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Phosphate fertilization in processing tomato irrigated by localized irrigation systems

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Abstract

The aim of this work was to evaluate different combinations of phosphate fertilizer sources on processing tomato (cv. BRS Sena) development and yield, irrigated by localized irrigation systems. The experimental design was in randomized blocks, in split plots, in a factorial scheme (3x5), with four replications. In the plots were used three irrigation systems: drip; subsurface drip and microsprinkler. In the subplots, five combinations of phosphate fertilizer: 100% of Thermophosphate; 100% Triple Superphosphate; 75% Thermophosphate + 25% Triple Superphosphate; 50% Thermophosphate + 50% Triple Superphosphate; and 25% Thermophosphate + 75% Triple Superphosphate. At harvest, the yield of green, ripe and rotten fruits; total yield; percertation of green, ripe and rotten fruits; firmness; pH; titratable acidity; total soluble solids; and fruit size and density were evaluated. Fertilization with Thermophosphate, or its association with Triple Superphosphate, is beneficial for tomato yield. Microsprinkler irrigation provides higher percentage of ripe fruits and lower incidence of green fruits and, when associated with phosphate fertilization of 100% of Thermophosphate, promotes higher yield. Drip and subsurface drip irrigations proved ineffective for the tomato when all the planting fertilization was concentrated in the planting groove. Phosphate fertilization with only Triple Superphosphate was not beneficial the yield, regardless of the irrigation system used. Fertilization with Triple Superphosphate alone or associated with Thermophosphate favored the concentration of maturation, total soluble solids content and tomato fruit acidity.

Keywords: industrial tomato, microirrigation, phosphate, postharvest, *Solanum lycopersicom L.*

Introduction

The use of localized irrigation systems can be very efficient for irrigation of processing tomato, due to the non-wetting of the leaf area, with water application only in the vicinity of the root system and the possibility of fertilization parceling. Thus, it may result in less fungicide application, higher fertilizer efficiency, yield increase, best of fruit quality, as well as reduced water application, weed control, costs and crop profitability (Silva et al., 2019; Silva et al., 2022).

Phosphate fertilization may be a limiting factor for tomato yield in Brazilian Cerrado areas (Marouelli et al., 2015; Marques et al., 2022). Phosphate fertilizers with high water solubility are most commonly used in planting areas due to their higher agronomic efficiency. However, these sources allow the occurrence of high initial levels of phosphorus (P) in the soil solution, suitable for the initial plant growth, however they are quickly converted into unavailable forms and may have their efficiency decreased throughout the crop cycle (Mohammad et al., 2004; Shedeed et al., 2009; Mueller et al., 2015; Pfaff et al., 2020; Ngo et al., 2022). Fact evidenced by Marouelli et al. (2015) in a Brazilian Cerrado area when evaluating the phosphate fertilization fractionation in Heinz 9992 hybrid, when they concluded that the highest crop yield occurs when at least half of the P fertilization is applied in part during the crop cycle.

In this context, there are little scientific researches on P sources (high solubility, slow, gradual or controlled availability) applied in the planting furrow for processing tomato in Brazilian Cerrado soils. In addition, the crop water supply method can significantly contribute to higher plant phosphorus availability (Liu et al., 2017; Cecilio Filho et al., 2020; Sobrinho et al., 2022). Fact also evidenced by Yang et al. (2011) in China, who concluded that both organic and inorganic P can be significantly affected by

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irrigation.

Oke et al. (2005), in Canada, with the industrial processing hybrid Heinz 9478, concluded that supplementation with different phosphorus sources did not interfere with tomato fruit quality parameters. Fandi et al. (2010), in Egypt, concluded that high phosphorus concentration in the nutrient solution increases tomato yield, while low P concentrations provide higher total soluble solids, titratable acidity and pH. Thus, the objective of this study was to evaluate different combinations of phosphate fertilizer sources applied in the tomato furrow for industrial processing, hybrid BRS Sena, irrigated by localized irrigation systems.

Material and Methods

The research was conducted at the experimental field of the Instituto Federal Goiano Campus Morrinhos, Goiás, Brazil, located at 885 meters' altitude, 17°49'19.5" south latitude and 49°12'11.3" west longitude, from May to September 2017. The soil of the experimental area is classified as Oxisols - Ustox (Dystrophic Red Yellow Latosol in EMBRAPA, 2018). Prior to the installation of the experiment, soil samples were taken for chemical and physical analysis in the 0-20 cm and 20-40 cm deep layers (**Table 1**). Nutrient replacement was based on expected yield of 130 t ha^{-1}.

Planting fertilization was: 60 Kg ha^{-1} of N, 600 Kg ha^{-1} of P_2O_5 and 90 Kg ha^{-1} of K_2O, the sources used were Urea (45% of N), Triple Superphosphate (44% of P_2O_5 and 10% and Ca), Mg Therophosphate (18% of P_2O_5, 18% Ca, 7% Mg and 10% Si) and KCl (60% of K_2O). Fertilization was performed manually in the planting furrow, approximately 0.15m deep, two days before seedling transplantation. The cover fertilization was carried out manually by broadcasting, on the projections of tomato planting lines at 30 days after seedling transplantation (DAS). The proportion of 70 Kg ha^{-1} of N and 60 Kg ha^{-1} of K_2O was used through the urea and potassium chloride sources, respectively. Were used 26-days-old tomato seedlings, hybrid BRS Sena. They were produced in plastic trays with 450 cells in a specialized nursery. The seedlings were manually transplanted under no-tillage system. Desiccation of the experimental area was performed eight days before seedling transplantation, with post-emergence herbicide applications (glyphosate at the dose of 3.0 L ha^{-1}) and pre-emergence (Sulfentrazone at the dose of 0.8 L ha^{-1} and S-Metolachlor in the dose of 1.0 L ha^{-1}). The post-emergence weed control was performed with application of 0.5 L ha^{-1} Clethodim 30 days after seedling transplantation. Pest and disease control were performed with products recommended for the crop, alternating with different active ingredient and mode of action, applied in a preventive manner.

The design was a randomized block design with four replications subdivided in the factorial scheme (3x5). In the plots were applied three irrigation systems in equal depths: S1 = surface drip (DRIP); S2 = buried drip (BUR. DRIP) at 20 cm deep; and S3 = micro sprinkler (MICRO SPR.). Each whole plot was divided into 5 plots (split-plots). Each split-plot had a different combination of phosphate fertilization: T1 = 100% Thermophosphate; T2 = 100% Triple Superphosphate; T3 = 75% Thermophosphate and 25% Triple Superphosphate; T4 = 50% Thermophosphate and 50% Triple Superphosphate; and T5 = 25% Thermophosphate and 75% Triple Superphosphate, applied two days before transplanting the seedlings in the planting furrow.

Each experimental plot consisted of five subplots. The subplots were composed of three rows of plants of 6.0 m in length, spaced 1.10 m apart and plants spaced at 0.30 m in the planting line. The subplots, plots and blocks were spaced 2.0; 3.0 and 6.0 m, respectively, to avoid interference between treatments. Prior to each irrigation, around the micro sprinkler irrigated plots, approximately 1.40 m high TNT (Nonwoven Fabric) barriers were installed to prevent drift of irrigation water in the conventional and buried drip irrigated plots. The protective structure being removed immediately after irrigation is completed.

Surface drip and subsurface drip irrigation were performed by a self-compensating dripper tube, with nominal diameter of 17 mm, wall thickness of 0.85 mm, with anti-drainage system, 30 cm spacing between emitters, nominal pressure 200 kPa and flow rate 2.2 L h^{-1}. Being that in the buried drip, it was installed at a depth of 20 cm in the ground. For micro sprinkler irrigation, rotors-type microsprinklers were used, with flow of 50 L h^{-1}, installed at a height of 80 cm from the ground, 200 kPa operating pressure, spaced 3 meters between line and

Table 1. Result of chemical and physical soil analysis of the experimental area

2016												
Sample	Chemical analysis									Particle size		
	pH water	P	K	Na	Ca	Mg	Al	H+Al	Organic matter	Sand	Silt	Clay
		------ mg dm^{-3} -----			------- $cmol_c$ dm^{-3} ---------				- g dm^{-3}	---------- g kg^{-1} --------		
0 - 20 cm	6.2	42.3	120.1	78.0	3.8	0.8	0.0	2.1	50.2	486	100	414
20 - 40 cm	5.8	4.3	72.6	74.0	1.3	0.7	0.0	2.3	46.0	494	121	385

Methodology used: pH - soil: water (1:2.5); P, K and Na – Mehlinch 1; Ca, Mg and Al – Potassium chloride; H+AL – calcium acetate at pH 7.0; Organic Matter - Wet Oxidation (organic carbon content x 1.724).

2.5 meters between microsprinklers, totaling 6 dancers (rotors) per subplot.

The crop evapotranspiration (ETc) was calculated taking into account the Class A Tank Evaporation (CAE) in mm, the pan Coefficient (Kp) and the Crop Coefficient (Kc) (Equation 1). The meteorological data during the experimental period were monitored by the automatic weather station of the Instituto Federal Goiano Campus Morrinhos, located about 400 meters from the experiment (Eq 1).

$$ETc = CAE.\ Kp\ .\ Kc \quad (1)$$

Where:

ETc is crop evapotranspiration (mm);

CAE is the evaporation of the class A tank (mm dia^{-1});

Kp is the coefficient of the class A tank; and,

Kc is the crop coefficient.

A mean Kp of 0.7 was adopted throughout the experiment, as recommended by Sentelhas & Folegatti (2003). Tomato Kc followed EMBRAPA recommendations (Brazilian Agricultural Research Company) (Marouelli *et al*., 1996): Stage I - Initial, seedling setting (Kc=0.55); Stage II - from the setting of the seedlings to the beginning of flowering (Kc=0.65); Stage III - Fruiting, from the end of phase II until the beginning of fruit maturation (Kc=0.85); Stage IV - from end of phase III to end of harvest (Kc=0.65).

The Total Blade Required (TBR) was calculated as a function of ETc and irrigation system efficiency (Eq. 2).

$$TBR = \frac{ETc}{EF} \quad (2)$$

Where:

TBR is the total blade required (mm);

ETc is the crop evapotranspiration (mm);

EF is the irrigation systems efficiency (0.9).

The irrigation times of the experiment were calculated as a function of the TBR, the application intensity of the micro sprinklers and the drippers. The total area was irrigated in the micro sprinkling treatments. The irrigation occurred only in the wet strip of the dripper in drip treatments, which was determined in field with soil and moisture content in field capacity.

The plants were irrigated daily until eight DAS. From then on, the crop was irrigated on Mondays, Wednesdays and Fridays, until 110 DAS, when irrigations were suspended until the time of harvest.

At 135 DAS, all treatments were manually harvested, collecting eight plants from the plot's useful area, whose yield values were extrapolated to ha. Total fruit yield (TY), green (GF), ripe (RF) and rotten fruit yield (RF) were then evaluated, all at t ha^{-1}. The percentage of green (%GF), ripe (%RF) and rotten (%RtF) fruits in relation to total yield was also determined.

After harvesting, 30 ripe fruits from each subplot were randomly selected for postharvest laboratory evaluations. The fruit shape was measured through the transverse (TD, mm) and longitudinal (LD, mm) diameter, measured with a digital caliper rule. For determination of the total soluble solids content (TSS, °Brix), titratable acidity (TAC, % of citric acid) and pH, it was used the juice of 20 fully ripe fruits of the sample, which were processed in fruit centrifuge to obtain the juice.

Two drops of the juice were placed over the prism of a 0 to 32 °Brix scale portable refractometer and then the read of the refractive index was proceeded (IAL, 2008). Using a portion of the juice, the direct pH reading was determined using a digital peameter. The titratable acidity (TAC) (Eq. 3), was determined by the official methodology described by IAL (2008), as sodium hydroxide neutralization titration (NaOH) 0.1 N, to pH 8 (Eq 3).

$$TAC = \left(\frac{V.F}{P.C}\right) \quad (3)$$

Where:

TAC is titratable acidity (%of citric acid);

V is the volume (ml) of sodium hydroxide spent on titration;

F is the correction factor for sodium hydroxide solution (0.1N of NaOH);

P is the mass of the sample in g or pipetted volume in ml; and,

C is the constant used for NaOH at 0.1N (value =10).

The firmness (FF, Pa) was determined by the planer method in 10 ripe fruits of the sample of each treatment. For greater confidence in the results two readings were performed on each fruit, ie, in each treatment 20 readings of firmness were made and from these the averaged per treatment was calculated. Taking into account the crushed area and the weight of the glass plate, the fruit FF was calculated (Eq. 4) (Calbo & Nery, 1995).

$$F = \left(\frac{W}{0.784.LL.SL}\right) \quad (4)$$

Where:

FF is the firmness of the fruit (Pa);

W is the weight of the flattened glass plate (4.811805 N);

LL is the largest length of the wrinkled area (m);

SL is the shortest length of the wrinkled area (m); and,

0.784 is correction factor of the wrinkled area in the fruit;

The evaluated parameters were submitted to analysis of variance (Fisher's F test), at 5% probability levels. In the variables in which significant effects of the treatments occurred, the Scott-Knott test was applied to compare the means at the 5% probability level.

Results and discussion

During the study, the weather station recorded a maximum temperature of 32.8 °C, a minimum of 6.9 °C, an average of 21.7 °C, an average relative humidity of 59.4% and a cumulative precipitation of 42.4 mm, being that 41 mm occurred up to 17 days after seedling transplantation (DAS) and the rest occurred on the eve of the harvest (**Figure 1**).

The average global solar radiation was 17 Megajoule (MJ) m^{-2} day^{-1}, the average and cumulative reference evapotranspiration (ETo) crop evapotranspiration (ETc) was 4.72 mm day^{-1}, 3.50 mm day^{-1}, 553.73 mm and 395.2 mm, respectively. The accumulated ETc (395.2 mm) was applied to the crop during the experimental period, regardless of the irrigation system (**Figure 2**).

There was a significant effect ($p \leq 0.01$) of the irrigation factor on the variables fruit green (GF), percentage of green (%GF), ripe (%RF), Frimness (FF), pH and longitudinal diameter (LD). The phosphate fertilization sources presented significant effect ($p \leq 0.01$) on GF, ripe fruit (RF), total yield (TY), %GF, %RF, FF, total soluble solids (TSS) and pH. The interaction fertilization x irrigation had significant effect ($p \leq 0.01$) for RF, FF and TY variables (**Table 2** and **3**). The other variables showed no significant statistical differences.

The highest yield and percentage of green fruits (37.63 t ha^{-1} and 27.97%) of the BRS Sena hybrid occurred in drip irrigated treatments. The lowest yield from GF (11.34 t ha^{-1} and 7.97%) were obtained in the treatments irrigated by microsprinkler, regardless of the source of fertilization. Fertilization with 100% Thermophosphate (T1) presented higher yield and percentage of GF. The other fertilization treatments did not differ, regardless of the irrigation system used (**Table 4**).

The highest RF yield (144.25 t ha^{-1}) achieved with the microsprinkler system occurred with the phosphate fertilization of 100% Thermophosphate (T1), although it did not differ from T3 and T4. When irrigation was performed by subsurface drip, the highest RF yield occurred with the fertilization of 25% Thermophosphate and 75% Triple Superphosphate (T5). However, when the crop was drip irrigated, the highest RF yield occurred with the fertilization of 75% Yorin and 25% Triple Superphosphate (T3) and 25% Thermophosphate and 75% Triple Superphosphate (T5) (Table 4). Analyzing P sources in relation to fertilization systems, the highest RF yield of tomato occurred when the crop was fertilized with 100% Thermophosphate (T1); and 50% Thermophosphate and 50% Triple Superphosphate (T4); and irrigated by the micro sprinkler system. The other forms of phosphate fertilization did not differ, regardless of the irrigation system (Table 4).

The highest RF incidence of BRS Sena hybrid (87.25%) occurred when the hybrid was irrigated by the microsprinkler irrigation system. The lowest incidence of RF (70.39%) was observed in drip irrigation, regardless of the forms of fertilization with P. Comparing P sources, fertilization with 100% Thermophosphate did not favor fruit maturation (69.64%) in relation to the other forms

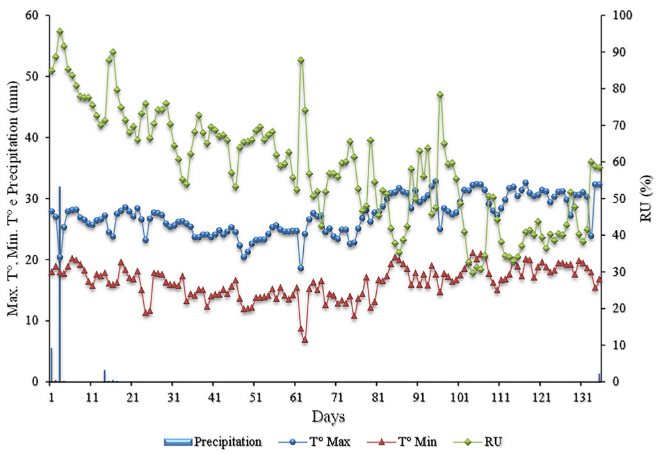

Figure 1. Daily values of maximum temperature (Max. T°), minimum (Min. T°), precipitation and relative humidity (RU) while conducting the experiment (05/18/2017 to 9/29/2017).

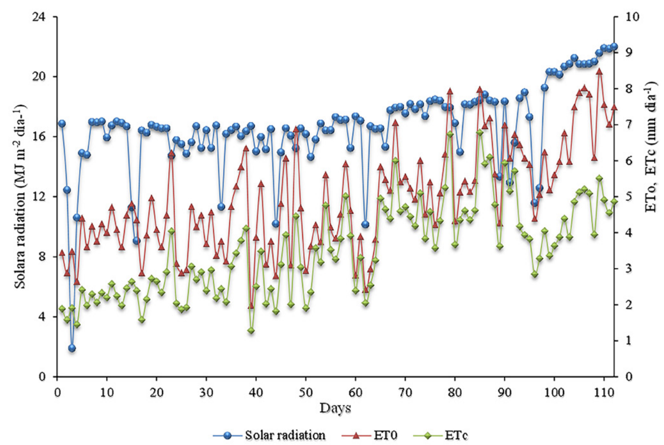

Figure 2. Daily values of solar radiation, reference evapotranspiration (ETo) and crop evapotranspiration (ETc) during the irrigation period of the experiment.

Table 2. Analysis of variance summary of the Green (GF), ripe (RF) and rotten (RtF) fruits, total yield (TPY), % of green (% GF), ripe (% RF) and rotten (% RtF) fruits of tomato (BRS Sena Hybrid), as a function of irrigation systems and phosphorus sources

Causes of Variation	DF	Medium Squares						
		GF	RF	RtF	TY	GF	RF	RtF
		t ha^{-1}				%		
Irrigation (I)	2	3542.74**	1944.24^{ns}	100.02^{ns}	396.21^{ns}	2074.13**	1433.34**	59.01^{ns}
Fertilizing (F)	4	720.64**	1815.72**	27.36^{ns}	3312.30**	326.59**	295.63**	9.80^{ns}
Block	3	17.17^{ns}	592.71^{ns}	30.01^{ns}	614.60^{ns}	92.67^{ns}	65.03^{ns}	14.27^{ns}
Error 1	6	260.90	2771.05	39.05	3532.89	85.51	72.85	18.96
I. X A.	8	57.86^{ns}	1649.19**	11.55^{ns}	1358.71**	70.18^{ns}	74.72^{ns}	3.97^{ns}
Error 2	36	55.25	404.89	19.07	386.19	59.12	47.20	7.41
TOTAL	59	14036.57	57325.38	1412.54	61855.30	8935.86	6978.48	612.58
CV 1 (%)		65.55	48.82	151.01	43.51	49.58	10.89	145.91
CV 2 (%)		30.16	18.66	105.49	14.39	41.23	8.77	91.25

DF - Degrees of freedom; ^{NS} - Not significant by the F test; ** - Significant at the 1% probability level by the F test; * - Significant at the 5% probability level by the F test; CV – Coefficient of variation.

Table 3. Summary analysis of variance of Firmness (FF), density (ND), total soluble solids (TSS), pH, titratable acidity (TAC), longitudinal diameter (LD) and transverse diameter (TD) of tomato fruits (Hybrid BRS Sena), as a function of irrigation systems and phosphorus sources

Causes of Variation	DF	Medium Squares					
		FF	TSS	pH	TAC	LD	TD
		Pa	°Brix		%	mm	Mm
Irrigation (I)	2	2229.591^{ns}	0.365^{ns}	0.177**	0.00029^{ns}	81.31**	7.84^{ns}
Fertilizing (F)	4	5367.552**	1.439**	0.087**	0.00078^{ns}	7.67^{ns}	1.88^{ns}
Block	3	4196.414^{ns}	0.128^{ns}	0.032^{ns}	0.00114^{ns}	11.53^{ns}	6.34^{ns}
Error 1	6	3176.456	0.364	0.010	0.00006	7.00	4.01
I. X A.	8	4995.670**	0.033^{ns}	0.021^{ns}	0.00015^{ns}	3.33^{ns}	2.87^{ns}
Error 2	36	1510.883	0.067	0.017	0.00036	4.86	3.11
TOTAL	59	16.117	11.72	1.652	0.0215	471.61	201.29
CV 1 (%)		19.75	11.59	2.10	3.54	3.79	4.25
CV 2 (%)		13.62	4.96	2.74	8.36	3.16	3.74

DF - Degrees of freedom; ^{NS} - Not significant by the F test; ** - Significant at the 1% probability level by the F test; * - Significant at the 5% probability level by the F test; CV – Coefficient of variation.

Table 4. Green Fruit (GF), ripe fruit (RF), total yield (TY), % of green fruits (%GF), % of ripe fruits (%RF), firmness (FF), total soluble solids (TSS), pH, longitudinal diameter (LD) of tomato fruits (Hybrid BRS Sena), as a function of irrigation systems and phosphorus sources

Features evaluated	Irrigation System	Phosphorus Sources					Average
		T1	T2	T3	T4	T5	
Green fruit(t ha^{-1})	MICRO SPR.	19.99	5.32	9.47	7.26	14.71	11.35 A
	BUR. DRIP	37.83	20.05	28.57	16.73	19.86	24.59 B
	DRIP	55.09	30.01	34.10	32.82	37.83	37.96 C
Average		37.63 b	18.46 a	24.04 a	18.94 a	24.13 a	24.64
% Green Fruit	MICRO SPR.	11.70	5.62	6.63	4.97	10.91	7.97A
	BUR. DRIP	30.83	16.79	21.46	15.95	13.70	19.75B
	DRIP	41.38	25.44	21.74	28.83	23.83	28.24C
Average		27.97 b	15.95 a	16.61 a	16.58 a	16.15 a	18.65
Ripe Fruit (t ha^{-1})	MICRO SPR.	144.25 Aa	87.74 Ab	124.82 Aa	132.83 Aa	105.85 Ab	119.10
	BUR. DRIP	86.11 Bb	91.97 Ab	103.25 Ab	103.35 Bb	132.99 Aa	103.54
	DRIP	82.65 Bb	89.18 Ab	124.01 Aa	84.52 Bb	123.77 Aa	100.83
Average		104.34	89.63	117.36	106.90	120.87	107.82
% Ripe Fruit	MICRO SPR.	84.22	90.50	87.92	90.88	82.71	87.25 A
	BUR. DRIP	67.63	81.66	76.90	80.18	80.95	77.46 B
	DRIP	57.07	73.69	77.28	69.11	74.79	70.39 C
Average		69.64 b	81.95 a	80.70 a	80.06 a	79.48 a	78.37
Total yield (t ha^{-1})	MICRO SPR.	171.35 Aa	96.85 Ac	141.92 Ab	146.28 Ab	128.37 Bb	136.95
	BUR. DRIP	125.82 Bb	113.71 Ab	133.90 Ab	124.72 Ab	161.77 Aa	131.98
	DRIP	140.01 Bb	120.43 Ab	159.68 Aa	120.16 Ab	164.03 Aa	140.86
Average		145.72	110.33	145.17	130.39	151.39	136.60
Firmness (Pa)	MICRO SPR.	295.48 Ab	389.03 Aa	239.63 Bb	290.95 Ab	266.59 Ab	296.33
	BUR. DRIP	270.60 Aa	283.03 Ba	297.08 Aa	297.24 Aa	263.53 Aa	284.44
	DRIP	275.38 Aa	288.94 Ba	307.80 Aa	257.04 Aa	257.95 Aa	275.28
Average		280.49	320.34	281.50	281.74	262.69	285.35
Total soluble solids(°Brix)	MICRO SPR.	5.10	5.85	5.53	5.33	4.90	5.34
	BUR. DRIP	4.85	5.68	5.35	5.33	4.80	5.20
	DRIP	4.93	5.38	5.35	5.10	4.60	5.07
Average		4.96 c	5.63 a	5.41 b	5.25 b	4.77 c	5.20
pH	MICRO SPR.	5.10	4.94	4.86	4.82	4.78	4.90 A
	BUR. DRIP	4.93	4.74	4.73	4.76	4.80	4.77 B
	DRIP	4.81	4.64	4.71	4.61	4.71	4.72B
Average		4.95 b	4.77 a	4.77 a	4.73 a	4.76 a	4.80
LD	MICRO SPR.	65.70	68.94	67.07	67.64	68.43	67.56 B
	BUR. DRIP	69.27	71.76	72.18	71.38	69.60	71.16 A
	DRIP	70.86	71.72	71.30	70.75	71.61	70.93 A
Average		68.61	70.80	70.18	69.92	69.88	69.88

Averages followed by the same capital letter in the column (irrigation system) and lower case letter in the line (doses), for the same characteristic evaluated, do not differ from each other by the Scott-Knott test, p < 0,05. T1 = 100% Thermophosphate; T2 = 100% Triple Superphosphate; T3 = 75% Thermophosphate and 25% Triple Superphosphate; T4 = 50% Thermophosphate and 50% Triple Superphosphate; and T5 = 25% Thermophosphate and 75% Triple Superphosphate.

of phosphate fertilization tested, which did not show significant differences, regardless of the irrigation system (Table 4).

The highest concentrations of green fruits in the drip and subsurface drip treatments were due to the delay in the initial development of the seedlings, caused by the salinity promoted by the fertilizers around the wet bulb of the plant root system. The problem was even more evident in the treatments that received Thermophosphate, due to the lower P concentration of this source, consequently higher fertilization and higher soil salinity in the wet bulb. This delayed the vegetative and reproductive cycle of tomato plants in these treatments, which resulted in higher incidence of green fruits at harvest.

In microsprinkler irrigation the problem was mitigated because the system irrigated the total area of the subplot and diminished the effects of salinity, which led to faster plant development and consequently uniform fruit maturation at harvest. This corroborates with the studies by Demontiêzo et al. (2016), that when researching the emergence and initial growth of 'Santa Clara' tomatoes, as a function of irrigation water salinity, concluded that higher water salinity negatively affected plant development.

The higher yield of ripe fruits when the crop is fertilized with Thermophosphate is mainly associated with the microsprinkler irrigation, this is due to the fact that this irrigation system provides for these circumstances a lower salinity effect on the wet bulb, thermophosphate salt content is lower and the triple superphosphate index higher. Fato que corroboram aos estudos de Demontiêzo et al. (2016); Liu et al. (2017) e Cecílio Filho et al. (2020), that achieved greater tomato yields with greater availability of phosphoorus in the soil. Also, Thermophosphate provided slow P release during the crop cycle. Results that corroborate with the information of Mohammad et al. (2004) and Marouelli et al. (2015), who concluded that fertilization with P gradually increases crop yield. Results that corroborate the information obtained by NGO et al. (2022) in Australia, which concluded that the ideal development of plants do not depend only on the immediately available P and that the supply of the nutrient during the culture cycle is importnate

The highest total fruit yield (171.35 t ha^{-1}) was provided with the microsprinkler system and with phosphate fertilization of 100% Thermophosphate. (T1). When irrigation was performed by buried drip, the highest yield of TY occurred with the fertilization of 25% Thermophosphate and 75% Triple Superphosphate (T5). However, when the crop was drip irrigated, the highest crop yield occurred with the fertilization of 75% Yorin and 25% Triple Superphosphate (T3) and 25% Thermophosphate and 75% Triple Superphosphate (T5). Comparing phosphate fertilizers in relation to irrigation systems, the highest TP of tomato occurred with fertilization with 100% Thermophosphate irrigated by micro sprinkler. When fertilization is performed with 25% Thermophosphate and 75% Super Triple (T5), the best irrigation systems were drip and subsurface drip (164.03 and 161.77 t ha^{-1}, respectively). The other sources of fertilization did not differ statistically, regardless of the irrigation system used (Table 4).

The results of the yield of the crop were advantageous to the fertilization of tomato with thermophosphate or to the association of thermophosphate with triple superphosphate, fact that corroborates with the results of Marouelli et al. (2015) in cerrado areas of Brasília, with the hybrid Heinz 9992, when they verified higher yield of the hybrid with the gradual fertilization of P and lower saline index, due to the use of thermophosphate to the crop. These results also corroborate with the information of Mueller et al. (2015) in Santa Catarina, when they observed higher yield of two tomato table cultivars when fertilization with P was done by sections. Information also evidenced by Mohammad et al. (2004) in Jordan and, Shedeed et al. (2009) in Egypt, who observed lower crop yield when applied 100% of P_20_5 in pre-planting.

Thermophosphate associated with microsprinkler irrigation provided higher yield (lowest saline index and source of gradual P release) and lower salinity near the root system of the crop due to the micro sprinkler system irrigate the total area, information already evidenced earlier. Microsprinkler irrigation enables greater expansion and elongation of the root system and consequent increase the absorption of P, which caused higher yield, a result also verified by Liu et al. (2017) in China.

In drip and subsurface drip irrigations, the root system is concentrated in a smaller volume of soil, corresponding to the wet bulb caused by irrigation, which somehow decreases the elongation of the root system and increases the osmotic potential in the wet bulb region. Higher osmotic potential promotes lower P uptake and plant development, according the information by Marouelli et al. (2015) and Liu et al. (2017). Information that also corroborates the studies of Sobrinho et al. (2022) on phosphate fertilization efficiency and irrigation levels in tomato culture.

When the fruits firmness was analyzed it was noticed that the treatment irrigated by microsprinkler and fertilized with 100% Triple Superphosphate (T2) produced fruits with higher FF. The other irrigation systems showed no differences, regardless of the form of phosphate fertilization. Comparing P sources, no significant differences were found between irrigation systems, except when using 100% Triple Superphosphate (T2).

In this treatment the fruits of tomato BRS Sena showed to be firmer when the crop was irrigated by micro sprinkler. When it was fertilized with 75% Yorin and 25% Triple Superphosphate (T3) and the irrigation was by drip and buried drip, firmer fruits were produced in relation to those irrigated by micro sprinkler. Fruit firmness is an important postharvest parameter as it significantly influences fruit shelf life and resistance to damage during harvest. With the transport of the fruits from the crop to the agroindustry occurs in bulk, it is preponderant for the quality of the fruits the arrival of the raw material to the processing unit (Melo & Vilela, 2005).

The localized irrigation systems tested did not significantly influence total soluble solids and fruit pH. The highest levels of total soluble solids occurred when the crop was fertilized with 100% Triple Superphosphate (T2). The other sources of phosphate fertilization did not differ statistically for these variables (Table 4). The lowest fruit acidity (pH = 4.95) was obtained in treatments fertilized with 100% Thermophosphate, while the other treatments presented higher acidity, but did not differ statistically (Table 4). The longitudinal diameter (LD) was influenced only by irrigation systems. Micro sprinkler irrigation presented smaller fruits (67.56 mm) when compared to the other two systems that did not differ from each other (Table 4).

The postharvest quality results corroborate with those found by Fandi et al. (2010) in Egypt, which found higher levels of total soluble solids and pH in tomato fruits, when they used lower concentrations of P in the nutrient solution of plant adduction. However, these results differ from those found by Oke et al. (2005) in Canada with the Heinz 9478 hybrid, where during a three-year evaluation period they found no significant evidence of the influence of phosphorus fertilization on postharvest quality variables. The results also corroborate those with Sobrinho et al. (2022b) in Rio Verde, Goiás, Brazil, who concluded that the use of P organo-mineral fertilizer source resulted in tomato fruits with greater titrable acidity and higher longitudinal diameters, regardless of irrigation Water Levels used.

Conclusions

Fertilization with Thermophosphate, alone or associated with Triple Superphosphate, is beneficial for the yield of processing tomato.

Microsprinkler irrigation provides higher percentage of ripe fruits and when associated with the phosphate fertilization of 100% Thermophosphate, promotes higher yield of BRS Sena hybrid.

Surface and subsurface drip irrigations proved ineffective for the tomato when all the base fertilization was concentrated in the planting furrow.

Phosphate fertilization with Triple Superphosphate alone is not beneficial for the productivity of BRS Sena tomato, regardless of the irrigation system used.

Fertilization with Triple Superphosphate alone or associated with Thermophosphate favors the concentration of maturation, the total soluble solids content and the acidity of the tomato fruits.

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