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Growth and yield traits of pickling cucumber plants to measure the impact of different irrigation management practices

Fernando Soares de Cantuário[1], Leandro Caixeta Salomão[1], Carmen Rosa da Silva Curvêlo[1], João de Jesus Guimarães[2], José Magno Queiroz Luz[3], Luiz Leonardo Ferreira[4], Alexandre Igor Azevedo Pereira[1]*

[1]Horta Field Lab, Instituto Federal Goiano, Campus Urutaí, GO, Brasil
[2]Departamento de Engenharia Agrícola, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, SP, Brasil
[3]Instituto de Ciências Agrárias, Universidade Federal de Uberlândia, Uberlândia, MG, Brasil
[4]Departamento de Agronomia, UNIFIMES, Mineiros, GO, Brasil

Abstract

Cucumber (*Cucumis sativus* L) is mostly cultivated by family-based farmers worldwide and processed to pickles by small to mid-sized industries generating employment and income. But irrigation management needs better investigation for adapting adequate sustainable practices. The rational use of irrigation water still has been neglected nowadays, but can improve cucumber production. The objective was to evaluate different irrigation levels on growth and yield parameters of the Amour F_1 cucumber hybrid through time under greenhouse. Treatments consisted of five irrigation levels (amounts of water applied of 62, 93, 124, 155 and 186 mm), ranging from water stress to excess water. The experimental design was randomized blocks, with four replications. Vegetative growth and yield showed different responses to the irrigation levels. Plant height and internode length were less influenced by the irrigation levels, throughout the time, than stem diameter and root length. Cucumber yield was low with 62 mm and 93 mm, higher with 124 mm irrigation, and delayed in time at 155 mm and 186 mm. Water excess (186 mm) was not beneficial for pickling cucumber plants, and the amount of 124 mm was satisfactory for their development and yield. The results of this study may allow adoption of sustainable irrigation practices with no waste of agricultural water, a scarce resource worldwide.

Keywords: Cucurbitaceae, Greenhouse, Water, Water Excess, Water Deficit.

Introduction

Pickling cucumber, *Cucumis sativus* L. (Cucurbitaceae), processed and marketed by industries, generates employment and income worldwide, including, in developing countries. Industries established in the south of Brazil aimed to adapt their pickling cucumber production system in more central areas of the country, where the Brazilian Savanna biome (Cerrado type) predominates. Purchase and sale contracts prior to planting with small and medium sized farmers guarantee commercialization and processing. The edaphoclimatic characteristics of the Cerrado are favorable for plant development, such as soybean, bean, cotton, tomato, potato, onion and garlic because, among other factors, the abundance of water for irrigation (Klink et al. 2005).

Technologies as greenhouses, drip irrigation, fertirrigation, grafts and mulching (Yaghi et al. 2013) allow high cucumber yields and fruit quality. Drip irrigation is been gradually adopted by vegetable crop producers in Goiás state, Brazil. Limited technical-scientific information, regarding irrigation management in cucumber plants reduces their full genetic potential in central areas of Brazil. In some cases, the lack of knowledge about irrigation management prevents farmers to supply sufficient cucumber fruits to industries.

Cucumber plants, as other vegetables, do not tolerate water stress or excess, because approximately 85% of its root zone is up to 30 cm below the soil surface (Randall and Locascio, 1988). Negative effects of water shortage or excess were reported for *Cucumis* species (Oliveira et al. 2011). Irrigation systems should provide enough water in the root zone while avoiding nutrient leaching to deeper soil layers (Blanco and Folegatti, 2001). This problem occurs in greenhouses due to soil salinization by excessive fertilizers and water use for cucumber growth, development and yield (Blanco et al., 2002).

Development of cucumber plant through the time (age-dependent analysis) must be investigated to know fertilizer use, cultural practices and harvesting (Espínola et al., 2001). Plant responses to different irrigation levels can also be incorporated to an age-dependent analysis perspective. The pickling cucumber plant has relatively short cycle and requires continued visual monitoring to adopt cultural practices, reflecting high yields. The monitoring of plant height, stem diameter and internodes length may indicate the correct management of cucumber plants with direct relationship with yield (Kahlen and Chen 2015). We investigated growth and yield parameters of pickling cucumber plants (Amour F_1 hybrid) subjected to different irrigation water levels through the time, and.

Results and Discussion

Greenhouse climatic conditions

The temperature (mean 28.25ºC) and relative humidity (mean 57%) were measured during our experimental procedures (Fig. 1), confirming the satisfactory climatic conditions for the cucumber growth, because no symptoms of temperature-dependent disorders were observed. Cucumber plants under unfavorable abiotic conditions, such as temperature and relative humidity, may encounter reduced number of female flowers, delay in fruit growth and symptoms of leaf mineral disorders (Yaghi et al., 2013). A better control of climatic variables in greenhouse can explain the fact that most pickling cucumber parthenocarpic hybrids (such as Amour F1 hybrid) are suggested to explored under protected cultivation. Once abiotic factors are adverse, the genetic potential of a given cucumber cultivar may be underexploited leading to a reduced plant yield by up to 46.3% (Reis et al., 1991).

Cucumber plant height

Cucumber plant height was similar among different irrigation levels at eight (F= 2.92, *P*= 0.06) and 15 DAT (F= 2.61, *P*= 0.07) but differed along the other time intervals (Fig. 2a). Higher plants were observed from 22th DAT until the last evaluation (64 DAT) with 155 mm level irrigation (Fig. 3a), but lower with 62 mm at the same time interval. In this case, linear regression models were the best fitted that helped observations of the plant height behavior according to the time intervals and treatments (Fig. 3a). Plant height regression equations and coefficients were 62 mm ($y= -0.39 + 0.55x$ and $R^2= 0.99$), 93 mm ($y= -0.49 + 0.60x$ and $R^2= 0.99$), 124 mm ($y= -0.48 + 0.60x$ and $R^2= 0.98$), 155 mm ($y= -0.52 + 0.64x$ and $R^2= 0.99$) and 186 mm ($y= -0.40 + 0.57x$ and $R^2= 0.98$).

The linear growth in height of cucumber plants over the time interval (Fig 2a) was similar to that observed for the cucumber cv. Hokushin, grafted on *Curcubita* spp., Excite-Ikki hybrid under different salinity and irrigation levels (Blanco et al., 2002). The maintenance of an irrigation depth up to 20 DAT can explain the lack of treatment effect in both eight and 15 DAT time intervals. However, irrigation level effects appeared from 22 DAT can confirm the great sensitivity of this plant to water deficit. Low water levels (62 mm) may have impaired cell division processes, responsible for plant growth (Anjun et al. 2011). Increasing differences with plant age can be explained because the different irrigation levels were applied continuously during the cucumber plants life-cycle.

Cucumber stem diameter

Stem diameter values were almost identical in more than half of the whole-time interval evaluated, regardless of the irrigation levels (Fig. 2b). The effect of the irrigation levels was observed at 15 (F= 3.10, *P*= 0.04), 22 (F= 5.97, *P*= 0.00), 29 (F= 3.74, *P*= 0.02), 57 (F= 16.19, *P*= 0.00) and 64 DAT (F= 25.07, *P*= 0.00) (Fig. 2b). Cubic polynomial regression models had the best fit to observe cucumber stem diameter behavior (Fig. 3b). Stem diameter was increased at 155 mm until the 22th DAT with stabilization between the 29th and 50th DAT. A new stem diameter growth from 57th to 64th DAT was observed (Fig. 3b). A stabilization was occurred between the time intervals of 29 and 50 DAT. Stem diameter growth performance was clearly less evident in the other irrigation levels evaluated. The final growth trend of stem diameter was lower with 125 mm irrigation level between the 57 and 64 DAT time interval (Fig. 3b). Stem diameter regression equations and coefficients were 62 mm ($y = -0.58 + 0.95x - 0.19x^2 + 0.14x^3$ and $R^2 = 0.90$), 93 mm ($y = -0.44 + 0.69x - 0.11x^2 + 0.67x^3$ and $R^2 = 0.90$), 124 mm ($y = -0.49 + 0.83x - 0.17x^2 + 0.14x^3$ and $R^2 = 0.89$), 155 mm ($y = -0.99 + 0.16x - 0.44x^2 + 0.39x^3$ and $R^2 = 0.91$) and 186mm ($y = -0.79 + 0.12x - 0.30x^2 + 0.24x^3$ and $R^2 = 0.88$).

Differences in the stem diameter observed near 46 DAT were also reported for the Japanese cucumber with soil-water tensions of 15, 30, 60 and 120 kPa (Oliveira et al. 2011). Many physiological changes occur according to the phenological cycle of the cucumber plant (Espínola et al., 2001) that may have influenced the polynomial curve behavior observed for the stem diameter as function of the irrigation levels. Cucumber plants tend to concentrate energy to build fruits, which reduces stem diameter expansion. The new stem diameter expansion are usually experienced near the final life-cycle, once the expense for fruit production is no longer relevant (Canizares and Goto 2002). The plasticity of stem diameter expansion in cucumber plants can be strongly influenced by management variables (Jaffar and Wahid 2014) and environmental effects, such as water stress.

Cucumber internode length

Internode length of cucumber plants at 8 (F= 1.55, *P*= 0.23) and 15 (F= 0.73, *P*>0.05) DAT was similar comparing all irrigation levels, but differed between treatments at the other time intervals (Fig. 2c). Cubic polynomial regression models showed the best fit to explain internode variation length, with a lower stabilization trend over the whole evaluation period. Lower values were observed at 186 mm irrigation levels (between 22 and 29 DAT) and at 125 mm (between 43 DAT and 50 DAT) (Fig. 3c). The plant internode length was shorter at the end of the evaluation period (64 DAT) when cucumber plants were submitted to the 124 mm irrigation level (Fig. 3c). Internode length regression equations and coefficients were 62 mm ($y= 0.35 + 0.34x - 0.56x^2 + 0.33x^3$ and $R^2= 0.96$), 93 mm ($y= 0.22 + 0.35x - 0.60x^2 + 0.37x^3$ and $R^2= 0.97$), 124 mm ($y= 0.29 + 0.32x - 0.46x^2 + 0.23x^3$ and $R^2= 0.96$), 155 mm ($y= -0.82 + 0.40x - 0.79x^2 + 0.56x^3$ and $R^2= 0.96$) and 186 mm ($y= 0.44 + 0.37x - 0.73x^2 + 0.52x^3$ and $R^2= 0.96$).

Differences in the internode length as a function of treatments may be a consequence of plant height responses and not necessarily the effect of the irrigation levels as observed in tomato plants (Sibomana et al. 2013). Positive and significant correlations ($R^2= 0.576$) between internode length and plant height of cucumber plants were also reported (Ando and Grumet, 2006). This reinforces the hypothesis that the internode length variation in cucumber

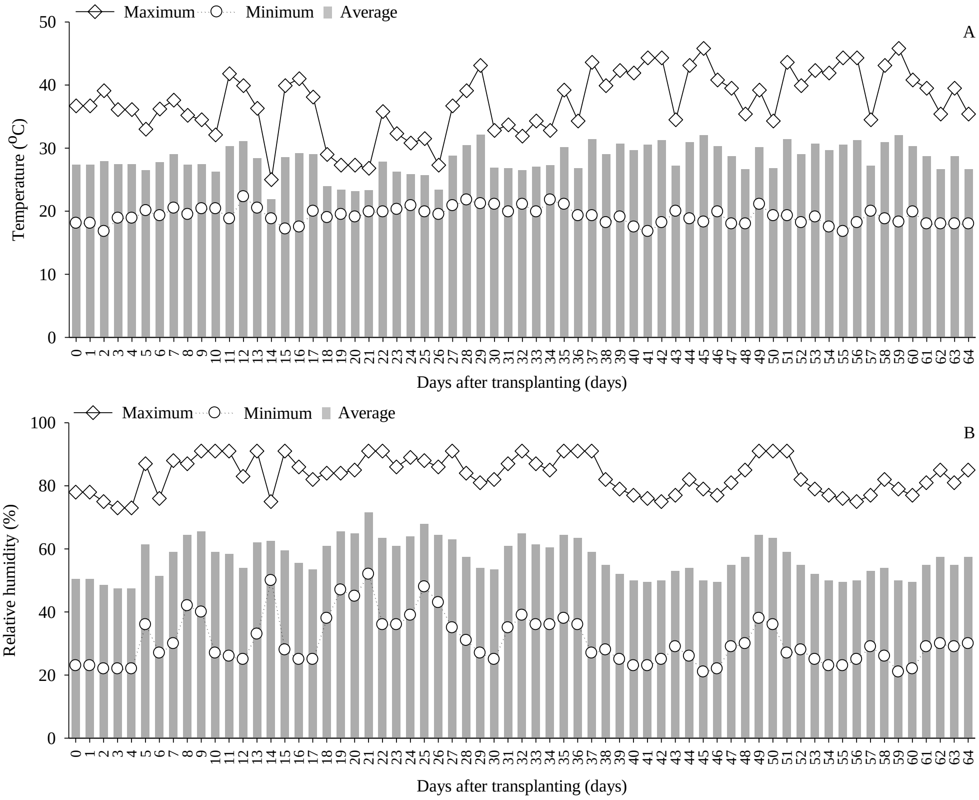

Fig. 1 Maximum, mean and minimum values of temperature (°C) (Fig. 1a) and relative humidity (%) (Fig. 1b) quantified during the experimental period under greenhouse condition.

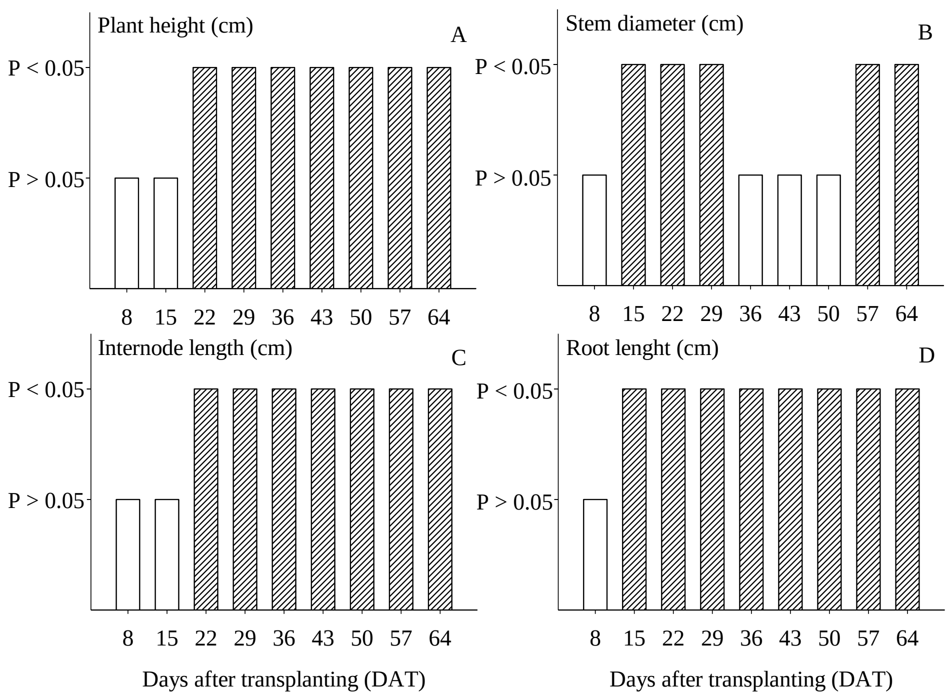

Fig 2. Graphical representation of the ANOVA for the dependent variables plant height (cm) (a), stem diameter (cm) (b), internode length (cm) (c) and root length (cm) (d) of Amour F1 pickling cucumber hybrid (*Cucumis sativus* L.) (Cucurbitaceae) plants submitted to irrigation levels (62, 93, 124, 155 and 186 mm) along different days after transplanting. $P < 0.05$ (significant at 5% probability level by F test and with bars filled with cross lines) and $P > 0.05$ (not significant at 5% probability level by F-test and with bars filled in white).

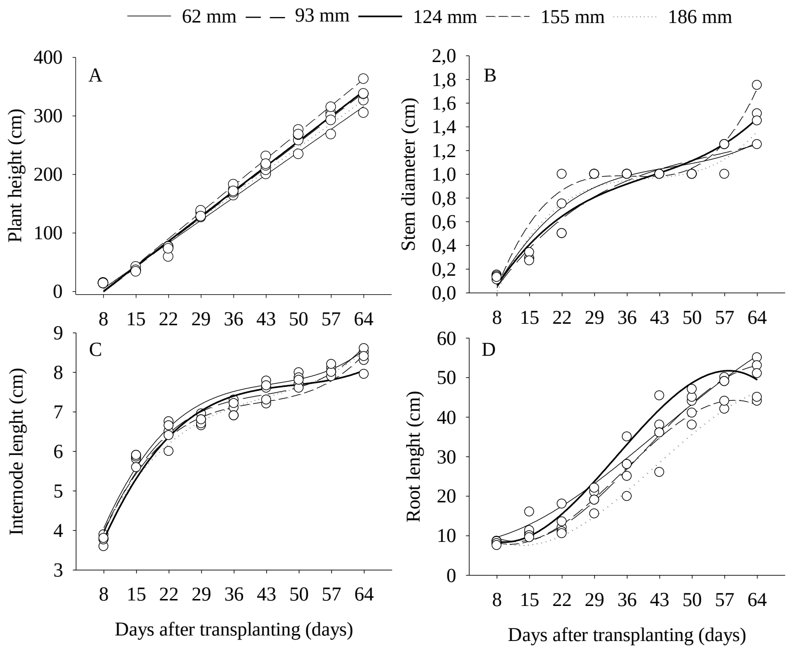

Fig 3. Regression analysis for plant height (a), stem diameter (b), internode length (c) and root length (d) of the Amour F1 pickling cucumber hybrid (*Cucumis sativus* L.) (Cucurbitaceae) according to the age-class (days after transplanting) and submitted to irrigation levels (62, 93, 124, 155 and 186 mm).

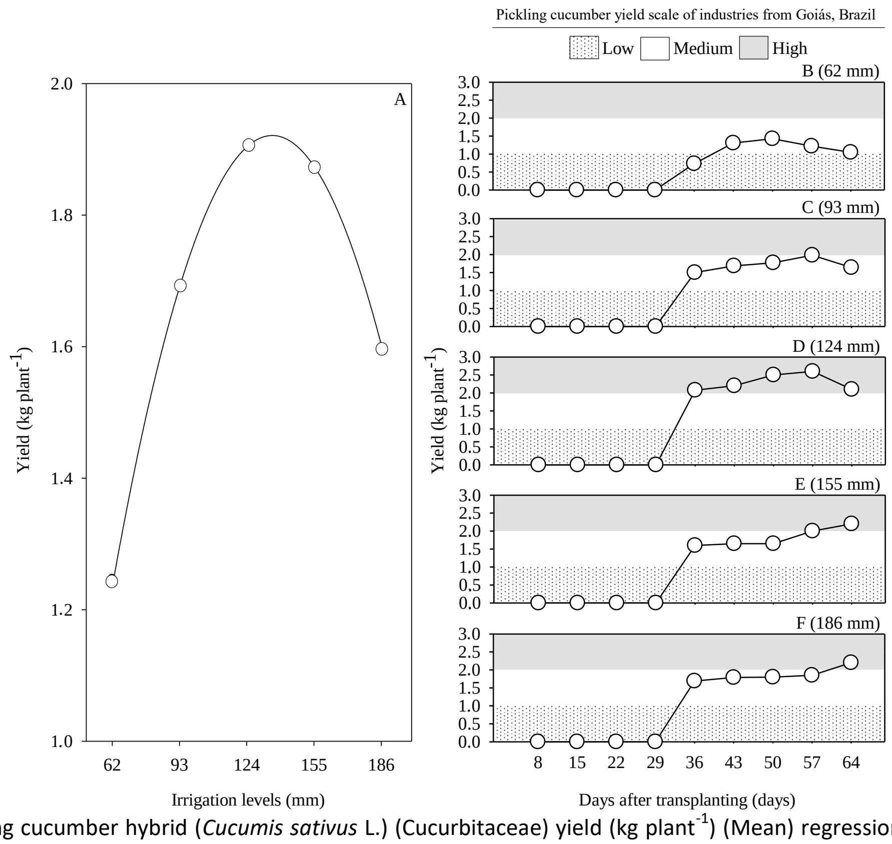

Fig 4. Amour F1 pickling cucumber hybrid (*Cucumis sativus* L.) (Cucurbitaceae) yield (kg plant^{-1}) (Mean) regression analysis (a) and according to the days after transplanting at 62 mm (b), 93 mm (c), 124 mm (d), 155 mm (e) and 186 mm (f). Yield values were established according to the industry standards as low yield: <1 kg plant^{-1}, medium yield: > 1 to 2 kg plant^{-1} and high yield: > 2 kg plant^{-1}.

plants tends to be induced by inadequate lighting conditions (Kahlen and Chen, 2015). Longer internodes benefit light distribution in adult plants; therefore, higher biomass production (Sarlikioti et al., 2011). However, increasing internode length in seedlings can be detrimental as reported in tomato with longer internodes originating adult plants with later production of flower buds (Glowacka, 2004).

Cucumber root length

Length of cucumber root differed between all-time interval periods, with an exception only at 8 DAT (F= 1.75, *P*= 0.18) (Fig. 2d). The cubic polynomial regression model had the best fit in this case (Fig. 3d). The longer cucumber roots were observed in 62 mm irrigation levels at most of the time intervals. The lowest root length was 186 mm (Fig. 3d). Root length regression equations and coefficients were 62 mm (y= 0.81 + 0.12x + 0.22x^2 - 0.17x^3 and R^2= 0.98), 93 mm (y= 0.16 - 0.13x + 0.66x^2 - 0.56x^3 and R^2= 0.99), 124 mm (y= 0.14 - 0.13x + 0.82x^2 - 0.82x^3 and R^2= 0.97), 155 mm (y= 0.14 - 0.12x + 0, 67x^2 - 0.64x^3 and R^2= 0.98) and 186 m (y= 0.16 - 0.14x + 0.61x^2 - 0.51x^3 and R^2= 0.96).

The higher root length at 124 mm irrigation level, mainly from the 29 DAT, indicates better water availability for plant and a maximum nutrient absorption capacity. Longer root lengths up to 22 DAT in plants with only 62 mm are due to the elongation of the root tissues searching for water in deeper layers. However, water stress limits cell division ceasing plant growth, and consequently, increasing the root zone of cucumber (Mundalia et al., 2015). Water excess did not necessarily indicate a favorable environment for cucumber root growth, since it was higher at 186 mm irrigation level. A better cucumber root development subjected to water stress has also been reported (Franco et al., 2011). Nutrient leaching, a common problem in drip irrigation, may have reduced nutrient availability for cucumber root development (Blanco and Folegatti, 2002).

Cucumber yield

The pickling cucumber yield varied at irrigation levels following a quadratic polynomial regression model (Fig. 4a). The highest cucumber yield was observed at 124 mm (2,205 kg $plant^{-1}$), while the lowest at 62 mm (1,248 kg $plant^{-1}$) (Fig. 4a). Intermediate yields, with values of 1,562, 1,600 and 1,690 kg $plant^{-1}$ were observed in 93 mm, 155 mm and 186 mm irrigation levels, respectively (Fig. 4a). Yield regression equation and coefficient were y= -0.40 + 0.42x -0.18x^2 and R^2= 0.69. Cucumber plants began to produce fruits from the 36^{th} DAT, independent of the irrigation levels (Fig. 4b to f). Plants submitted to 124 mm were the only ones to maintain high yield values in all five crops evaluated (Fig. 4d). Irrigation levels of 62 mm and 93 mm provided cucumber plants with medium yields throughout the evaluated harvest days (Fig. 4b and c, respectively). High yield values were observed only at 64 DAT for irrigation levels of 155 (Fig. 4e) and 186 mm (Fig. 4f), while at the other time intervals, medium yields were achieved.

The variation of pickling cucumber yield in irrigation levels followed a quadratic polynomial regression model, evidencing a strong relationship between increased water availability and cucumber yield (Yuan et al. 2006; Oliveira et al. 2011). This may be associated to water excess and nutrient leaching out of the plant root zone. Water excess may also limit oxygen flow between soil pores, impairing root respiration (Whitmore and Whalley 2009). The lower pickling cucumber yield, with 62 mm and 93 mm, characterizes a water stress condition showing the need of irrigation management to balance the physiological plant demands and preventing water losses, a scarce environmental resource in many parts of the world, including use of resistance elicitors in cucumber plants against stress (Ouzounidou et al., 2016).

Materials and Methods

Experimental site

The experiment was conducted from September to December 2016, at the Horta Field Lab (South latitude 17º29'10'', West longitude 48º12'38'' and altitude of 697 m), Federal Institute Goiano, Urutaí campus, state of Goiás, Brazil. The climate of the region, according to the classification of Köppen, is tropical with dry winter and rainy summer, type Cwb. Cucumber plants were cultivated in agricultural greenhouse, simple arc type, with East-West orientation and made by metallic structure (30 m long, 7 m width and 6.2 m arc height) covered with low-density polyethylene (LDPE) film (0.15 mm thick) and its sides with anti-aphid mesh.

The soil of the experimental area was classified as dystrophic Yellow Red Latosol, sandy loam soil, with the following characteristics: Organic matter= 24 g dm^{-3}; pH ($CaCl_2$)= 6.0; P_{resin}= 300 mg dm^{-3}, K^+= 4.98, Ca^{2+}=57, Mg^{+2}= 22, H + Al= 104, CTC= 104 $Cmol_c$ dm^{-3}, and Total sand= 275, Clay= 160, Silt =241 g kg^{-1} with 80% of saturation bases (at 0-20 cm depth) and organic matter= 16 g dm^{-3}; pH ($CaCl_2$)= 5.7; P_{resin}= 280 mg dm^{-3}, K^+= 4.34, Ca^{2+}=55, Mg^{+2}= 14, H + Al= 20, CTC= 93 $Cmol_c$ dm^{-3}, and Total sand= 329, Clay= 186, Silt =202 g kg^{-1} with 78% of saturation bases (at 21-40 cm depth).

Experimental design and treatments

The experimental design was randomized blocks with five treatments represented by five irrigation levels (amounts of applied water of 62, 93, 124, 155 and 186 mm) and four replications. A 12-plant plot spaced 0.20 m between plants and 0.80 m between planting lines represented an experimental unit.

Irrigation management

Cucumber plants were irrigated with 124 mm, and 100% of water replacement to increase soil moisture to field capacity, considering mean depth values of cucumber root system as 0.30 m. The maximum crop evapotranspiration was estimated by the expression Etc = (Eto) (Kc); where ETo was the reference evapotranspiration and Kc the crop coefficient. A drip irrigation system was used in each plant line receiving an irrigation lateral line (auto-compensated driplines) of 18 mm diameter, with emitters spaced 0.3 m. The irrigation system had a 1 HP motor pump. A Venturi type fertilizer injector, plus a 120-mesch screen filter, valves and pressure gauges besides the irrigation system were installed shortly after pumping water. Polyethylene liners were buried longitudinally between the beds at 0.50 m depth to avoid interference between the irrigation treatments.

Plant material and management

Cucumber Amour F1 hybrid (Bejo Sementes do Brasil Ltda., Bragança Paulista, São Paulo, Brazil) was used as plant material. The seedlings were sowed in styrofoam 162 cells trays. Transplantation of seedling was carried about 12 days after sowing, leaving one seedling per pit. The irrigation management according to the treatments started at 20 days after transplanting (DAT), a period necessary for the standardization and verification of cucumber seedling viability. Unviable seedlings were replaced by healthy ones from the stock, and with the same age up to 20 DAT. Fertilizers with macro and micronutrients were applied by drip irrigation according to soil chemical analysis and Trani et al. (2011) recommendations. Weeds were controlled by manual weeding and pests and diseases with periodic pesticide spraying. Chemical products applied during the experiment based on the manufacturer package, with the use of Personal Protective Equipment (PPE) according to Brazilian legislation.

The cucumber plants, from 18 DAT, were tutored by chains with a base support for eight strands of plain wire fixed on wood piles up to 3.0 m height. Fruits, flowers, leaves and lateral stems were removed to a height of 20 cm from the plant base, when they reached about 50 cm. Pruning was repeated until plants reached about 1.0 m, eliminating all structures up to 30.0 cm. This cultural management is important to maintain high productive rates of cucumber plants (Nomura and Cardoso 2000) and followed technical recommendations from Conservas Oderich SA (an industry that processes and markets pickled cucumbers and where the idea of this study came from).

Traits measured

Temperature and relative humidity, inside the greenhouse, were monitored daily with a digital thermohygrometer (Incoterm®, model 7666) installed in a meteorological shelter at the center of the greenhouse at 1.5 m height. The minimum, mean and maximum temperature and relative humidity were recorded, daily. Cucumber plant height, stem diameter, internode length and root length were quantified under nine intervals (8, 15, 22, 29, 36, 43, 50, 57 and 64 days after transplanting, DAT). Commercial fruits (absence of cracks or bent) and length (between 6 and 8 cm) began to be harvested at 39 DAT, with intervals of two days, depending on the time needed to reach the harvesting point. Fruits per plant were counted and weighed to estimate the yield values. The average cucumber yield was based on the number of fruits and fruit mass per plant per irrigation level. Yield was demonstrated in mass per plant (kg $plant^{-1}$). Plant yield as a function of the nine-time intervals after transplanting (8, 15, 22, 29, 36, 43, 50, 57 and 64 DAT) was also quantified.

Statistical analysis

All data had their normality verified by the Lilliefors adherence test and also by the proportion of the histogram obtained by the SAEG® software (UFV, Viçosa, MG, Brazil). All variables quantified followed normal distribution, and consequently, their values and means were presented without transformation. Data used for regression analyzes were plotted in a dispersion diagram to verify the growth and yield variables of the cucumber plants as a function of the evaluation days, per treatment. After this procedure, ANOVA for regressions were performed and compared to obtain the best fit regression model. The regression coefficient (adjusted R^2) and the F test values and significance were used to verify if the proposed model was adequate to describe the responses. Coefficients were described in the figures, individually, per regression analysis. Statistical analyzes (ANOVA and regression analysis models) were obtained using SAEG® software, and figures were performed by SigmaPlot® software, version 11 (Systat Software Inc, San Jose, California, EUA).

Conclusions

Plant height and internode length responses were not as influenced by the irrigation levels as stem diameter and root length. This indicates that in pickling cucumber, stem diameter and root length may be easy-to-check indicators for farmers to predict plant adaptation for a given irrigation management. Cucumber yield was low at 62 mm and 93 mm, while higher in 124 mm irrigation, and delayed at 155 mm and 186 mm. The benefits of using 124 mm irrigation level (100% of water replacement to increase soil moisture to field capacity) for the cucumber development and yield, may reduce excessive spending of water in agriculture as well mitigate negative impacts of water deficit to *Cucumis sativus* plants.

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