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DRIP PULSES AND SOIL MULCHING EFFECT ON AMERICAN CRISPHEAD LETTUCE YIELD

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ABSTRACT: An experiment was conducted in a greenhouse at the Federal University of Lavras cultivated with American lettuce, cv. Raider-Plus. The aim of this study was to evaluate the effects of irrigation water depths applied by drip pulses and of soil coverage on crop yields and efficiency of water use. The experimental design used was randomized blocks with eight treatments and three replications, totaling twenty-four plots. The treatments consisted of soil with and without coverage (double-sided white and black plastic) associated with four irrigation management levels. Irrigation management consisted in reposition of irrigation depths based on crop evapotranspiration (ET_c) with D_1 -100% of ET_c, applied continuously (control), and D_2 - 100% of ET_c, D_3 - 75% of ET_c, and D_4-50% of ET_c, applied by pulses. Irrigation by pulses consisted in splitting the depths into six irrigation pulses with intervals of fifty minutes of rest. It was observed that pulse irrigation saved 25% of water in treatment without mulching and 50% when plastic mulching was used, contributing substantially to improve irrigation water efficiency.

KEYWORDS: water-use efficiency, greenhouse, water depth.

GOTEJAMENTO POR PULSOS E COBERTURA DO SOLO NA PRODUTIVIDADE DA ALFACE-AMERICANA

RESUMO: Um experimento foi conduzido em ambiente protegido, na Universidade Federal de Lavras, com a cultura da alface-americana cv. *Raider-Plus*. O objetivo do trabalho foi avaliar os efeitos de lâminas de irrigação aplicadas via gotejamento por pulsos e da cobertura do solo sobre a produtividade e a eficiência do uso da água. O delineamento experimental foi o de blocos ao acaso, em que foram utilizados oito tratamentos e três repetições, perfazendo um total de vinte e quatro parcelas experimentais. Os tratamentos constituíram-se do solo com e sem cobertura (plástico dupla face branco/preto), associado a quatro manejos de irrigação. Os manejos de irrigação consistiram na reposição de lâminas de irrigação, com base na evapotranspiração da cultura (ET_c), sendo L1 ; 100% da ETc, aplicada de forma contínua (testemunha), e L2; 100% da ETc, L3; 75% da ETc e L4; 50% da ETc, aplicadas por pulsos. A irrigação por pulsos consistiu no parcelamento da lâmina, em seis pulsos de irrigação, com intervalos de cinquenta minutos de repouso. Foi observado que o gotejamento por pulsos proporcionou a economia de 25% de água no tratamento sem cobertura plástica e a economia de 50% de água no tratamento com cobertura plástica do solo, o que resultou no aumento da eficiência do uso da água.

PALAVRAS-CHAVE: eficiência do uso da água, ambiente protegido, lâminas de irrigação.

INTRODUCTION

Farming techniques that increase yield and quality with rational use of natural resources have become more popular. This is the main objective of modern agriculture, which is increasingly

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focused on investing in new technologies to enhance yield, reduce costs, and sustainably improve the quality of products.

Recently, the irrigation by pulses technique has been studied, which consists in practice of a short period of irrigation, followed by a resting phase and another short irrigation period; this cycle is repeated until the irrigation depth is completely applied.

Pulse drip irrigation has been tested on several crops around the world, such as on pepper in Israel (ASSOULINE et al., 2006), on corn in Egypt (ZIN EL-ABEDIN, 2006), on tomato in the United States (WARNER; HOFFMAN; WILHOIT, 2009), and on potato in Egypt (ABDELRAOUF et al., 2012; BAKEER et al., 2009). These studies investigated positive impacts on yield, improvements in product quality, savings in water use, reductions in emitter obstruction, etc.

Another technique of great contribution to food production is the covering of soil with plastic material (mulching); a method that aims to control weeds and reduce water loss through evaporation. It also facilitates harvesting and commercialization, as the end product is healthier and cleaner. However, when covering the soil, important parameters of microclimate are altered, such as soil temperature and this influences water evaporation and microorganisms growth - factors that directly affect water consumption, as well as crop growth and development (GONÇALVES; FAGNANI; PERES, 2005). The mulching has become more widespread in recent years, mainly in the cultivation of several vegetables, such as American crisphead lettuce.

Crisphead lettuce has been acquiring greater importance, mostly in the South region of Minas Gerais (RESENDE et al., 2009). This cultivar is characterized by a compact head and is ideal for the *fast food* market segment. It also possesses thick and crunchy leaves, as well as greater post-harvest durability (SALA; COSTA, 2012).

Lettuce production goes through periods of unfavorable meteorological conditions at times of the year. One of the existing alternatives to minimize the effect of agro climatic adversity is greenhouse cultivation. This technique aims to obtain greater yield, with improved quality of final product throughout the year, by offering effective protection from climate events, such as frost, excessive rainfall, and decreased night temperature. It also protects soils from leaching, reduces fertilization and pesticide costs, and hinders possible infestations by pests and diseases that could increase crop production costs and eventually cause damage to the environment.

Lettuce is a crop that demands high levels of water and when cultivated in a greenhouse, irrigation is indispensable and the only way to replace the water consumed by the plant.

Considering the lettuce water requirements and the benefits reported through studies about pulse drip irrigation and soil coverage, this study aimed at evaluating the effects of irrigation water depths applied via drip irrigation, with and without mulching, on yields of greenhouse grown crisphead lettuce, as well as on system water-use efficiency.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse (arc model), covered with transparent plastic film of 0.15 mm thickness. This structure was installed at an experimental area belonging to the Engineering Department of the Federal University of Lavras (UFLA), from May to July 2011. This area is located at 21° 13' 48" of south latitude, 44° 58' 36" west longitude, and at an altitude of 902 m.

According to Köppen classification, the region presents C*wa* climate, in other words, rainy mild climate (mesothermal), with dry winter and rainy summer, average temperature of the coldest month bellow 18 °C and above 3 °C; and summer presents average temperature of the hottest month above 22°C (DANTAS; CARVALHO; FERREIRA, 2007).

Meteorological data from inside the greenhouse were obtained through a portable and automatic agro meteorological station, DAVIS brand, VANTAGE PRO 2 model, installed in the greenhouse center (2 m of height), with constant monitoring of temperature, and air relative humidity.

The soil from experimental area was classified as dystroferric Red Latosol, of which sieve analysis indicated average values of 68 dag kg^{-1} of clay, 22 dag kg^{-1} of silt, and 10 dag kg^{-1} of sand, soil density of 0.98 $kg.dm^{-3}$, and particle density of 2.84 $kg.dm^{-3}$. Soil moisture at field capacity (-10 kPa) was of 0.361 cm^3 cm^{-3}, and permanent withering point was of 0.217 cm^3 cm^{-3}. Soil chemical analysis was carried out in the soil laboratory of the Department of Soil Science (DCS-UFLA), after sampling made in the experimental area, before initial soil preparation, at depth of 0.0 to 0.30 m (Table 1).

TABLE 1. Chemical characteristics of soil before fertilization.

pH	M.O.	P	Ca	Mg	H+Al	SB	CTC	V	K	B	Cu	Fe	Mn	Zn
	g dm^{-3}	mg dm^{-3}	--------mmol$_c$dm^{-3}----------					%	----------------mg dm^{-3}----------------					
6.8	26.1	11.88	38.3	5.4	14.8	14	31	45.9	98	0.1	8.5	59	55	0.3

The area was prepared with one plowing and one harrowing, in sequence, seedbeds with 1.2 m of width, 1.50 m of length, and 0.15 m of height, were constructed with the aid of a hoe. In this occasion, phosphor fertilizer was incorporated to the soil (100 kg/ ha of P), following recommendations from the Soil Fertility Commission of Minas Gerais State: fifth Approximation (GOMES; SILVA; FAQUIN, 1999). The same guide was also basis for fertilization which accounted for 150 Kg/ ha of N, 60 kg/ ha of K_2O, 3 kg/ ha of Zn and 1 kg/ ha of B.

The double-sided black and white mulching was placed on seedbeds one day before treatment initiation, face installed downwards, in contact with the soil.

We used the Raider-Plus cultivar of American crisphead lettuce of Seminis Vegetable Seeds, Inc. This breeding line is characterized for presenting an 85-day cycle, big-sized and compact plants with tougher leaves of light green coloration. It is indicated for winter cultivation and ideal for fresh markets and processing.

Seeding was carried out on April 16th, 2011, in 200-cell polystyrene trays filled with commercial substrate (Plantmax HT, Eucatex). Two sprays with pyrethroid insecticide (Karate® - 40 g/hl) and copper oxychloride-based fungicide (Melody Cobre® - 150g/hl) were carried out. Seedlings were accompanied in greenhouse during 25 days, and were manually transplanted on May 10th, 2011 to seedbeds previously dampened. The seedlings were spaced in 0.30 x 0.30 m, with bed spacing of 0.25 m, totaling 78,660 plants per hectare.

Before transplanting, the soil was irrigated until reaching field capacity; and during the 7-day seedling acclimatization period, water applications corresponding to 100% of ETc were carried out, being estimated based on readings from mini-tank evaporimeter installed inside the greenhouse.

A drip irrigation system was installed with inline pressure-compensating emitters, which consist of emitters inserted in the hose during extrusion process. We used nozzles of *NAAN PC* model with nominal flow of 1.6 L h^{-1} and distant 0.30 m from each other. The drip tape (DN 16 mm) was placed in the plot in order to assist two plant lines, working with operating pressure of around 140 kPa, which was controlled through a pressure-regulating valve inserted in the control head, before electrical command valves (solenoids). One valve was used for each treatment; such valves were activated through a Programmable Logic Controller (*RAIN BIRD*), previously programmed, in each irrigation, to work for as long as necessary aiming to replace the required demand to fill water depth.

The beds (1.5 x 1.2 m) were irrigated by two sidelines of dripping, parallel to the greatest length, spaced in 0.60 m between each other and 0.30 m between drippers, totaling 10 application points per plot (Figure 1).

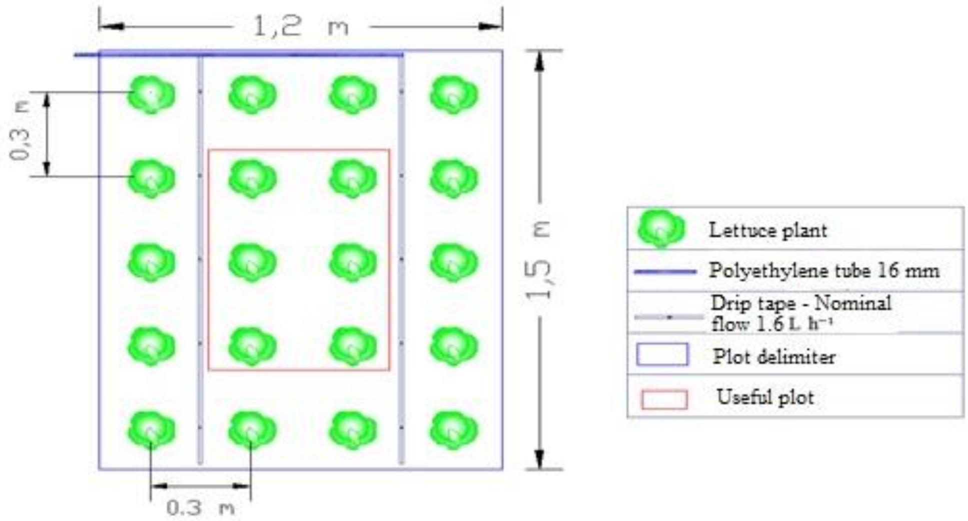

FIGURE 1. Experimental plot with irrigation system.

Tests were conducted to determine dripper average flow and distribution uniformity coefficient (DUC). The DUC was proposed by Keller & Karmeli (1975) and compares the average of 25% of the lowest observed flow values with the flow total average to determine water application uniformity of irrigation systems by dripping. Values of 1.86 L h^{-1} for flow and 0.99 for DUC were found, indicating high water distribution uniformity within the plots.

The adopted experimental designed was randomized blocks (RBD), in factorial scheme (2 x 3 + 2) x 3 (coverage x pulse drip irrigation + two controls) with three replications, using eight treatments in total, and totaling 24 plots. The controls consisted in reposition of 100% of ETc, applied through continuous dripping, one with and another without plastic coverage. Each experimental plot was composed of four plant lines spaced 0.30 m between lines and 0.30 m between plants, in a total of 20 plants per plot (Figure 1).

The treatments consisted of soil with and without mulching (double-sided black and white plastic) associated with four irrigation management levels. The irrigation management levels consisted in reposition of irrigation water depths (ID), based on crop evapotranspiration (ETc), with D1 - 100% of ETc applied continuously (control) and D2 - 100% of ET, D3 - 75% of ETc and D4 - 50% of ETc, applied by pulses. Pulse irrigation involved splitting ID into six irrigation pulses with intervals of fifty minutes (irrigation/ rest). Pulses started at 9 am and had enough duration to apply one sixth of programmed water depth. An electronic controller and solenoid valves controlled irrigation times.

The applied water depth, with irrigation schedule of two days, was calculated in accordance with [eq. (1)]. An evaporation mini-tank was used (minimized class A tank) for evaporation estimation. The mini-tank Kp adopted value was 1, which was also adopted by BANDEIRA et al. (2011). The adopted Kc (0.60, 0.8, 1.05 and 1.0) was recommended by MAROUELLI, SILVA and SILVA (1996).

$$NID = \frac{EVm\,.Kp.Kc}{Ea} \qquad (1)$$

In which,

NID = necessary irrigation depth, mm;

EV_m = mini-tank evaporation measured within the period, mm;

K_c = crop coefficient;

K_p = tank coefficient,

E_a = water application efficiency of the adopted irrigation system (0.95).

Different water depths were obtained for each treatment regarding different functioning times of dripping lines. This time was obtained through [eq. (2)].

$$Ti = \frac{LIN.sp.slp}{e.q} \tag{2}$$

In which,

Ti = irrigation time for each treatment, h;

sp = spacing between plants, 0.30 m;

slp = spacing between plant lines, 0.30 m;

e = number of emitters per plant (0.5),

q = average flow of dripper, 1.86 L h^{-1}.

Top dressings were divided into three applications (15, 30, and 45 days after transplanting), spreading a total of 280 g of K_2O and 560 g of N over the total area (plots). These doses were applied in solution form with the aid of a syringe, precisely on soil around the dripper, using potassium chloride and calcium nitrate as nutrient sources.

Aiming to prevent nutritional deficits, which could arise during crop development, three foliar fertilizations were carried (*Nitrofoska A*) during the whole lettuce cycle (12, 28, and 37 days after transplanting). This fertilizer presents in its formulation the following nutrient concentration: 10% of N, 4% of P_2O_5, 7% of K_2O, 0.02% of B, 0.05% of Cu and 0.02% of Mn.

Regarding plant health, two sprays with pyrethroid insecticides and copper oxychloride-based fungicide were conducted during the experimental period. Weeds found were manually removed from treatments without soil coverage.

In this study, total yield and commercial head yield were evaluated, (obtained after removing external leaves with yellowish coloration and/ or burn edges), as well as the water-use efficiency for each treatment (relation between yield and total volume of water used in production). For this purpose, on July 10th 2011, six plants of each experimental plot were harvested, totaling 18 plants per treatment.

After harvesting, the plants were weighted, and in sequence taken to a forced ventilation oven at 65 ºC during 72 h, to achieve constant mass. Fresh and dry mass were determined using a scale of 0.01 g precision.

The experimental data were submitted to variance analysis (ANOVA). When considered significant by the F test, means were compared by the Tukey test at 5% of probability, aiming to verify existence of any significant difference among treatments. All the statistical analysis was conducted with the aid of SISVAR statistical software, 4.6 version (FERREIRA, 2003).

The water-use efficiencies (WUE) of American crisphead lettuce crop, in planting systems with and without soil coverage, were obtained in kg of lettuce fresh mass per m^3 of water applied through irrigation.

RESULTS AND DISCUSSION

Air relative humidity and temperature variations during experiment are shown in Figure 2. It is observed that air average humidity and temperature were 65.3% and 18.3 ºC, respectively. These average values of temperature were considered adequate for lettuce growth (15 and 20 °C), according to SANTANA, ALMEIDA AND TURCO (2009).

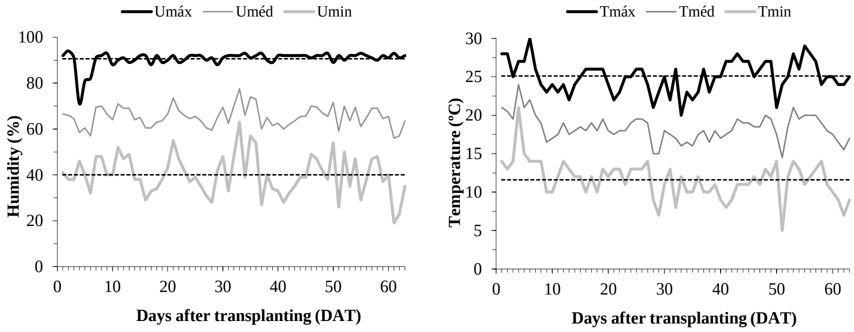

FIGURE 2. Maximum, minimum and average values of air relative humidity and of air temperature inside the greenhouse.

Table 1 displays accumulated values of irrigation water depths applied for different percentages of studied ETc, during experimental period.

TABLE 1. Irrigation water depths (mm) in American crisphead lettuce, cv. Raider-Plus, cultivated in greenhouse and irrigated through pulse and continuous drip irrigation, with and without mulching.

Treatment (% ETc)	Initial depth (mm)	Differentiated depth (mm)	Total Depth (mm)
100-continuous	24	127.32	151.32
100-pulses	24	127.32	151.32
75-pulses	24	95.49	119.49
50-pulses	24	63.66	87.66

The variance analysis (Table 2) identified that there was no significant difference among blocks; however, there was significant effect at 1% of probability in all applied depths, for mulching and for depth x mulching interaction. The non-significant effect among blocks may be due to soil and climate heterogeneity inside the greenhouse.

TABLE 2. Variance analysis summary for commercial yield (CY) and total yield (TY) of American crisphead lettuce grown with or without plastic mulching, and under effect of different water depths via pulse and continuous drip irrigation.

Variation cause	DF	Average Square	
		CY	TY
Blocks	2	0.16^{ns}	3.72^{ns}
Depths (L)	3	38.29^{**}	50.02^{**}
Coverage (C)	1	499.05^{**}	704.49^{**}
L x C	3	81.66^{**}	140.97^{**}
Residue	14	3.26	6.23
CV (%)		6.14	5.43
General Average		32.03	46.03

Significant at 1% (**) of probability; (^{ns}) not significant by F test

Table 3 represents the comparison between averages of commercial and total yields of crisphead lettuce for different irrigation and coverage treatments, according to the Tukey test, at 5% of probability ($p < 0.05$).

TABLE 3. Commercial and total yield averages of crisphead lettuce regarding interaction between factors (coverage x irrigation).

Treatments (% ET_C)	Commercial Yield ($Mg\ ha^{-1}$)		Total Yield ($Mg\ ha^{-1}$)	
	Without coverage	With coverage	Without coverage	With coverage
50-Pulses	19.47 Bb	38.91 Aa	30.04 Bb	54.44 Aa
75-Pulses	31.52 Ab	38.71 Aa	44.75 Ab	53.78 Aa
100-Pulses	28.14 Ab	36.45 Aba	42.16 Aa	50.71 ABb
100-Continuous	30.74 Aa	32.28 Ba	45.50 Aa	46.87 Ba

*Averages followed by the same letter do not differ statistically among themselves, upper casein column and lower case in line, by the Tukey test at 5% of probability.

In treatments without mulching, there was no significant difference of commercial and total yields among treatments for water depth of 100% of ET_c through continuous dripping, as well as treatments in which 100% and 75% of ET_c was applied by pulses. It means that, drip irrigation by pulses, in spite of not incrementing yield, assisted in saving 25% of water without affecting crop yield. Similar results were obtained by ABDELRAOUF et al. (2012) and BAKEER et al. (2009), when comparing continuous dripping with dripping by pulses in potato crop. These authors reported that pulse drip irrigation also enabled savings of 25% of irrigation necessity.

The treatment in which 50% of ET_c was applied without coverage was the one that had worst performance and statistically differed from the others, showing that the water replacement in this treatment was not enough to attend lettuce hydric demands.

Regarding yields obtained by using soil coverage (Table 3), it is verified that greater commercial and total values (38.91 and 54.44 $Mg\ ha^{-1}$) were achieved by the treatment with 50% of depth applied through drip irrigation by pulses. This treatment did not differ statistically from treatments where 75 and 100% of depth was applied through dripping by pulses; however, it differed from that in which 100% of depth was applied through continuous dripping. It is concluded that the interaction between pulse drip irrigation and mulching enabled 50% of water savings.

It is also highlighted that, except from treatment using continuous drip, the use of plastic mulching increased yield if compared to uncovered soil, reinforcing that the interaction of pulse drip irrigation and mulching favors not only yield, but also promote water savings.

Increased yields promoted by soil covering is related to factors like greater weed and soil temperature control, water evaporation reduction, aside from lower leaching and nitrate volatilization (ALMEIDA et al., 2009; ZRIBI; FACI; ARAGÜES, 2011). In general, soil coverage allows improved microbiological conditions and enables a favorable environment for superficial root growth (SÁ et al., 2010); and, as pulse irrigation provides water in greater frequency within this layer, it is likely to happen yield enhancement.

WARNER, HOFFMAN and WILHOIT (2009), when comparing continuous and pulse drippings, also certified that the second was able to reduce water use in about 40%, without affecting tomato quality and production.

The variance analysis summary of water-use efficiency for commercial and total yields is found in Table 4. Through these findings, it is noteworthy mention that the applied water depths, soil coverage, and the interaction between irrigation depths and mulching affected significantly ($p<0.01$) water-use efficiency.

TABLE 4. Variance analysis summary of water-use efficiency for American crisphead lettuce commercial (WUE CY) and total (WUE TY) yields, with and without plastic mulching, and under effect of different irrigation water depths through pulse and continuous drip irrigation.

Variation Causes	DF	Average square	
		WUE CY	WUE TY
Blocks	2	0.35^{ns}	4.95^{ns}
Depths (L)	3	224.12**	438.29**
Coverage (C)	1	450.06**	672.04**
L x C	3	125.43**	230.64**
Residue	14	2.45	5.82
VC (%)		5.97	6.43
General Average		26.21	37.52

Significant at 1% (**) of probability; (^{ns}) not significant by F test

Table 5 demonstrates the average values of water-use efficiency at harvesting, considering different water depths applied continuously (control) and by pulses in cultivations with and without soil coverage use.

TABLE 5. Water-use efficiency (WUE) for American crisphead lettuce commercial and total yields, regarding factors interaction (coverage x irrigation).

Treatments (% ET_C)	Depth (mm)	WUE Commercial Yield (kg m^{-3})		WUE Total Yield (kg m^{-3})	
		Without coverage	With coverage	Without coverage	With coverage
50-Pulses	89.66	22.21 Bb	44.15 Aa	34.27 ABb	62.10 Aa
75-Pulses	120.49	26.39 Ab	32.59 Ba	37.47 Ab	45.03 Ba
100-Pulses	151.32	18.59 Bb	24.09 Ca	27.86 Cb	33.51 Ca
100-Continuous	151.32	20.32 Ba	21.34 Ca	30.07 BCa	30.97 Ca

* Averages followed by the same letter do not differ statistically among themselves, upper case in column and lower case in line, by the Tukey test at 5% of probability.

It is noted that, without mulching, the treatment that obtained the best result, in terms of water-use efficiency, for commercial as well as total yield, was the one with 75% of ETc applied through dripping by pulses. With coverage use, the greatest water-use efficiency (44.15 and 62.10 kg m^{-3}, commercial and total yield, respectively) was obtained in treatment that 50% of ETc was applied via drip irrigation by pulses. It was also verified that as irrigation depths increased, there was a drop in water-use efficiency. LIMA JÚNIOR et al. (2010), who noticed that WUE decreased with the increment in applied depth, observed a similar performance in lettuce.

LIMA JÚNIOR et al. (2010), investigating the same cultivar of American crisphead lettuce, using continuous irrigation, observed that uncovered soil reached the maximum value of water-use efficiency of 56.31 kg m^{-3}, with application of water depth of 74.53 mm. Also studying the same cultivar, GEISENHOFF (2008) reported that mulching obtained the maximum value of WUE of 47.44 kg m^{-3} for tension of water in soil of 50.3 kPa.

It is worth mentioning that the best WUE can present a production lower than commercial standard. However, as observed, the interaction of drip irrigation by pulses with coverage resulted in greater production and, consequently, greater water-use efficiency, differently from the studies cited above.

CONCLUSIONS

American crisphead lettuce irrigation via dripping by pulses enabled 25% of water savings in treatment without plastic mulching and 50% of water savings in treatments with plastic mulching, both of which has resulted in increased water-use efficiency.

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