Influence of water deficit on growth and development of Valencia orange (*Citrus sinensis* Osbeck) fruits in the piedmont of Meta department, Colombia

Efecto del déficit hídrico en el crecimiento y desarrollo de frutos de naranja Valencia (*Citrus sinensis* Osbeck) en el piedemonte del Meta, Colombia

Diana Lucía Garzón Correa[1], Javier Enrique Vélez-Sánchez[1], and*
Javier Orlando Orduz Rodríguez[2]

[1]Department of Civil and Agricultural Engineering. Universidad Nacional de Colombia. -. Bogotá. Colombia. [2]Research Center La Libertad, Colombian Corporation of Agricultural Research (Corpoica), Villavicencio, Colombia. *Corresponding author: jevelezs@unal.edu.co

Rec.: 05.12.12 Acep.: 21.08.13

Abstract

In Colombia the area planted with citrus is marginal when compared to the potential area for cultivation, due to factors such as water deficit, nutrition and efficiency of fruit formation. The aim of this study was to evaluate the effect of water deficit by controlled application of water through soil profile in orange crop var. Valencia (*Citrus sinensis* Osbeck) in the foothills of Meta department, Colombia. The irrigation treatments (T) were: T1 = 100% of crop evapotranspiration (ETc); T2 = 50% ETc; T3 = control = 0% ETc. Irrigation was applied from the beginning of flowering in February to fruit formation in April 2011. The experimental design was completely randomized blocks with three replicates per treatment. The variables evaluated were: soil moisture (θg), plant water status (Ψstem), phenology, budding, flowering, formation, growth and fruit quality. The trees in the T1 had higher number and size of fruit, but no differences were found (P> 0.05) in yield and quality compared to the control, the θg and Ψstem were different (P <0.05) between treatments and the control showed reduced values 13.82% and -2.5 MPa, indicating moderate stress.

Key words: *Citrus sinensis* Osbeck, fruit, Meta - Colombia plant production, soil water deficit.

Resumen

En Colombia el área sembrada con cítricos es marginal, si se compara con el área potencial de cultivo, debido a factores como déficit de agua, nutrición y eficiencia de la formación de frutos. El objetivo del presente estudio fue evaluar el efecto del déficit hídrico mediante la aplicación controlada de láminas de riego en el cultivo de naranja Valencia (Citrus sinensis Osbeck) en el piedemonte del Meta (departamento del Meta, Colombia). Los tratamientos (T) de riego fueron: T1 = 100% de la evapotranspiración del cultivo (ETc); T2 = 50% ETc; T3 = testigo = 0% ETc. El riego se aplicó desde el inicio de la floración en febrero hasta la formación del fruto en abril de 2011. El diseño experimental fue bloques completamente al azar con tres repeticiones por tratamiento. Las variables evaluadas fueron: humedad del suelo (θg), estado hídrico de la planta (Ψtallo), fenología, brotación, floración, formación, crecimiento y calidad del fruto. Los árboles en el T1 presentaron un mayor número y tamaño de fruto, pero no se encontraron diferencias (P > 0.05) en producción y calidad respecto al testigo; la θg y el Ψtallo fueron diferentes ($P < 0.05$) entre tratamientos y el testigo mostró los menores valores, 13.82% y -2.5 MPa, lo cual indica un estrés moderado.

Palabras clave: *Citrus sinensis* Osbeck, déficit de humedad en el suelo, fruto, Meta - Colombia producción vegetal.

Introduction

Colombia has 62,409 ha grown in citrus form which 51,665 ha have monocultures and 10,743 ha are associated crops; from them, orange occupies 36,943 ha (59.2% of the total) with a production around 474,313 t and approximate yield of 15 t/ha (ENA, 2010). This fruit is grown in zones with diverse weather conditions; among them is the Meta piedmont where Valencia orange is abundant. This zone has some comparative advantages for the commercial cropping of orange that are associated to weather, soil and location close to the most important consumption center of the country. The soils are in high percentage class IV (265,000 ha) which are optimal for this crop (Roman and Owen, 1991), they are well drained, slightly acidic, with low organic matter content, low base saturation and medium aluminum saturation. In 2006 there were 4500 ha sown in citrus, from which 60% was orange, 20% tangerine, 15% acid lime and 5% tangelo (Orduz *et al*., 2009).

In tropical conditions, the main flowering inducing factor in citrus is the water stress, since it regulates the timing, intensity and distribution of flowering (Cassin *et al*., 1969; Reuther, 1973; Davenport, 1990). The flowering, budding and formation of fruits are the most significant changes in fruit tree phenology, being these the most critical and sensitive stages to weather conditions such as drought, humidity excess and extreme temperatures (Aubert and Lossois, 1972). With water deficit stem growth and root system ceases; additionally, depending on the stress intensity, leaf wilting and reduction in stomatal conductance, net assimilation of CO_2 and root conductivity could happen (Davies and Albrigo, 1994). During this period, vegetative buds develop their capacity to flower and in the induction process are included the events from transition from vegetative growth till inflorescence production (Davenport, 1990).

The piedmont of the department of Meta (Colombia) has a single mode rainfall regime, the rainy season comprises the months from March till November and the dry season is from December till end of February. In these conditions Arrayana tangerine has the main flowering season after a 90 days period of water stress and an accumulated water deficit of 247 mm (Orduz and Fisher, 2007).

The goal of irrigation in citrus is to keep the crop stable to get high yields and improve fruit quality, as well as, to minimize the negative effects caused by water stress. From the total area sown in the country with citrus, 42.8% is technicized and has a maximum yield of 40 t/ha and the other 57.2% corresponds to the traditional crop with yields around 15 t/ha. In the departments of Risaralda, Caldas, Quindio, Valle and Southwest of Antioquia is the largest technicized area (MADR, 2010).

Water present and available in the soil determines the water stress in the plant. Kramer (1989) found a direct relation between the water potential values in the leaves (Ψstem) and the volumetric water content of the soil (θv); thus, a long term decrease of plant water potential is affected by the soil water conditions. Lugo *et al.* (1996) found minimum values of potential of -2.42 MPa, equivalent to a moderate stress (Syvertsen, 1982; Southwick and Davenport, 1987). In several fruit species it has been evaluated the intensity of the stress by measuring the leaf water potential with the technique developed by Scholander *et al.* (1965), which has differences according to the time of the day in which the reading is done since it relies on the water vapor pressure deficit (VPD). The objective of this study was to determine the intensity of the water deficit and its effect on the growth and development of Valencia orange (*Citrus sinensis* Osbeck) by application of water lamina in crops of the department of Meta, Colombia.

Materials and methods

The study was done in 2011 in the Research Center La Libertad from Corpoica, Villavicencio (Department of Meta, Colombia), at 4° 03' N and 73° 29' w, 336 MASL, in a 12 years old Valencia orange crop, grafted on Cleopatra tangerine, sown at a distance of 8 x 6 m on 1 ha area. The soil corresponds to a high terrace (class IV) considered as optimal for citrus crops in the piedmont of Meta, topography is flat, slope varied between 1% and 3%, texture is clay sandy and organic matter levels varied between 2.5% and 3%. The average bulk density is 1.49 g/cm^3, field capacity and permanent wilting point are 27% and 12%, respectively, pH is 4.4, aluminum saturation is 71%, with good internal and external drainage and good effective depth.

To calculate the water balance it was taken into account the monthly average rainfall, effective precipitation, evaporation, evapotranspiration and Kc coefficient of the crop. Weather data were obtained from the meteorological station of IDEAM located at the research center La Libertad and the determination of the lamina to irrigate was based on the crop evapotranspiration (ETc) calculated with the following equation (FAO, 2006)

$$ETc = ETo \times kc$$

where, ETc is the evapotranspiration of the crop, ETo is the potential evapotranspiration of reference, Kc is the crop coefficient 0.75 for rainy months and 0.80 for dry months (FAO, 2006).

The treatments (T) were: T1: irrigation with 100% ETc; T2 = irrigation with 50% ETc; T3 = control without irrigation 0% ETc. the experimental design was completely randomized with three replicates per treatment and two sampling units per replicate, for a total of 18 trees. Irrigation was applied manually to each tree during flowering-fruit formation stage on a period of 56 days (February 18 – April 15).

Water status of the soil and the plant

Water content of the soil (θg) was determined gravimetrically after each irrigation, for that, nine altered samples at 10, 20 and 30 cm depth were taken from a representative tree per treatment.

To measure the plant water status the pressure bomb (Soil Moisture Equipment mod. 3000, USA) was used. The water potential of the stem (Ψstem) was measured at midday in two leaves covered 1h before with zip-lock plastic bags and covered with aluminum foil in six trees per treatment. The measurements were done weekly during the irrigation treatments.

Evaluation of the phenological behavior of the crop

To evaluate the effect of irrigation on the phenological behavior of the crop, measurements based on the BBCh scale (Agustí *et al.*, 1995), which specifically represents each phenological stage, both vegetative and reproductive, and allows the quantitative evaluation of the irrigation effect in each plant. To observe the new stages five branches per cardinal point were selected (20 branches per tree) in three trees per treatment.

Fruit growth

In May, 2011 were selected and labeled five fruits per cardinal point in three trees per treatment (180 fruits in total) to measure the equatorial diameter and fruit high each 15 days till harvesting (December, 2011). The measurements were performed with an electronic digital calibrator of 0.01mm precision. The graphs of fruit growth were adjusted by the following logistic equations:

$$y = \frac{a}{1 + be^{-cx}}$$

where, y is the response variable in function of x (time in days); a is the maximum value that can have y, when x tends to infinitive; be^{-cx} is a buffer factor, where b is an amplitude factor, e is the Euler's number and c is a stability factor.

Measurement of production

It was measured by counting and weighting the production of each tree. The quality analysis of the fruit, total soluble sugars °brix, titratable acidity, pH level and maturity index were made in five fruits per tree, in three trees per treatment, 2 months before harvesting (November 2). The growth analysis was done at the harvesting time in 180 fruits. The maturity index (IM) was defined as the ratio between the total sugars content (°brix) and the percentage of citric acid (%A).

Statistical analysis

The results were analyzed by coefficient of variation, standard error and Tukey's test and multiple range of Duncan ($P < 0.05$) using the SAS 9.2 software (SAS Institute Inc., 1994).

Results and discussion

Water balance

Between January and February 2011 water deficit happened but, with the beginning of the rainy season excess of water was presented. The lower rainfall (24.1 mm) happened in January and the highest (440.4 mm) in April (Figure 1), a different behavior to the normal weather that characterized this region with 3 months of water deficit. On the other hand, the previous precipitation in December 2010 (422.4 mm) was one of the highest recorded in the last 30 years, since the average for this month is normally 98 mm.

Irrigation was applied in 17.02.2011 and matched the appearance of the first buds after an extemporaneous precipitation till the beginning of the rain, in April. The water volume applied weekly varied between 763 y 298 l/week, equivalent to 223.5 and 111.8 mm for the T1 and T2 treatments. During this period rainfall contributed with 175.3 mm. In Table 1 is presented the amount of added water, equivalent to a daily lamina of 3.92 and 1.96 mm in treat-

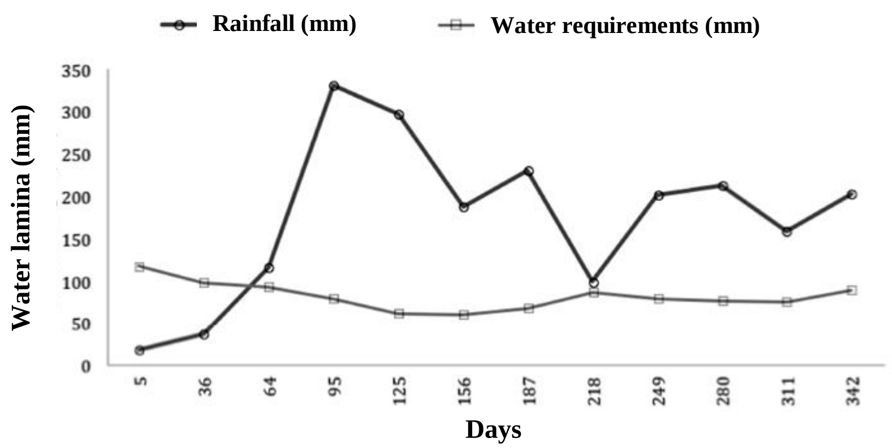

Figure 1. Water balance of Valencia orange crop and volume of water added. C.I. La Libertad. 2011. Department of Meta, Colombia.

ments T1 and T2 being the rainfall 3.08 mm, which agrees with the water lamina proposed in the experiment. The reduction of irrigation represented an annual saving of 111.7 mm, equivalent to a relative saving of 50%.

Water relations

As expected, gravimetric water (θg) showed differences (P < 0.05) between the T1 treatment and the control with lower values (13.82%) during the water deficit days. In the treatments T1 and T2 the average value for θg was 22.21% and 20.52%, respectively, reaching the higher values at day 88 (25.98% y 22.76%), values that are close to the maximum holding capacity of the soil (27%) and similar to the water content found by Vélez *et al.* (2007). Orange trees in the control treatment deployed, in average, 64% of the soil water reserve, although this was recovered with rainfall.

The θg value did not varied between T1 and T2 in the three studied soil depths but, it did varied for the control treatment at 20 and 30 cm depth because at these depths the sand content is higher, occurring more infiltration (Table 2). After day 90, when the rainfall was 79 mm, the soil humidity for the three treatments did not show differences (P > 0.05) (Figure 2).

The Ψstem value for T1 treatment changed between -0.51 y -1.61 MPa, values that are similar to the ones suggested by García *et al.* (2010) for well hydrated orange trees var. Navelina. With water deficit, as expected, the Ψstem tended to decrease in the control treatment. The lowest value, -2.5 MPa, was presented in day 76 (17-03-

Table 1. Precipitation (P), applied water to the T1 and T2 treatments and evapotranspiration of the crop (ETc) of Valencia orange, department of Meta, Colombia.

Period	P (mm)	T1 (mm)	T2 (mm)	ETc (mm)
18-21 February	4.2	17.5	8.7	21.7
22-25 February	0.8	17.5	8.7	18.3
26-01 February-March	13.0	17.5	8.7	30.5
02-06 March	2.0	20.0	10.0	22.0
07-10 March	9.0	16.0	8.0	25.0
11-14 March	3.0	16.0	8.0	19.0
15-18 March	1.2	16.0	8.0	17.0
19-22 March	34.0	16.0	8.0	50.0
23-26 March	41.7	16.0	8.0	56.0
27-31 March	0.0	20.0	10.0	20.0
01-04 April	0.0	13.6	6.8	14.0
05-09 April	32.0	17.0	8.5	47.0
10-15 April	34.4	20.5	10.2	55.0
Total	175.3	223.5	111.8	395.5

Table 2. Values of soil water -θg in the day 84 and coefficients of variation (CV) for each treatment and depth. Department of Meta, Colombia.

Treatment (depth, cm)	T1 (θ_g %)	CV	T2 (θ_g %)	CV	Control (θ_g %)	CV
10	21.91a	4.77	19.86a	3.95	18.14 a*	5.32
20	20.66a	3.95	19.68a	1.95	16.93 b	3.56
30	22.08a	5.08	20.77a	3.80	16.5 b	3.53

* Values in the same column with equal letters do not differ significantly, according to Duncan's test (P > 0.05).

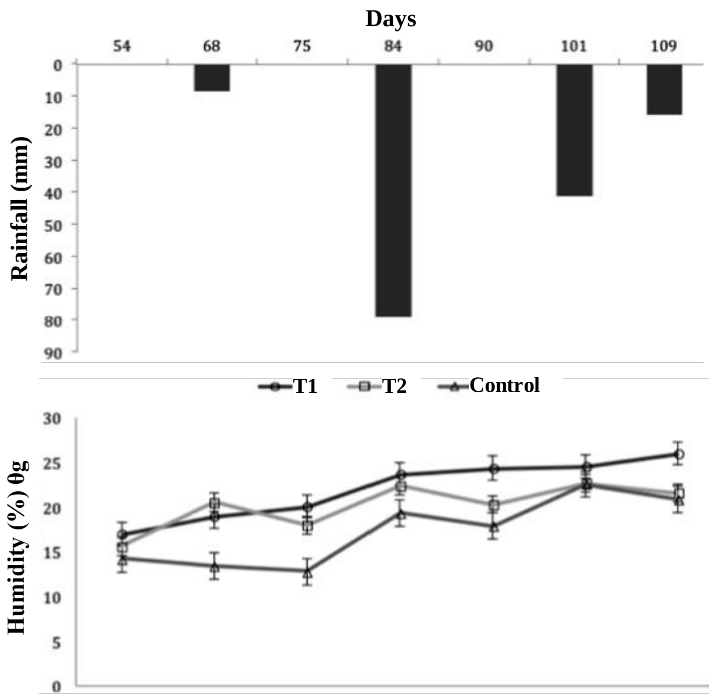

Figure 2. Rainfall and soil water (θg%), at 0.3 m depth. Department of Meta, Colombia.

2011) when the highest temperature was recorded (33.2 °C) and the lowest relative humidity (72.5%), which caused differences between the treatments (P < 0.05). The days 82 (23-03-2011) and 96 (06-04-2011) differences were found (P < 0.05) between the control and the T1 and T2 treatments (Figure 3).

The highest Ψstem was observed in T1, which evidence the influence of the added water for each treatment and the precipitation, since in days 68, 84 and 104, when rainfall was 8.5, 34.6 and 13 mm, respectively; the Ψstem values were practically equal, showing the fast dehydration of the trees after rain, although the difference against the control stayed. Dell'Amico *et al.* (2011) in the Southeast of Spain working with tangerine cv. Fortune that were subjected to a drought cycle during the rapid fruit growth phase, till getting a Ψstem value of -2.5 MPa at midday, found similar results to the ones of this study, being this one an indicator of the differences favoring the well irrigated plants.

Plant phenology

Flowering started between the days 62 and 69, two weeks after 26 mm precipitation happened (17-02-2011), followed by 4 weeks of dry period, which allows a fast response to water by the plants, which started to show vegetative buds and flowering (Table 3). Irrigation helped a higher number of fruits in formation on the trees (between parenthesis) in the (114) and T2 (97) treatments in comparison to the control (41), in which the moderate stress increase the abscission and provoke fruits falling in comparison to T1 and T2 treatments (P < 0.05) (Figure 4).

The vegetative development of the plants was not different between treatments (P > 0.05). Davies and Albrigo (1994) indicate that under tropical conditions, were drought periods are presented, irrigation could improve the yield inclusively in high precipitation regions. A water deficit affects negatively vegetative growth (Quiñones *et al.*, 2007; García-Sánchez *et al.*, 2003; Or-

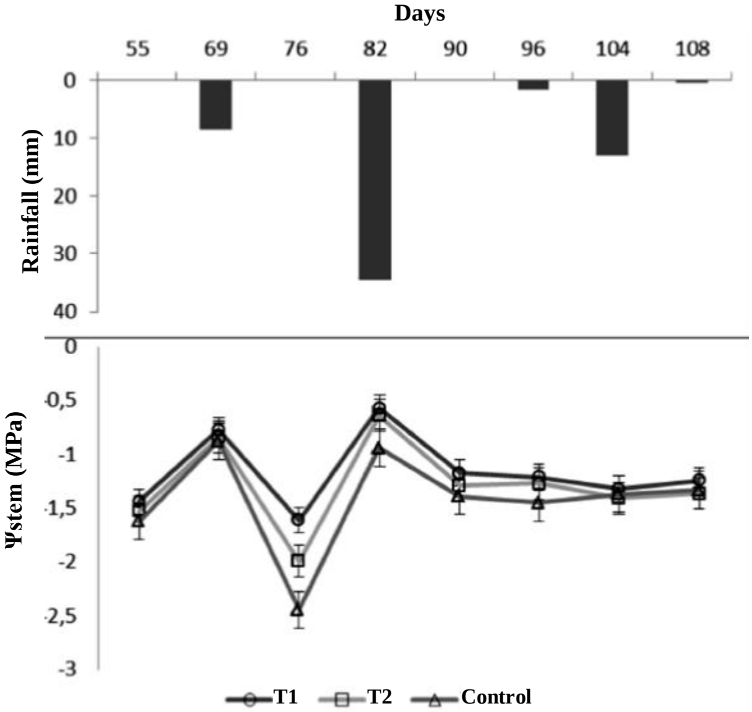

Figure 3. Changes in the stem water status (Ψstem) and precipitation in the place of the study. Department of Meta, Colombia.

Table 3. Multiple test of Duncan's test for the number of observations in twenty branches per tree in six trees per treatment. Department of Meta, Colombia.

Treatment	Green bud	White bud	Open flower	Small fruits
Control 1	388.67a	311a	280.67a	114 a*
Control 2	379.00a	320.7a	264.67a	97 a
Control 3	385.33a	316a	294.00a	41 b

* Values in the same column with equal letters do not differ significantly, according to Duncan's test (P > 0.05).

tuño *et al.*, 2004), this effect depends on the intensity and duration of the drought occurring in the crop cycle (Ballester *et al.*, 2011).

Fruit production and quality

The fruit production did not show differences between treatments (P > 0.05) because the orange plants are still capable of having acceptable yield when, the water stress levels in the first phase of fruit growth are not extremely severe, before a water supply happens, as occurred in this study. The highest production and the highest number of fruits per tree was observed in T1 treatment, although it was not significant (P > 0.05), which shows the effect of competence between the fruit weight and their number per tree, independently of the water stress (Agustí *et al.*, 2003) (Table 4). Valencia orange, established at a density of 208 tress/ha presented a stable production, being 20.5 t/ha for the control treatments and 27 t/ha for T1 treatment.

Fruit growth

One month after fruit setting, the diameter of the fruits was 29.43 mm in T1 treatment

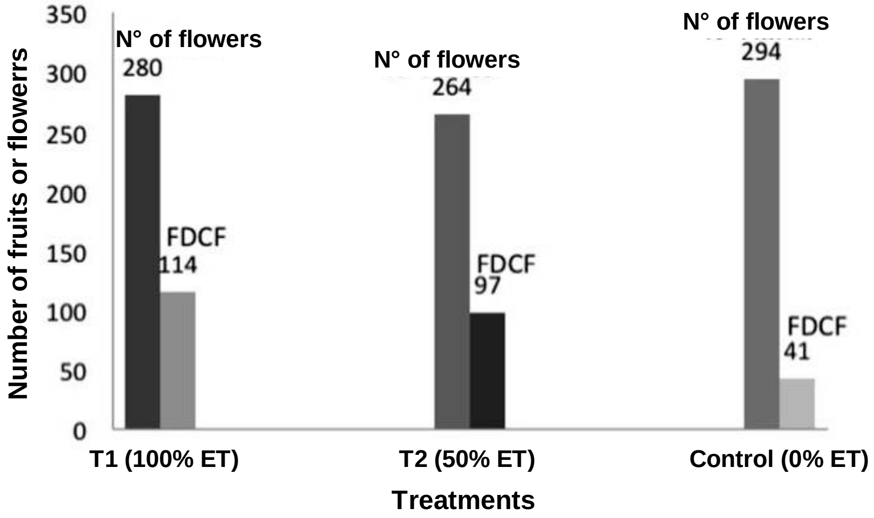

Figura 4. Average number of flowers and fruits after final fruit set (FDCF). Average of fruits in 20 branches per tree in six trees per treatment. Departament of Meta, Colombia

Table 4. Number of fruits and average production per tree. Department of Meta, Colombia

Treatment	N° of fruits	CV (%)	Production (kg)	CV (%)
T1	644a	27.84	128.81a	7.89
T2	435a	43.58	108.51a	13.48
Control	378a	18.78	98.29a	12.52

Averages of six trees/treatment.

* Values in the same column with equal letters do not differ significantly, according to Duncan's test (P > 0.05).

and 33.17 mm in T2 treatment. At the harvesting time the diameters were 66.98 mm (T1) and 72.77 mm (T2) (Figure 5), values that are similar to the ones found by Tejacal *et al.* (2009) for the same Valencia orange variety used in this study.

Although there are no differences between fruit diameters (P > 0.05), the smallest ones were in T2 and control treatments versus the ones of T1 treatment (Figure 5). This could be the result of the water deficit presented in February during the initial phases of fruit formation and growth, which is a critical period for cell division, pericarp thickness increase and formation of juice sacs. According to Vélez *et al.* (2007) the citrus accumulate dry matter during the water stress periods that is used for compensatory growth in irrigation or rainy season.

The model that best describes the fruit equatorial diameter behavior in function to the days after flowering for T1 treatment was the following:

$$y = \frac{71.74}{1 + 4.37^{-0.018x}} \qquad R = 0.93$$

The average fruit weight at harvesting time in December 2011 was 227 g; the juice percentage was 54.4%, similar to 57% found in Valencia orange (Sánchez *et al.*, 1987); the volume was 259.7 cm^3 (P > 0.05). In Carabobo, Venezuela, Laborem *et al.* (1993) found an average weight between 237.3 g and 44.81% of fruit juice in Valencia oranges on a rootstock of Cleopatra tangerine, similar values to the ones presented in this study (Table 5).

Fruit quality

The evolution of the total soluble solids (SST), the percentage of citric acid and maturity index from the week 28 till 40 (Table 5) did not show any differences (P > 0.05), possibly due to the fact that in the stages 2 and 3 of fruit development there was no water deficit. From the week 28 after anthesis was finished till the moment of harvesting, the SST increased and the percentage of citric acid decrease for the T1, T2 and control treatments. The percentages of citric acid (0.99) were similar to the ones found by Russian (2006) for Valencia orange on Cleopatra tangerine (1.06) at the harvesting time. The maturity index for the fruits in T1 increased and by week 36 they were suitable for consumption.

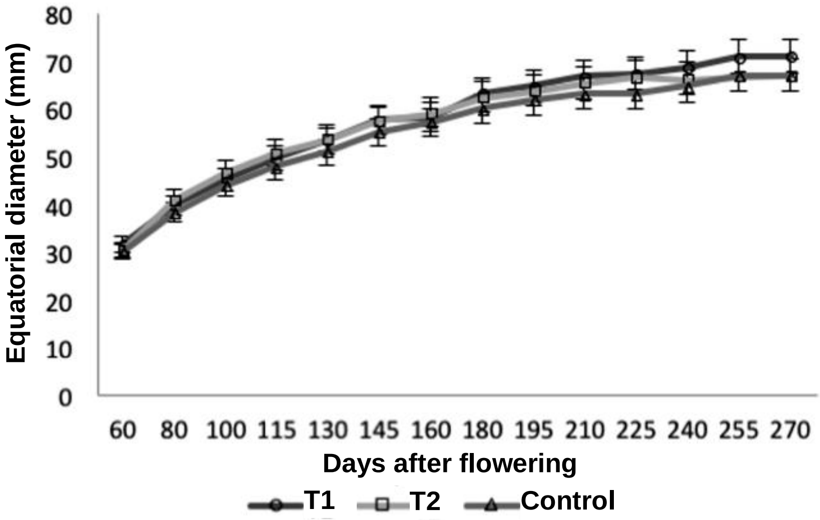

Figure 5. Equatorial diameter of the fruit during growth for the T1, T2 and control treatments. Departament of Meta, Colombia.

Table 5. Physico-chemical characteristics of Valencia oranges fruits with different treatments. Department of Meta, Colombia.

Week	Treatment	Juice (%)	°Brix	pH	Fruit volume (cm³)	Citric acid (%)	Maturity index
28	T1	45.74	7.80	2.81	197.17	1.74	4.48
	T2	48.55	7.97	2.88	191.19	1.65	5.05
	Control	47.99	8.30	2.89	181.79	1.53	5.44
32	T1	46.71	8.80	3.18	208.00	1.23	7.25
	T2	47.93	8.83	3.28	211.30	1.12	7.95
	Control	44.56	9.27	3.25	233.40	1.16	8.20
36	T1	52.00	8.80	3.21	244.54	1.17	9.67
	T2	48.38	9.13	3.25	235.58	1.11	8.33
	Control	49.22	9.07	3.18	244.82	1.17	8.01
40	T1	54.94	10.65	3.46	249.16	0.98	10.86
	T2	52.21	10.08	3.57	259.69	0.91	10.97
	Control	56.08	10.70	3.51	256.97	0.99	10.08

The acid and sugar contents slightly increase in the control treatment, since the excess of water at the maturity stage can reduce the total soluble solids content and the acidity due to dilution, reducing the internal quality of the fruit. The opposite, a moderated water deficit during fruit ripening can increase the content of total soluble solids and acids (Vélez *et al.*, 2007). These results agree with the ones found by Laborem *et al.* (1993) when studying fruit quality of Valencia orange on Cleopatra tangerine.

General considerations

The fact that the plants in T1, T2 and control treatments showed clear differences in leaf turgor at the beginning of the experiment when rainfall was scarce (Figure 3), indicates that during the drought periods the available water did not fulfilled the water crop requirements. The fast recovery of the stem water potential recorded for T2 and control treatments, when the water supply increased by rainfall, has been observed with frequency in other wooden fruit trees exposed to moderate and severe stress (Torrecillas *et al.*, 1996; Ruiz-Sánchez *et al.*, 1997; Ortuño *et al.*, 2006). Torrecillas *et al.* (1995) considered that the behavior of the stomatal conductance on moderate water stress is directly controlled by a hydroactive mechanism. Ruiz-Sánchez *et al.* (1997) working with severe stress in lime crop, concluded that such levels affect the recovery and other aspects of primary and secondary metabolism of the plant.

In this study, the behavior of the total fruit yield shows that the stress imposed by T2 treatment and the control did not reach the level to affect this parameter. For this reason, it can be considered that the plants in these treatments had a moderate stress level between the days 69 and 82; to the contrary, with the intense precipitation of day 82, all the plants, including those without irrigation (control), were completely recovered. This indicates that when the plants are under moderate stress and a suitable amount of water is applied that satisfies the hydric demand, they can recover without affecting the fruit productivity and quality.

The fact that the Valencia orange fruits of the stressed plants showed similar characteristics on the internal and external quality in comparison to the treatment with abundant water (T1), matches the obtained results in other wooden fruit species. Mellisho *et al.* (2012) in pomegranate (*Punica granatum* L.) observed a similar behavior to the one found in this study under moderate water stress, whereas in severe water stress situations the fruit yield and quality is affected. Horner (1990) considered that moderate water stress can lead to plant growth reduction and increasing concentration of non-nitrogen secondary metabolites; however, when water tension is increased in the stomata there is a reduction in CO_2 assimilation and the plant prioritize the synthesis of primary metabolites together with fruit growth. These considerations explain, in part, the observed results in T2 and control treatments of this experiment.

It is important to insist that during the water deficit estate, most of the fruits act as carbon reserve (photosynthates) that are available when the irrigation is starts again, promoting higher fruit growing indexes (Cohen and Goell, 1984; Mills *et al.*, 1996; Caspari *et al.*, 1994). In this study, the fruit growing index was observed in T1 and T2 treatments when the rainfall compensate this demand

Conclusions

- The results of this study showed that during the different stages of Valencia orange fruit growth and development in the studied conditions, a moderate stress in the first stages of fruit growth can be supplied with rainfall on the following phases, without affecting quality and production.

- The stem water potential clearly indicated the plant behavior at the applied water levels, showing in the control that this variety has a fast recovery under suitable water supply conditions. Although the stress phase (phase I) did not affect the fruit equatorial diameter, it affected the final development.
- Water stress did not significantly affect the trees productivity in the studied treatments but, an increase in flower abortion of the plants with less water lamina was observed.
- The average of the obtained yield and quality of orange fruits allows the consideration that the Valencia variety (*Citrus sinensis* Osbeck) presents acceptable production levels in the conditions of the piedmont in Meta, Colombia.

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