

Full Length Research Paper

Growth and production of a Japanese cucumber crop under pulse irrigation

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Water is the most important production factor in agriculture, since even small restrictions to the water supply can result in decreased productivity. Due to climatic reasons, water supply is limited in many parts of the world, resulting in a need to develop techniques that increase the water use efficiency. Pulse irrigation consists of the application of an irrigation depth, relative to the actual irrigation needed, split throughout the day. The objective of this study was to verify the effects of pulse irrigation on cucumber plants that were either subjected to a water deficit or were sufficiently supplied with water, considering the hypothesis that the application of water during times of greater evapotranspiration demand will promote benefits to the crop in comparison with the continuous irrigation in the early hours of the day. A completely randomised design was used and the treatments were distributed in 3×4 and 4×4 factorial scheme in the first and second cycles respectively. The first factor was the replenishment of the irrigation depth relative to the crop evapotranspiration, while the second factor was the number of pulses; there were a total of 48 and 64 plots in the first and second cycles, respectively. The application of the treatments was started in the vegetative phase and in the reproductive phase for the first and second cycles respectively. It was concluded that smaller irrigation depths than the crop requires can be applied by pulses without resulting in a reduction in the vegetative growth in Japanese cucumber.

Key words: Drip irrigation, water savings, reduced irrigation depth, *Cucumis sativus*, protected environment.

INTRODUCTION

One of the challenges when irrigating is to reconcile increased productivity with the use of diminishing amounts of water. The interest in producing more with less water is warranted as water is a limiting factor for production in various parts of the world (Ali and Talukder, 2008). For

some regions of Brazil, water is considered an economic asset and its use is associated with the collection of taxes through river basin committees (CBH) (Kelman and Ramos, 2005). It is important to perform irrigation management to achieve the greatest productivity per unit

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Table 1. Physical and chemical variables of the soil in the experimental area.

Variable	Value
Soil bulk density (Mg m^{-3})	1.01
Coarse sand content (g kg^{-1})	50.0
Fine sand content (g kg^{-1})	72.60
Silt content (g kg^{-1})	120.60
Clay content (g kg^{-1})	756.80
CaCl_2 Ph	6.00
Organic matter content (g dm^{-3})	8.03
Phosphorous content (mg dm^{-3})	32.41
Potassium content ($\text{cmol}_c \text{ dm}^{-3}$)	0.31
Calcium content ($\text{cmol}_c \text{ dm}^{-3}$)	6.16
Magnesium content ($\text{cmol}_c \text{ dm}^{-3}$)	1.68
Aluminium content ($\text{cmol}_c \text{ dm}^{-3}$)	0
Cation exchange capacity ($\text{cmol}_c \text{ dm}^{-3}$)	11.00
Base saturation (%)	74

of water applied, resulting in reduced costs and environmental impact. The application of water should be judicious, based on measurements of climatic and soil phenomenon, in accordance with the method of irrigation utilised.

The water use efficiency (WUE) can be understood as the relationship between the productivity and the applied irrigation depth (Oliveira et al., 2011). The increase in WUE is interesting if it is associated with acceptable levels of productivity. In other words, the WUE needs to be optimised without incurring decreased productivity. Various irrigation techniques have been investigated in order to increase the WUE, the partial irrigation of the root system and deficit irrigation have both shown promise in this objective, even though these techniques have resulted in lower productivity (Ali and Talukder, 2008).

The relationship between cucumber crop yield and the total irrigation depth follows a quadratic model and it presents a maximum productivity (Oliveira et al., 2011). It is suggested that the excessive vegetative growth arising from the supply of excessive water can result in lower root activity, an increase in disease incidence due to the growth of the canopy and a lower harvest index, calculated by the ratio between the production and total biomass. Thus, the increase in biomass production comes at the cost of increased irrigation depths that can result in a reduction in the water use efficiency (Ali and Talukder, 2008).

Irrigation through pulses enables the reduction of the irrigation depth without reducing the crop yield. In lettuce the replenishment of 75% of the crop evapotranspiration, divided into six pulses with a 50 min interval, resulted in greater water use efficiency and a non-significant difference in yield in relation to a continual replenishment of 100% of the ET_c (Almeida et al., 2015). The pulsed

irrigation also results in a reduction in the irrigation depth required in potato and in the occurrence of emitter blocking (Abdelraouf et al., 2012).

The cucumber (*Cucumis sativus*) has great economic and social importance among the vegetables grown by Brazilian agribusiness. The Brazilian annual cucumber production exceeds 200.000 t. Furthermore, cucumber has nutraceutical properties and can be used in cosmetics and medicines (Carvalho et al., 2013).

Greenhouse farming has advantages comparing to field farming. Growing in a protected environment allows controlling adverse conditions of climate and incidence of diseases and pests (Streck et al., 2003). However, greenhouse crop growth hinders access of pollinators to the crop. Japanese cucumber is a partenocarpic crop and it is well adapted to greenhouse conditions because it does not require pollination (Carvalho et al., 2013).

The hypothesis of this work was that the splitting of the application of irrigation depth throughout the day would result in an increase in cucumber growth, yield and WUE, since the water application would be conducted for a longer period during the day and, consequently, during the moments of highest evapotranspiration demand.

The objective of this work was to verify the effects of pulsed irrigation, irrigation depth and its interactions on Japanese cucumber growth and production.

MATERIALS AND METHODS

The experiment was conducted in a protected environment at the Irrigation Technical Center (CTI) of the Department of Agronomy of the State University of Maringá (UEM), located in Maringá, PR, between the months of 07/2014 and 01/2015. The soil analysis (Table 1) was performed at the Laboratório Rural de Maringá.

The partial soil water retention for the layer 0 to 0.3 m (Equation 1) was determined according to Almeida et al. (2010) and Tavares et al.

(2008). The water potential measurements were made by nine tensiometers installed at a depth of 0.15 m, while soil moisture estimates were made using nine Time Domain Reflectometer (TDR) probes installed at the same depth with an inclination of 45°. Moistening of the soil was accomplished through continuous irrigation for three days and readings were taken six hours after cessation of the irrigation. Taking into account Equation 1, it was calculated that to raise the water potential from -30 to -10 kPa it was necessary to apply a 24 mm irrigation depth to the 0 to 0.3 m layer. It justified disregarding losses through deep percolation in the water balance equation, since the greatest irrigation depth applied on the same day was equal to 20.1 mm.

$$\theta = 0.2191 + \frac{0.4334 + 0.2191}{\left[1 + (0.1738|\Psi|)^{0.6911}\right]^{1.9320}} \quad (1)$$

Which are θ = soil moisture ($\text{m}^3 \text{m}^{-3}$), and Ψ = water potential (kPa). The saturation pressure (e_s) was calculated every 30 min from 06:00 until 21:00. The calculation of e_s (Equation 2) was based on the recommendation by Allen et al. (1998).

$$e_s = 0.618 \cdot \exp^{\frac{17.27T_{\text{med}}}{237.3 + T_{\text{med}}}} \quad (2)$$

Which are T_{med} - mean of the daily mean temperatures of each time from all the days of irrigation ($^{\circ}\text{C}$). The actual vapour pressure (e_a) for each time was calculated through Equation 3.

$$e_a = \frac{\text{RH}_{\text{min}} \cdot (0.618 \cdot \exp^{\frac{17.27T_{\text{max}}}{237.3 + T_{\text{max}}}}) + \text{RH}_{\text{max}} \cdot (0.618 \cdot \exp^{\frac{17.27T_{\text{min}}}{237.3 + T_{\text{min}}}})}{2} \quad (3)$$

Which are RH_{min} - mean of the minimum relative humidity values expressed in decimals; RH_{max} - mean of the maximum relative humidity values expressed in decimals; T_{max} - mean of the highest temperatures ($^{\circ}\text{C}$); T_{min} - mean of the lowest temperatures ($^{\circ}\text{C}$).

The preparation of Japanese cucumber seedlings, cv. Hokushin, was performed in trays with 162 cells. A row of six seedlings spaced 0.5 m apart were planted in each plot, which resulted in the spacing 1.0 × 0.5 m. The planting was conducted when the seedlings had their first true leaf completely expanded. The nitrogen and potassium fertilisations were conducted every two weeks according to Ribeiro et al. (1999). The nutrient sources utilised were urea and potassium chloride.

In each plot a polyethylene irrigation pipe 3 m in length and 16 mm in diameter with self-compensating drippers *on line*, with a flow rate of 8 L h⁻¹ spaced 0.2 m apart. In addition, a regulator was installed at the start of the irrigation pipe, which allowed the irrigation of each plot individually. The flow of each emitter in the experimental area was measured to obtain the Emission Uniformity (Keller and Karmeli, 1975), whose value was equal to 94%. A schematic map of the experimental area is represented in Figure 1.

The calculation of the reference evapotranspiration (ET_o) was performed through the Penman-Monteith-FAO equation on a daily basis (Allen et al., 1998): The meteorological parameters from within the protected environment were monitored through a Campbell automatic station, adjusted to collect data every 2 s and provide the average of each variable at 30 min intervals. The data were recorded using a datalogger CR1000. The crop coefficient (K_c) was estimated using the equation adjusted by Blanco and Folegatti (2003).

Irrigation management of the area was conducted using the

water balance method. The wall, 0.5 m in height, that demarcated the protected environment, the presence of a mesh with a pore size of 40 mesh and the growing conditions with raised beds permitted the surface runoff, the water flow in the soil and the precipitation to be disregarded. For this reason, Equation 4 was used for the water balance and can be expressed as:

$$\Delta A = IETc \quad (4)$$

Which are ΔA = variation in the water storage of the 0 to 0.3 m layer (mm per day); I = irrigation depth (mm per day); ET_c = crop evapotranspiration (mm per day).

Before the application of the treatments, the soil in the experimental area was irrigated until the humidity was near field capacity in the layer 0 to 0.30 m deep. From this point on, irrigation was conducted three times per week; these were designed to replenish the deficit derived from evapotranspiration according to the treatments. The irrigation water utilised was sourced from a semi artisanal well and exhibited an electrical conductivity between 0.2 and 0.4 dS m⁻¹.

A completely randomised design was used and the treatments were distributed in a factorial design (Table 2). Each treatment had four replications, totalling 48 and 64 in the first and second cycle respectively. Each plot consisted of six plants, and the response variables were measured for the four central plants.

In the first cycle, the application of the treatments started 25 days after planting (DAP), when at least 50% of the plants had two completely expanded leaves. In the second cycle, the treatments were applied 35 DAP, when the plants had 1.80 m, at least 50% of the plants had five completely opened leaves and one flower on the main branch.

The irrigation time of the day was the same to all treatments in each cycle and it was calculated considering the replenishment of water storage deficit in the plot was provided by the drippers, according to the equation:

$$T_i = \frac{DA}{qn} \quad (5)$$

Which are T_i = irrigation time of the day (min); D = water storage deficit in the 0 to 0.3 m layer (mm); A = surface area of the plot (m^2); q = flow rate of the dripper (L min⁻¹); n = number of drippers per plot.

The pulse irrigation time was calculated considering the IDRE and number of pulses according to the treatment. Therefore, treatments with higher number of pulses had smaller pulse irrigation time. Similarly, treatments with higher IDRE had higher pulse irrigation time, according to the equation:

$$T_p = T_i \frac{\text{IDRE}}{P} \quad (6)$$

Which are T_p = pulse irrigation time (min); IDRE = irrigation depth replenishment relative to the crop evapotranspiration expressed in decimals; P = number of pulses;

In the first cycle the plant height and number of nodes 61 days after planting (DAP), the diameter of the stem (mm) 100 DAP and the fruit mass (g) produced up to 100 DAP were measured. In the second cycle, the total fruit mass (g) produced up until 83 DAP and root mass (g) after the end of the cycle was measured. The water use efficiency (g mm^{-1}) was calculated as the ratio between the mass of harvested fruits in the plot (g) and the total irrigation depth (mm) in the two cycles.

The root samples were obtained using a sampler 0.20 × 0.25 × 0.30 m. The soil volume collected was washed in a 2 mm sieve to separate the roots. The root samples of each plant were placed in

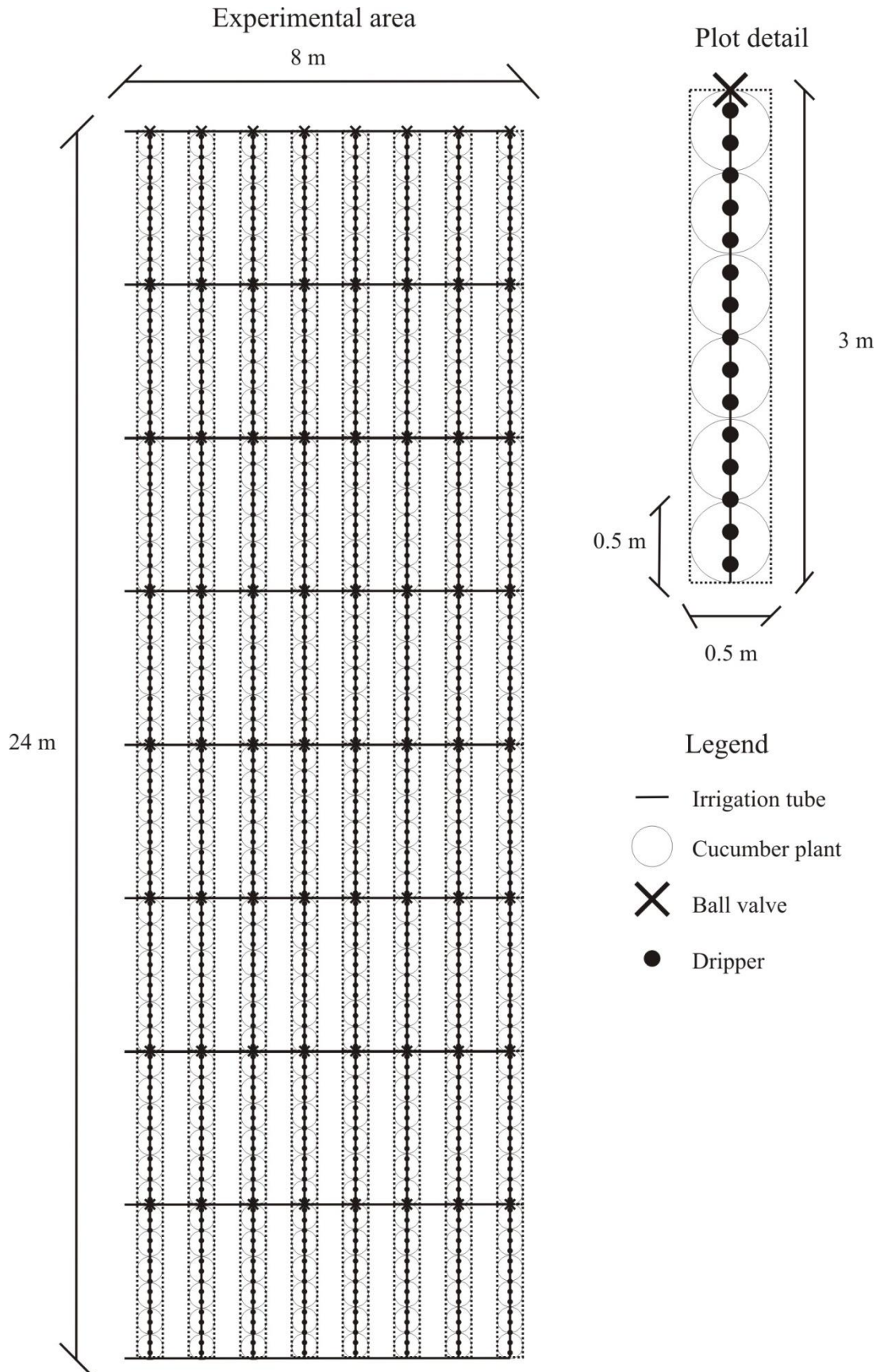


Figure 1. Esquematic map of the experimental area and a plot detail.

Table 2. Description of first and second cycle treatments.

Cycle	IDRE ¹ (%)	Number of pulses	Treatment	Interval between pulses (min)	Relative pulse irrigation time ² (%)	Time interval of first pulse application of the day ³
1	50	1	1T50-1	-	100	09 h 15 min - 10 h 00 min
		2	1T50-2	240	50	08 h 35 min - 09 h 00 min
		4	1T50-4	120	25	08 h 15 min - 08 h 35 min
		8	1T50-8	60	12,5	08 h 00 min - 08 h 15 min
	75	1	1T75-1	-	100	09 h 15 min - 10 h 00 min
		2	1T75-2	240	50	08 h 35 min - 09 h 00 min
		4	1T75-4	120	25	08 h 15 min - 08 h 35 min
		8	1T75-8	60	12,5	08 h 00 min - 08 h 15 min
	100	1	1T100-1	-	100	09 h 15 min - 10 h 00 min
		2	1T100-2	240	50	08 h 35 min - 09 h 00 min
		4	1T100-4	120	25	08 h 15 min - 08 h 35 min
		8	1T100-8	60	12,5	08 h 00 min - 08 h 15 min
2	75	1	2T75-1	-	100	09 h 40 min - 10 h 40 min
		2	2T75-2	320	50	08 h 45 min - 09 h 20 min
		4	2T75-4	160	25	08 h 20 min - 08 h 45 min
		8	2T75-8	80	12,5	08 h 00 min - 08 h 20 min
	100	1	2T100-1	-	100	09 h 40 min - 10 h 40 min
		2	2T100-2	320	50	08 h 45 min - 09 h 20 min
		4	2T100-4	160	25	08 h 20 min - 08 h 45 min
		8	2T100-8	80	12,5	08 h 00 min - 08 h 20 min
	125	1	2T125-1	-	100	09 h 40 min - 10 h 40 min
		2	2T125-2	320	50	08 h 45 min - 09 h 20 min
		4	2T125-4	160	25	08 h 20 min - 08 h 45 min
		8	2T125-8	80	12,5	08 h 00 min - 08 h 20 min
150	1	2T150-1	-	100	09 h 40 min - 10 h 40 min	
	2	2T150-2	320	50	08 h 45 min - 09 h 20 min	
	4	2T150-4	160	25	08 h 20 min - 08 h 45 min	
	8	2T150-8	80	12,5	08 h 00 min - 08 h 20 min	

¹Irrigation depth replenishment relative to the evapotranspiration; ²Ratio between the pulse irrigation time and total irrigation time of the day; ³that is first irrigation pulse of 1T50-8, 1T75-8 and 1T100-8 treatments were applied between 08 h 00 min and 08 h 15 min.

paper bags and dried at 60°C until achieving a constant weight. Multiple regressions were performed when the interactions between number of pulses and IDRE were significant ($p < 0.05$). The selection of the variables was performed using the Stepwise procedure, with $p < 0.10$ to enter a variable to the model and $p < 0.05$ to keep a variable in the model. The statistical analysis and graphs were made using SISVAR (Ferreira, 2008) and Sigma Plot 11.0 software.

RESULTS

The majority of the maximum daily temperatures showed values higher than the optimum maximum temperature, while the minimum daily temperatures measured in the first cycle were below the optimum minimum temperature (Figure 2A and B). The mean daily temperatures observed in the second cycle were, on average, higher than the first cycle, and showed values in the optimum temperature range (Carvalho et al., 2013). There were no

frosts during the experimental period. It was observed that the pressure deficit tended to increase up to 15:00 during the first cycle (Figure 2C) and up to 13:30 during the second cycle (Figure 2D). The irradiance was greater close to 12 h 00 min during the two cycles.

The difference between the accumulated water depths in the treatments regarding the irrigation depth replenishment relative to the crop evapotranspiration (IDRE) tended to increase with the temperature (Figure 3). However, there was no variation of accumulated applied irrigation depth between the levels of the factor number of pulses at the same level of the factor IDRE. Twenty-seven irrigations were performed during the first cycle, totalling 120.5; 180.7 and 240.9 mm of water applied for the levels 50, 75 and 100% of the factor IDRE, respectively. In the second cycle, 20 irrigations were performed, totalling 175.6; 234.1; 292.7 and 351.2 mm of water applied for the levels 75, 100, 125 and 150% of the

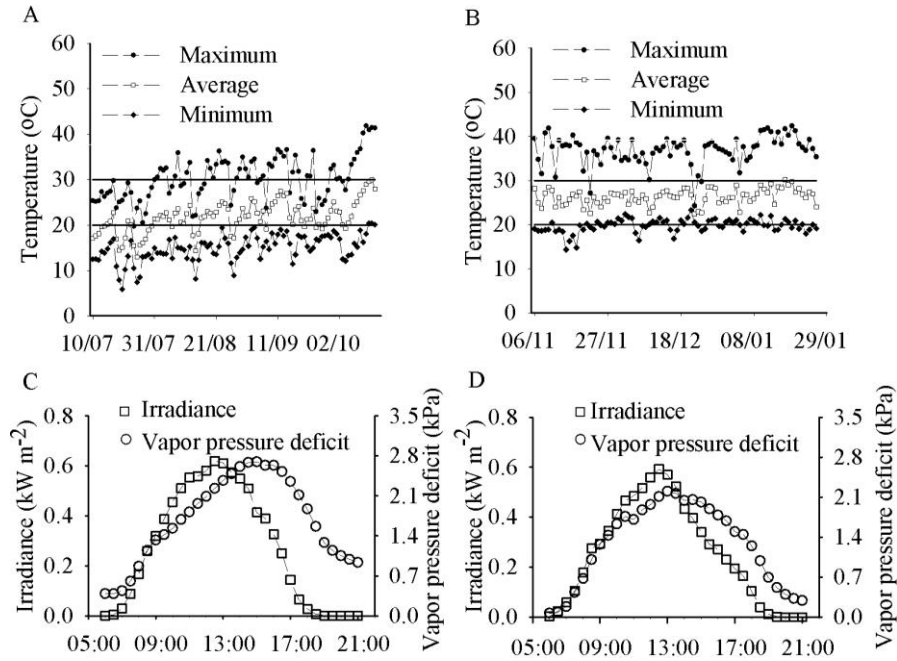


Figure 2. Temperatures within the protected environment during the first (A) and the second (B) cycles in comparison with the optimum range for the development of the crop, and average values for pressure deficit and irradiance on irrigation days during the first (C) and second (D) cycles.

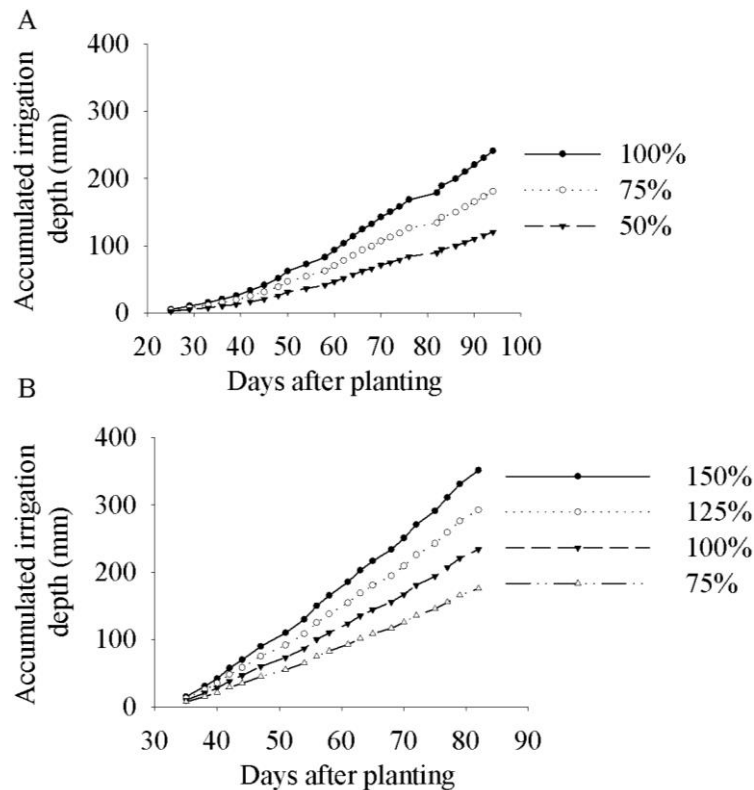


Figure 3. Accumulated irrigation depth in the treatments relating to the replenishment of the irrigation depth relative to crop evapotranspiration in the first (A) and second (B) cycles.

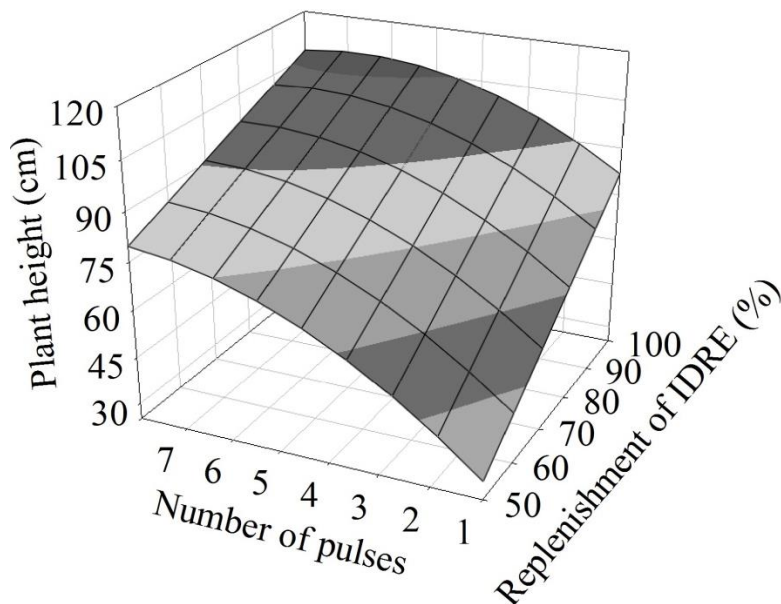


Figure 4. Influence of the number of pulses and of the replenishment of the irrigation depth relative to the ET_c on plant height in the first crop cycle (07/2014 to 10/2014).

factor IDRE, respectively.

For the same level of IDRE, the variation of the plant height with number of pulses (Figure 4) occurred in a quadratic form. Under water deficit conditions, that is, with the replenishment of 50% IDRE, there was an increase from 30.7 to 79.7 cm, that is, 160% with the application split over the day. Under conditions of adequate water supply, that is, with the replenishment of 100% of the IDRE, there was an increase from 81.8 to 107.4 cm, that is, 31%. The model suggests that, despite the fact that splitting the application of the irrigation depth into various pulses during the day resulted in increased plant height independently of the IDRE response, the effect was more notable under water restriction conditions.

Considering the replenishment through a single pulse, the increase in the application of the irrigation depth from 50 to 100% of the ET_c resulted in an increase from 30.7 to 81.7 cm, that is, a 166% increase in plant height. When considering the application through eight pulses, the increase in irrigation depth resulted in an increase in plant height of 79.7 to 107.4 cm, that is, 35%. This analysis allows us to conclude that the increase in irrigation depth shows a greater effect on plant height when applied in instalments throughout the day.

Height of the plants irrigated with 50% of the IDRE through eight pulses was equal to 79.7 cm, while plants irrigated with 100% of the IDRE through a single pulse were 81.7 cm. This means that the use of half of the necessary irrigation depth applied through instalments resulted in plant heights similar to the plants with 100% of

the necessary water needs supplied through a single pulse.

Effect of the splitting of the water application on number of nodes and stem diameter was not significant. On the other hand, the data relating to the IDRE levels could be significantly fitted to a linear model. It was expected that the growth variables would increase with the replenishment of the soil moisture up to 100% of the crop needs (Figure 5).

Fruit mass harvested in the first cycle was significantly affected by the studied factors (Figure 6). Splitting application of 100% of the IDRE into 7 pulses provides the largest predicted value for fruit mass. The same irrigation depth applied through eight pulses results in a lower fruit mass of 0.8%. For this reason, it is possible to consider that the increase in the number of pulses for values greater than the optimum value, within the interval relating to the levels of the factor number of pulses, showed a low significant effect on the fruit mass harvested.

It was observed that the level of the factor number of pulses showed an effect on the fruit mass, which was described by a polynomial model. When replenishing 50% of the IDRE, there was a 163% increase in the fruit mass with the increase in the number of pulses, while at the same time the 100% replenishment of the IDRE caused an increase equal to 30% (Figure 6). The analysis allowed us to conclude that the increase in production with irrigation by pulses is greater under conditions of water restrictions than under adequate water supply conditions.

The increased replenishment of the IDRE resulted in a linear increase in the fruit mass (Figure 6). For the

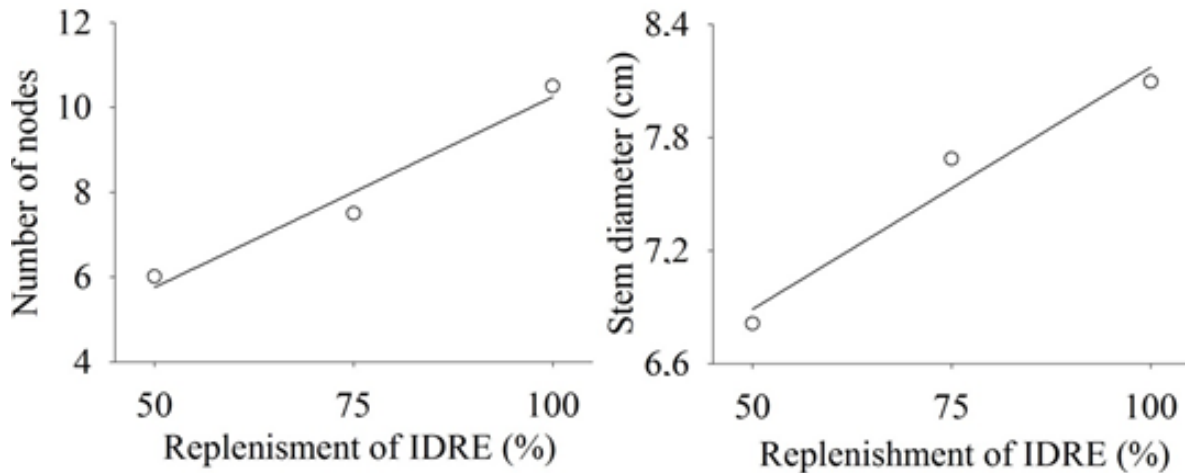


Figure 5. Influence of the number of pulses and of the replenishment of the irrigation depth relative to the ETc on number of nodes and stem diameter in the first crop cycle (07/2014 to 10/2014).

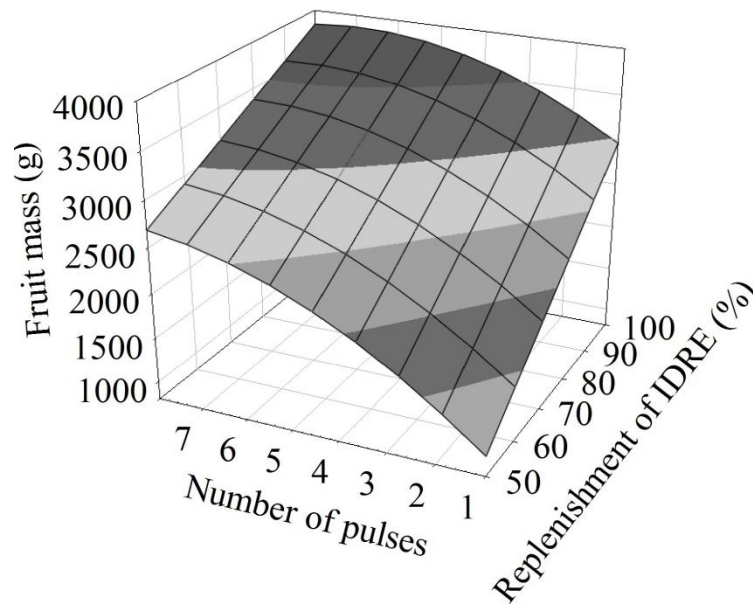


Figure 6. Influence of the number of pulses and of the replenishment of the irrigation depth relative to the ETc on fruit mass in the first crop cycle (07/2014 to 10/2014).

irrigations through one and eight pulses, the increases were 190 and 43%, respectively, which allowed us to conclude that the increase in irrigation depth was more effective if conducted through a single irrigation pulse. Plants subjected continuously to water deficit tend to reduce their cycle and productivity (Ambachew et al., 2014).

Plants with 50% of the IDRE split into eight pulses and those with 100% of the IDRE applied through one pulse were estimated to produce 2689 and 2964 g of fruit respectively, that is, the pulse irrigation with deficit resulted in less production in relation to irrigation that

supplied all the water needs of the crop through a single pulse.

In Figure 7 it was observed that number of pulses had a quadratic effect on the WUE of the plants in the first cycle. With the replenishment of 50 and 100% of the IDRE, the increases were 158 and 23% respectively, showing that the splitting of the water application has a greater effect under water restriction conditions.

For the irrigation through one pulse, increasing the replenishment of the IDRE increased the WUE by 42%. This also suggests that the water deficit results in a water

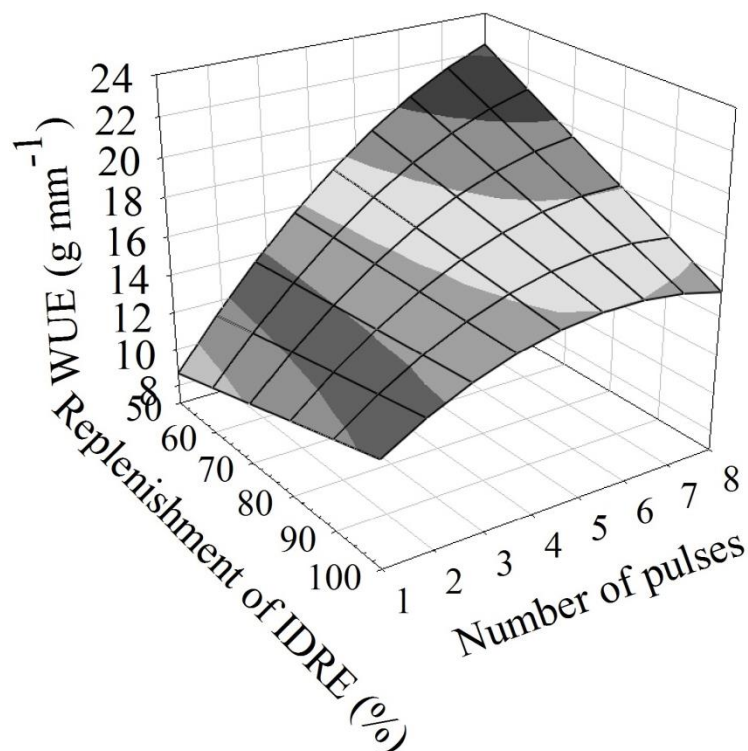


Figure 7. Influence of the number of pulses and of the replenishment of the irrigation depth relative to the ETC on water use efficiency in the first crop cycle (07/2014 to 10/2014).

Table 3. Correlation matrix between the response variable of the first cycle.

Parameter	Plant height	Fruit mass	Number of nodes	Stem diameter
Plant height	1.00	0.82	0.49	0.43
Fruit mass	-	1.00	0.52	0.41
Number of nodes	-	-	1.00	0.66
Stem diameter	-	-	-	1.00

balance favourable to the vegetative growth and maintenance of turgor in detriment to the production of fruit. One of the probable causes of the detriment to production is the slower growth and emission of branches under such conditions.

When considering the water application split into eight pulses, the increased replenishment of the IDRE resulted in linear decrease in WUE by 32%. The greatest WUE was observed with the replenishment of 50% of the IDRE through eight pulses. This suggests that the plant, despite showing reduced growth characteristic with such a level of replenishment, presented a balance of water use favourable to the production of fruit in detriment to vegetative growth. Plants that had their water needs met through the application of eight pulses showed more vegetative growth, which could result in balance of water

use more favourable to the maintenance of the vegetative part.

The variables plant height and fruit mass in the first cycle could be significantly fitted to similar multiple regression models, which suggests the existence of a correlation between them. In the correlations matrix (Table 3), it was found that the correlation between the above variables is greater than between the others, which suggests that the main branch height is related to the vegetative vigour of the plant, greater emission of branches and, consequently, female flowers from which the fruit originate. Treatments were applied later in the second cycle than in first cycle in order to prevent effect of reduced growth on production.

The water deficit presented a greater effect on the reduction of the productivity when imposed on the

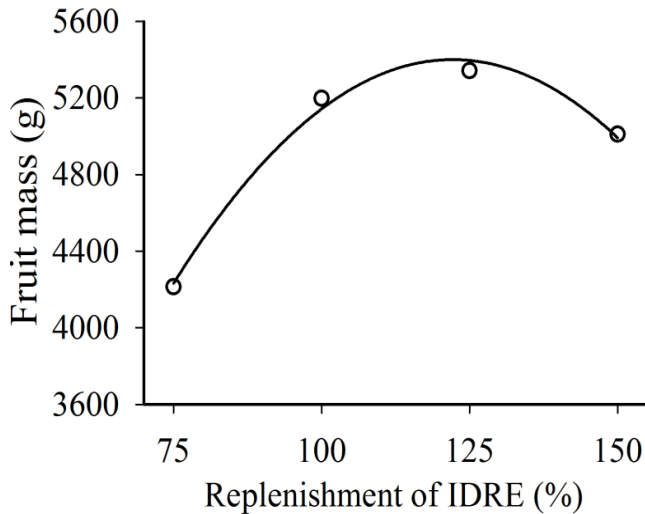


Figure 8. Influence of the replenishment of the IDRE on the fruit mass in the second cycle (12/2014 to 01/2015).

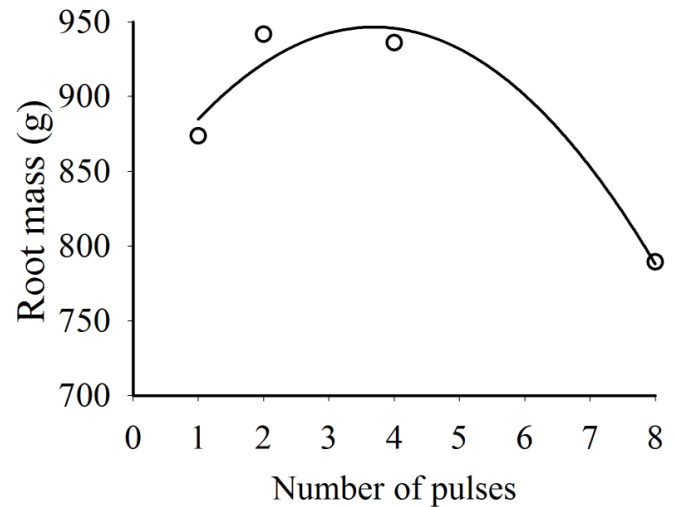


Figure 9. Influence of the number of pulses on root mass in the second cycle (12/2014 to 01/2015).

reproductive stages of the crop. However, such effects are milder if the deficit occurs in the vegetative stage. Therefore, it is feasible as a strategy to conserve water, at least in some crops, by irrigating with less irrigation depth than is required during the vegetative stages and irrigating with proper irrigation depth during the reproductive stages (Ambachew et al., 2014). In the second cycle, the treatment applications commenced when all the plants had the same height, with completely open flowers on the main branch.

The fruit mass measured in the second cycle was significantly affected only by the factor replenishment of IDRE (Figure 8). The greatest value for fruit mass is obtained through the replenishment of 129% of the IDRE. The crop of Japanese cucumber grown in the protected environment presented a variable production in relation to the replenishment of the irrigation depth in the soil, with both the deficit and the excess being detrimental (Oliveira et al., 2011).

Root mass was significantly affected by the splitting of the irrigation (Figure 9). Root mass obtained by 4 pulses is higher than that obtained by any other number of pulses.

DISCUSSION

The growth of the plant tissue is related to cellular expansion and division. The cellular expansion is the physiological process most affected by water deficit. As the severity of the deficit increases, other processes related to cellular division are affected, such as the synthesis of cell walls and proteins (Taiz and Zeiger, 2013). It is likely due to these reasons that the plant height was lower with the 50% replenishment of IDRE in

relation to the complete irrigation.

Pulse irrigation with deficit resulted in a reduction in water losses not associated with production, such as deep drainage and evaporation. For this reason, the ratio between the irrigation depth absorbed by the roots and the irrigation depth is greater in the pulse irrigation with deficit than in the pulse irrigation with 100% of ET_c . This result is associated with lower soil moisture levels, which shows that under such humid conditions, the roots are conditioned to absorb water at lower water potentials. The pulse irrigation with deficit is a promising technique for increasing the efficiency of irrigation (Phogat et al., 2013).

The water deficit is associated with the reduction of turgidity plants, the reduction of nutrient absorption and stomatal closure (Allen et al., 1998), while excess water can cause nutrient leaching and reduce oxygen availability to the roots, which can damage processes related to respiration and trigger cell death (Colmer, 2003). To achieve the optimal development of the crop, the porosity of the soil should be filled with air and water in a proportion that permits the water and aeration needs of the crop to be met.

Drip irrigation is designed to maintain soil moisture, in the layer explored by the root system, at optimal levels for the crop (Frizzone et al., 2012). The reduction of the water depletion period in the soil is beneficial for the development of the crop (Araújo et al., 2012). Further to this, daily irrigation maintains relatively stable soil moisture, which results in an increase in the emission of fine roots and cucumber crop growth (Liang et al., 2014). However, it would be more suitable to analyse the benefits of maintaining the moisture levels while taking into account the times of greatest transpiration demand.

The application through a single pulse occurred for a period of 45 min, while the irrigation through eight pulses occurred intermittently for a period of 7 h 00 min and 09 h 30 min in the first and second cycle respectively. It is likely that the intermittent water application maintains the water potential values in the surface layer of the soil at a relatively high level, resulting in water absorption during the periods of high demand with greater ease. On the other hand, irrigation through a single pulse allowed the decrease in water potential values throughout the day due to the water interaction time with the soil matrix. The distribution of the water in the soil results in greater energy expenditure for absorption during the periods of greater vapour pressure deficit.

The cucumber crop evapotranspiration in the protected environment is related to the air temperature, vapour pressure and solar radiation (Zhang et al., 2010). The vapour pressure deficit includes the effects of the three variables in evapotranspiration, because of this the actual vapour pressure and air temperature are used to calculate it, both of which are influenced by solar radiation.

The intensity of the application in the drip irrigation is, frequently, greater than the infiltration capacity of the soil at the point of the drip. As a result of the irrigation in these conditions, there is an accumulation of water on the surface of the soil in the region close to the dripping point and an elevation of the moisture up to saturation. Once the water application has ended, the soil water tends to distribute due to the water potential gradient. The wet bulb volume tends to increase at the same time as the water potential tends to diminish, which results in a reduction in the water potential gradient. The wet bulb expansion ends when the water potential gradient is not sufficient.

During the bulb formation process, albeit temporarily, water is held to high water potentials. For this reason, it can be absorbed more easily by the plants. Irrigation by pulses allows the water in the layer relating to the depth of the effective root system to stay longer at high water potentials, favouring the absorption during periods of higher vapour pressure deficit. In other words, the water is in a higher energy state in the soil during times of increased demand for absorption.

Conclusions

Water is the most important production factor in agriculture and its scarcity is a reality in many parts of the world. Irrigation new strategies must be researched in order to reduce the water consumption without reducing productivity. Pulse irrigation has the potential to save about half irrigation water in greenhouse. The results showed that the splitting of the irrigation is advantageous if carried out before cucumber plants reach the top wire

of the staking. Plants irrigated with half of the irrigation depth through eight pulses throughout the day tended to grow and produce to a similar extent as plants with 100% of the irrigation depth required through a single pulse. However, pulse irrigation presents no advantages if initiated when Japanese cucumber plants reach the top wire of the staking.

Conflict of Interests

The authors have not declared any conflict of interests.

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