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Impact assessment of drippers' distribution around the tree on soil moisture, roots and fruits growth of Citrus

A. Abouatallah[1], R. Salghi[1*], A. El Fadl[2], N. Affi[2], Y. Ghnizar[2], A. Zarrouk[3], B. Hammouti[3]

[1]Equipe de Génie de l'Environnement et de Biotechnologie, Ecole Nationale des Sciences Appliquées d'Agadir, Université Ibn Zohr, B.P 1136 Agadir, Morocco
[2]Institut Agronomique et Vétérinaire Hassan II, Complexe Horticole d'Ait melloul, BP 121 Ait Melloul, Morocco
[3] LCAE-URAC18, Faculté des Sciences, Université Mohammed I[er] B.P. 717, 60000 Oujda, Morocco.

ABSTRACT

In this study, we attempted to assess the effect of various drippers' distribution around the tree on soil moisture, salinity, flowering and fruit development. The trial focused on a 5 years old Clementine of 'Nules' grafted onto sour-orange under drip system on a clay loam soil. Four treatments (8 drippers per tree double lines, 6 drippers per tree double lines, 4 drippers per tree double lines and 4 drippers per tree single drip-line) were compared with control (2 drippers per tree on single line). The results show that the treatment with six drippers around the tree, gave the best distribution of fine roots and soil moisture, while moisturizing only the root zone without causing water losses, therefore a better water use efficiency. Treatments using eight drippers or four drippers per tree on single or double drip-line are more stressful so more favorable to flowering. Although, no effect is observed on fruit set and fruit drop. However, fruit size was higher in the double drip-lines treatments, especially in those with four or six drip emitters.

Keywords: Water saving, Dripper spacing, Soil moisture, roots distribution, Fruit size, Citrus.

INTRODUCTION

Drip irrigation has become widely adopted thanks to its great potential for improving water management by improving crop yield and quality using less water and localizing chemical applications, thereby enhancing the efficiency of irrigation and reducing the risk of pollution [1]; it's a necessary solution for horticultural crops in order to address the problems of water scarcity [2]. However, these objectives can only be achieved if the irrigation system is correctly designed (e.g. emitter discharge rate, emitter spacing, tape lateral spacing) and well managed (e.g. irrigation scheduling and fertilization strategy) for any given set of soil, crop and climatic conditions [3,4].

The extent of wetted soil volume under drip irrigation is a function of the emitter discharge and spacing but depends mainly on the soil type and the total water added [5]. The ability to estimate the dimensions of the wetting bulb i.e., water extending laterally and vertically away from an emitter is an important criterion for the design of drip systems to ensure efficient irrigation and to avoid the movement of water beyond the root zone [6,7,8,9].

Relatively little information is available on the spatial distribution of soil water under drip irrigation, and how it is affected by root distribution, emitter placement and irrigation amounts. It's clear that variables such as emitter position relative to the active roots as well will affect the soil water regime and the spatial changes in soil water content as controlled by root water uptake and leaching. A better understanding of these interrelationships will provide alternative means for proper and efficient drip irrigation water management practices [10]. The success of a localized irrigation system is possible if there is a good understanding of the infiltration phenomena and water distribution in the soil. Under drip irrigation, the water application frequency is high and water losses outside the root-zone generate poor efficiency of the irrigation system [11]; this means the infiltration period is a very important stage of the irrigation cycle and must be controlled [12]. During infiltration, the soil water content changes both spatially and temporally and redistribution of water in the soil is strongly dependent on the irrigation method, soil type, vegetation root distribution and rates of water application. Spatial variations in soil properties induce spatial variations in water distribution patterns between drippers [13], which arises problems for sensor placement in the field relative to drippers (or crop rows) and make the interpretations of data on soil water information difficult [14,13].

Moreover, understanding of soil moisture dynamics and root water uptake in root zone is important in selecting appropriate irrigation schedule to increase water use efficiency and crop yield [15]. But, Very few direct measurements of the water distribution under field conditions have been undertaken. Although some authors studied drip irrigation of a citrus orchard and measured the radial distribution of water potential from an emitter in the root zone of orange tree [16]; Higher available soil moisture was observed in drip irrigation plots compared to furrow irrigation in two soil depths of 0–15 cm and 15–30 cm [17,18]. In fact, Soil moisture status affects the growth, shape, structure, physiological function, and water uptake characteristics of crop root system as well as rootshoot ratio [19,20,21]. Thus, certain soil moisture would positively affect the increasing of root system [22], and the position of lateral root depended on the water content of different soil layers [23].

Moreover, maintaining high water content increases leaching and reduces soil oxygen levels which decrease plant growth [24,25,26]. However, partial soil wetting induced by low discharge point source emitters enables root growth in zones that are exposed to both high water content and oxygen supply [27,28]. Maintenance of high moisture in a portion of the root zone, minimizes drying and wetting fluctuations [29] and increases water flow and nutrient availability to roots [30,31,32]; in contrast, the asymmetry in spatial distribution of fine roots could be the consequence of multi-year deep percolation of applied water [33].

The rational management of drip irrigation needs a judicious combination of dripper spacing, discharge rate, irrigation duration, and the time interval between two successive irrigations [34,35]. The choice of dripper spacing depends on several factors such as discharge rate, crop, and soil hydraulic properties [36,37]. The typical dripper spacing is in the range of 0.15-1m [38,39].

In this experiment, we investigated the effect of different dripper spacing on wetted soil volume, root distribution and yield of citrus in order to optimize water supply. Several combinations of dripper spacing and number per tree were studied. The most used ones were chosen namely 2, 4, 6 and 8 drippers per tree.

MATERIALS AND METHODS

The experimental plot has an area of 10000 m² and domiciled at COPAG Cooperative located in Taroudant region on the left side of Oued Souss with the Lambert coordinates 157725E , 395675N and 243 m from the sea level. The trial was carried out on a 6 years old citrus orchard, clementine 'Nules' grafted onto sour-orange respecting the standard spacing of 5m between trees and 4 m between rows (*i.e.*; 500 trees/ha). The soil is loamy with 16% clay, 43,5% silt and 40,5% sand.

The plot is equipped with various instruments used for applied research and drip irrigation system. Each tree row has a single polyethylene pipe with integrated self compensating drippers that are placed at 80 cm from one to another on the pipe and their flow is about 3.5 l/hour at a pressure varying within the range of 1 to 4 bars. It's provided with a plug for closing not wanted drippers.

Considering the discharge rate and the variable number of drippers per tree, the flow per hectare will change as a result of a situation to another.

Experimental design

For our study, we adopted a completely randomized design (DCA), with five treatments and five replicates per treatment. Each experimental unit consists of a row of ten trees. (figure 1)

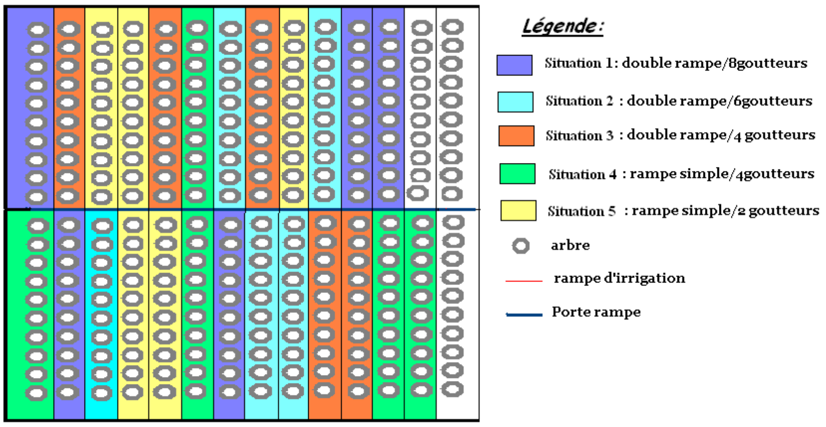


Figure 1. Experimental design adopted with the different situations corresponding to different number of drippers and drip-lines

Figure 2 Figure 2shows the arrangement of drippers around the tree and single or double drip-line situations. Table 1 shows the calculation of the hourly discharge for each situation.

Table 1. Details of drippers number per tree and hourly discharge for each situation

Irrigation situation (treatments)	Dripper number per tree	Discharge rate (l)	System discharge (mm/h)
1	8	3,5	1,4
2	6	3,5	1,05
3	4	3,5	0,7
4	4	3,5	0,7
5	2	4,0	0,4

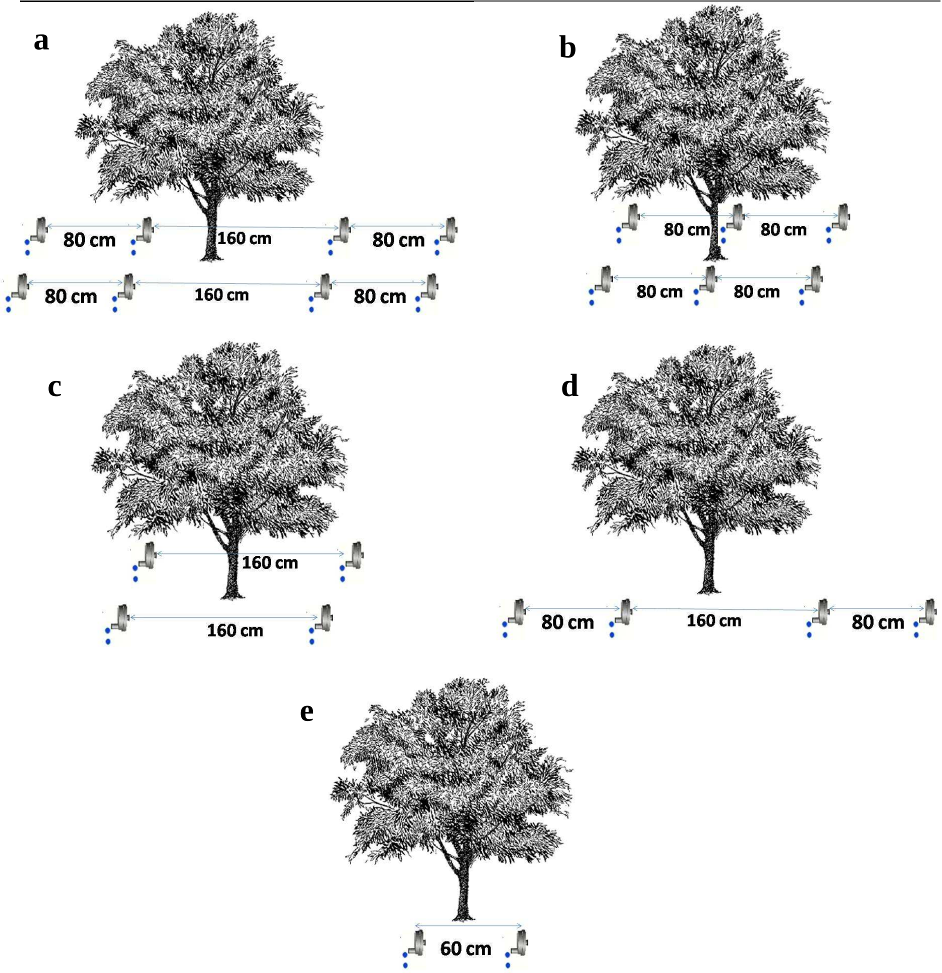


Figure 2. drippers arrangement around the tree: a. situation 1: double lines with 8 drippers/tree b. Situation 2: double lines with 6 drippers/tree c. Situation 3: double lines with 4 drippers/tree d. Situation 4: single line with 4 drippers/tree e. Situation 5 (control): single line with 2 drippers/tree.

Water supply was daily calculated according to evapotranspiration value (ETo) given by the weather station and using the Penman-Montheith formula [40]. Then, crop evapotranspiration (ETc) was estimated by introducing the crop coefficient Kc :

ETc (mm/day) = Kc x ETo (mm/day)

The crop coefficient (Kc) is function of the trees cover. In our case, we have a young orchard with a cover of 22.61%. Therefore, the adopted value for Kc was 0.4. Figure 3Figure 3 shows the variation of ETo, calculated according to the Penman formula and compared to the ETo used in the orchard.

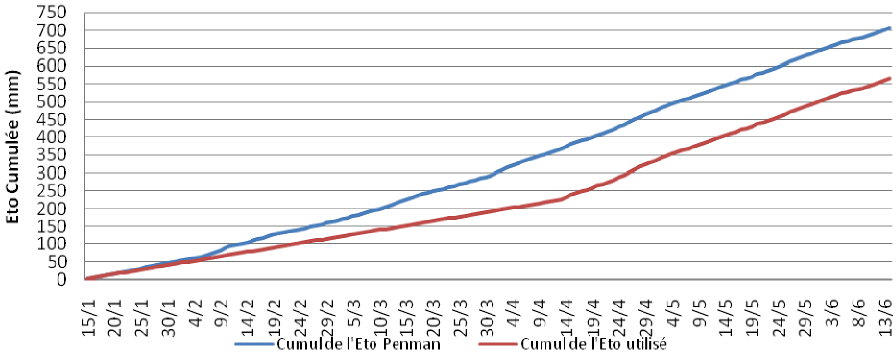


Figure 3 : Cumulative Penman-ETo used for irrigation purposes in the orchard during the experiment

Irrigation duration is determined by the formula:

Irrigation duration = ETM / hourly system discharge

Table 2 shows the irrigation time and the system discharge rate. The tested treatments are fractions of 0.57 n, 0.38 n and 0.28 n over n dose used by the control.

Table 2. Variation of the irrigation time and discharge rate of the system for each situation

Irrigation situation (treatments)	System discharge rate (mm/h)	Irrigation time
1	1,4	43 min (0,28 n)
2	1,05	58 min (0,38 n)
3	0,7	1h 26min (0,57 n)
4	0,7	1h 26min (0,57 n)
5 control	0,4	2h 30min (n)

In this way, the table 3 summarizes the applied irrigation program.

Table 3. Irrigation program used during the experimental period

Period	Penman ET_0 (mm)	Used ET_0 (mm)	Kc	Dose (mm)	Irrigation frequency	Penman Water volume		Used water volume	
						mm	l/tree	mm	l/tree
15-01 to 14-02	104,34	77,5	0,4	1	31	41,74	834,72	31	620
15-02 to 14-03	116,18	72,5	0,4	1	29	46,47	929,44	29	580
15-03 to 14-04	151,99	81,53	0,4	1,05	31	60,8	1215,92	32,61	652,24
15-04 to 14-05	173,39	173,39	0,4	2,31	30	69,36	1387,12	69,36	1387,12
15-05 to 15-06	160,6	160,6	0,4	2,07	31	64,24	1284,8	64,24	1284,8
Total	706,5	565,52	-	-	152	282,6	5652	226,21	4524,16

Measurements and observations

Characterization of soil water retention using Richards apparatus: soil sampling was done in the first 50 cm profile and samples were taken at intervals of 10 cm of depth. Metal cylinders of 4.2 cm in diameter and 4 cm in depth were used for *in situ* samplings. A single sample is the mixture of 6 samplings done at the same depth for each one of the four treatments. Laboratory analysis was undertaken in the Horticultural Complexes of Hassan II Institute.

Soil moisture: Wet bulb is determined by digging horizontal and vertical profiles. We determine fresh weight by collecting and weigh samples at 15 cm soil depth. Then simples will be dried at a temperature of 50°C during 48 hours to measure immediately dry weight.

Soil salinity: soil samples are taken by means of an auger at 30 cm distance from the emitter and different depths of 10, 30, 50 and 70 cm. The laboratory method adopted was 1/5 for measuring the electrical conductivity

Characterization of the root profile in the soil: it allows architectural visualization of the roots in the soil, in relation to the relative distance to the drippers and to the tree trunk. A square-shaped screen (1 m in each side) composed of elementary openings of 10 cm x 10 cm is placed against the vertical wall of the profile; roots located in each opening were counted after their classification according to their diameter (Ø < 1 mm ; 1≤ Ø < 3 mm ; Ø ≥ 3 mm).

Flowering and fruit development: To determine the flowering rate, fruit set and fruit drop, we selected randomly at the same height four branches at all tree's sides, where the number of flowers and number fruit set are counted. Fruit growth was determined by weekly measurements of four fruits diameter chosen from each side of the tree.

The MINITAB computer software was used for statistical analysis. Table 4Table 4Table 2 shows the statistical analysis method that was adopted for software treatment.

Table 4. Adopted analysis method of the variance

SDV	DDL	SCE	CM	F_{obs}
Situation	5	SCE_a	CM_a	$[CM_a/CM_r]$
Résiduelle	9	SCE_r	CM_r	
Total	14	SCE_t		

RESULTS AND DISCUSSION

Water retention curve or pF curve

Different curves are obtained in the same profile; this means that we have two different soil horizons. But the tendency is quite similar, so is the water transfer capability.

The humidity at wilting point (HPF) corresponding to pF=4.2 and determined graphically for different depths is about 24%. The humidity at field capacity (HCC) corresponding to pF=2.7 is about 34.38%, this is similar to the standards of a sandy loam soil. The reserve capacity (RU) is about 90 mm per meter of soil depth.

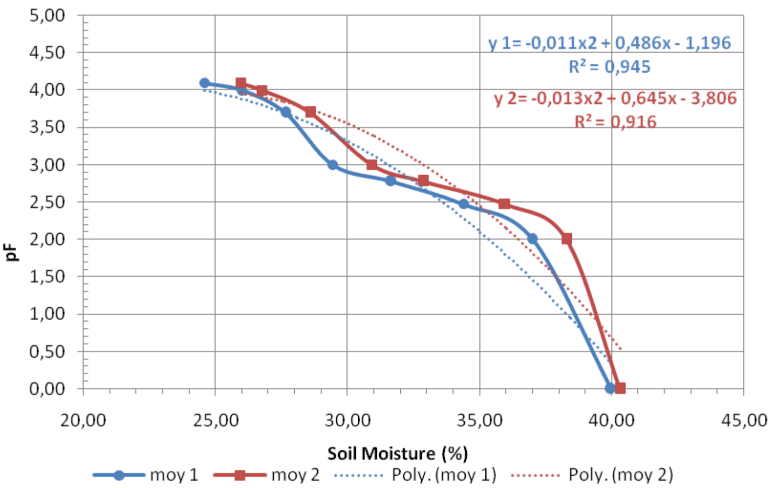


Figure 4. Water retention curve the two horizons of the soil

The soil characteristic points are summarized in table 5Table 5 :

Table 5. Soil characteristic points relatives to water at different depths

Profondeur	HCC (% pondéral)	HPFP (% pondéral)	Da	Porosité %
10	20,24	15,47	1,6	38,31
20	19,03	14,68	1,77	31,85
30	22,54	16,75	1,44	44,8
40	24,1	12,98	1,47	43,47
50	24,17	18,45	1,57	39,59
Moyenne	21,9	15,66	1,57	39,6

Soil moisture monitoring

Figure 5

Figure 5 shows the distribution of the five treatments soil moisture obtained by gravimetric analysis of soil samples before irrigation.

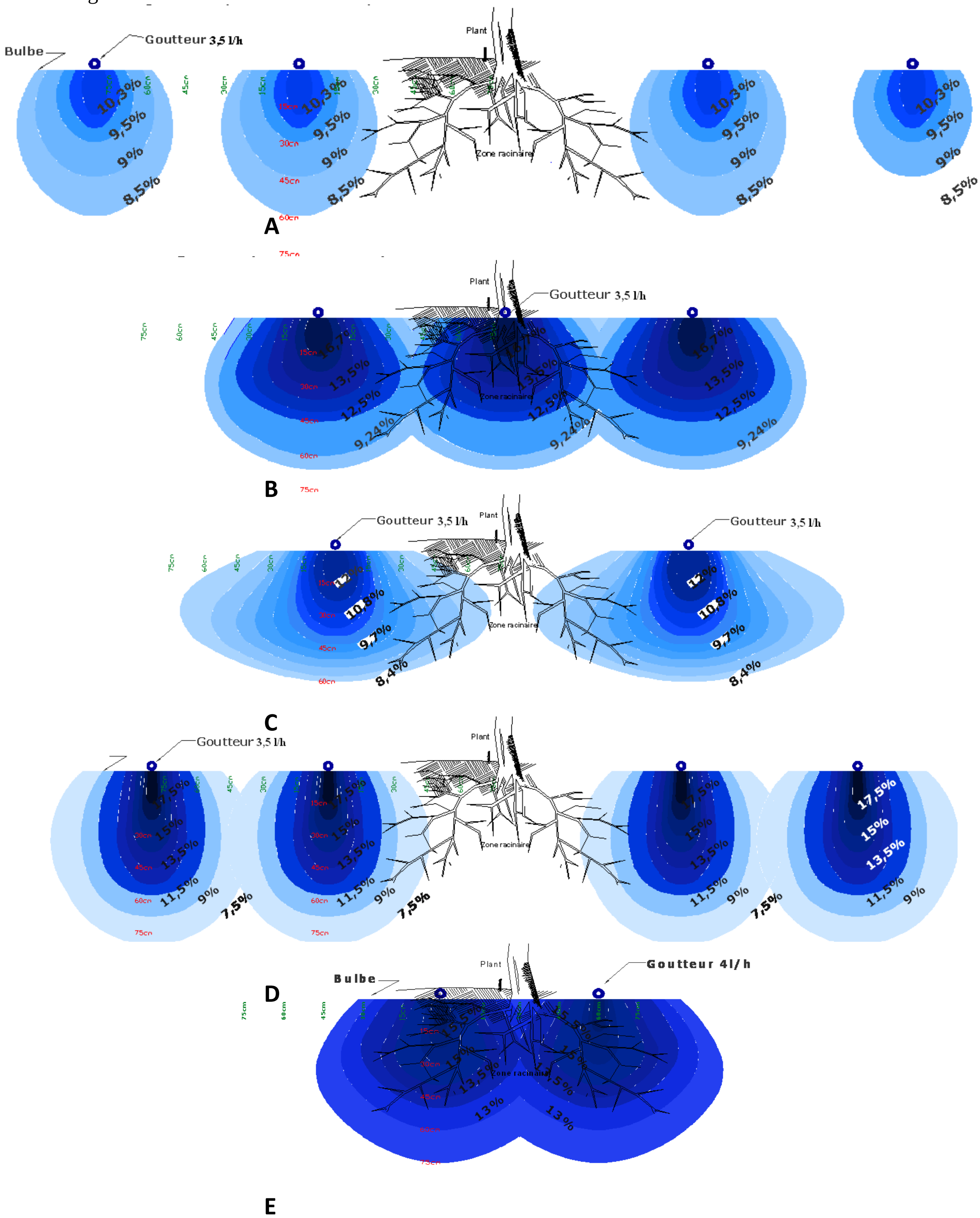


Figure 5. Visual representation of the soil wet bulb (A: 8 drippers per tree, discharge 3.5 l/h, double line, B: 6 drippers per tree, discharge 3.5 l/h, double line, C: 4 drippers per tree, discharge 3.5 l/h, double line, D: 4 drippers per tree, discharge 3.5 l/h, single line, E: 2 drippers per tree, discharge 4l/h, single line)

We note that water is well distributed laterally on Situation 1, but the soil moisture is rarely below 9% (HPF), the soil well irrigated part is the one between trees. In case of situation 2 and 3, while all soil moistures are ideal for roots growth, below 16% both horizontally and laterally well distributed, no infiltration below 60cm is observed. However, in situation 4, soil moisture is slightly higher under drip without exceeding the HCC, but moving towards the tree, soil is much drier with a slight water loss at 60 cm depth. Finally, a good lateral distribution of soil moisture is observed for the control, but with a very important water infiltration below 60cm depth.

Table 6. Wet bulb characteristics for all situations

Situation	Dripper number per tree	Bulb depth	Bulb diameter	Bulb volume (m^3/dripper)	Total bulb volume (m^3/tree)
1	8	0,55	0,64	0,47	3,77
2	6	0,63	0,64	0,54	3,24
3	4	0,55	0,64	0,47	1,89
4	4	0,70	0,64	0,60	2,40
5 Control	2	0,90	0,64	0,77	1,54

We note that the situation 1 gives a greater wetted volume over a very large area but not deep. On the other hand, the situation 2 has enough volume over a large area and enough deeper. Situations 3, 4 and the control gave lower wetted volumes.

Soil salinity

Salts have been accumulated in the first 30 cm depth (figure 6). The comparison between the different situations shows that the salinity increases when the wetted surface is larger, probably due to the fertigation technique, but remain below the tolerated level by citrus crop (1dS/m).

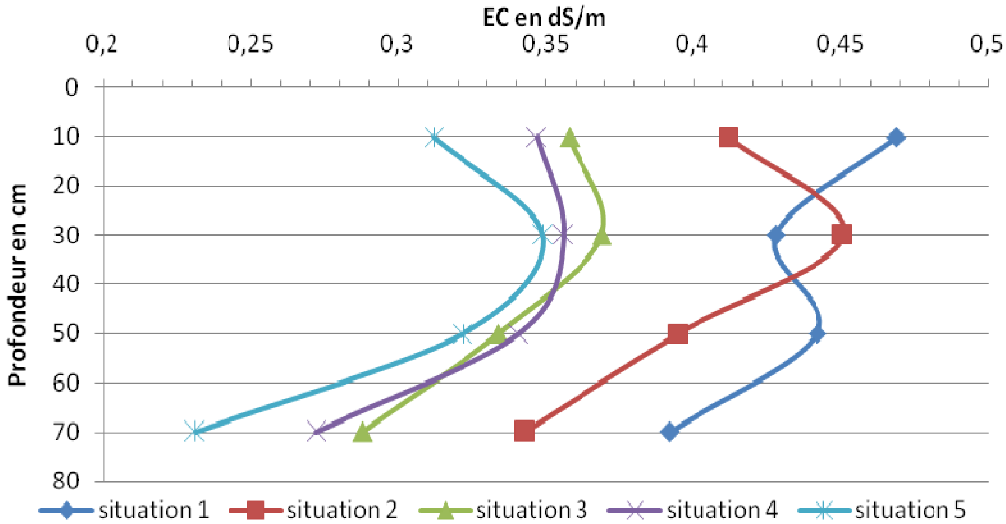


Figure 6. Salt profiles in the different situations

Root profiles

Figure 7Figure 7 shows that the number of roots in situations 2 and 4 was greater than the one in situations 1, 3 and 5. Thus, in situation 1, the roots are concentrated beyond 50cm depth because of of water research phenomenon. In contrast, roots are well distributed in situation 2 thanks to the homogeneity of the wet bulb. Situation 3 and 4 developed roots at a depth of 50 cm where soil moisture is enough sufficient closes to the wet bulb. But in the control (situation 5), roots are only present in the area around the drippers (figure 8).

The number of fine roots (less than 3 mm in diameter) is higher in the case of the situation 2 and 5 and concentrated in the area where soil moisture is around HCC, which confirms the results obtained by many authors [41].

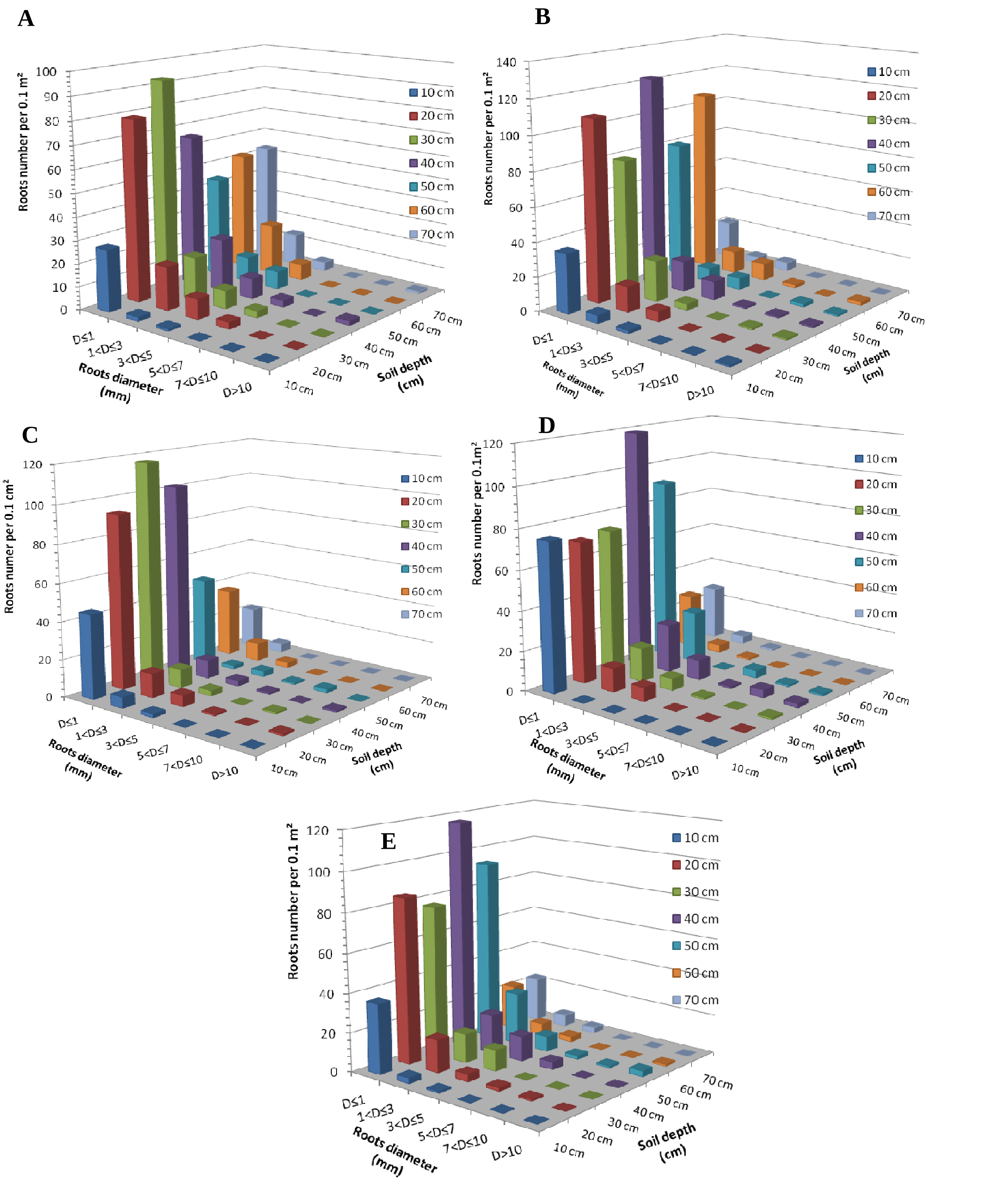


Figure 7. Total root's distribution around the tree (A: 8 drippers per tree, discharge 3.5 l/h, double line, B: 6 drippers per tree, discharge 3.5 l/h, double line, C: 4 drippers per tree, discharge 3.5 l/h, double line, D: 4 drippers per tree, discharge 3.5 l/h, single line, E: 2 drippers per tree, discharge 4l/h, single line)

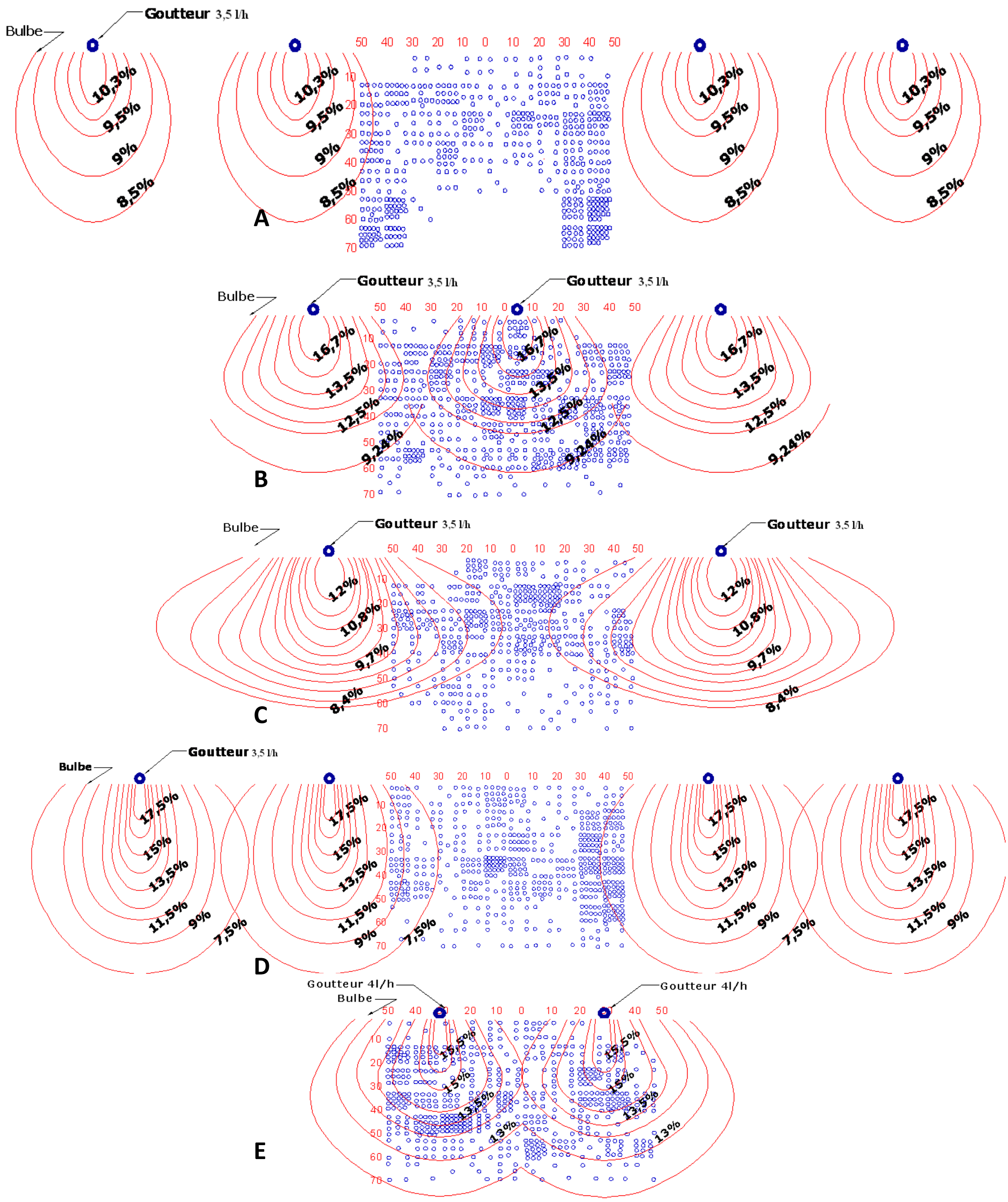


Figure 8. Fine root's distribution of 3 mm in diameter around the tree coupled to soil moisture (A: 8 drippers per tree, discharge 3.5 l/h, double line, B: 6 drippers per tree, discharge 3.5 l/h, double line, C: 4 drippers per tree, discharge 3.5 l/h, double line, D: 4 drippers per tree, discharge 3.5 l/h, single line, E: 2 drippers per tree, discharge 4l/h, single line)

Flowering
The statistical analysis of flowering on current year wood gave no significant difference. In contrast, it showed a very highly significant difference for the one on 2 years old wood (figure 8Figure 9). Densities of 8, 6 and 4 drippers induced more flowering rates, but they caused more water stress (old wood flowering). At last, less water stress in situation 2 and 5 is justified by the presence of the majority of the fine roots in the area with soil moisture closest to HCC (figure 9).

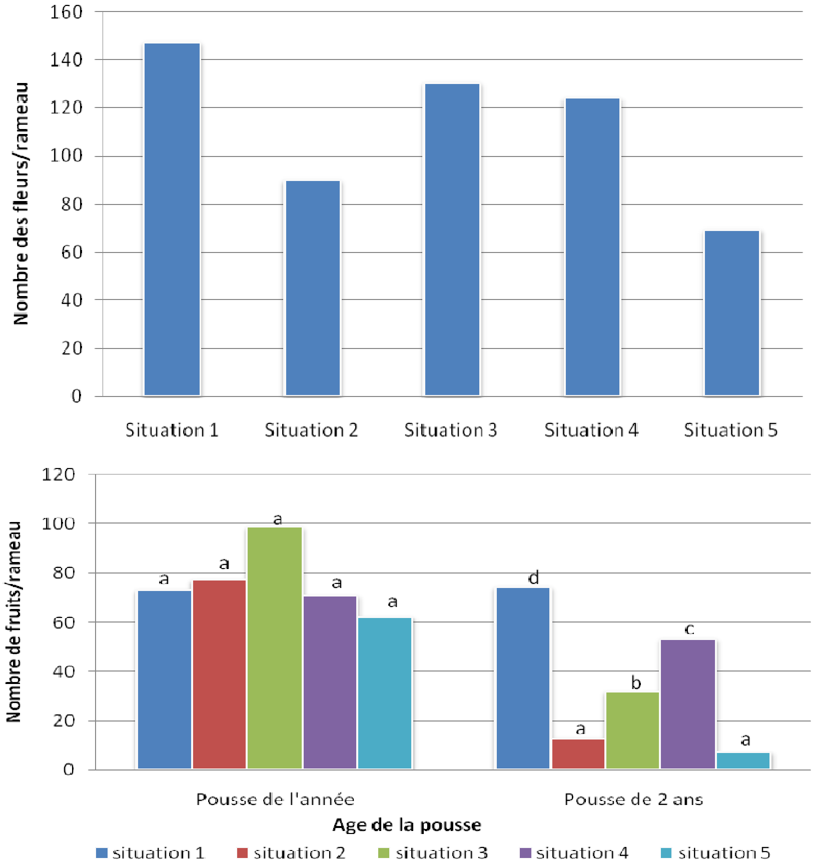
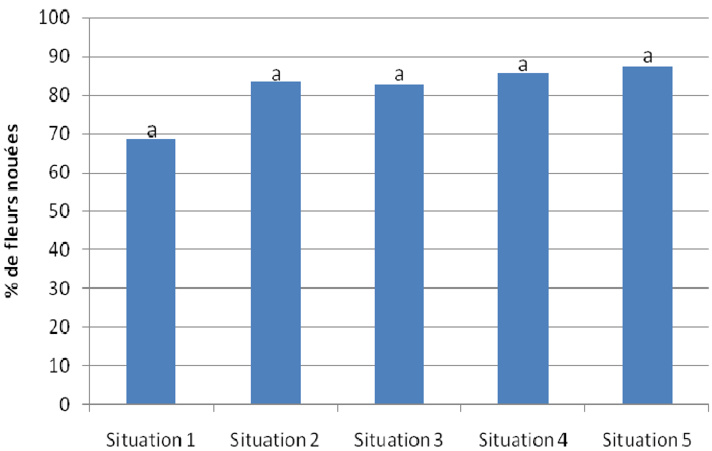


Figure 9. Total number of flowers per branch and age for the different studied situations

Fruit set
The fruit set rate was 80% higher on situations 2, 3, 4 and 5, 80%; however, the situation 1 shows the lowest one but without statistical significant difference (figure 10Figure 10).



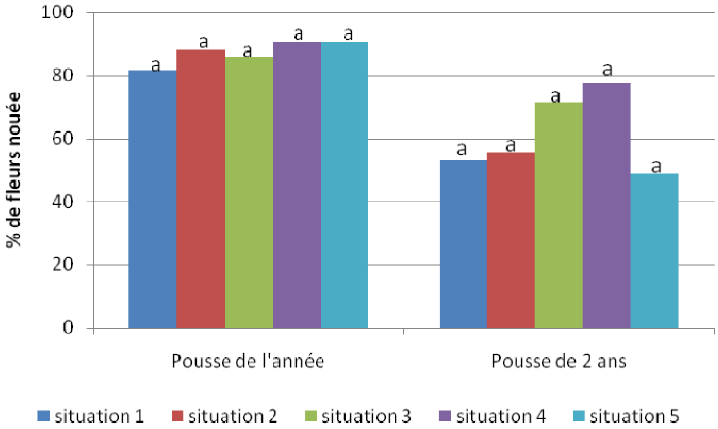


Figure 10. Fruit set rate per branch and age for the different studied situations

Fruit dropping

After statistical analysis, it seems that water regimes have no direct effect on fruit dropping, in fact high evaporating demand and temperature of April was behind the high fruit drop (figure 11).

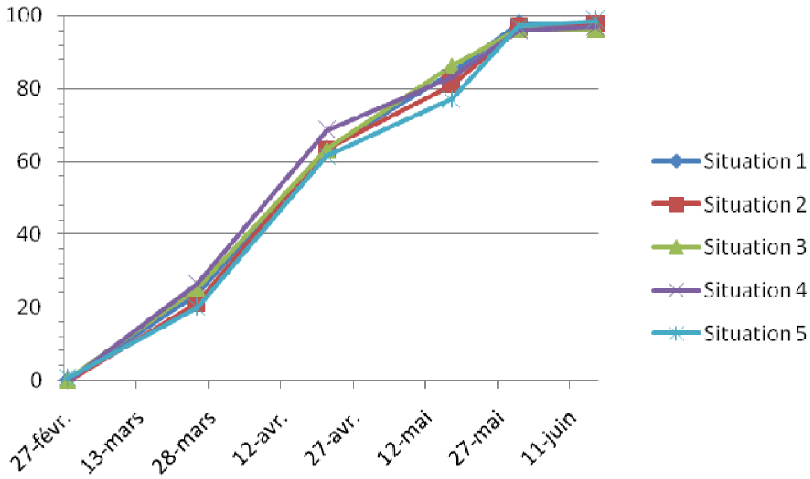


Figure 11. Fruit dropping rate for the different studied situations

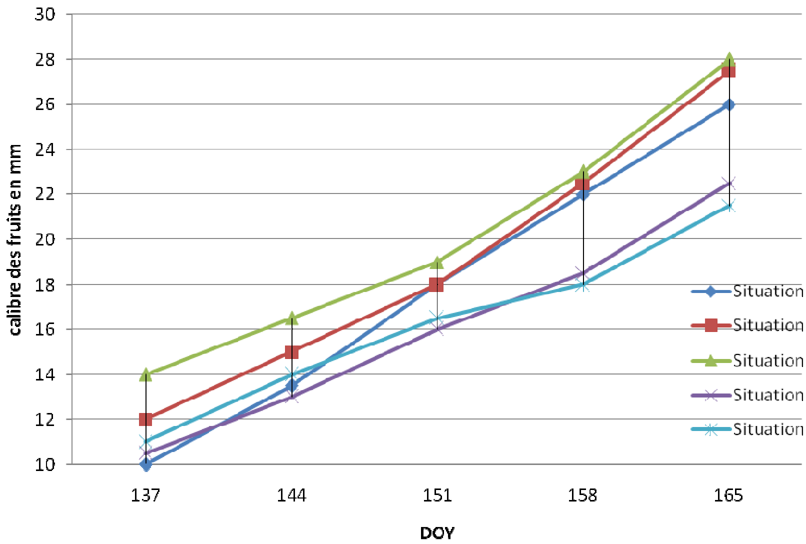


Figure 12. Fruit size growth on the different studied situations

Fruit size

The different distributions of the emitters around the tree showed a very significant effect, statistically proved, on fruit size growth which is higher in situation 1, 2 and 3 (figure 12). Moreover the double drip-line influences positively the fruit development. The best performances are obtained in the case of six drippers arranged on double lines; these results confirm the positive effects on plant growth obtained by many authors witch attribute it to near constant conditions in the root zone allowing plants to grow roots in areas with favorable water, nutrient or salt concentrations [42,43,44,45].

CONCLUSION

Dripper's distribution around the tree has a noticeable effect on the total flowering with a higher intensity on the 2 years old wood in the stressful situations. Fruit set and fruit drop were not affected by the different treatments. However, the double drip-line improves fruit size with strong performances in case of six drippers mounted on double line.

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