a sample of approximately 500 g. The IWUE was calculated as the relationship between the yield and the $I_{applied}$ (Tolk and Howell, 2003). Immediately prior to harvest, 1 m from each of the planting rows (north, centre and south, in B3 and B2; north and south, in b) was sampled to determine the yield and average tuber weight to detect potential between-row differences.

2.4. Experimental design and statistical analysis

A randomised block design with three replications was used. Each replicate combination consisted of a flat raised bed [b (consisting of an area of 24 m^2), B2 and B3 (36 m^2 for both)] or two ridges (36 m^2). The data were analysed with an analysis of variance using the statistical program Statgraphics 5.1 plus (Statgraphics Plus for Windows 5.1, 2005; Statistical Graphics Corporation, Rockville, Maryland, USA). Differences between the means were compared using an LSD test at $P \leq 0.05$.

3. Results and discussion

3.1. Irrigation management

The FC at a depth of 0.1 m for all management strategies was 0.15 m^3 m^{-3} in 2011 and 0.17 m^3 m^{-3} in 2013; thus, the irrigation start for all management strategies was 0.13 m^3 m^{-3} in 2011 and 0.14 m^3 m^{-3} in 2013**.**

For the chufa crop within the traditional cultivation area, considering the positive results presented herein (yield up to 2.38 kg m^{-2} and IWUE values up to 6.07 kg m^{-3}) and those from previous studies [where the irrigation started when the VSWC at 0.1 m soil depth dropped to 80% and 90% (Pascual-Seva et al., 2014 and 2015; unpublished experiments carried out in 2009)], it appears adequate to initiate each irrigation event when the VSWC value at a 0.1-m soil depth decreased to 85% FC.

Figure 3 shows the VSWC for the different management strategies at 0.1-m and 0.3-m depths during the vegetative growth stage until the autumn rains started, as well as the water input from each rainfall event. The VSWC at 0.1-m and 0.3-m depths remained within a relatively narrow range until the autumn rains began for all of the strategies, both in 2011 and in 2013 (Figure 3).

Table 2 shows the seasonal rainfall, reference evapotranspiration (ETo), and an estimation of the water requirements [ETo - Effective rainfall, considering ETo (instead of ETc because Kc of chufa crop is unknown, and the Effective rainfall calculated from rainfall data using the method of the U.S. Bureau of Reclamation (Stamm 1967) as presented by Montoro et al. (2011)] from planting to 12 October (a date that can be considered as the end of the irrigation period, coinciding with the last irrigation event in 2013), the number of irrigation events, and the $I_{applied}$ (total and per plant) for the different planting configurations and both seasons. In general terms, the $I_{applied}$ in 2011 (on average 335 mm) was lower than that in 2013 (on average 396 mm), agreeing with lower amounts of estimated water required in 2011 (647 mm) than in 2013 (773 mm). In 2011, rains occurred primarily in spring (Figure 1), thus delaying the start of irrigation in relation to 2013 (13 June in 2011 vs. 28 May in 2013; Figure 3), and from September – October, moving toward the end of the irrigation period (11 September in 2011 vs. 12 October in 2013), consequently reducing the number of irrigation events (on average 27.8 in 2011 and 30.5 in 2013).

Regarding the percentage of $I_{applied}$ in relation to the seasonal ETo - Effective rainfall, these values represent 51.7% and 51.2%, respectively, for 2011 and 2013. These values are lower than those that were obtained in previous studies, both in ridges (on average 93.8%; Pascual-Seva et al., 2015) and in flat raised beds (on average 141.8%; Pascual-Seva et al., 2014) in which the management was automated, with each event being started when the VSWC at a 0.10-m depth in ridges reached 85% of the FC value and stopped when the sum of the VSWC values at 0.10-m, 0.20-m and 0.30-m depths in ridges reached the corresponding FC value. The percentages that were obtained in this study show a better adjustment of the $I_{applied}$ to water requirements (considered better adjusted to the water retention capacity of the soil in the root zone) than in the previous studies. Therefore, it can be stated that for drip irrigated flat raised beds, considerable water savings are achieved when the irrigation start is scheduled based on its own VSWC instead of the VSWC in ridges, and the irrigation duration is based on time (40 min).

Irrigation water applied in R and in B2 (293 and 284 mm, respectively in 2011 and 362 and 342 mm in 2013) was smaller than in B3 and b (381 mm in both cases in 2011, and 425 and 455 mm for B3 and b, respectively, in 2013). Given that all of the irrigation events (for all configurations) lasted 40 min, these differences are basically due to the different number of emitters per area, which was higher in B3 and b than in B2 and R, as mentioned in Section 2.2. This difference was not offset by the increase in the number of irrigation events, with both seasons having more irrigation events in B2 and R than in B3 and b (Table 2). The $I_{applied}$ per plant (Table 2) was higher in R (167,000 plants ha^{-1}; 17.54 L plant^{-1} in 2011 and 20.48 L plant^{-1} in 2013) than in the flat raised beds (250,000 plants ha^{-1}; on average 13.9 and 15.5 L plant^{-1} in 2011 and 2013, respectively)

The increase in VSWC at a depth of 0.3 m can be considered an indicator of deep percolation, given that roots do not reach this depth. Figure 3 shows that for all of the planting configurations and both experimental seasons, the average VSWC at the 0.3-m soil depth remained within a narrow range, indicating that deep percolation was smaller in this irrigation management. Comparing the VSWC variations for each irrigation event, larger variations per irrigation event are shown in B3 and R than in B2 and b. This result is in part due to a lower level of adjustment to the water retention capacity of the soil and in part by the different position of the probes in relation to the driplines (under the pipelines in B3 and R) and to the different bed widths (Figure 2), which does not allow the percolation levels between the different bed types to be compared. To compare the deep percolation among the different planting configurations and irrigation layouts, probes should be placed at an identical distance from the emitter in every strategy. In particular, probes should be located under the emitter, the most critical point for determining deep percolation.

3.2. Productive response

Figure 4 shows the changes in the plant height, average leaf and tuber biomass, and harvest index for all of the management strategies. Although data were determined for each plant row in each season, the average values are presented, as in Pascual-Seva et al. (2015), given that there were no significant differences among the values corresponding to different plant rows and the two growing seasons. The plant height increased up to 102 cm (Figure 4) in agreement with Pascual-Seva et al. (2013a), and no differences were observed among planting configurations. Plant height and leaf biomass peaked at the end of July; thereafter, leaf senescence began. Initially, the aboveground biomass accounted for most of the plant biomass (harvest index < 0.5), but starting at the end of August, the aboveground biomass was exceeded by the tuber biomass because of the translocation to the tubers and leaf senescence, which is consistent with Pascual-Seva et al. (2014 and 2015). The lowest leaf and tuber biomass of plants, by surface unit, occurred in the case of R, a consequence of their lower planting density. Nevertheless, there were no differences among harvest indexes because the lower values of the two parameters for R were compensated for in their ratio. The lowest tuber biomass of plants corresponded to R, which is consistent with the results obtained at harvest time on a plot scale (Table 3).

Table 3 presents the yield, the average tuber weight, and IWUE corresponding to the commercial harvest period. Tuber yield was significantly affected by the planting configuration ($P \leq 0.05$). The tuber yield obtained in R (2.14 kg m^{-2}) was lower than that obtained in b (2.36 kg m^{-2}), B3 (2.38 kg m^{-2}) and B2 (2.35 kg m^{-2}), without any differences ($P \leq 0.05$) among them.

Despite the differences among growing seasons that are typical in traditional chufa cultivation (Pascual-Seva et al., 2013a), tuber yield was unaffected ($P \leq 0.05$) by the growing season, and their values are consistent with those obtained in previous investigations conducted with drip irrigation, both in flat raised beds (Pascual-Seva et al., 2014) and in ridges (Pascual-Seva et al., 2015). The average tuber weight was not affected ($P\leq0.05$) by the planting configuration nor by the growing season.

The optimization of plant density is of great importance in maximizing yield, particularly for root and tuber crops (Leskovar et al., 2012), because excessive plant density per unit area may result in competition between plants for growth resources (as solar radiation, water, and nutrients), whereas suboptimal densities lead to underuse of these inputs (Caliskan, 2009; Leskovar et al., 2012). The increased yield with increasing plant density up to a certain threshold may have occurred in a previously conducted study on flat raised bed furrow irrigation of chufa (Pascual-Seva et al., 2012), which reported higher yield in beds with two planting rows (222,000 plants ha^{-1}) than in ridges (167,000 plants ha^{-1}) and a significant interaction between the growing season and planting configuration, with significant differences between beds with two and three (250,000 plants ha^{-1}) planting rows and between beds with three planting rows and ridges, depending on the growing season. Similar results have been reported in other root and tuber crops [i.e., potato (Caliskan et al., 2009) and onion (Brewster and Salter, 1980; Leskovar et al., 2012)]. In the present study, with the same plant density in b, B2 and B3 (250,000 plants ha^{-1}) and lower plant density in R (167,000 plants ha^{-1}), the yield of R was significantly lower ($P\leq0.05$) than that of b, B2 and B3, with no significant differences ($P\leq0.05$) observed between them.

Regarding the plant row layout, Howeler et al. (1993) demonstrated for both potato tuber yield and the root yield of sweet potato small differences between the yields as obtained in row-ridge and in two-row bed planting methods. In potatoes, Essah and Honeycutt (2004) reported higher total yields and marketable yields for raised beds using green-sprouted seed tubers, but this result was not observed for non-sprouted seed tubers. In sweet potatoes, Nasare et al. (2009) reported no significant increase in tuber yield when broad bed furrows were used rather than ridges and furrows. Leskovar et al. (2013) reported that a single line per bed for artichoke crops significantly increased the head number of jumbo and large sizes per plant compared to double lines in only one of the two years of the study. In the present study, all bed types produced a higher yield than did R ($P \leq 0.01$), but no significant differences ($P \leq 0.05$) were detected among them, nor among the average tuber weight as obtained for ridges and beds. In accordance with these results and consistent with Mundy et al. (1999), the technique of using raised beds appears promising if the proper equipment (adapted to the bed dimensions) is available. The IWUE was affected ($P \leq 0.01$) by both the growing season and the planting configuration (Table 3). The IWUE, in addition to the yield, depends on the $I_{applied}$, which in turn depends on the evapotranspiration, the rainfall and its distribution; therefore, its value may change with the growing season meteorology. With the irrigation management presented herein, b and B3 resulted in statistically lower ($P \leq 0.05$) IWUE values (5.69 and 5.92 kg m^{-3}, respectively) than R (6.63 kg m^{-3}), which in turn was lower ($P \leq 0.05$) than B2 (7.58 kg m^{-3}). Given that yield in flat raised beds resulted in higher values ($P \leq 0.05$) than in R, with no differences between them, these differences in IWUE were a result of variations in $I_{applied}$, which were analysed in section 3.1. The main goal of both researchers and growers is to increase either yields or profits. Strategies to achieve maximum yield (although decreasing IWUE) are the most profitable option when water availability is not an issue. However, if water is a limiting factor, strategies to achieve maximum IWUE will be the best option. In this sense, it should be stated that flat raised beds led to the highest yield, and B2 in particular led to the highest IWUE.

The IWUE values that were obtained in this experiment increased considerably compared to previous investigations (on average 3.76 kg m^{-3}, for beds with drip irrigation automated as a function of the VSWC in ridges; Pascual-Seva et al., 2014). Given that the corresponding yields were similar, these increases in the IWUE were a consequence of a reduction in $I_{applied}$, particularly in $I_{applied}$ per event, adjusting $I_{applied}$ to water requirements in each planting configuration and consequently reducing deep percolation. Among the different studied drip irrigation management options for chufa cultivated in flat raised beds (Pascual-Seva, 2011, Pascual-Seva et al, 2014 and the herein presented results), it can be stated that in the traditional chufa cultivation area, the best option is to start each irrigation event when the VSWC at a 0.10-m soil depth in each bed decreases to 85% FC with irrigation over 40 min.

A comparison of the diverse planting rows in the different bed types (Tables 4 and 5) shows that neither the yield nor the average tuber weight was affected by their position. These results agree with those obtained in the previously cited studies on flat raised beds with drip irrigation (Pascual-Seva et al., 2014) and furrow irrigation (Pascual-Seva et al., 2012). Nevertheless, although they were not significant ($P \leq 0.05$), higher values of both parameters were observed for the north row; this trend could be related to a higher soil moisture but must be analysed in further studies, with soil moisture sensors being placed in the different planting rows. In beds with three plant rows, the use of two or three driplines did not affect the yield or the average tuber weight, no differences were observed between plant rows (Table 5), and higher IWUE values were obtained in B2. Therefore, the two-dripline layout would be the most advisable option, given that it requires a lower investment, and especially because it leads to the highest IWUE.

4. Conclusions

Chufa planting in flat raised beds and using drip irrigation increases the yield relative to the traditional ridge planting system without diminishing the average tuber size;

therefore, it would be advisable for chufa growers to adopt these planting configurations. For drip-irrigated flat raised beds, considerable water savings and consequent increases in the irrigation water-use efficiency are achieved when the irrigation start is scheduled based on the soil moisture measured in each bed type and the irrigation duration is based on time. Beds with three plant rows using two driplines lead to the highest irrigation water-use efficiency; thus, this layout would be the most advisable option for chufa crop in the traditional cultivation area. In future studies, it would also be of interest to analyse the productive response of the chufa crop to cultivation in two plant row beds with one dripline.

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