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EFFECT OF THE TYPE OF SPRINKLER AND HEIGHT ABOVE THE SOIL ON ONION (ALLIUM CEPA L.) CROP

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ABSTRACT In arid or semiarid regions such as Castilla-La Mancha (Spain), a sustainable use of water for agriculture should be carried out. Under these conditions it is necessary to use potentially efficient irrigation systems, such as drip and sprinkler irrigation systems. Centre pivots are a very interesting alternative among other sprinkler irrigation systems. In order to obtain the combination that best fits the field conditions (soil, wind, crops, etc.), it is important to determine the behaviour of the different sprinklers and their height above the ground level. The main goal of this work is to characterize the water application process in a centre pivot, above the crop and at soil level, by using two types of sprinklers and two heights above ground level, and studying its effect on onion (Allium cepa L.) yield. The case study has been analyzed during one irrigation season (2008) in a plot irrigated with a central pivot irrigation system, located in Albacete (Spain). In the irrigation system, two repetitions of the most common commercial types of sprinklers in the Region were installed in the centre pivot, Rotating Spray Plate (RotatorTM) and Fixed Spray Plate (LENTM), and each one for two heights above the ground level (1 m and 2.5 m). During the irrigation season several evaluations of irrigation system were performed, obtaining parameters related to the distribution of water above the crop (Christiansen uniformity coefficient, distribution uniformity, etc.). In addition, for each combination of sprinkler and height, crop yield, biomass and harvest index were calculated. In order to monitor the soil moisture, WatermarkTM sensors, which measure soil water potential, together with EnviroScanTM sensors, which measure volumetric soil water content, were installed. Results show that, with the Rotating Spray Plate Sprinklers (RotatorTM), slightly higher irrigation uniformity is obtained for individual irrigation events, mainly for a height of 2.5 m. In relation to soil moisture distribution within the soil, it could be concluded that soil moisture redistribution improves the obtained uniformity coefficient above the crop even when the low application uniformity is maintained in time. Regarding to crop yield, the differences between the several combinations of sprinklers and heights were not statistically significant.

Keywords: centre pivot irrigation system, sprinkler, irrigation uniformity, Allium cepa L., crop yield.

INTRODUCTION The efficient use of water and energy in agriculture is gaining in importance due to the general decrease in water availability for agricultural uses and increasing energy costs. This affects the viability of irrigation activity in many areas throughout the world.

When designing an irrigation system, irrigation engineers try to maximize irrigation efficiency, which depends on both water losses and uniformity of water distribution (Stern and Bresler, 1983; Tarjuelo *et al.*, 2000; Ortiz *et* al., 2009). The best design and management of an irrigation system should minimize water losses and maximize distribution uniformity (Brennan, 2008).

There are different types of irrigation system, but sprinkler irrigation is considered to be the most efficient (McLean *et al.*, 2000; Al-Jamal *et al.*, 2001). Centre pivots are a very interesting alternative among other sprinkler irrigation systems.

The heterogeneity of water application can affect the crop yield (Letey *et al.*, 1984; Ruelle *et al.*, 2003; Dechmi *et al.*, 2004). Most of the studies carried out in relation to this subject show that a lack of uniformity translated into a lower mean yield (Ortega *et al.*, 2004a; Ortega *et al*, 2004b). Knowledge of the influence of uniformity on yield is important for the proper design, management and economic evaluation of an irrigation system (Stern and Bresler, 1983). In addition, water application uniformity by irrigation systems has a great influence on water and energy consumption as well as possible environmental impact (Louie and Selker, 2000; McLean *et al.*, 2000).

Onion (*Allium cepa* L.) is the most widely produced and consumed bulb vegetable throughout the world. Onion is used worldwide among all nationalities and cultures and is available in most markets of the world during all seasons of the year. When grown in semi-arid climates, such as that used in the present study, onions are considered to have a high water demand (Jiménez *et al.*, 2009; López Urrea, 2009).

Some studies analyse the agronomic effects of irrigation uniformity on an onion crop (Al-Jamal *et al.*, 2001). This is important in the context of arid or semiarid areas with limited water resources, such as Albacete (Spain), where water is extracted from aquifers which are in serious danger of over-exploitation.

The main goal of this work is to characterize the water application process in a centre pivot, above the crop and at soil level, by using two types of sprinklers and two heights above ground level, and studying its effect on onion yield.

MATERIAL AND METHODS

Experimental design A field experiment was performed during irrigation season 2008 in an 18.4 ha plot irrigated with a centre pivot system, located in Albacete (Spain). The experiment was carried out in an onion crop that covered a quarter of the area watered by the centre pivot system. The climate classification of Papadakis (1966) placed the study area in a warm Mediterranean climate. The soil plot was a Xeric Torriorthent with a loam texture of 4% coarse sand, 28% fine sand, 44% silt and 24% clay, according to the USDA (1979). Moreover, the area is characterised by flat topography and soils have good drainage, with few signs of water erosion and a medium depth (>600 mm).

The irrigation machine used had five spans, four of them of 50 m and one of them of 38 m, together with an overhang of 4 m. In all of them the sprinklers had pressure regulators with output pressure set to 140 kPa, and the pressure at the fixed pivot point was 210 kPa. The lateral pipe was 168.3 mm in diameter. The designed (gross) flow rate was 86.4m^3 h^{-1} with a system capacity of 1.3 l s^{-1} ha^{-1}. The maximum rotation speed was 1.9 m min^{-1}, with an irrigation time of 13.3 h.

Two repetitions of the most common commercial types of sprinklers in the Region were installed in the centre pivot, Rotating Spray Plate (Rotator^{TM}) and Fixed Spray Plate (LEN^{TM}). Each one were placed 2.5 m and 1 m using polythene flexible drop pipes (Fig. 1). The Rotator^{TM} used a moving plate to disperse water further than a stationary plate could. The plate rotated as the water discharged from a nozzle impacted against it. The LEN^{TM} is a low pressure sprinkler with stationary plates that deflect water ejected from a nozzle causing the stream to fan out into a circular pattern. The two Fixed Spray Plate are designed to give very well defined streams of water that are less distorted by wind by using a variable number of grooves on a single plate.

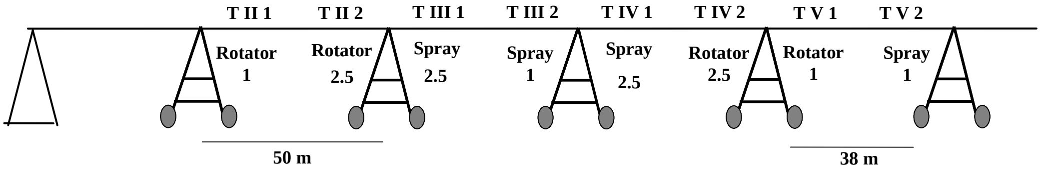


Figure 1. Diagram of the positioning of sprinklers on the machine.

Irrigation management The meteorological variables were measured by an automated meteorological station located at 150 m from the plot. The average value of the recorded data during the time the lateral of the centre pivot was moving across the line of catch cans (water collectors) was taken into account. Irrigation was scheduled using a simplified water balance method within the root area, following the food and agriculture organization (FAO) methodology (Pereira and Allen, 1999). According this methodology, total amount irrigation water applied was close to 5000 m^3 ha^{-1}. Onion was directly sowed. Other farm tasks and crop operations were those normally carried out by farmers in the area (De Juan *et al*., 2003). The total water applied (irrigation plus effective precipitation) throughout the experimental season was controlled. Effective precipitation was calculated from the moisture variation in the upper 400 mm of the soil, which was considered to be the effective rooting depth according to samples taken in the field.

Control of water application 24 irrigation events were evaluated following the methodology proposed by Merrian and Keller (1978), Merrian *et al*. (1980), and Heermann (1990), as well as International ANSI/ASABE Standards S436.1 (2001) and ISO-11545 (2001). In field tests, plastic catch cans with 160 mm diameter openings and 150 mm in height were spaced 2 m apart in the radius direction and placed 500 mm above the ground. The water depth collected was calculated by dividing the volume caught by the open area of the catch can. In each evaluation, flow was measured at the entrance of the centre pivot and at the beginning of each span using a portable ultrasonic flow meter (2.5 % accuracy). In addition, a pressure transducer (1 % accuracy) was installed at the beginning of each span to measure the pressure during irrigation so as to relate it to discharge.

For each evaluation of the system, the uniformity coefficient of Heermann and Hein (Heermann and Hein, 1968) and the distribution uniformity for each one of the eight treatments (combination sprinkler-height) were calculated.

Soil water control The soil water potential and moisture content were measured in the eight treatments. The soil water potential was measured using Watermark^{TM} sensors. In spans 2, 3, and 4, for each treatment, eight Watermark^{TM} sensors were placed, four of them at depth of 200 mm and the rest at depth of 400 mm. The two treatments of the last span had six Watermark^{TM} sensors each one, placed three of them at depth of 200 mm and the rest at depth of 400 mm. In all of them, these data were registered every 8 h.

The soil moisture content was measured by means of Enviroscan^{TM}, a sensor which utilizes the Frequency Domain Reflectometry (FDR) technology. In spans 2, 3, and 4, for each treatment, four Enviroscan^{TM} probes were placed at depths of 100, 200, 300 and 400 mm. The two treatments of the last span had three Enviroscan^{TM} probes each one, placed at the same depths. Data were registered every 10 min and the mean of those values registered every hour was stored.

Yield control The crop growing stages were monitored by using the phenological scale proposed by Feller *et al.* (1995). Yield and its components were determined for each treatment (sprinkler – height combination) after manual harvest of one third of the area of each one. In addition, the bulbs were classified by diameter.

Additional qualitative characteristics of the harvested onions were assessed in the laboratory. These were the estimation of firmness, using a texture analyser with a cylinder probe of 3 mm diameter, soluble solid content, using a digital refractometer, pH, using a pH meter, and total acidity by means of a potentiometric titration with a 0.1 N standardized sodium hydroxide (NaOH) solution.

Statistical analysis In order to estimate the effect of sprinkler type and height above the ground on water distribution uniformity and crop yield, an analysis of variance (ANOVA) was performed by considering some variables related with water distribution, such as average uniformity coefficient of individual irrigation events (CUh) and accumulated uniformity coefficient (CUac), together with variables related with yield and its components, and irrigation water use efficiency (IWUE).

The statistical analyses were performed using Statgraphics Plus^{TM} software (v. 5.1 for Windows, Statistical Graphics Corp., Herndon, VA, USA).

RESULTS

Control of water application The mean water depth collected (MWD) during the irrigation season is shown in Figure 2. This irrigation parameter shows high similarity for each combination of sprinkler and height above the ground level, comprised between 10.32 mm (Spray 2.5 m) and 11.33 mm (Rotator 1 m). These values show a proper degree of fitting of the sprinkler location along the centre pivot system. Rotator sprinklers at 1 m and 2.5 m have the highest MWD values. According the coefficient of variation (CV) values, which is close to 25 % in all sprinkler-height combinations, MWD variability is high, due to the different amount of water applied in each one irrigation event of the season.

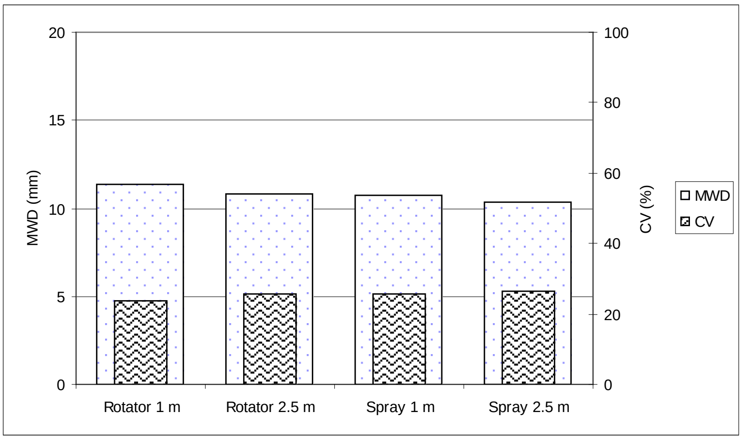


Figure 2. Mean water depth collected (MWD) and coefficient of variation (CV) in each sprinkler-height combinations.

Regarding water application uniformity, most of sprinkler-height combinations have an average uniformity coefficient (CUh) close to 85 %, except for Rotator 2.5 m, which have the highest CUh (92.55 %)(Fig. 3). Despite the high variability of MWD in each irrigation event during the irrigation season, CUh shows a lower variability than MWD in each sprinkler-height combinations, with a CV lower than 6 % in all of them (Fig. 4). The highest variability is shown for Spray 1 m, with CUh values comprised between 72.7 % and 92.9 % in some irrigation events (Fig. 3). In addition, CUh values do not show significant differences among the four sprinkler-height combination (Fig. 4).

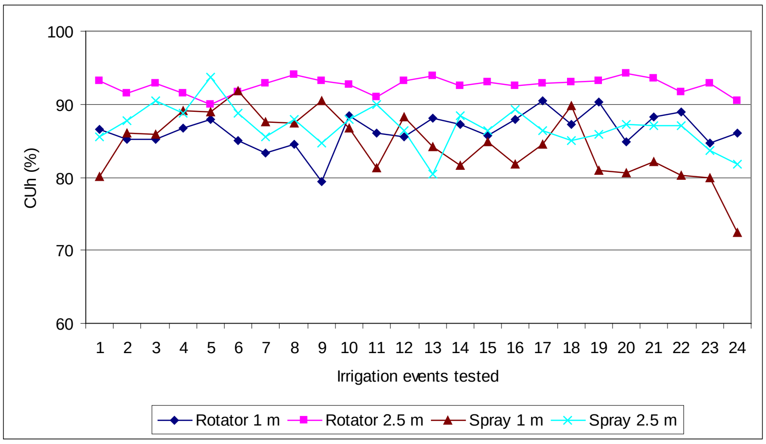
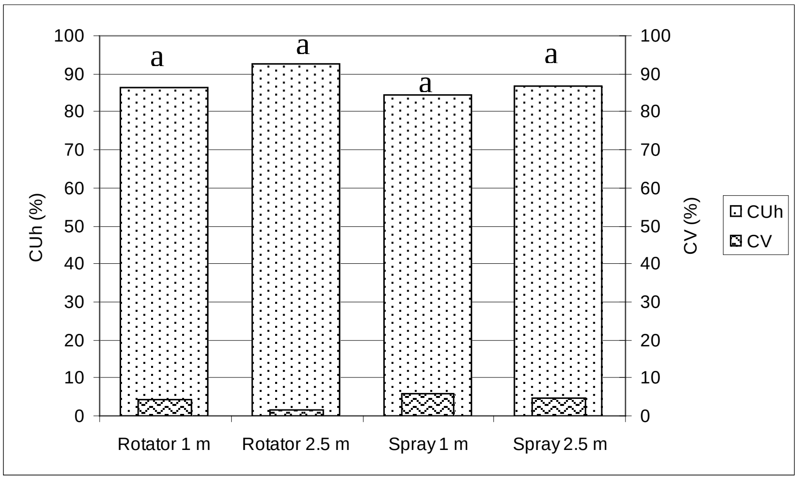


Figure 3. Trend of the uniformity coefficient (CUh) through the irrigation events tested.



Different letters indicate statistically significant differences ($p < 0.05$)

Figure 4. Average uniformity coefficient (CUh) and coefficient of variation (CV) in each sprinkler-height combination.

Considering the average of the accumulated uniformity coefficient (CUac), there is a remarkable improvement in comparison to individual irrigation events. So, CUac reaches values comprised between 89.9 % (Rotator 1 m) and 95.2 % (Rotator 2.5 m). The highest increase of the uniformity coefficient is shown in sprinklers Spray at 1 m and 2.5 m, with an average increase close to 7.2 %. On the other hand, the average increase of the uniformity coefficient, for sprinklers Rotator at 1 m and 2.5 m, is close to 3.5 %.

Soil water Regarding the trend of soil water content, it has been similar in each repetition of sprinkler-height combination. As an example for the eight sprinkler-height combinations studied, Fig. 5 shows the trend of soil water potential and soil moisture content for T IV.1 (Spray 2.5 m).

Considering soil water potential (Fig. 5a), the highest values of this parameter are shown in sensors located at 200 mm depth, which shows a lower soil moisture content than sensors located at 400 mm. It can be explained due to percolation losses of water, which happen below to 200 mm, and because the high root onion density is close to 250 mm. In addition, although there have been a high activity of sensors located at 200 mm and 400 mm, it has been higher in sensors located at 200 mm. This activity is well shown in Fig. 5a, mainly from the middle of July until the end of August, when sensors readings are remarkable. It is explained since in that period of time the plant has a high water demand, especially because is the period when the bulb is growing.

Regarding soil moisture content (Fig. 5b), the trend is very similar to soil water potential. So, the highest soil moisture content is shown in the deepest areas, comprised between 300 mm and 400 mm. In case of 100 mm and 200 mm depth, the soil moisture content is reduced.

As a result to be highlighted, the most of soil water potential sensors did not work right when the water potential reached values higher than 150 cbar, since the maximum value that it can register is about 200 cbar.

Comparing stretches with high and low MWD, such as T II.1 (Rotator 1 m) and T IV.1 (Spray 2.5 m), respectively, the soil moisture content is slightly higher in the first one. In fact, in T II.1, comparing with T IV.1, the increase of soil moisture content reaches values close to 3.3 %, 2.5 %, and 4.6 %, for 200 mm, 300 mm, and 400 mm, respectively. It might be related to the kind of texture in T II.1, which is clay texture from 0 to 200 mm depth and from 200 mm to 400 mm depth, and being clay-loam texture from 0 mm to 400 mm in T IV. 1. Moreover, in T II.1, the water retention capacity is about 1.63 mm cm^{-1} and 1.57 mm cm^{-1}, from 0 to 200 mm depth, and from 200 mm and 400 mm depth, respectively, which is a bit higher than the ones in T IV.1, about 1.49 mm cm^{-1} (0 to 200 mm depth), and 1.48 mm cm^{-1} (200 mm to 400 mm).

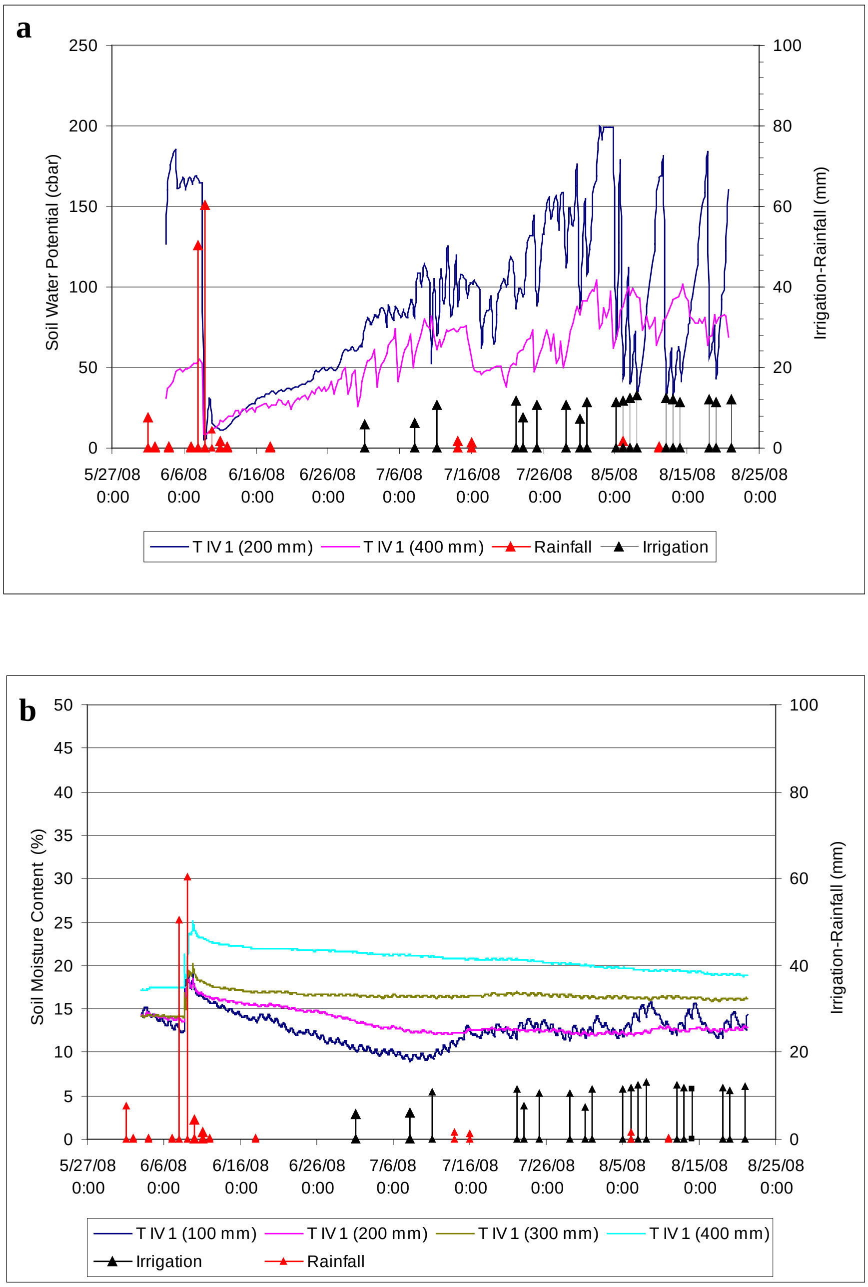
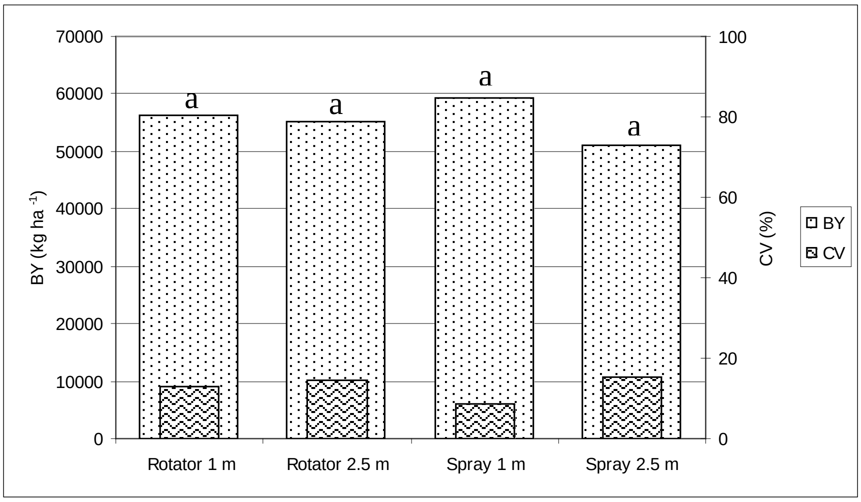


Figure 5. Soil water potential (a) and soil moisture content (b) trend during the irrigation season for T IV.1

Crop yield Regarding the mean values of bulb yield (BY), there have not been significant differences between the different sprinkler-height combinations (Fig. 6). Sprinkler Spray at 1 m shows the highest BY, close to 59000 kg ha^{-1}, a 17 % higher than Spray at 2.5 m, which is the sprinkler-height combination that has the lowest BY. In the rest of combinations (Rotator 1 m and Rotator 2.5 m) BY reaches values about 55000 kg ha^{-1}, approximately.

Comparing CUh with BY, Spray at 1 m is the combination which shows the highest BY and the lowest CUh (84.4%), meanwhile the lowest BY is reached in sprinkler Spray at 2.5 m, which has a CUh (86.9 %) slightly higher than the previous one.

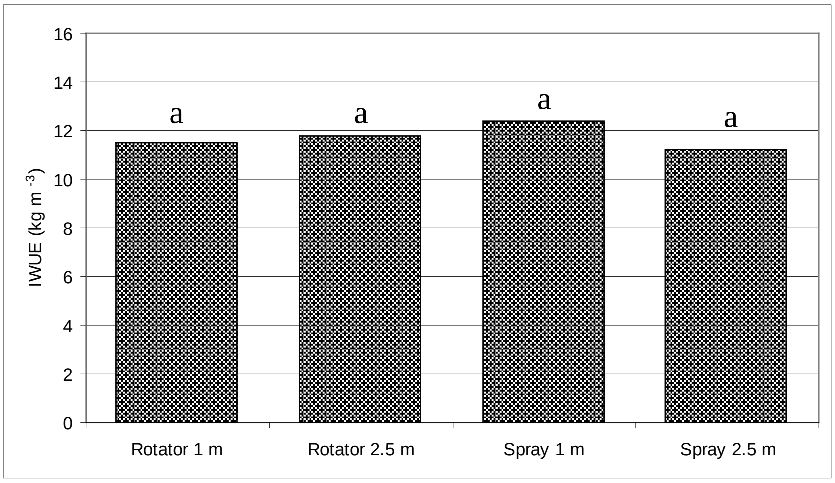


Different letters indicate statistically significant differences ($p < 0.05$)

Figure 6. Mean bulb yield (BY) and coefficient of variation (CV) in each sprinkler-height combination.

Considering irrigation water use efficiency (IWUE), estimated by dividing bulb yield (BY) and total water depth collected (TWC), some differences can be shown, although those are not statistically significant. The highest IWUE are shown in sprinkler Spray at 1 m height (12.32 kg m^{-3}) and sprinkler Rotator at 2.5 m (11.75 kg m^{-3}), which have the highest TWC (close to 480 mm) too. On the other hand, sprinkler Spray at 2.5 m shows the lowest IWUE (11.22 kg m^{-3}) and TWC (454 mm).

These values show that the final crop yield depends more on the total water applied than on water application uniformity with the different sprinkler-height combinations. It could be explained since there could be a high level of soil water uniformity respect to water application uniformity above the ground level.



Different letters indicate statistically significant differences ($p < 0.05$)

Figure 7. Irrigation water use efficiency (IWUE) in each sprinkler-height combination

CONCLUSION Regarding the different kind of sprinklers no significant differences have been found.

Considering one kind of sprinkler there is not significant differences comparing several heights above the ground level.

According to the results obtained, it is necessary to continue developing this work in the following years in order to characterize the water application process in a centre pivot.

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