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CROP PRODUCTION

Water use efficiency of different production techniques for zucchini

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ABSTRACT. The effects of pulse drip, drip line position and soil mulch on water use efficiency in yields of zucchini cv. Clarinda were evaluated. The experiment was conducted in the experimental area of the Engineering Department of the Federal University of Lavras, Lavras, Minas Gerais State, Brazil, for two years. For the first year of the experiment, the experimental design was a randomized block design with a 2 x 2 x 2 factorial design (continuous and pulse drip irrigation, surface and subsurface dripping, with and without plastic mulch), with four replications. For the second year of the experiment, the design was completely randomized in a 2 x 2 x 2 factorial design with eight treatments and five replications. In relation to the position of the drip line, the subsurface drip line was installed at a 0.15-m depth, and the soil mulch was made with double-sided plastic (white/black). The results indicated that pulse drip irrigation did not affect the yield of zucchini and that soil mulch increased the yield and water use efficiency. In terms of the drip line position, the subsurface drip line increased the yield in the first year, but it had no effect on water use efficiency.

Keywords: plastic mulch; drip pulse irrigation; subsurface drip; irrigated horticulture.

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Introduction

Techniques that increase the yield and quality of crops while sustainably using resources, especially water resources, are increasingly desirable due to the frequent occurrence of water crises. It is estimated that irrigated agriculture is responsible for 40% of the production of all food consumed in the world (Paulino, Folegatti, Zolin, Sánchez-Román, & José, 2011); however, it requires the most water. Therefore, it is necessary to search for methods that can optimize water use to reduce water consumption in irrigated agriculture without damaging crop yields.

A reduction in the applied water volume is beneficial to preserving its availability for consumption and to reduce production costs and leaching of nutrients and pesticides into groundwater (Campagnol, Abrahão, Mello, Oviedo, & Minami, 2014). Water use efficiency (WUE) is the ratio between the amount of agricultural production per area and the volume of water used to obtain t the crop. Therefore, to reach a maximum yield, it is necessary to reduce the amount of applied water without significantly decreasing the yield or increasing the production by area using the same amount of irrigated water (Campagnol et al., 2014). Thus, the estimated yield should be obtained by economically optimal irrigation depth applications, to achieve a greater WUE by plants.

The pulse drip technique consists of a series of cycles where each cycle consists of an irrigation phase and a rest phase so as not to dry the humid bulb formed in the soil, and this technique has been studied in some cultures in different regions of the world, such as for the potato in Egypt (Abdelraouf, Abou-Hussein, Refaie, & El-Metwally, 2012), for soybeans in Egypt (Eid, Bakry, & Taha, 2013), for tomatoes in Saudi Arabia (Elnesr, Alazba, El-Abedein, & El-Adl, 2015) and for crisphead lettuce in Brazil (Almeida, Lima, & Pereira, 2015). In these studies, positive effects were observed in terms of increasing yields, quality improvement of products, and water use savings, among others.

Another technique that provides an important contribution to food production is soil mulch, which is mainly used to control invasive plants and reduce water losses through evaporation. Soil mulch also allows the harvesting of the fully clean fruits, facilitating and optimizing the harvest, and commercializing the process, while vegetables harvested in soil without mulch need to undergo a cleaning process (Olinik, Oliveira Junior, Keep, & Reghin, 2011). However, when mulching the soil, important microclimate parameters are altered, such as soil temperature (Ribas, Streck, Silva, Rocha, & Langner, 2015), which influences evaporation and growth of microorganisms, which directly influence water consumption and crop growth and development.

Zucchini has stood out in horticulture as having a great potential for commercialization, representing a production option for the entire year for the producers and wide acceptance by the consumer market. In Brazil, zucchini (*Cucurbita pepo* L.) is among the ten vegetables of greatest economic value, mainly grown in central and southern Brazil (Costa, Rezende, Freitas, Gonçalves, & Frizzone, 2015). Information on production and planting areas is scarce, with the Brazilian 2006 production at 384,916 tons and harvested area at 88,203 ha (IBGE, 2010).

The production methods or techniques (drip irrigation, plastic soil mulch, and subsurface irrigation) have many compatible advantages. However, the practice of these techniques, the knowledge of the behaviours and the study of the phenomena are fundamentally important for zucchini production.

This study aimed to evaluate zucchini yield and water use efficiency as influenced by pulse drip irrigation and soil mulch during the two years of evaluation.

Material and methods

Two experiments were performed, one experiment in 2014 and the other in 2015.

First experiment

The first experiment was conducted from October to December 2014 in the experimental area of the Engineering Department of the Federal University of Lavras, Lavras, Minas Gerais State, Brazil, at an altitude of 892 m.

According to the Köppen climatic classification of (Dantas, Carvalho, & Ferreira, 2007), the climate of Lavras is Cwa, i.e., temperate and rainy (mesothermic), with dry winters and rainy summers and subtropical. The average temperature of the coldest month is below 18°C and above 3°C, and in the summer, the average temperature of the hottest month is above 22°C (22.1°C in February). The average annual temperature of Lavras is 19.4°C, the relative humidity is 76.2%, the average annual rainfall is 1,529.7 mm, and the average annual evaporation is 1,034.3 mm.

To control the humidity control and to avoid rainfall, a high tunnel system was used with a low-density 150-μm polyethylene film, with the front and sides opened halfway (umbrella system). The tunnel was mulched every day at 6:00 p.m. and unmulched at 6:30 a.m. in the event of rain.

Inside the tunnel, at a high point towards the centre, a thermohygrometer was installed to monitor the air temperature (maximum and minimum) and the relative humidity (maximum and minimum) at a height of 1.3 m. Readings were performed daily at 5 p.m.

The soil was classified as red latosol with a clay texture, with the following chemical composition for the layer from 0 to 0.30 m: $pH_{(water\ 2.5:1)}$ = 5.5, K^+ = 48 mg dm^{-3}, $P_{(Mehlich-1)}$ = 0.28 mg dm^{-3}, Ca^{2+} = 1.8 $mmol_c$ dm^{-3}, Mg^{2+} = 0.7 $mmol_c$ dm^{-3}, H+Al = 3.62 $mmol_c$ dm^{-3}, Zn = 0.62 mg dm^{-3}, Fe = 57 mg dm^{-3}, Cu = 6.0 mg dm^{-3}, and B = 0.15 mg dm^{-3}.

Liming and fertilization were performed based on a soil chemical analysis, following the recommendations for the crop in the state of Minas Gerais, Brazil (Carrijo, Correia, & Trani, 1999). Liming was performed based on the base saturation method by applying 2,000 kg ha^{-1} of limestone to the whole area. Mineral fertilization was applied in terms of 1,120 kg ha^{-1} of simple superphosphate, 310 kg ha^{-1} of potassium chloride, 15 kg ha^{-1} of zinc sulphate, 10 kg ha^{-1} of borax, and 10 kg ha^{-1} of copper sulphate. N doses were applied as urea. Fifteen days before sprout transplanting, the all the P and micronutrients were applied as well as 40% of K and 30% of the evaluated N dose, in addition to 1.5 kg m^{-2} of organic compound. The remaining N and K were applied in two mulch applications around the plants, followed by irrigation. The first mulch was placed 15 days after the transplanting and the second mulch was placed 25 days after the first transplanting.

To perform irrigation management, a characteristic water retention curve was obtained according to the Van Genuchten (1980) model.

The zucchini seedlings were transplanted after 26 days in sowing beds constructed to be 0.1 m in height and 0.60 m in width. Surface and subsurface drip and double-sided plastic (white/black) with the white side facing upwards were installed in the treatments with mulch. Each plot measured 2.8 m in length, where four zucchini plants were planted spaced 0.70 m apart with a margin of 0.40 m between each plot. The useful area of the plot was 2.8 m^2.

After transplanting, daily irrigation was performed at the 5 mm water depth to favour the setting of the seedlings. This procedure was adopted for ten days. Subsequently, irrigation was performed according to the readings from the granular matrix sensors installed at 0.15 m depth and recorded in dataloggers. Two sensors were installed per plot; one sensor was installed at 0.15 m, and the other sensor was at a depth of 0.30 m and 0.10 m from the plant.

In all irrigation treatments, an attempt was made to increase the field capacity of the moisture that corresponds to the water tension in the soil at the moment of irrigation. The beginning of irrigation was established as when the decision sensors reached the critical soil water tension of 20 kPa (Costa et al., 2015).

The experimental design was in randomized blocks in a 2 x 2 x 2 factorial design with eight treatments and four replications. Treatments differed in relation to the frequency of water application (continuous and pulsed), in relation to the drip line position (surface and subsurface) and in relation to the soil mulch (without and with plastic mulch). The zucchini cultivar was Clarinda, from the company Monsoy LTDA.

A drip irrigation system was installed, with pressure-compensating and anti-draining emitters integrated in the tube Hydro PCND model with nominal flow rate of 2.35 L h^{-1} and spaced 0.70 m apart. One dripper per plant was used, operating at a service pressure of approximately 10 mca, which was regulated through a pressure regulator inserted into the control head before the electric control valves (solenoids). One valve was used for each treatment, and they were actuated through a programmable logic controller previously programmed in each irrigation to run the necessary time, with the aim of restoring the necessary water depth.

The pulse drip consisted of splitting the irrigation depth into six irrigation pulses with 50-min intervals (irrigation/rest). The pulses started at 8:00 a.m. and had the necessary duration to apply one-sixth of the programmed water depth.

Cultural practices and the phytosanitary control were implemented when necessary, according to Filgueira (2007). Soon after the emergence of the first flowers, the presence of insect pollinators, mainly bees, was verified, which provided efficient pollination of the flowers and formation of fruits, thus manual pollination was not required.

The harvests started 29 days after the transplant and were performed daily in the morning until plant productive capacity was depleted (35 days of harvest). The commercial (CY) and total yield (TY) (kg ha^{-1}) were evaluated to compare zucchini plant yields under different treatments. The evaluation was based on the result was the product of the average mass of the total and commercial fruits (fruits of commercial size and without any injury) by the number of fruits per plant and the number of plants per hectare (14,285 plants per hectare) and the WUE, which related to the TY obtained by the area (kg ha^{-1}) and the water depth (mm) used during cultivation.

The experimental data were submitted to an analysis of variance. When the data were significant based on the F test, the mean data were compared by the Tukey test at a 5% probability level to verify the existence of some significant difference among the treatments. All statistical analyses were performed with the aid of the statistical software SISVAR version 4.6 (Ferreira, 2014).

Second experiment

The second year of evaluation was conducted from October to December 2015 in the experimental area of the Engineering Department of the Federal University of Lavras, Lavras, Minas Gerais State, Brazil.

For humidity control and to avoid rainfall, cultivation in a greenhouse with dimensions of 15 m long, 7 m wide and 3.2 m high was chosen. Inside the greenhouse, a thermohygrometer was installed to monitor the air temperature (maximum and minimum) and the relative humidity (maximum and minimum) at a height of 1.3 m. Readings were performed daily at 5 p.m.

The soil was classified as red latosol, with a clay texture, with the following chemical composition for the layer from 0 to 0.30 m: $pH_{(water\ 2.5:1)}$ = 7.3, K^+ = 76 mg dm^{-3}, $P_{(Mehlich-1)}$ = 1.42 mg dm^{-3}, Ca^{2+} = 6 $mmol_c$ dm^{-3}, Mg^{2+} = 2.2 $mmol_c$ dm^{-3}, H+Al = 1.19 $mmol_c$ dm^{-3}, Zn = 1.0 mg dm^{-3}, Fe = 41.76 mg dm^{-3}, Cu = 3.52 mg dm^{-3}, B = 0.21 mg dm^{-3}, SOM = 3.99 dag kg^{-1}, and P_{rem} = 5.63 mg L^{-1}.

Liming and fertilization were performed based on a soil chemical analysis, following the recommendations for the crop in the state of Minas Gerais, Brazil (Carrijo et al., 1999). For mineral fertilization, 132 kg ha^{-1} of P_2O_5, 130 kg ha^{-1} of K_2O, 30 kg ha^{-1} of zinc sulphate, and 20 kg ha^{-1} of boric acid were applied. Two topdressing fertilizations with application of 54 kg ha^{-1} of N and 75 kg ha^{-1} of K_2O were applied in each mulch.

To perform irrigation management, a characteristic water retention curve was obtained according to Van Genuchten (1980) model.

The zucchini seedlings were transplanted after 15 days of being in sowing beds constructed to be 0.1 m in height and 0.70 m in width. Surface and subsurface drip and double-sided plastic (white/black) with the white side facing upwards were installed in the treatments with mulch. Each plot measured 2.1 m in length, where three zucchini plants spaced 0.70 m apart were planted with a margin of 0.30 m between each plot. The useful area of the plot was 2.1 m^2.

After transplanting, daily irrigation was performed, at a 5-mm water depth to favour the setting of seedlings. This procedure was adopted for ten days. Subsequently, irrigation was performed according to the reading of the tensiometer values installed at a 0.15-m depth. Two tensiometers were installed per plot; one tensiometer was installed at a depth of 0.15 m, and another was at a depth of 0.30 m and 0.10 m from the plant.

For all irrigation treatments, an attempt was made to increase the field capacity moisture that corresponds to the water tension in the soil at the moment of irrigation. The beginning of irrigation was established as when the decision tensiometers reached the critical soil water tension of 20 kPa (Costa et al., 2015).

The experimental design was completely randomized in a 2 x 2 x 2 factorial design with eight treatments and five replications. Treatments differed in relation to the frequency of water application (continuous and pulsed), in relation to the drip line position (surface and subsurface) and in relation to the soil mulch (without and with plastic mulch). The zucchini cultivar was Clarinda.

The irrigation system installed was similar to the one adopted in the first year, with pressure-compensating and anti-draining emitters integrated in the tube Hydro PCND model with a nominal flow rate of 2.35 L h^{-1} and spaced 0.70 m apart. The same design as the first year was also used, with electric control valves and one programmable logic controller.

The pulse drip consisted of splitting the irrigation depth into six irrigation pulses with 30-min intervals (irrigation/rest). The pulses started at 8:00 a.m. and had the necessary duration to apply one-sixth of the programmed water depth.

Cultural practices and phytosanitary control were implemented when necessary, according to Filgueira (2007). Twenty-two days after the transplant, the first male and female flowers emerged. Thus, the process of manual pollination was initiated.

Harvests started 27 days after the transplants and were performed daily in the afternoon over 30 days. For a comparative study among the productivities of zucchini plants in the different treatments, TY, CY (kg ha^{-1}) and WUE were evaluated.

The experimental data were submitted to an analysis of variance, and the averages were compared by the F test. Statistical analyses were performed with the aid of the statistical software SISVAR, version 4.6 (Ferreira, 2014).

Results and discussion

Variations in the relative humidity and temperature that occurred during the experiment are shown in Figure 1. Humidity and average temperature were 61.8% and 24.4°C, respectively, during the first year of the experiment. In the second year, the humidity and the average temperature were 54.4% and 28.8°C, respectively. Temperatures between 18°C and 25°C are considered as the optimum range for growth and production of zucchini. Temperatures outside these ranges harm fruit setting and hence yield (Olinik et al., 2011).

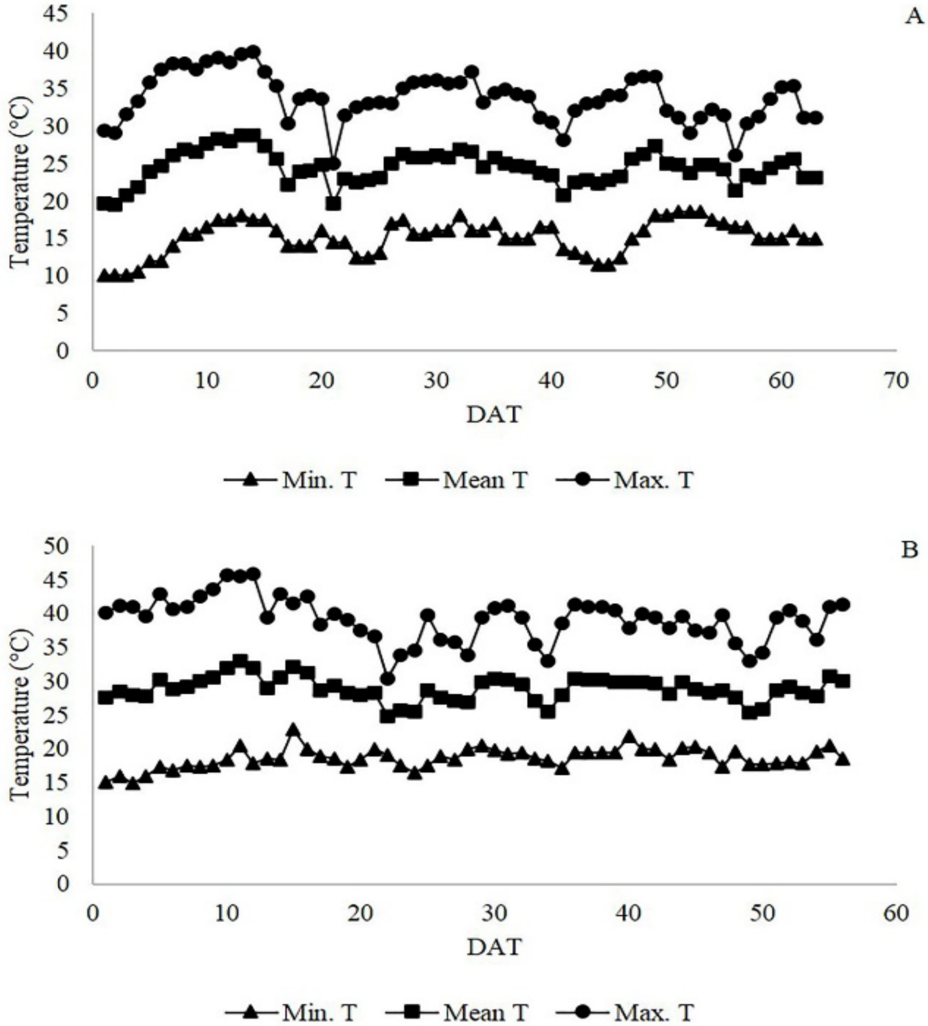

Figure 1. Maximum, mean, and minimum temperatures during the experiment in the first (A) and second years (B).

First experiment

According to the analysis of variance (Table 1), there was significant effect of soil mulch on the TY. For the CY, there was an effect of the drip line position and of the soil mulch. Regarding the WUE for both the TY and CY, there was a significant effect of the interactions between the frequency of water application x drip line position and the frequency of water application x soil mulch. There were no significant effects for the other interactions.

Table 2 represents the comparison among the averages of TY and CY of zucchini for the different studied treatments. There was no difference in the treatments with continuous and pulse drip for any of variables. The line position interfered only in the CY, with a greater observed CY in the subsurface line. The highest TY and CY were obtained through the use of plastic soil mulch.

The increase in yield due to soil mulch is related to factors such as greater weed control and soil temperature, a reduction in soil water evaporation, and lower leaching and nitrate volatilization (Zribi, González, & Lafarga, 2011). In general, the presence of soil mulch promotes improvements in microbiological conditions of the environment and provides a favourable environment for the abundant growth of surface roots (Sá, Ferreira, Briedis, Vieira, & Figueiredo, 2010).

Table 1. Summary of the variance analysis table for the variables total yield (TY), commercial yield (CY), water use efficiency-total yield (WUE-TY) and water use efficiency-commercial yield (WUE-CY) for zucchini in the first year of the experiment.

		Mean squares			
Sources of variation	G.L.	TY (kg ha^{-1})	CY (kg ha^{-1})	WUE-TY (kg ha^{-1} mm^{-1})	WUE-CY (kg ha^{-1} mm^{-1})
Frequency (F)					
Position (P)					
Mulch (M)	1	693116031.4095 **	467124283.8152 **	56113.3375 **	43212.1202 **
F x P	1	77012954.4324 ns	43945359.3750 ns	6657.7145 **	4748.7385 **
F (subsurface)	1	-	-	-	9.0150 ns
F (surface)	1	-	-	-	10091.7093 **
P (continuous)	1	-	-	-	2560.3600 **
P (pulse)	1	-	-	-	2195.3910 **
F x M	1	71928467.7757 ns	51499172.2080 ns	4806.1659 **	3899.3281 **
F (with mulch)	1	-	-	-	57.3806 ns
F (without mulch)	1	-	-	-	9193.9332 **
M (continuous)	1	-	-	-	36536.4110 **
M (pulse)	1	-	-	-	10575.0372 **
P x M	1	57079510.5265 ns	53327388.8322 ns	122.5787 ns	135.5481 ns
F x P x M	1	1244075.6626 ns	3051042.8288 ns	920.9559 ns	563.9761 ns
Error	24	21294975.5149	12892849.1142	442.1201	264.3767
Total means		36060.27	33560.27	156.38	145.19
C.V. (%)		12.80	10.70	13.45	11.20

*and **Significant at 1% and 5%, respectively, by the F test; ns = not significant.

Table 2. Averages of the TY and CY of zucchini in the first year of the experiment.

Treatments	Variables	
	TY (kg ha^{-1})	CY (kg ha^{-1})
Pulse	35982.14 a	33668.15 a
Continuous	36138.39 a	33452.38 a
Surface	34404.76 a	32023.81 b
Subsurface	37715.77 a	35096.73 a
With mulch	40714.29 a	37380.95 a
Without mulch	31406.25 b	29739.58 b

Averages followed by the same letter do not differ from each other according to the F test ($p \leqslant 0.05$).

Table 3. Applied irrigation depths (mm) in the culture of zucchini cv. Clarinda, cultivated under the influence of continuous and pulse drip, surface and subsurface and without and with soil plastic mulch in the first year of the experiment.

Treatments	Total water depth (mm)
Continuous - Surface - Without mulch	341.17
Continuous - Subsurface - Without mulch	331.16
Continuous - Surface - With mulch	216.29
Continuous - Subsurface - With mulch	212.28
Pulse - Surface - Without mulch	227.85
Pulse - Subsurface - Without mulch	243.26
Pulse - Surface - With mulch	173.29
Pulse - Subsurface - With mulch	224.65

Based on the irrigation management adopted during the experiment, the total depths applied were specific to the different treatments and are shown in Table 3. The highest water consumption was observed in the continuous drip treatments without mulch with surface and subsurface drip lines (341.17 mm and 331.16 mm, respectively), whereas the lowest consumption was observed in the subsurface pulse drip irrigation treatment and with soil mulch (173.29 mm). Thus, a difference of 167.88 mm (49.20%) was observed in the total water depth, between the largest and smallest applied depth. It was also observed that both the pulse drip and the soil mulch acted in reducing the applied depth during the crop cycle.

Table 4 shows the average values of the WUE for the TY and CY for the line positions and water application type. The maximum values were obtained in treatments with water application via a surface pulse drip of 183.37 kg ha^{-1} mm^{-1} and 169.83 kg ha^{-1} mm^{-1} for WUE-TY and WUE-CY, respectively. However, the lowest values were obtained in treatments with water application via a surface continuous drip of 128.63 kg ha^{-1} mm^{-1} and 119.60 kg ha^{-1} mm^{-1} for WUE for the TY and CY, respectively.

Table 4. Average WUEs for the TY and CY of zucchini as a function of the interaction of line position and water application type in the first year of the experiment.

Treatments	WUE–TY ($kg\ ha^{-1}\ mm^{-1}$)		WUE-CY ($kg\ ha^{-1}\ mm^{-1}$)	
	Pulse	Continuous	Pulse	Continuous
Subsurface	155.29 aB	158.25 aA	146.40 aB	144.90 aA
Surface	183.37 aA	128.63 bB	169.83 aA	119.60 bB

Averages followed by the same lowercase letter in the columns and capital in the rows do not differ from each other by the F test at 5% ($p \leq 0.05$).

Table 5 demonstrates the interactions among the water application type and the soil mulch. The highest WUE values were observed when irrigation was performed by pulses and with soil mulch (198.95 kg ha^{-1} mm^{-1} and 183.83 kg ha^{-1} mm^{-1}) for WUE-TY and WUE-CY, respectively.

Table 5. Average WUE for the TY and CY of zucchini as a function of the interaction of soil with and without mulch and water application types in the first year of the experiment.

Treatments	WUE–TY ($kg\ ha^{-1}\ mm^{-1}$)		WUE-CY ($kg\ ha^{-1}\ mm^{-1}$)	
	Pulse	Continuous	Pulse	Continuous
With mulch	198.95 aA	197.57 aA	183.83 aA	180.04 aA
Without mulch	139.71 aB	89.31 bB	132.41 aB	84.47 bB

Averages followed by the same lowercase letter in the columns and capital in the rows do not differ from each other by the F test at 5% ($p \leq 0.05$).

The treatments with pulse drips obtained a greater WUE when compared to the treatments with continuous drips. The same outcome was observed in relation to soil mulch, which provided a greater WUE compared to soil without mulch.

In relation to the benefits caused by pulse drip, similar results were obtained by Abdelraouf et al. (2012), who compared continuous drip with pulse drip in a potato crop. These authors verified that a pulse drip provided savings in terms of the application of water via irrigation.

Second experiment

In the second year of the experiment, there was no interaction among the factors. Plastic mulch influenced the TY and CY, and WUE was significant only for the type of water application (Table 6). The use of plastic mulch provided a double TY and CY when compared to soil without mulch (Table 7).

Olinik et al. (2011) evaluated two cultivars of zucchini, Novita Plus (cv. Caserta type) and Samira (cv. Lebanese type) under six types of soil mulch (black polyethylene, silver polyethylene, white polyethylene, black polypropylene, rice husk and soil without mulch) with drip irrigation in an open field. The highest productivities were observed with the silver polyethylene mulch and were 10,240 and 9,080 kg ha^{-1} for Nativa Plus and Samira, respectively, which are below the values obtained in this research for the mulching treatments.

Pôrto et al. (2012) evaluated the yield of zucchini cv. Caserta irrigated by conventional sprinklers and varying the nitrogen fertilization, where the maximum yield of zucchini fruits (29,878 kg ha^{-1}) was obtained with an estimated dose of 331 kg $ha^{-1}$of N. This zucchini fruit yield is higher than that found in the present study, which can be explained by their application of nitrogen fertilization.

Table 6. Summary of the variance analysis table for the variables TY, CY, WUE-TY and WUE-CY for zucchini in the second year of the experiment.

Sources of variation	Mean squares				
	G.L.	TY ($kg\ ha^{-1}$)	CY ($kg\ ha^{-1}$)	WUE–TY ($kg\ ha^{-1}\ mm^{-1}$)	WUE-CY ($kg\ ha^{-1}\ mm^{-1}$)
Mulch (M)	1	1021399170.0000 **	904174581.0729 **	6107.8180 ns	3643.3266 ns
Frequency (F)	1	37350141.6654 ns	21882855.9051 ns	57705.2929 **	52904.5296 **
Position (P)	1	33759634.2702 ns	14019661.1416 ns	9710.7024 ns	11171.9720 ns
C x F	1	43273922.1688 ns	26005352.0131 ns	5807.6180 ns	4056.8002 ns
C x P	1	14293940.3491 ns	70870026.9031 ns	7364.1680 ns	2898.6765 ns
F x P	1	10196182.8688 ns	20783994.1389 ns	19774.9196 ns	9899.5183 ns
C x F x P	1	7044001.5051 ns	200696.8056 ns	1453.9536 ns	2541.3142 ns
Error	32	40074533.8962	40494287.4349	5469.5151	5198.7543
Total means		16012.98	14128.93	191.35	168.80
Coefficient of variation (%)		39.53	45.04	38.65	42.71

**Significant at 1% by the F test; ns = non-significant.

Table 7. Averages of the TY, CY, WUE-TY and WUE-CY of zucchini for soil mulch treatment in the second year of the experiment.

Variables	Treatments	
	With mulch	Without mulch
CY (kg ha^{-1})	18883.33 a	9374.52 b
TY (kg ha^{-1})	21066.19 a	10959.76 b
WUE–TY (kg ha^{-1} mm^{-1})	178.10 a	203.71 a
WUE-CY (kg ha^{-1} mm^{-1})	159.26 a	178.35 a

Averages followed by the same letter do not differ from each other by the F test at ($p \leqslant 0.05$).

Plastic mulch can result in a higher yield of zucchini and allows the harvesting of the fully cleaned fruits, which facilitates and optimizes the harvesting and commercialization processes, while vegetables harvested in soil without mulch or with rice husk mulch need to undergo a cleaning process (Olink et al., 2011).

Araújo and Botrel (2010) evaluated CO_2 doses and the use of plastic mulch in the yield of zucchini cv. Caserta, and the yield with soil mulch was 15,433.7 kg ha^{-1} with a dose of 58.65 kg ha^{-1} of CO_2, while for bare soil, the highest yield was 11,820.8 kg ha^{-1} for a doses 84.51 kg ha^{-1} of CO_2. These yield values are similar to those obtained in this study, demonstrating that soil with mulch provides a higher yield, which also occurred in this study, where the highest yield was achieved in soil with mulch.

The WUE was influenced only by the type of water application, i.e., continuous and pulse drips. The continuous drip provided the highest WUE values (Table 8).

Table 8. Averages of TY, CY, WUE-TY and WUE-CY of zucchini for the water application type treatment in the second year of the experiment.

Variables	Treatments	
	Continuous	Pulse
CY (kg ha^{-1})	13389.29 a	14868.57 a
TY (kg ha^{-1})	15046.67 a	16979.29 a
WUE–TY (kg ha^{-1} mm^{-1})	229.34 a	153.37 b
WUE-CY (kg ha^{-1} mm^{-1})	205.17 a	132.43 b

Averages followed by the same letter do not differ from each other by the F test ($p \leqslant 0.05$).

The drip line position did not influence the evaluated parameters, and observed averages are shown in Table 9.

Table 9. Averages of TY, CY, WUE-TY and WUE-CY of zucchini for the drip line position treatment in the second year of the experiment.

Variables	Treatments	
	Surface	Subsurface
CY (kg ha^{-1})	13536.91 a	14720.95 a
TY (kg ha^{-1})	15094.29 a	16931.67 a
WUE–TY (kg ha^{-1} mm^{-1})	175.77 a	206.93 a
WUE-CY (kg ha^{-1} mm^{-1})	152.09 a	185.51 a

Averages followed by the same letter do not differ from each other by the F test ($p \leqslant 0.05$).

Zotarelli et al. (2008) used the cultivar Wildcat in Florida and obtained a CY of 38,600 kg ha^{-1} with drip and fertigation lines positioned on the soil surface; and the authors obtained a CY of 36,000 kg ha^{-1} with irrigation and fertigation lines positioned at 0.15-m below the soil surface; and the highest yield (43,100 kg ha^{-1}) was with the drip line positioned at 0.15-m below the soil surface and the fertigation line positioned on the soil surface. The authors achieved the highest zucchini yield with a drip line in the subsurface position; however, in the present study, line position did not influence the zucchini yield.

Based on the irrigation management adopted during the second year of the experiment, the total depths applied were specific to the different treatments and are shown in Table 10. The highest water consumption was observed in the pulse drip treatments with mulch and with the subsurface drip line (109.10 mm), whereas the lowest water consumption was observed in the surface pulse drip irrigation treatment without soil mulch (48.40 mm). This behaviour was different from that observed in the first year. Thus, a difference of 60.71 mm (55.64%) was observed in the total water depth, between the largest and smallest applied depth.

Table 10. Applied irrigation depths (mm) in the culture of zucchini cv. Clarinda, cultivated under the influence of continuous and pulse drips, surface and subsurface and without and with soil plastic mulch in the second year of the experiment.

Treatments	Total water depth (mm)
Continuous - Surface - Without mulch	85.60
Continuous - Subsurface - Without mulch	68.82
Continuous - Surface - With mulch	101.04
Continuous - Subsurface - With mulch	69.83
Pulse - Surface - Without mulch	79.56
Pulse - Subsurface - Without mulch	48.40
Pulse - Surface - With mulch	109.10
Pulse - Subsurface - With mulch	101.32

Conclusion

Considering that irrigation water depth is an important parameter in the calculation of efficiency indexes, the use of the soil mulch is beneficial under these study conditions.

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