CHEMICAL ENGINEERING TRANSACTIONS

VOL. 87, 2021

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Laura Piazza, Mauro Moresi, Francesco Donsì

ISBN 978-88-95608-85-3; **ISSN** 2283-9216

DOI: 10.3303/CET2187070

Diagnosis of Irrigation Management in the Industrial Tomato Crop in Goiás, Brazil

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The irrigation management practices by the producers of industrial tomatoes have been done in an empirical way, which can harm the crop yield and the water resources. Thus, this study aimed to analyze water use, comparing the irrigation management that the producer uses with what should be carried out in the cycle of industrial tomatoes in Goiás. For this purpose, fourteen industrial tomato production areas were monitored during the 2018, 2019, and 2020 harvest. The applied irrigation depths were recorded using rain gauges installed in the cultivation areas. The water demands were estimated from the crop coefficients recommended by Embrapa and by the reference evapotranspiration according to the Penman-Monteith Model, obtained from meteorological data from stations installed in loco. The results showed that water demands ranged from 269.2 to 422.6 mm between 109 and 131 days of the cycle. The diagnosis revealed that there were errors in the irrigation management in all evaluated areas when analyzing the total water applied in the cycle. The average error was 83.3 mm for excess (57% of areas) and 31.1 mm for deficit (43% of areas). The phenological cycle of the crop was divided into four phases. On average, there was excess in two phases, error for the deficit in one phase, and correct irrigation in other. In phase I, there was 35.7% correct irrigation, 50% (35.0 mm) of error for excess, and 14.3% (17.9 mm) of error for the deficit. In phase II, 14.3% of correct irrigation were observed, 85.7% (46.9 mm) of error for excess. In phase III, there was 7.1% of correct irrigation, 14.3% (44.7 mm) of error for excess, and 78.6% (38.2 mm) of error for the deficit. There was 21.4% correct irrigation in phase IV, 42.9% (44.8 mm) of error for excess, and 35.7% (22.1 mm) of error for the deficit.

1. Introduction

Tomato for industrial processing is the 12th product of economic importance for agribusiness (Rocco and Morabito, 2016). Brazil occupies 8th place in world production, with more than 60 thousand hectares cultivated and more than 4 million tons annually produced for industrial (WPTC, 2019). Goiás state is the largest producer, with 70% of the national production of tomatoes for industrial processing (HORTIFRUTI-CEPEA, 2019), concentrating the cultivation in the central-southern region of the state, where in addition to the edaphoclimatic conditions favorable to this crop concerning other traditional farming areas in the country (Silva Junior et al., 2015), is where more than ten agroindustries for processing are located.

In Brazil, irrigation of industrial tomatoes is done mainly by sprinkling, in which sprinkling represents 90% of the irrigated area, and drip irrigation 10% for tomato cultivation. In Goiás, 100% of the crop is irrigated, and almost all industrial tomato production is carried out using sprinkling by a center pivot (Marouelli et al., 2012).

Adequate soil moisture for tomato cultivation must be maintained during the whole cycle so as not to limit plant growth, development, and fruit yield (Marouelli et al., 2012). Water deficit is the main factor of decrease tomato yield (Mesquita et al., 2019a). On the other hand, excess water can promote lower product quality for the industry (Mesquita et al., 2019b). Thus, knowing the crop evapotranspiration is essential to guarantee the sustainability of production (Barbosa et al., 2020).

Tomato is one of the most demanding vegetables in water, with water requirements above the average among vegetables, 300 to 600 mm (Marouelli et al., 2012). The tomato cycle can be divided into four phases. The first

Paper Received: 29 September 2020; Revised: 15 February 2021; Accepted: 22 April 2021
Please cite this article as: Alves Jr J., Sena C.C., Domingos M.V., Knapp F.M., Almeida F.P., Battisti R., Casaroli D., Evangelista A.W., 2021, Diagnosis of Irrigation Management in the Industrial Tomato Crop in Goiás, Brazil, Chemical Engineering Transactions, 87, 415-420 DOI:10.3303/CET2187070

phase from one to two weeks, from seedling transplanting to the seedling setting (beginning of new shoots). The second phase from five to six weeks, from plant setting to flowering. The third phase, from five to six weeks, from flowering to fruit maturation. And the fourth phase, three to four weeks, maturation to harvest. It is important to know the beginning and end of the phases, allowing better programming of the variation of irrigation depth along the cycle (Marouelli et al., 2012).

The irrigation depths, in the cycle, must be calculated by the sum of crop evapotranspiration, between one and another irrigation, estimated from reference evapotranspiration, obtained from local meteorological data, and by crop coefficients representative of each phase. The average values of crop coefficients for industrial tomato for Goiás region, by Embrapa (Marouelli et al., 2012).

However, the current irrigation management practiced by most tomato producers has been done empirically, causing a great impact on water resources (Bonissoni, 2019). Also, there is little research in this area. Because producing little tomato with a lot of fertilizer and pesticides, it leads to food production with a higher risk of contamination, generating environmental impacts with the leaching of fertilizer and pesticides and greatly impacting water resources.

Thus, the present study aimed to diagnose the use of irrigation water in the production of industrial tomatoes, in the main producing regions of Goiás, in areas with a central pivot, quantifying and qualifying the current irrigation management practiced by producers, comparing with recommended management, considering local edaphoclimatic conditions.

2. Material and method

The study was carried out in 14 areas located in seven rural properties of industrial tomato cultivation irrigated by center pivot from February to October of 2018 to 2020. Details of geographical coordinates, elevation, and area are shown in Table 1.

Table 1: Description of the evaluated areas, geographical coordinates, elevation, and area in the diagnosis of water irrigation in industrial tomatoes production in Goiás state, Brazil.

	Locality	Latitude	Longitude	Elevation (m)	Area (ha)
A1	Anápolis	16°26’18.07” S	48°50’18.01” W	998	110.0
A2	Gameleira de Goiás	16°38’24.51” S	48°62’01.89” W	950	50.0
A3	Hidrolândia	17°03’30.50” S	49°11’30.00” W	705	100.0
A4	Palmeiras de Goiás	16°41’45.14” S	49°53’04.55” W	670	50.0
A5	Piracanjuba	17°32’34.86” S	48°56’53.60” W	691	100.0
A6	Silvânia	16°45’57.70” S	48°40’05.88” W	950	101.6
A7	Itaberaí	16°02’43.00” S	49°72’10.00” W	701	50.0

The climate of the analyzed localities is Aw-type, characterized by a rainy season between October and April and a dry season from May to September (Cardoso et al., 2014). The region's soil is classified as a Latossolo Vermelho distrófico. Information about tomato hybrids, planting and harvest dates, yield, total soluble solids, and average air temperature and thermal accumulation during crop cycle are shown in Table 2.

Table 2: List of cycle days, transplant and harvest dates, average air temperature (Temp), thermal accumulation (AT), yield (Yield), total soluble solids (SST), and hybrids used in localities of industrial tomato cultivation in Goiás.

Locality	Cycle	transplant	Harvest	Temp (ºC)	AT (ºC)	Yield (t ha^{-1})	SST (ºBrix)	Hybrid
A1	127	15/may	18/sep	19.6	1227.8	81.86	4.04	N901
A2	114	23/may	13/sep	19.9	1127.1	102.16	4.65	CVR6116
A3	125	29/may	30/sep	22.0	1505.2	86.72	4.68	N901
A3	124	28/mar	29/jul	21.3	1383.2	103.91	4.48	CVR2909
A4	109	06/may	22/sep	23.1	1428.9	90.61	4.71	N901
A4	113	17/jun	07/oct	24.1	1605.0	80.11	4.09	N901
A4	127	23/mar	27/jul	21.9	1508.2	96.13	4.75	H1301
A5	125	23/may	24/sep	21.5	1331.0	102.56	4.43	N901
A5	112	26/mar	15/sep	20.6	1186.7	87.49	4.56	CVR2909
A5	121	20/may	17/sep	21.5	1390.7	88.71	4.15	N901
A6	129	08/may	13/sep	21.2	1443.8	114.04	4.12	N901
A6	120	16/may	12/sep	21.0	1318.4	58.17	4.52	H9553
A6	131	12/may	19/sep	20.9	1436.0	124.14	4.60	HM7885
A7	115	23/may	14/sep	21.6	1337.3	78.34	4.88	N901

Transplanting was carried out in a double row, with a spacing of 0.90 m between planting rows, 0.30 m between plants in the row, and 1.50 m between double rows. In areas A5 (Piracanjuba 2018 and 2019) and A6 (Silvânia 2018), the conventional planting system was adopted; in the other areas analyzed, the no-tillage system was used. For planting fertilization, 1.3 t ha^{-1} of NPK formulation 04-30-16 + 0.2% B + 0.2% Zn + 0.2% Mn were applied, and in topdressing 20 kg ha^{-1} of mono ammonium phosphate (MAP), divided into two applications (first and second week after transplantation by fertigation), following the standard protocol of agricultural department from agroindustry. In localities, at equidistant points, the granulometry, soil bulk density in 0.0-0.1, 0.1-0.3, and 0.3-0.5 m soil layers, and resistance to soil penetration (using an electronic meter penetrometer penetroLOG - Falker) in 0.0-0.1, 0.1-0.3, and 0.3-0.5 m soil layers were determined. The methodologies used are following Embrapa (2017), adopting limit parameters of 2000 kPa for mechanical resistance to soil penetration and 1500 kg m-3 (1.5 g cm-3) for soil bulk density according to Melo et al. (2017) and the textural classification of the soil according to Lemos and Santos (1982).

For soil moisture monitoring, three sensors were installed in studied areas. Each set contained a Decagon ECRN-50 rain gauge and three EC-5 sensors at depths of 0.1, 0.3, and 0.5 m, aligned to pivot radius, connected to Decagon EM50 data logger.The reference evapotranspiration was determined by Penman-Monteith (Allen et al., 1998) using climatological data obtained from Metos® weather stations (iMetos 3.3) installed near study areas. To estimate the crop evapotranspiration, Kc values recommended by Embrapa (Marouelli et al., 2012) were used. The effective depth of the crop root system was used, according to Marouelli and Silva (2002), for each phenological stage (Table 3).

Table 3: Phenological phases of the industrial tomato crop, thermal accumulation, and crop coefficients for tillage and no-tillage soil conditions.

Phases	days	Kc (no-tillage)	Kc(tillage)	Thermal accumulation (°C)
Phase I	+/- 8	0.45	0.90	91
Phase II	+/- 35	0.50-1,05	0.65-1.1	424
Phase III	+/- 45	1.05	1.10	951
Phase IV a	+/- 20	1.05-0.35	1.10-0.35	1246
Phase IV b	+/- 15	0.35	0.35	1366

* Phase I: from transplantation to the setting of the seedlings (thermal accumulation of 91 GD); Phase II: from the setting of the seedlings to full bloom (424 GD); Phase III: from the flowering to the beginning of maturation (951 GD); Phase IV a: from the maturation to 50% mature fruits (1246 GD); and IV b: from 50 to 90% mature fruits/harvest (1366 GD).

The application intensity (IA) was calculated according to Eq. 1.

$$IA= \frac{2 \times 1000 \times r \times Q}{r^2 \times d} \qquad (1)$$

Where, IA - water application rate (mm h^{-1}); r - distance from the center of the pivot to the last sprinkler (m); Q - the total flow of the center pivot (m^3 h^{-1}); d - sprinkler wet diameter (m).

The time spent by the pivot to pass by position was calculated. The number of positions was calculated by dividing the perimeter of the last tower (RUT) by the wet diameter of the last sprinkler (Eq. 2).

$$T_g= \frac{T}{NP} 60 \qquad (2)$$

Where, Tg - time spent by the pivot to irrigate each position (min); T - time required for the center pivot to complete a turn (min); NP - number of positions be irrigated in total area (Eq. 3);

$$NP= \frac{P}{D} \qquad (3)$$

Where, NP - is the total number of positions to be irrigated by the center pivot; P - the perimeter of the last tower (m); and D - wet diameter of the last sprinkler (m). The risk of water runoff in the soil was determined when the intensity of water application at the end of the center pivot was greater than the rate of water soil infiltration. For water soil infiltration rate, average values recommended by Fiorin (2008) were used for each soil granulometry. Thus, for each evaluated equipment, the percentimeter regulation limit was obtained to avoid water runoff on the soil surface.

3. Results and discussion

Table 4 shows that in all areas analyzed, irrigation management was not performed correctly. There was water deficit or excess in the cycle when comparing the water requirement of industrial tomatoes obtained by the standard equation indicated by FAO with specific crop coefficients for the region. The largest water deficit observed was 107.6 mm in Area 6, and the largest water excess was 204 mm in Area 4. The general water requirement for industrial tomatoes was 351.4 mm, with greater need, 436.8 mm in a 125-day cycle (from May to September), and shorter, 280.3 mm in a 112-day cycle (from March to July), both in Area 5. This low water requirement is because higher consumption phases occurred in wintertime, and there were precipitations during Phase II, totalizing 280 mm. Soil moisture in root zone remained in optimum range (excess of phase II must have compensated the deficit in phase III), except in the end cycle, where the soil moisture shows above the field capacity, due to excessive rainfall, but was obtained a good yield of 102.56 t ha^{-1} and 4.43 ^{o}Brix of N-901 Hybrid. When analyzed by phase, the water balance in the first phases of the production of industrial tomato presented more water excess in general than deficit. The largest water excess in phase I and phase II ranged from 200.8 mm (A5) to 2.4 mm (A3). The water excess in the first three phases, especially in phases 2 and 3, may have caused nutrient losses by leaching, which may have left the plants more vulnerable to disease attack, which occurred in Areas 3 and 1. The water deficit in phase IV of the cycle may have accelerated maturation and may have been the cause of low productivity, 81.86 t ha$^{-1,}$ and quality of 4.04 ^{o}Brix in N-901 Hybrid (A1). The rain during phase IV may have been the cause of the low yield, 86.72 t ha^{-1}, despite the good production quality of 4.68 ^{o}Brix using the N-901 Hybrid (A3). Also, during the week of harvest, the rains may have been the cause of low yield, 80.11 t ha$^{-1,}$ and quality 4.09 ^{o}Brix in N-901 Hybrid.

In area 6 (in 2018), the water requirement of the crop was 417.4 mm (129 days) and in 2019 was 408.2 mm (120 days). The irrigation management was different; the first year had a water excess of 63 mm and the second-year water deficit of 31 mm. This probably caused a reduction in fruit growth and abortion, which reflected in low yield (2nd), 58.17 t ha^{-1}, quality 4.52 ^{o}Brix, in the H-9553 hybrid (Table 2), and 114.04 t ha^{-1} and 4.12 ^{o}Brix, in the N-901 hybrid (1st). The average irrigation depth applied in each irrigation in all areas analyzed was 10.82 mm, ranging from 6.0 mm (A6, 2019) to 14.3 mm (A2).

The water application intensity at the end of each analyzed pivot ranged from 75.9 (A5) to 54.0 (A6) mm h^{-1}. Based on these data, we observed that in all areas except the A6 in 2018 and 2019, the medium and maximum irrigation depth application resulted in water runoff on the soil surface. The number of irrigations per cycle was 35 (average), varying between 13 irrigations occurring in Area 5 (2019) due to rainfall and 53 irrigations in Area 6 (2018) due to low irrigation depth pivot (5.3 mm day^{-1}). 32.5% of irrigation was carried out erroneously, and more than half of irrigations did not cause water runoff in soil. In areas A1, A2, A4 in 2019, and A5 in 2018, more than half of irrigations caused runoff of water in the soil surface. In other areas, the error percentage in water application varied between 8% (A6) and 48% (A3).

Based on the locations evaluated, 45% of the areas (A1, A3, A5, and A6) presented compacted soils in the 0-0.5 m soil layer. In Anápolis, despite average soil bulk density showing 1.41 g cm^{-3}, in the surface layer, 0-0.10 m, the soil bulk density of 1.53 g cm^{-3} was observed, value already considered compacted for industrial tomato crop in the Cerrado region (Melo et al., 2017). Soil bulk density values above the tolerated limit (1.5 g cm^{-3}) were also observed at some points in the deepest layers (from 0.1 to 0.5 m). In A3, A5, and A6, similar results were observed, although the average soil bulk density in the profile (0-0.5 m) was 1.35, 1.36, and 1.40, respectively, density values above 1.5 g cm^{-3} were found in all layers. Despite the average resistance to soil penetration in A1, in 0-0.06 m soil layer was 1489.7 kPa, in 0.06-0.40 m soil layer, where tomato roots are normally concentrated, points with resistance were observed above 2,000 kPa, representing compaction for industrial tomato crop (Melo et al., 2017). Also, in A4 (2018), A5 (2018 and 2019), and A6 (2018 and 2019), although the average resistance of soil penetration did not reveal compaction, compaction points were observed in A4 (2018) in the 0.15-0.50 m soil layer, in A5 (2018) and A6 (2018) in the 0.05-0.60 m soil layer, A6 (2019) in the 0.15-0.45 m soil layer, and A5 (2019) in the 0.10-0.50 m soil layer. In A5 (2018), compaction was observed in all areas, in 0.26-0.35 m soil layer, A3 in all areas, in 0.20-0.40 m soil layer, in A4 (2019) in 0.10-0.35 m soil layer, and in A7 in all areas, in 0.15-0.50 m soil layer.

4. Conclusions

The diagnosis revealed that there were errors in irrigation management in all evaluated areas when analyzing total water applied during the cycle of industrial tomato. The average irrigation error was 66.9 mm for water excess (77.8% of areas), and 25.3 mm for water deficit (22.2% of areas). In all evaluated areas, the crop phenological cycle was divided into four phases, and on average, there was an error due to water excess in two phases, error due to water deficit in one phase, and correct irrigation in other phase. Analyzing phase I, there was 33.4% of correctness in irrigation, 55.5% (18.5 mm) of error due to excess and 11.1% (5.1 mm) of error due to deficit. There was no correct answer in phase II, 87.5% (45.9 mm) of error due to excess and 12.5% (11.9 mm) of error due to deficit. In phase III, there was 11.1% of correct irrigation, 22.2% (26.1 mm) of error due to excess, and 66.7% (41.3 mm) of error due to deficit. In phase IV, there was 33.4% of success in irrigation, 44.4% (34.3 mm) of error due to excess and 22.2% (17.9 mm) of error due to deficit. The study also revealed that on average 44% of irrigations were carried out with wrong frequency, operating center pivot equipment below the minimum allowed speed, which may have caused water runoff. In this way, studies focused on irrigation management in industrial tomato, must still be carried out, in order to propose improvements, methods and tools, as seen in this work, that allow a profitable, efficient and sustainable production chain.

Table 4: Diagnosis of irrigation management in production of industrial tomatoes areas irrigated by center pivot in Anápolis, Gameleira de Goiás, Silvânia, Piracanjuba, Hidrolândia, and Palmeiras de Goiás (from 2018 to 2020).

Area		Phase I	Phase II	Phase III	Phase IV	Total
				mm		
A1	Rainfall	6.4	0.0	50.2	8.2	64.8
(127 days, N901)	Crop ET	35.4	84.7	188.2	76.5	384.8
	Irrigation	5.0	142.0	193.0	45.0	385.0
	Water balance	-24.0	+57.3	+55.0	-23.3	+0.19
A2	Rainfall	2.8	0.0	0.0	0.0	2.8
(114 days, CVR 6116)	Crop ET	20.2	90.0	207.8	41.7	359.6
	Irrigation	20.0	136.0	165.0	36.3	357.3
	Water balance	+2.6	+46	-42.8	-5.4	-2.3
A3	Rainfall	0.0	0.0	0.0	17.4	17.4
(125 days, N901)	Crop ET	19.3	74.5	158.7	76.8	329.3
	Irrigation	15.0	100.0	150.0	60.0	325.0
	Water balance	-4.3	+25.5	-8.7	+0.6	-4.3
A3	Rainfall	10.2	99.6	3.2	0.2	113.4
(124 days, CVR2909)	Crop ET	10.0	56.4	149.9	69.4	285.8
	Irrigation	2.5	5.5	61.8	50.8	120.5
	Water balance	+2.6	+48.9	-85.0	-18.5	-51.9
A4	Rainfall	0.6	0.2	16.4	73.6	90.8
(109 days, N901)	Crop ET	17.9	69.3	161.3	82.2	333.7
	Irrigation	43.0	85.0	115.0	40.0	299.4
	Water balance	+25.0	+15.7	-46.3	+31.4	-34.3
A4	Rainfall	0.0	4.4	27.6	21.4	53.4
(113 days, N901)	Crop ET	19.8	81.3	166.1	95.8	363.0
	Irrigation	13.0	105.0	132.0	145.0	395.0
	Water balance	-6.8	+23.7	-34.1	+49.2	+85.4
A4	Rainfall	126.8	95.2	2.6	3.2	227.8
(127 days, H1301)	Crop ET	8.7	52.7	134.7	73.1	269.2
	Irrigation	0.0	30.8	137.5	93.5	261.8
	Water balance	118.1	+73.3	+5.4	+23.6	+220.4
A5	Rainfall	0.0	0.6	4.6	52.2	57.4
(125 days, N901)	Crop ET	28.5	96.6	218.8	78.7	422.6
	Irrigation	51.0	137.0	188.0	81.6	457.6
	Water balance	+22.5	+41.0	-35.4	+55.1	+35.0
A5	Rainfall	10.4	198.8	134.6	6.8	350.6
(112 days, CVR2909)	Crop ET	17.7	69.0	133.2	67.0	286.9
	Irrigation	6.0	25.0	33.0	67.4	131.4
	Water balance	-11.7	+154.8	+34.4	+7.2	+195.1
A5	Rainfall	0.8	0.0	1.0	0.0	1.8
(121 days, N901)	Crop ET	131.0	71.1	187.4	90.5	362.1
	Irrigation	39.0	71.8	160.3	91.5	362.5
	Water balance	+26.8	+0.7	-26.2	+1.0	+2.2
A6	Rainfall	2.0	6.8	0.0	13.8	22.6
(129 days, N901)	Crop ET	24.7	84.9	199.8	103.9	413.2
	Irrigation	20.0	101.0	182.0	155.0	458.0
	Water balance	-2.7	+12.9	-17.8	+64.9	+44.8
A6	Rainfall	23.4	0.0	0.0	0.0	23.4
(120 days, H9553)	Crop ET	10.6	75.5	209.4	73.1	368.6
	Irrigation	23.4	123.0	141.0	60.0	347.0
	Water balance	+11.0	+47.5	-68.4	-13.1	+1.8
A6	Rainfall	0.4	2.2	0.6	0.0	3.2
(131 days, HM7885)	Crop ET	11.5	80.9	203.4	98.4	394.2
	Irrigation	32.5	75.0	132.5	65.8	305.8
	Water balance	+21.4	-3.8	-70.3	-32.6	-88.4
A7	Rainfall	0.0	0.0	0.0	0.0	0.0
(115 days, N901)	Crop ET	11.3	64.1	165.2	75.1	315.7
	Irrigation	31.8	80.0	137.0	52.0	300.8
	Water balance	+20.4	+15.9	-28.2	-23.1	-15.0

(+) Excess and (-) water deficit.

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