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Tomato in the semi-arid: Plastic mulching, plant population and irrigation

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Abstract

Plastic mulches have been extensively used in tomato fields around the world; its use has been growing in Brazil, especially in semi-arid regions. However, whether plastic mulches are beneficial to tomato grown in the Brazilian semi-arid and should replace other traditionally used practices is little known. Two on-farm experiments were carried out aiming at assessing the yield response of 'Trucker' hybrid tomato to plastic mulching in interaction with other practices, viz, irrigation, earthing up, and plant population. The first experiment consisted of a randomized block design with six treatments arranged in a 3 x 2 factorial and replicated four times: three crop practices (earthing up, plastic mulching and bare soil) combined with two plant populations (12,500 and 10,416 plants ha^{-1}). The second experiment was a randomized complete block design with four replications, in a split-plot arrangement. Irrigation levels (305, 440, 495, 610 and 725 mm cycle^{-1}) were assigned to plots, and mulching and earthing up to subplots. Fruit diameter, fruit weight and crop yield were evaluated. Plastic mulching had no effect on crop yields and water-use efficiency at both experiments. Overall, the results suggest planting 'Trucker' tomato at 12,500 plants ha^{-1}, 580-630 mm cycle^{-1} of irrigation, and without plastic mulching.

Keywords: Cropping systems, water productivity, plant population, earthing up, crop yield

Introduction

Tomato plays a relevant socio-economical role as a major cash crop (Carvalho et al., 2014; Gatahi, 2020); however, tomato cultivation demands high-input crop systems to prevent losses associated with soil fertility, water, pests, and diseases (Monte et al., 2013). The success of a crop system depends on soil and climate conditions, growers' purchasing power, and cultivar (Schwarz et al., 2014). Therefore, decision-making should be backed with site-specific knowledge, either empirical or based on experimental research.

Most tomato growers in the Brazilian semi-arid region have traditionally earthed up (or hilled up) tomato plants. This practice consists of moving fertilizer-enriched soil from inter-rows to the base of the plant. Earthing up may stimulate the production of adventitious roots, which are formed from tissues other than roots, such as stem and leaves (Geiss et al., 2009; Steffens & Rasmussen, 2016). A greater root volume resulted from the formation of adventitious roots leads to increased water and nutrient uptake as well as reinforcing plant anchorage (Gonin et al., 2019). Additionally, earthing up may indirectly control weeds (Ronchi et al., 2010). Despite these claims, no studies evaluating this practice in tomatoes have been found in the literature.

Due to the lack of science-based evidence, plastic mulching comes into play to replace earthing up when growing tomatoes because the two practices cannot coexist. Plastic mulches are used with the aim of limiting soil water evaporation, controlling weeds and enhancing soil structure (Kasirajan & Ngouajio, 2012; Yu et al., 2018). It may improve yields by preserving soil water, controlling weeds, reducing soil erosion, promoting early fruit ripening, and improving seedling establishment (Ingman et al., 2015). Although positive effects of plastic mulching on tomatoes have been reported (Pinder et al.,

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2016; Berihum et al., 2011; Aliabadi et al. 2019; Biswas et al., 2015; Tipu et al., 2014; Sekara et al., 2019), the response of tomatoes grown under tropical, semi-arid climates is little known, especially when associated with other practices, such as increased plant population and irrigation.

Whether one practice is better than the other is up to debate, and field experiments are needed to shed some light on this matter. The objectives of this study were: (i) to investigate the effect of irrigation levels and plastic mulching on the performance of fresh market tomato plants; and (ii) to compare plastic mulching to earthing up at different plant populations.

Material and Methods

Two on-farm experiments were carried out in northeastern Bahia state, Brazil. One site is about 60 km away from the other site. The first experiment aimed to determine the best irrigation depth, with plastic mulching and earthing up. The second experiment aimed to compare plastic mulching with earthing up at different plant populations.

First experiment

The field experiment was carried out between 1 October 2018 (sowing) and 19 February 2019 (last harvest) on a commercial farm located in Poções, Bahia state, northeastern Brazil (S14°31'47'', W40°18'06'', mean elevation of 760 m). Annual mean temperature and rainfall are 19.8°C and 572 mm, respectively. The climate is classified as BSh (hot semi-arid climate according to Köppen-Geiger classification). While a total rainfall of 246 mm had been recorded between late November and early December, daily reference evapotranspiration (ETo) added up to 495 mm for the whole experimental period, so a water deficit condition predominated during the conduction of the experiment. (Figure 1)

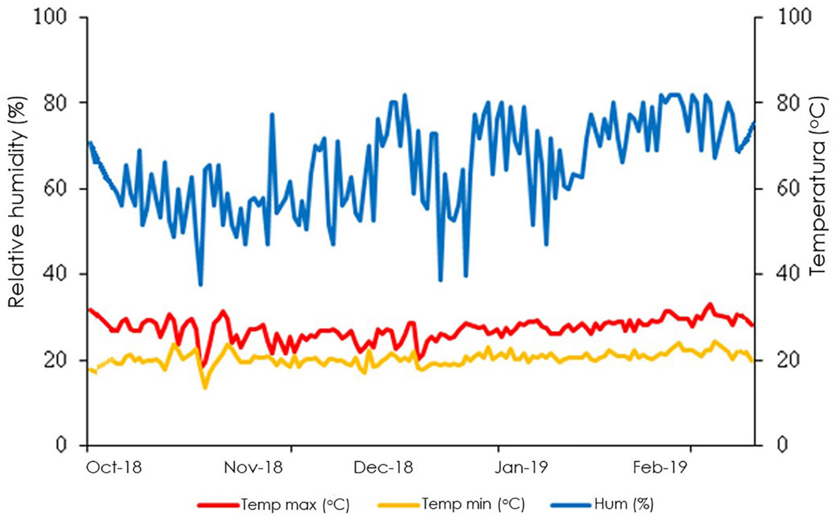

Figure 1. Maximum and minimum temperatures and mean relative humidity recorded over the experimental period in Poções, Bahia state, Brazil.

Soil samples were collected at 0-20 depth on the site prior to planting and sent to a laboratory for testing. The results are as follows: P (resin) = 2 mg dm^{-3}; K (resin) = 0.23 Cmol$_c$; Ca = 2.70 Cmol$_c$; Mg = 1.80 Cmol$_c$; Al = 0.20 Cmol$_c$; H = 5.0 Cmol$_c$; C = 0.23 Cmol$_c$ and CEC (cation exchange capacity) = 4.93 Cmol$_c$ dm^{-3}. It was classified as sandy clay soil with field capacity and permanent wilting point being 18.6% and 13.3%, respectively.

Uniformly-sized 30-day old seedlings of a determinate hybrid globe tomato 'Trucker' were transplanted to the field at a spacing of 0.6 m within rows and 1.5 m between rows. The experimental field was 504 m^2 (18 m x 28 m) and consisted of 20 plots and 40 subplots (each plot was composed of two subplots). There was an additional 3-m-wide traffic path between blocks 1 and 2 and blocks 3 and 4.

Treatments consisted of five irrigation levels (305, 440, 495, 610, and 725 mm cycle^{-1}) combined with either plastic mulching or earthing up. The treatments were laid out in a randomized block design with four replicates and arranged in a split plot design: irrigation levels were assigned to plots and mulching/non-mulching treatments to subplots. Each experimental plot was composed of 23 plants (20.7 m^2) and each subplot was composed of a 7.2 m-long row of plants containing 12 plants (10.8 m^2). The first and last plants of each subplot were border.

Fertilizers were applied at transplanting (basal application), at a rate of 1.0 t ha^{-1} of 4N-14P-8K and 2.0 t ha^{-1} of single superphosphate (18% P_2O_5). Seven days later, 400 kg ha^{-1} of single superphosphate was applied as topdressing right before earthing up plants. The remaining fertilizers were applied via fertigation.

Fertilization followed technical recommendations of the company that provided the tomato seeds as part of a technological package aimed at highest yields.

Irrigation management

In both experiments, tomato plants were drip-irrigated daily. The irrigation system run time varied over the crop cycle as follows: 30 min d^{-1} from transplanting to 30 days after transplanting (DAT); 45 min d^{-1} from 31 to 50 DAT; and 60 min d^{-1} from 51 to 106 DAT. Therefore, for the irrigation experiment, irrigation levels applied to each treatment were attained using different emitter discharge rates: 1.6, 2.3, 2.6, 3.2, and 3.8 L h^{-1} for 305, 440, 495, 610 and 725 mm $cycle^{-1}$, respectively; total ETo during the irrigation experiment was 494 mm, recorded from a weather station located 36 km from the site, so we considered irrigation levels to be 62, 89, 100, 123, and 147% of total ETo, respectively. Irrigation levels were not based on ETo, but on field capacity. ETo was used only to associate it with the amount of water applied to reach field capacity; coincidently, the amount of water applied to control plants was similar to that of 100% ETo.

Second experiment

The second farm is located in Vitória da Conquista, Bahia state, Brazil (14°53'08'' S, 40°48'02" W, and mean elevation of 846 m altitude). The climate is dry and hot, with a rainy season between November and March. Average annual rainfall and temperature are 730 mm and 20.2 °C, respectively.

Figure 2 shows temperature and relative humidity of the second experiment, recorded from a weather station located 20 km from the farm.

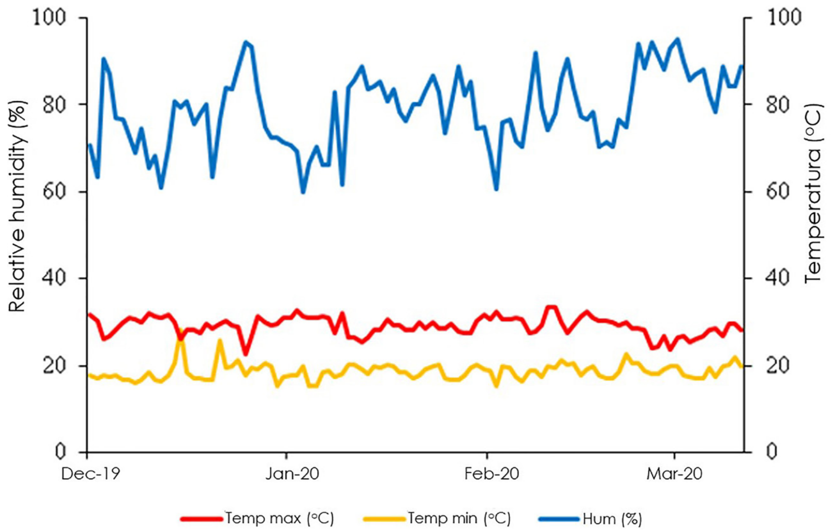

Figure 2. Climatic variables recorded over the experimental period in Vitória da Conquista, Bahia state, Brazil.

In comparing with Figure 1, we can see that climatic conditions were similar, though mean relative humidity was slightly lower in Poções. Total rainfall in Vitória da Conquista over the experimental period was 437 mm, as against 246 mm recorded in Poções, which may explain the difference in relative humidity.

The soil, a sandy clay latosol (oxysol), was conventionally tilled. Soil samples were collected before planting and sent to a soil laboratory for testing. Its chemical properties were: pH, 5.8; organic matter, 3.2%; P, 1.0 mg dm^{-3}; Ca, 3.2 $cmol_c$ dm^{-3}; Mg, 2.2 $cmol_c$ dm^{-3}; Al, 0.1 $cmol_c$ dm^{-3}; Sum of bases, 5.7 $cmol_c$ dm^{-3}; cation exchange capacity, 10.8 $cmol_c$ dm^{-3}, effective cation exchange capacity, 5.8 $cmol_c$ dm^{-3}; and base saturation, 53 %.

Basal fertilization was carried out with 3,000 kg ha^{-1} of single superphosphate and 500 kg ha^{-1} of NPK 4-30-10. Twenty days after transplanting the seedlings, 1,000 kg ha^{-1} of single superphosphate was top dressed. The remaining fertilizers were applied through fertigation and followed technical recommendations of the company that provided the tomato seeds.

Treatments consisted of three crop practices (earthing up, plastic mulching and bare soil) randomly combined with two plant populations (10,416 and 12,500 plants ha^{-1}), for a total of six treatments replicated four times (24 experimental units). The plant populations, 10,416 and 12,500 plants ha^{-1}, were achieved by using the spacing 1.6 x 0.6 m and 1.6 x 0.5 m, respectively.

Each experimental unit was a row composed of 13 plants. Observational units were nine plants located in the middle of the row, while the remainder was border.

White plastic mulch was manually laid on soil and holes were made on mulches in accordance with the plant spacing respective to each treatment. Then, 30-d-old 'Trucker' tomato seedlings, a hybrid variety with determinate growth habit and beefsteak tomato fruits, were transplanted to field on December 12nd, 2019. On January 3rd, 2020, plants were earthed up according to the treatment. Earthing up was carried out with a hoe, moving fertilizer-rich soil from between rows to the base of the plant.

Plants were drip irrigated every day. Pest and disease control as well as crop practices were performed in the same way as the remaining plants at the farm.

Measurements

Yield components were measured throughout the harvest. At each harvest, 10 fruits were randomly collected from each subplot and weighed (fruit weight – FW) using a scale. Using the same fruits, fruit diameter (FD) was determined with a 0.01 mm digital caliper.

Total fruit yield (Y) was determined throughout the harvest. Marketable fruits (undamaged, red or turning red fruits) from each subplot (10 plants) were harvested, weighted at each harvest, and added together to determine Y as kg plant^{-1}. Based on the plant population, yield per plant was converted into t ha^{-1}.

Water use efficiency - WUE (kg ha^{-1}mm^{-1}) was calculated for the irrigation experiment as the ratio of fresh total yield (kg ha^{-1}) to the total amount of irrigation water applied over the crop cycle (mm).

Data analysis

Data were subjected to normality test (Lillifors) and homogeneity of variances (Cochran and Bartlett). Then, data were tested by analysis of variance. If significant by F test, means were compared using Tukey's HSD test ($p \leq 0.05$). For the irrigation experiment, regressions were carried out to explain irrigation effects. The analyses were carried out using R (R Development Core Team, 2020).

Results and Discussion

Fruit diameter (FD) and fruit weight (FW)

In both experiments, plastic mulching had no effect on FD and FW. In the second experiment, plant populations had no effect on fruit size and weight, which averaged 72.46 mm and 128.93 g, respectively. This is particularly important because decreased fruit size is a problem when increasing plant population. Such results are site-specific as Santos et al. (2010) reported yield increases of large fruits as plant population increased from 10,660 to 14,448 plants ha^{-1}.

Results are not consistent with studies on plastic mulching in tomatoes in the literature (Tipu et al., 2014; Biswas et al., 2015; Sekara et al., 2019; Aliabadi et al., 2019). However, responses of tomato to mulching depend on climate and soil conditions at the growing site, as well as the cultivated variety (Zhang et al., 2017). Plastic mulching is more popular in countries with temperate climate where other tomato varieties are grown, often under rainfed conditions (Kader et al., 2018).

In both experiments, plastic mulching had no effect on Y compared to earthing up. Irrigation levels significantly influenced fruit weight (FW), fruit diameter (FD), and total yield (Y). Total yield as a function of irrigation levels was fitted to a quadratic model, with maximum yield of 77.2 t ha^{-1} at 579.15 mm (Figure 3D). In this study, there was a 4.3% decrease in yield from the maximum value at 579.15 mm cycle^{-1} to that of the highest irrigation level (725 mm cycle^{-1}).

Water use efficiency (WUE) as a function of irrigation levels was fitted to a linear model showing a reduction of 46% in WUE from 305 to 725 mm (Figure 3C). WUE response to water levels was different from that of yield; the treatment promoting higher crop yield does not necessarily have higher WUE. The highest WUE was obtained at the lowest irrigation level, corresponding to 62% of ETo (305 mm).

The combination of drip irrigation and mulching may improve tomato yield at minimum water use (Biswas et al., 2015). In this study, plastic mulching had no effect on WUE. This result is different from that of Campagnol et al. (2014) who reported that WUE increased with decreasing irrigation level in mulched plants compared to those without mulching; however, crop response to irrigation strategies such as plastic mulching varies according to soil and climate (Zhang, 2017). Having only these findings as reference, plastic mulching is not recommended with the aim of increasing WUE and yield of tomatoes grown under the climate and soil conditions of both studies.

In both experiments, in 2018-2019 (Poções) and 2019-2020 (Vitória da Conquista) seasons, plastic mulching and earthing up had no significant influence on tomato yield when compared to bare soil (control). In the first experiment, yields were 74.7 and 72.2 t ha^{-1} for mulched and bare soil, respectively. As for the second experiment, yields were 70.2, 72.7 and 72.35 t ha^{-1} for bare soil, earthing up and plastic mulching, respectively. These yields are consistent with Brazil's average (70 t ha^{-1}) and above Bahia state's average (45 t ha^{-1}) (Ibge, 2020). Although earthing up is traditionally recommended for tomatoes, based solely on empirical evidence, the practice failed to increase yields when comparing to bare soil and mulching in both Poções and Vitória da Conquista. The similar yields and climatic conditions (Figure 1 and 2) provide reliability to the results.

In the second experiment (Vitória da Conquista), plant populations had a significant effect on yield (Figure 4). A highest plant population leads to increased yield per unit area as the number of harvested plants is higher, resulting in greater yields.

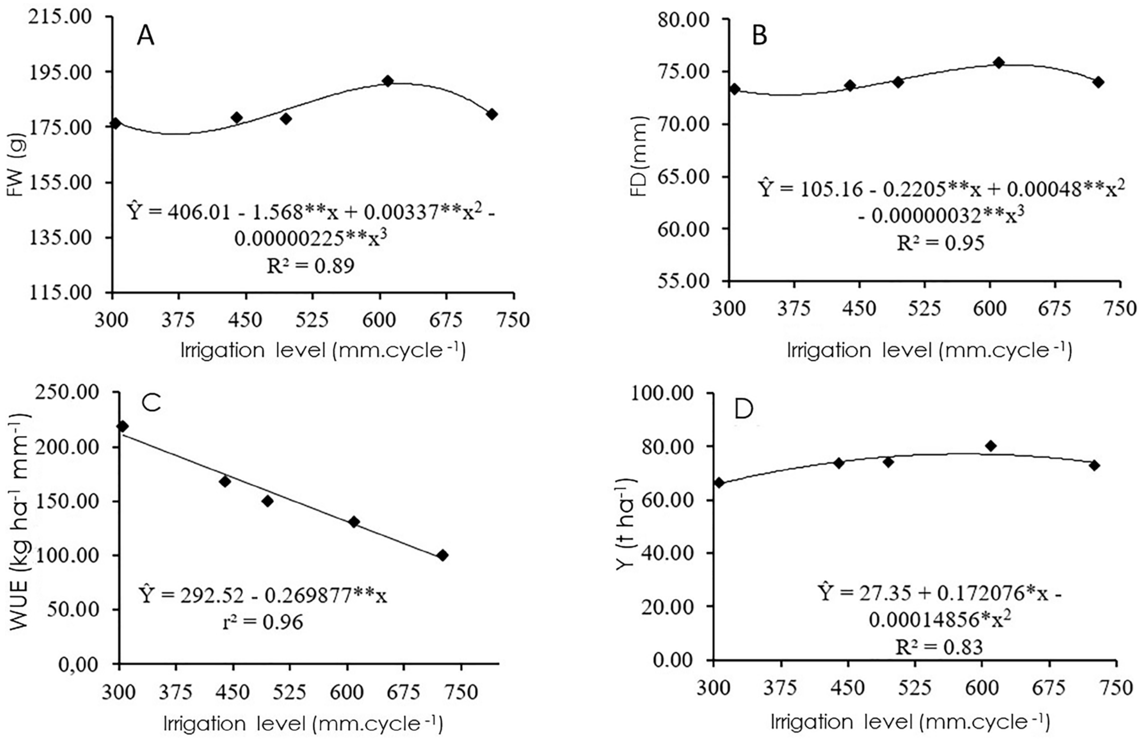

Figure 3. Fruit weight (A), fruit diameter (B), water use efficiency (C), and total yield (D) as a function of different irrigation levels.
****; *** Significant at 1 and 5%, respectively, by analysis of variance of the regression.

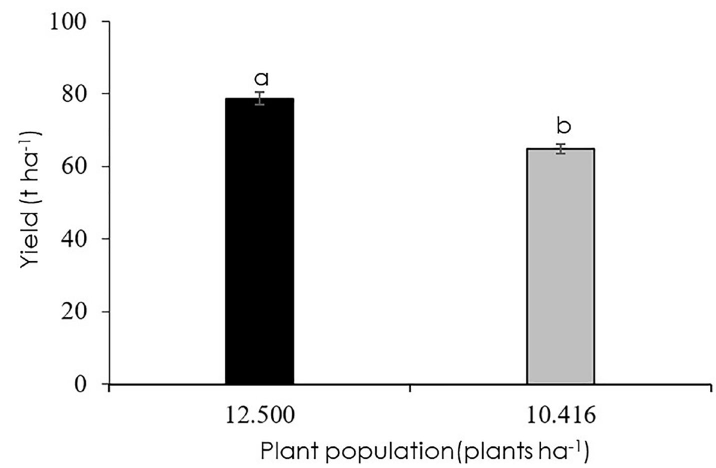

Figure 4. Yield of tomato plants as affected by different plant populations. Different letters over the bars differed from one another based on Tukey test at 0.05 significance level. Error bars correspond to standard error: 1.75 and 1.27 for 12,500 and 10,416 ha^{-1}.
Different letters on bars indicate significant differences between plant populations according to Tukey test ($P < 0.05$). Vertical bars correspond to standard error.

Studies on increasing plant population density are interesting when working with processing tomatoes (Warner et al., 2002; Tuan & Mao, 2015), but for the fresh market, to which belongs 'Trucker' tomatoes, increasing plant density is a risky practice due to likely reductions in fruit size and higher costs related to increased crop practices (Wegayehu et al., 2015; Maboko et al., 2017).

Decreased fruit size may occur due to the higher competition among plants for water, nutrients, and light (Craine & Dybzinski, 2013). In this study, an 18% increase in yield was recorded when plant population increased from 10,416 to 12,500 plants ha^{-1} (Figure 4). This increase is highly consistent with the increase in the number of plants per unit area, about 17.7%; therefore, yield per plant remained, so did fruit size. Similarly, Santos et al. (2010) reported an 18% increase in yield of 'Tasti Lee' tomato when plant population increased from 10,660 to 14,448 plants ha^{-1}.

Thus, based on our result, using neither earthing up nor plastic mulching is recommended for 'Trucker' tomato plants grown in the semi-arid region of Bahia state, Brazil. These practices may represent an additional cost that is not beneficial to improving tomato yields.

Conclusions

Irrigation levels between 579.15 and 642.52 mm cycle^{-1} increase mean fruit diameter, mean fresh fruit weight, and total yield.

WUE decreases with increasing water level.

Plastic mulching does not increase WUE in 'Trucker' tomato grown under soil and climate conditions of this study.

Mulching and earthing up fail to increase yields of 'Trucker' tomato plants grown under semi-arid conditions. Tomato yield increases with modest increase in plant population when increasing plant population from 10,416 to 12,500 plants ha^{-1}.

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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.