Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 19 June 2023
https://doi.org/10.14295/CS.v14.3926

Water and energy use efficiency in the production of tomato under different water conditions

Lucas Henrique Maldonado da Silva[1,3]*, Roberto Rezende[1], André Felipe Barion Andrean[1], Gustavo Soares Wenneck[1], Daniele de Souza Terassi[1], Raiana Crepaldi de Faria Nocchi[1], Vinicius Villa e Vila[2]

[1]State University of Maringa, Maringá, Brazil
[2]Superior School of Agriculture "Luiz de Queiroz", Piracicaba, Brazil
[3]Faculty of Technology and Science Northern Paraná, Paranavaí, Brazil
*Corresponding author, e-mail: lucasmaldonado7@gmail.com

Abstract

The efficient use of water and energy is fundamental to a sustainable agricultural practice. Deficit irrigations can contribute to saving water and energetic resources. This work aimed at analyzing the influence of water reposition in the water and energy efficiency use for growing tomato cocktail type tomato. The experiment was conducted in vegetation house, and the randomized design was adopted with five levels of water reposition (25, 50, 75, 100 and 125% of evapotranspiration in culture (ETc)) and six repetitions. The morphological contents were evaluated (number of bunches, number of abortions, fresh mass of aerial part, stem diameter and height), SPAD index (*Soil Plant Analysis Development*), water demand, productivity, energy use and energy productivity. Data were analyzed through variance analysis, average comparison, regression analysis and correlation. Water deficit affects growth, development and productivity of cocktail type tomato. The morphological development and the production yield show high correlation with water availability. The water replacement of 75% of ETc has shown better efficiency in water and electricity use in growing cocktail type tomato.

Keywords: drip irrigation, energy yield, water stress

Introduction

The agricultural sector has been largely questioned regarding the use of natural resources, more specifically water and energy; water management of crops must be based on technical criteria in search of the maximum efficiency (D'ambrosio *et al*., 2018). When the irrigation is based on technical criteria, it enables a raise in the agricultural production and optimizes the use of water and electricity, raising the efficiency in the use of these resources (Wu *et al*., 2021).

It is estimated that until 2050 an amount of 9.060 km³ of water will be needed to supply the agricultural demands (Zheng et al., 2018). The raise in the efficiency in the use of this water and the necessary electricity to move this resource until the necessary place is extremely important to the sustainability of the agricultural activity. Methods such as dripping irrigation and regulated water deficit promote a water and energy economy, improving the energetic productivity and the efficiency in water use (Scardigno, 2020).

The determination of evapotranspiration in the culture (ETc), which quantifies the plant's perspiration and soil evaporation, is a fundamental aspect to water management (Sales *et al*., 2017), enabling the adoption of irrigation with regulated water deficit (Martin *et al*., 2012; Hayashi & Dogliotti, 2021). With the use of regulated water deficit there is a significant water economy and time reduction in the function of pumping, without drastically changing the productive levels of culture (Hayashi & Dogliotti, 2021; Rguez *et al*., 2018; Wu *et al*., 2021).

Tomato crop is one of the most produced in the world, and in the year of 2019, it has shown a worldwide production of around 181 million tons in 5 million of hectares. Brazil stands out with a production of 3.92 million tons in 54.5 thousand hectares, getting average

Received: 21 February 2022
Accepted: 25 April 2022

productivity 71.8 $t.ha^{-1}$, higher than the world average productivity of 35.9 $t.ha^{-1}$ (FAO, 2019).

According to Silva *et al*. (2020a), to produce one kg of fresh tomato it is necessary 133.67 L of water. Considering the elevated production in national and international scope, the adoption of regulated water deficit along with dripping irrigation, it reduces the use of millions of liters of water and also reduce the energy use, providing economic and environmental benefits. This way, this work aimed at analyzing the influence of water reposition in the efficiency of water and energy use in growing cocktail type tomato.

Materials and Methods

The experiment was conducted in a vegetation house from Irrigation Technic Center (CTI) at Maringá State University (UEM), in the municipality of Maringá-PR (23º 25´ S, 51º 57´ O and 542 m altitude). The climate is type Cfa wet mesothermal according to Koppen, with annual average precipitation of 1500 mm and average temperature between 21.1 ºC and 22 ºC (Wenneck *et al*., 2021). The cultivation was accomplished between the months of March and July with average temperature of 21.8 ºC and relative humidity of 66%.

A fully randomized outline was adopted with five water reposition conditions (25 50, 75, 100 and 125% of evapotranspiration of culture (ETc)) and six repetitions. The treatment which had 100% of ETc water reposition was considered the control treatment. The evapotranspiration of culture was determined daily through constant water table lysimeter. The differentiation in water reposition was initiated 14 days after seedlings transplant.

Cultivation was accomplished in greenhouse with a roof built in the shape of an arc and having 30 m length, 5.7 m width and 2.5 m height. The sides are covered with anti-aphid screen and the roof covered with 150 micron of thick low-density polyethylene plastic film, with anti-UV treatment.

Tomato seeds, hybrid Tucaneiro, with indeterminate growth, cocktail-type fruits of bright red color, weighing between 35 and 50 g and a cycle of 90 days were used. The seedlings were produced in polyethylene trays of 128 cells, being kept in greenhouse until transplant, which has occurred 32 days after sowing.

Cultivation was done with one seedling per plastic vase (10 dm^3) filled with sol classified as distroferric red Nitisol (Santos *et al*., 2018), with great clay texture. Fertilizing was held based in nutrient contents from soil and according to recommendations to culture (Pauletti *et al*., 2017).

The soil used contained 69% clay, 12% of silt and 19% of sand. The chemical analysis demonstrated 1.40% of organic material, pH in $CaCl_2$ from 5.20, CTC in 9.28 $cmol_{c.}dm^{-3}$, total sum of bases of 5.25 $cmol_{c.}dm^{-3}$, V% of 56.57. The calcium, magnesium and potassium contents demonstrated was 3.99; 1.00; and 0.26 $cmol_{c.}dm^{-3}$ respectively. The phosphorous content presented was 3.08 $mg.dm^{-3}$.

The water reposition was performed through a dripping irrigation system, and the fertigation was performed every two weeks. The irrigation system was composed by a motor pump set powered 0.5 cv, disc filters, drawer registers, manometers and connections, main line of PVC pipes size 50 mm, derivation line PVC 32 mm, side lines of flexible pipes of polyethylene 16 mm, and drippers. The self-compensating drippers have operated with a nominal flow of 1.8 $L.h^{-1}$ and service pressure of 4 m.c.a.

During the conduction of culture, plants were submitted to sprout, tutoring, besides applications of insecticides and fungicides. Two applications were performed (35 and 55 days after transplant) of neem oil (fitoneem 85%) in dose of 3 mL per liter. Along the insecticide application it was also applied cupro dimy in dose of 15 mL per liter. 90 days after transplant (DAT) the morphological components were assessed. The SPAD index (*Soil Plant Analysis Development*) was determined in leaves from superior third, with equipment SPAD-502 Plus® (Minolta). It was quantified the number of bunches, plant's high, number of abortions considering the formation of sepals without fruits, base diameter and average third of stem, plant's fresh mass and productivity based on fresh mass of fruits.

The water footprint represents the ratio between necessary water consumption to produce 1 kg of the product. This relationship considers different sources of water which is deposited during the crop cultivation, such as the green water which comes from the rain, blue water coming from sources of fresh water, and gray water necessary to absorb pollution caused by the activity (Bleninger & Kotsuka, 2015). The water footprint was calculated considering only the blue water due to the fact that the water deposited in the crop was exclusively through irrigation, and the pollution caused was the same for all treatments for the quantity of fertilizers was the same for all treatments.

To analyze the energy yield and energy use, data were extrapolated to the area of a hectare, considering density of 12.000 plants by hectare, with the productivity being expressed in ton. Ha^{-1}. For the electricity consumption, it was considered the consumption of a pump bomb of 5 cv (21.6 $m^3.h^{-1}$ flow and electricity consumption of 3.68 kWh). The energy yield and the energy use were calculated according to equation 1 and 2, respectively according to Sepat *et al*. (2013).

$$PE = \frac{PROD}{CEE}$$

PE – Energy yield (kg. kWh^{-1})
PROD – Productivity (kg. ha^{-1})
EC – Electricity Consumption (kWh. ha^{-1})

$$UE = \frac{CEE}{PROD}$$

UE – Energy use (kWh.ton^{-1})
CEE – Electricity Consumption (kWh. ha^{-1})
PROD – Productivity (kg. ha^{-1})

Data have undergone the analysis of variance and average comparison by Tukey test ($p<0.05$). It was done a Pearson's correlation side analysis. The regression analysis was done between productivity and water consumption aiming at finding a model to estimate the productivity according to water consumption. The statistical analysis was performed through software R (R Foundation, Viena - Austria).

Results and Discussion

Indicator features of development and productivity in the tomato crop are shown In **Table 1**. Considering the treatment with reposition of 100% from ETc as control, the productivity was reduced by imposition of water deficit, with fall in productivity of 75.40; 50.63 and 14.89% for water reposition of 25, 50 and 75% from ETc, respectively.

The fall in productivity is linked to changes in physiological process of plant. The water stress causes cell responses with the aim of helping plant to survive during this unfavorable period. Photosynthesis is one of the most affected processes with the lack of water, since the plant closes its stomas to reduce the transpiration and keep the water balance. However, this also reduces the fixation of CO_2 and consequently the photosynthetic rate, enabling the plant to produce less photo-assimilated and reducing its growing and productivity (Reissig, 2018).

The youngest the plant is the most sensitive to water deficit. Loyola *et al*. (2012) demonstrated that tomato plants with 6 weeks undergone water stress during only 12 days have shown reduction in water relative content in leaf in 50%, reflecting in conductance stomatal conduction and the photosynthesis.

Water deficiency negatively affects cellular responses, whereas increased water availability affects cellular responses positively, favoring the maintenance of water balance and photosynthesis. Excess water replacement (125% of ETc) showed an increase of 17.04% in productivity. Ullah *et al*. (2020), demonstrated that tomato plants at 71 DAT that received excess of water (125% and 150% ETc) had higher photosynthetic rates and stomatal conductance compared to control plants (100% ETc), positively influencing yield.

The other morphological characteristics such as shoot fresh mass, diameter of the base and middle third of the stem, height and number of bunches per plant showed no significant difference between the 100% and 125% ETc depths (Table 1). The addition of 25% in the water supply increased the fruit mass and did not change morphological characteristics.

The water deficit has affected the morphological characteristics. The diameter of the middle third of the stem decreased with the imposition of water deficit, but there was no significant difference between the replacement of 25, 50 and 75% of ETc, with the smallest diameters observed (Table 1).

The plant fresh mass (MF) and the stem base diameter (DB) showed respectively 69.04 and 50.11% lower values for the 25% water depth when compared to the control treatment (100% of ETc). The treatments of

Table 1. Indicators of water development, productivity and consumption in cocktail type tomato crop grown in different conditions of water reposition

Water Reposition (% ETc)	PROD (g per plant)	BU	AB	PH ($L.kg^{-1}$)	MF (g)	DB (mm)	DM (mm)	ALT (cm)	SPAD
25	427.00 e	6.00 b	2.00 ns	42.97 ns	207.00 c	6.33 c	7.44 b	99.00 b	63.34 ns
50	856.75 d	7.00 a	2.00	42.81	400.00 b	8.44 b	7.74 b	124.75 a	63.65
75	1477.00 c	7.00 a	2.00	36.81	526.50 b	9.92 b	8.92 ab	138.00 a	63.38
100	1735.50 b	7.00 a	3.00	41.71	668.50 a	12.69 a	10.48 a	130.00 a	62.04
125	2031.25 a	7.00 a	2.00	44.63	712.00 a	13.55 a	9.81 a	141.50 a	61.28
P-Value	<0.001	<0.001	0.8434	0.1549	<0.001	<0.001	<0.001	<0.001	0.8965

PROD = Productivity; BU = number of bunches per plant; AB = number of abortions per plant; PH = Water Footprint; MF = fresh mass; DB = base diameter in stem; DM = diameter of average third in stem; ALT = Height; SPAD = SPAD index. Average followed by the same letters in column do not differ significantly by the Tukey test 5% of significance.

50% and 75% of ETc showed an intermediate reduction for both variables, not differing between them, but differing from the treatments 100% and 125%, which showed the highest values for plant fresh mass and the base diameter of the stem.

The primary and secondary growth can be affected by water availability (Pacheco, 2017). Under stress conditions, plants change their growth rates in a coordinated way, acting on different processes such as cell wall synthesis, cell division and protein synthesis. Negatively affecting growth that can be observed through variables such as stem diameter, plant height and fresh mass (Taiz et al., 2017).

The water footprint did not show a significant difference, and this occurred because the productivity reduced in proportion to the reduction in the volume of the water used. The number of abortions per plant and the SPAD index also showed no significant difference ($p>0.05$) between the water replacement levels evaluated.

The number of bunches was lower only for the 25% ETc depth (Table 1). This characteristic is directly linked to the height of the plants, with a significant positive correlation of 0.54 (**Table 2**). With lower growth (height), the plant emits fewer leaves and bunches, as obtained by Guedes *et al*. (2015), who when subjecting tomato plants to saline stress obtained lower height and number of bunches per plant.

Table 2. Correlation between growth and development indicators of cocktail tomato grown under different water replacement conditions

	DH	PROD	BUNCHES	MF	DB	DM	ALT
DH	1.00	-	-	-	-	-	-
PROD	0.98	1.00	-	-	-	-	-
BUNCHES	0.62	0.65	1.00	-	-	-	-
MF	0.94	0.93	0.67	1.00	-	-	-
DB	0.95	0.93	0.57	0.92	1.00	-	-
DM	0.76	0.72	0.67	0.78	0.77	1.00	-
ALT	0.76	0.80	0.54	0.78	0.75	0.55	1.00

DH = Water availability; PROD = Productivity; BUNCHES = number of bunches per plant; MF = fresh matter; DB = stem base diameter; MD = diameter of the middle third of the stem; ALT = Height of the plant.

Fresh plant mass and stem base diameter showed a positive correlation with the yield (Table 2), demonstrating a relationship between morphological development and yield. Silva *et al*. (2020b) obtained similar results for the correlation between variables indicative of vegetative development and productivity for industrial tomato cultivar BRS Sena.

Water availability showed a high correlation with productivity (0.98), plant fresh mass (0.94) and stem base diameter (0.95), demonstrating that the absence of water stress allows for adequate plant growth and development of the plants.

Table 3 shows the significance for the regression models, with mathematical equations being determined to predict yield (Y) as a function of water replacement depth (x), according to equations 3, 4 and 5 with coefficient of determination (R^2) of 0.9746 for linear equation; 0.9911 for quadratic equation and 0.9945 for quartic equation.

Table 3. Regression analysis of yield and irrigation depth in cocktail tomato cultivation

FV	GL	SQ	QM	F CALC	F TAB
TREATAMENT	4	6.8567	1.71416	190.00	3.06
REG LINEAR	1	6.6822	6.68225	740.67 *	4.54
REG SQUARED	1	0.1133	0.11331	12.56 *	4.54
REG CUBICAL	1	0.0094	0.00939	1.04 ns	4.54
REG QUARTIC	1	0.0517	0.05171	5.73 *	4.54
RESIDUE	15	0.1353	0.00902		
TOTAL	19	6.99			

$$Y = 0.01635x + 0.07932 \quad (3)$$

$$Y = 0.02714x + 0.00007197x^2 - 0.2355767 \quad (4)$$

$$Y = -0.0114x + 0.003256x^2 - 0.00003126x^3 + 0.0000001015x^4 + 1,691 \quad (5)$$

Biological effects are better explained by linear and nonlinear models of order 2. Analyzing the coefficient of determination, it is possible to verify that the quartic equation was not able to add a greater significant explanation of the data in relation to the quadratic equation. Therefore, the quadratic model (**Figure 1**) was chosen in order to determine the irrigation depth related to the maximum point of the model (188% of ETc).

Using equation 4, the maximum point was obtained with replacement of 188% of ETc, with an estimated productivity of 2.33 kg per plant. Even the value extrapolating the largest water replacement of the

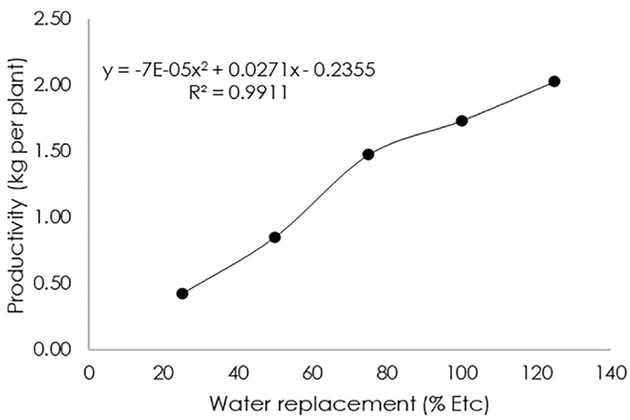

Figure 1. Quadratic model representing the relationship between yield and replacement water in cocktail tomato cultivation.

study (125%), the virtual water replacement (188% of the ETc) was analyzed with the other conditions observed during the experiment in order to determine the changes in energy productivity and energy use and better understand the need for further studies with slides above 100% ETc (**Table 4**).

Table 4. Evaluation of energy productivity and energy use in relation to water availability in cocktail tomato cultivation

	Water replacement (% ETc)					
	188	125	100	75	50	25
Volume (m^3. ha^{-1})	1631.31	1084.65	867.72	650.79	433.86	216.93
Energy Consumption (Kwh.ha^{-1})	277.93	184.79	147.83	110.88	73.92	36.96
Productivity (ton. ha^{-1})	27.96	24.38	20.83	17.72	10.28	5.12
Energetic productivity (kg.kWh^{-1})	100.60	131.90	140.87	159.86	139.09	138.64
Energy use (Kwh.ton^{-1})	9.94	7.58	7.10	6.26	7.19	7.21

Table 4 shows the values of energy productivity and energy use for each water replacement condition used and the calculated virtual replacement. These two variables can indicate whether the change in the water regime will influence energy consumption to obtain a certain productivity, and in the end, it can diagnose whether the water replacement in question can improve the efficiency of water and energy use or not.

Using the control treatment (100% ETc) as a reference, it is possible to verify that the treatment with a 75% ETc water replacement showed an increase in energy productivity by 13.47% and a reduction in energy use of 11.87%.

This demonstrates that in addition to reducing the water deficit by 25% of the volume of water needed, it also reduces the consumption of electricity, presenting a greater cost-benefit ratio in terms of productivity and energy consumption. This fact can be explained by the fact that the reduction in production did not occur in a linear fashion, with the 25% reduction in the total volume of water impacting a 14.93% reduction in productivity.

Certain deficient water replacement, even with loss of productivity, increase efficiency in the use of water and electricity. This result is similar to that found by Sinha *et al*. (2017) who also demonstrated increased energy productivity and reduced energy use when working with 80% ETc water replacement in sunflower.

This fact does not happen for the 50 and 25% ETc water replacement, energy productivity and energy use are similar to the control treatment (100%), thus not presenting gains in the reduction of electric energy consumption. This is due to the great impact that these treatments have on productivity, with linear reductions in final production per hectare of 50.65 and 75.42% for the 50 and 25% ETc water replacement, respectively.

When supplying a volume of water greater than 100% of the ETc, energy productivity tends to decrease and consequently increase energy use. The ETc depth of 125% presents a 17% increase in productivity, which is disproportionate to the increase in the volume of water supplied. This fact causes a reduction in energy productivity of 6.37% and an increase in energy use of 6.78%.

The calculated virtual water replacement (188% of ETc) representing the point of maximum productivity follows the same trend as the 125% water replacement. Water consumption increases by 88% for productivity to increase by 34.23%. This impact can also be seen in energy productivity, which decreases by 28.60% and energy use increases by 40%. This demonstrates that excess replacement do increase productivity, but not in a way that can bring better efficiency in the use of water and energy.

Conclusions

Considering the conditions in which this experiment was accomplished, it can be observed that the imposition of water deficit causes, in the development and productivity of cocktail type tomato.

The morphological development and productive yield of cocktail tomato are highly correlated with water availability.

The evaluation of the change in the water regime in relation to energy productivity and energy use demonstrates that the ETc 75% water level has better efficiency in the use of water and electricity in the cultivation of tomato cocktail type in a protected environment.

Through the second-degree equation, obtained to determine the productivity as a function of the water replacement used, it is concluded that the water replacement of 188% can present the highest productivity, however, it is the least efficient treatment in relation to the use of electric energy and use of Water.

Further studies working with water depths between 100 and 200% ETc should be considered in order to better understand the impact of this excess water on cocktail-type tomato productivity.

Acknowledgements

The present work was carried out with the support of the National Council for Scientific and Technological Development (CNPq) and the company *Isla Sementes* LTDA.

References

Bleninger, T., Kotsuka, L.K. 2015. Conceitos de água virtual e pegada hídrica: estudo de caso da soja e óleo de soja no Brasil. *Revista Recursos Hídricos* 36:15–24.

D'ambrosio, E., Girolamo, A.M., Rulli, M.C. 2018. Assessing sustainability of agriculture through water footprint analysis and in-stream monitoring activities. *Journal of Cleaner Production* 200:454–470.

Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.A., Lumbreras, J.F., Coelho, M.R., Almeida, J.A., Araujo Filho, J.C., Oliveira, J.B., Cunha, T.J.F. 2018. *Sistema brasileiro de classificação de solos*. Embrapa, Brasília, Brasil. 354p.

FAO. Food and Agriculture Organization of the United Nations FAOSTAT: Statistical database. 2018. https://www.fao.org/faostat/en/#data/QCL <Acesso em 10 Fev. 2022>.

Guedes, R.A.A., Oliveira, F.A., Alves, R.C., Medeiros, A.S., Gomes, L.P., Costa L.P. 2015. Estratégias de irrigação com água salina no tomateiro cereja em ambiente protegido. *Revista Brasileira de Engenharia Agrícola e Ambiental* 19:913–919.

Hayashi, R., Dogliotti, S. 2021. Productividad del agua en maíz, con diferentes niveles de riego deficitario en clima húmedo. *Agrociencia Uruguay* 25:1-10.

Loyola, J., Verdugo, I., González, E., Casaretto, J.A., Ruiz-Lara, S.2012 Plastidic isoprenoid biosynthesis in tomato: Physiological and molecular analysis in genotypes resistant and sensitive to drought stress. *Plant Biology* 14:149–156.

Martin, J.D., Carlesso, R., Aires, N.P., Gatto, J.C., Dubou, V., Fries, H.M., Scheibler, R.B. 2012. Irrigação deficitária para aumentar a produtividade da água na produção de silagem de milho. *Irriga* 1:192-200.

Pacheco, A.B. 2017. *Tomateiro cereja sob disponibilidades hídricas e doses de potássio com irrigação semiautomatizada em ambiente protegido*. 85f. (Dissertação de Mestrado) - Universidade Federal do Mato Grosso, Rondonópolis. Brasil.

Pauletti, V., Motta, A.C.V. 2017. *Manual de adubação e calagem para o estado do Paraná*. Editora SBCS, Curitiba, Brasil. 289p.

Reissig, G.N. 2018. *Efeito do déficit hídrico e hipóxia pós-colheita no sistema antioxidante enzimático e não enzimático de frutos de tomate 'micro-tom'com diferentes expressões de MT-sHSP23.6*. 101f. (Tese de Doutorado) - Universidade Federal de Pelotas, Pelotas, Brasil.

Rguez, S., Djébali, N., Slimene, I.B., Abid, G., Hammemi, M., Chenenaoui, S., Bachkouel, S., Daami-Remadi, M., Ksouri, R., Hamrouni-Sellami, I. 2018. Cupressus sempervirens essential oils and their major compounds successfully control postharvest grey mould disease of tomato. *Industrial Crops and Products* 123:135–141.

Sales, D.L., Alves Júnior, J., Casaroli, D., Evangelista, A.W.P., Souza, J.M.F. 2017. Estimativa de evapotranspiração e coeficiente de cultura do tomateiro industrial utilizando o algoritmo safer. *Irriga* 22:629-640.

Scardigno, A. 2020. New solutions to reduce water and energy consumption in crop production: a water–energy–food nexus perspective. *Current Opinion in Environmental Science and Health* 13:11–15, 2020.

Sepat, N.K., Sepat, S.R., Sepat, S., Kumar, A. 2013. Energy use efficiency and cost analysis of tomato under greenhouse and open field production system at Nubra valley of Jammu and Kashmir. *International Journal of Environmental Sciences* 3:1233-1243.

Silva, B.B.C., Grzebieluckas, C., Socoloski, A., Santos, J.S.C, Ribeiro, M.A. 2020. Custo da pegada hídrica da produção de tomate: um estudo em Tangará da Serra – MT. *Revista Gestão & Sustentabilidade Ambiental* 9:395-408.

Silva, C.J., Frizzone, J.A., Silva, C.A., Pontes, N.C., Silva, L.F.M., Basílio, E.E. 2020 Desenvolvimento do tomateiro industrial em resposta a diferentes níveis de irrigação. *Irriga* 25:432–448.

Sinha, I., Buttar, G.S., Brar, A.S. 2017. Drip irrigation and fertigation improve economics, water and energy productivity of spring sunflower (Helianthus annuus L.) in Indian Punjab. *Agricultural Water Management* 185:58–64.

Soares Wenneck, G., Saath, R., Rezende, R., Andrean, A.F.B.A., Santi, D.C., Terassi, D.S. 2021. Análise econômica da utilização de silício no cultivo de couve-flor em ambiente protegido na região noroeste do Paraná. *Irriga* 1:335–343.

Taiz, L., Zeiger, E., Moller, I.M., Murphy, A. 2017. *Plant physiology and development*. Artmed, Porto Alegre, 858 p.

Ullah, I., Hanping, M., Shabbir, A., Ullah, M.S., Jabran, K., Javed, Q., Buttar, N.A., Azeem, A. 2020. Physiological response of tomato plants under different irrigation levels and nutrient concentrations in greenhouse. *Pakistan Journal of Agricultural Sciences* 57:599–608.

Wu, Y., Yan, S., Fan, J., Zhang, F., Xiang, Y., Zheng, J., Guo, J. 2021. Responses of growth, fruit yield, quality and water productivity of greenhouse tomato to deficit drip irrigation. *Scientia Horticulturae* 275:109-121.

Zheng, H., Bian, Q., Yin, Y., Ying, H., Yang, Q., Cui, Z. 2018. Closing water productivity gaps to achieve food and water security for a global maize supply. *Scientific Reports*

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.