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ORIGINAL ARTICLE

Gas exchange and yield of industrial tomato under different types of irrigation and non-woven fabric plant cover[1]

Trocas gasosas e produtividade do tomateiro industrial sob diferentes tipos de irrigação e tela não-tecida para cobertura da planta

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HIGHLIGHTS:

Uninterrupted white and red non-woven cover favors tomato physiological characteristics.
Coverage with red non-woven fabric removed between 30 and 60 days after transplanting reduces fruit yield.
Surface (conventional) and subsurface (underground) drip systems are equally efficient in water replacement of tomato plants.

ABSTRACT: This study aimed to evaluate the effects of different colors and management of polypropylene non-woven fabric coverings and two different localized irrigation systems on the physiological characteristics and yield of industrial tomatoes. The experiment was installed in a randomized block design arranged in a split-plot scheme with four replications. Surface and subsurface drip were used in the plots, and five plant cover strategies with non-woven fabric in the subplots: i) without non-woven fabric; ii) coverage with white non-woven fabric; iii) coverage with white non-woven fabric, removed between 30 and 60 days after transplanting the seedlings; iv) coverage with red non-woven fabric; v) coverage with red non-woven fabric, removed between 30 and 60 days after transplanting. Photosynthesis, transpiration, electron transport rate, stomatal conductance, carbon concentration, total fruit yield, and water use efficiency were evaluated. ANOVA and the Scott-Knott test were used. Transpiration is favored by the white non-woven fabric and the stomatal conductance by the white and uninterrupted red one. However, the tomato yield is not influenced by the coverings, except for the red one, removed only between 30 and 60 days after transplanting, which is the worst condition for industrial tomato production. Surface and subsurface irrigation can be used with the same efficiency.

Key words: *Solanum lycopersicum*, agrotextile, protected cultivation, drip irrigation

RESUMO: O objetivo deste estudo foi avaliar os efeitos de diferentes colorações e manejos de coberturas de tela não-tecida, e de dois diferentes sistemas de irrigação localizada sobre características fisiológicas e produção de frutos do tomateiro industrial. O experimento foi instalado em delineamento de blocos ao acaso, com 4 repetições, em parcelas subdivididas. Gotejamentos superficial e subterrâneo foram utilizados nas parcelas; e 5 estratégias de cobertura da planta com tela não-tecida nas subparcelas: i) sem cobertura; ii) cobertura com tela não-tecida branca; iii) tela não-tecida branca, retirado entre 30 e 60 dias após o transplante; iv) tela não-tecida vermelha; v) tela não-tecida vermelha, retirado entre 30 e 60 dias após o transplante. Avaliou-se: taxa fotossintética, de transpiração e de transporte de elétrons; condutância estomática; concentração de carbono; produção total de frutos e eficiência do uso da água. Foram utilizados ANOVA e teste de Scott-Knott. A transpiração é favorecida pelas coberturas brancas, a condutância estomática, pelas coberturas brancas e vermelha ininterrupta, porém a produtividade não é influenciada pelas coberturas, exceto a vermelha, retirada entre 30 e 60 dias após transplante, que é a pior condição para o tomate industrial. Irrigações superficial e subterrânea podem ser utilizadas com mesma eficiência.

Palavras-chave: *Solanum lycopersicum*, agrotêxtil, cultivo protegido, gotejamento

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Introduction

Covering plants with screens and shading nets, such as polypropylene non-woven fabric, is promising to increase crop yield due to the alleviation of climatic adversities, loss of water from the soil, severe attacks by pests and diseases, among others (Mahmood et al., 2018).

The non-woven fabric has resistance to agricultural use; it provides a suitable environment for cultivation, reducing the incidence of pests and fruit scalding effect due to excess solar radiation, with increased yield and quality (Kosterna, 2014; Braga et al., 2017).

For many crops, the use of non-woven fabrics has a positive effect (Medeiros et al., 2007; Santos et al., 2014; Benincasa et al., 2014). For other crops, the results are not yet conclusive due to plant physiological changes, mainly gas exchange, which can be influenced by the different colors of non-woven fabric (Silva et al., 2019b).

According to Factor et al. (2009), covering the tomato (*Solanum lycopersicum*) plant with white non-woven fabric reduces fruit yield compared to tomato without cover. For Lemos et al. (2022), non-woven covering reduced tomato yield for the cultivar Débora but not for the cultivar Saladete, compared to cultivation without covering. Nonetheless, studies on tomato cover with non-woven are still scarce and divergent, justifying new research on the subject.

In Brazil, irrigation for industrial tomatoes is currently conducted by sprinkler via center pivot; however, localized drip irrigation is promising (Martínez & Reca, 2014; Silva et al., 2019a; Nascimento et al., 2020) due to greater efficiency in the water use, as it is usually used in table tomatoes, demanding more information about the efficiency of the drip systems for tomato.

Based on the above, this study aimed to evaluate the effects of different colors and management of polypropylene non-woven fabric coverings and two different localized irrigation systems on the physiological characteristics and yield of industrial tomatoes.

Material and Methods

The present study was conducted from 21/05/2019 to 27/09/2019, under field conditions, at the Instituto Federal Goiano, Campus of Morrinhos, Morrinhos, GO, Brazil: 885 m of altitude, 17°49'19" S, and 49°12'11" W, AW-type climate, semi-humid tropical, with rainy summer and dry winter, with average annual temperature of 23.3 °C and average annual precipitation of 1346 mm, according to the Koppen classification (Cardoso et al., 2014).

The soil of the experimental area was classified as Oxisol (USDA, 1999), presenting its specific chemical characteristics (Table 1). The experimental field preparation began with desiccation, conducted 20 and 10 days before transplanting the seedlings, using, respectively, a non-selective herbicide (glyphosate at a dose of 3 L ha^{-1}) and a pre-emergent herbicide (sulfentrazone at a dose of 0.8 L ha^{-1} and S-Metolachlor at a dose of 1 L ha^{-1}), both registered in the Ministério da Agricultura e Pecuária - MAPA. Subsequently, soil fertilizing was balanced based on its chemical and physical analysis (Table 1), as CFSGO (1988) recommended for tomato cultivation.

Table 1. Soil chemical characteristics in the 0 to 20 cm depth

pH (H_2O)	P	K	Ca	Mg	Al	H + Al	OM	BS
	(mg dm^{-3})		(cmol$_c$ dm^{-3})				(%)	
6.1	14.9	90.0	3.09	1.19	0	2.70	3.60	75.56

P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium; Al - aluminum; H + Al - potential acidity; OM - organic matter; BS - base saturation

Due to good base saturation conditions (75.56%), liming was not performed. The fertilization recommendation was 50 kg ha^{-1} of N, 400 kg ha^{-1} of P_2O_5, 90 kg ha^{-1} of K_2O, and 2 kg ha^{-1} of boron. The fertilizer was applied manually in the planting furrow at 0.15 m depth two days before transplanting the seedlings. Topdressing fertilization was conducted at 20, 30, 40, 50, and 60 days after transplanting (DAT) the seedlings, with 70 kg ha^{-1} of N and 60 kg ha^{-1} of K_2O, divided into five equal applications and conducted via fertigation (CFSGO, 1988).

Seedlings of industrial tomatoes, hybrid Heinz 9553, were produced in a specialized nursery (Seedlings Brambilla) from commercial seeds, sown in plastic trays of 450 cells, containing standard commercial substrate based on coconut fiber, peat, and expanded vermiculite. Tomato seedlings were transplanted to the field 30 days after sowing, maintaining approximately 3.33 plants per linear meter.

The experiment was set up in a randomized block design, with four replications arranged in a split-plot scheme. The plots used two localized irrigation systems (surface drip and subsurface drip at 20 cm depth), where both received equal irrigation depths. A line of drippers per plant row was used, with self-compensating emitters and an anti-drainage system, spaced 0.3 m apart, with one dripper per plant, with a flow rate of 2.2 L h^{-1} and a service pressure of 150 kPa.

The subplots were composed of five strategies of plant cover with non-woven fabric: i) open-air cultivation, without the use of non-woven fabric; ii) uninterrupted coverage with white non-woven fabric; iii) covering with white non-woven fabric, removed only in the interval between 30 and 60 DAT, here called white (30-60 DAT); iv) uninterrupted coverage with red non-woven fabric; and v) covering with red non-woven fabric, removed only in the interval between 30 to 60 DAT, here called red (30-60 DAT). In plant covers iii and v, the crop was uncovered during its period of greatest flowering intensity (30 to 60 DAT) to assess the incidence of any impact of covered crops on flower pollination.

The technique for using non-woven fabric in the present study was adapted from the widespread use of this material for covering melon plants (Medeiros et al., 2007; Santos et al., 2014; Benincasa et al., 2014). The use of different colors of non-woven fabric occurred to understand the variation in physiological characteristics, which are influenced by the different colors of the cover (Silva et al., 2019b). The period between 30 and 60 DAT matches the tomato pollination. Thus, the cover was removed during this period to assess the interference of the non-woven fabric cover on tomato cross-fertilization, in addition to self-fertilization, which occurs in greater proportions. Removing the cover can allow pollinating agents (insects and wind, mainly) to transfer pollen from one flower to another.

Each subplot consisted of three rows of plants, 6.0 m long each, spaced 1.1 m apart. The plot's useful area comprised the eight plants in the central row, with the two lateral rows considered as borders. Plots and blocks were spaced 2.0 and 3.0 m apart, respectively, so irrigation interference between treatments did not occur (Figure 1A and B).

Meteorological data were obtained from the automatic meteorological station of the Instituto Federal Goiano, Campus Morrinhos, GO, located at 400 m from the experiment (Figure 2). The maximum and minimum temperatures occurred at 125 and 50 DAT, with 35.0 °C and 3.1 °C, respectively. During the experiment, the average relative air humidity (RH) was 56.9%, the average global solar radiation was 16.64 MJ m^{-2} day^{-1}, and precipitation was 22 mm (Figure 2).

The crop evapotranspiration (ETc) of the tomato was calculated according to the evaporation from the Class A evaporation pan (ECA), Class A evaporation pan coefficient (Kp), and the crop coefficient (Kc) (Bernardo et al., 2019) by the Eq. 1.

$$ETc = ECA \times Kp \times Kc \qquad (1)$$

where:

ETc - crop evapotranspiration (mm);
ECA - Class A evaporation pan (mm day^{-1});
Kp - Class A evaporation pan coefficient; and,
Kc - crop coefficient.

An average value of Kp equal to 0.7 was adopted throughout the experiment, according to Sentelhas & Folegatti (2003). For tomato Kc, FAO (Food and Agriculture Organization of the United Nations) recommendations were followed (Allen et al., 1998): Stage I - vegetative (0.6); Stage II – from the end of stage I to 70 to 80% of vegetative development (beginning of flowering) (0.85); Stage III – from the end of phase II to the beginning of maturation (1.15); Stage IV – from the end of phase III to the end of the harvest (0.9).

The total irrigation required (TIR, mm) was calculated (Eq. 2) based on crop evapotranspiration and drip system efficiency (90%), similar to Guimarães et al. (2019).

$$TIR = \frac{RIR}{E_i} = \frac{ETc}{0.90} \qquad (2)$$

where:

RIR - real irrigation required (mm);
Ei - drip system efficiency (dimensionless); and,
ETc - crop evapotranspiration (mm) with the same value as the RIR.

The operating times of the irrigation system by position were controlled by closing dampers at the plot beginning (Eq. 3).

$$T = \frac{TIR \times Wws \times Sd}{q_d} \qquad (3)$$

where:

T - irrigation time per position (minutes);
Wws - width of the wet strip (1.2 m);
Sd - the spacing between drippers (0.3 m); and,
q_d - flow rate of the dripper (2.2 L h^{-1}).

Figure 1. Plant cover with white (A) and red (B) non-woven fabric for tomato plants (hybrid Heinz 9553) during the experiment

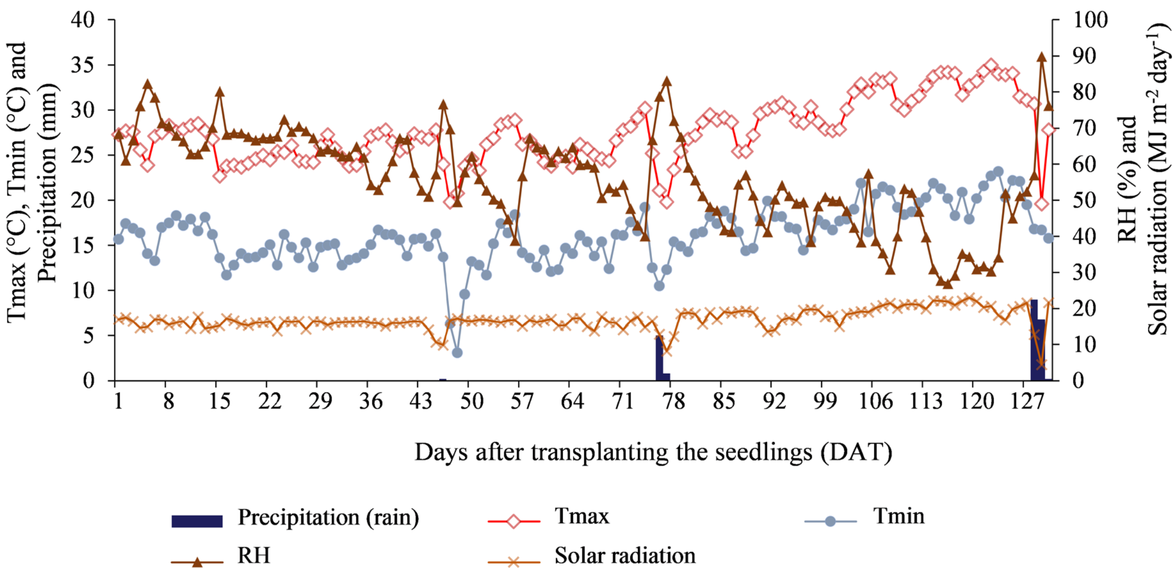


Figure 2. Daily values of maximum temperature (Tmax, °C), minimum temperature (Tmin, °C), solar radiation (MJ m^{-2} dia^{-1}), precipitation (mm), and relative air humidity (RH, %) during the experiment (21/05/2019 to 27/09/2019)

The phytosanitary management of the tomato was conducted in a preventive way, aiming to keep the plants free of pests and diseases and guarantee their full development. Insecticides and fungicides were applied using a knapsack sprayer (foliar spray), removing the non-woven cover only at the application time and covering the plants immediately afterward.

Tomato gas exchanges were estimated at 55 and 80 DAT between 8:30 a.m. and 11:30 a.m., using the first leaflet of fully expanded leaves from the middle third of representative plants in the plot regarding height and leaf area. The gas exchange evaluations were conducted using portable equipment for measuring infrared gas exchange (IRGA) with an open system equipped with a fluorescence chamber integrated with a multiphase fluorometer (LI-6800-01, LI- COR Inc., Lincoln, NE, USA).

At 55 DAT, the plants are fully flowering and beginning to fruit, with maximum vegetative development. From 80 DAT onwards, fruit maturation intensifies, leading to the senescence of older leaves, making IRGA readings difficult.

During the assessments with the IRGA, a constant flux density of actinic light photons of 2000 μmol m^{-2} s^{-1} was adjusted using the multiphase fluorometer itself as a light source. The relative humidity inside the chamber was maintained at 50%, and the CO_2 concentration was at 400 μmol mol^{-1}. To monitor the air temperature inside the chamber, a thermoelectric sensor was used, located at the equipment bottom, kept at 25 °C.

The IRGA allowed the evaluation of the photosynthetic rate (A, μmol m^{-2} s^{-1}), transpiration rate (E, mmol m^{-2} s^{-1}), stomatal conductance (gs, mol m^{-2} s^{-1}), internal and external carbon concentration ([Ci/Ca]), and electron transport rate (ETR, μmol m^{-2} s^{-1}), performed at 55 and 80 DAT.

The water use efficiency (WUE, μmol CO_2 $mmol^{-1}$ H_2O) was also calculated using Eq. 4.

$$\mathrm{WUE} = \frac{A}{E} \tag{4}$$

where:

WUE - water use efficiency [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$];

A - photosynthetic rate (μmol m^{-2} s^{-1}); and,

E - transpiration rate (mmol m^{-2} s^{-1}).

The tomato fruit harvest was conducted manually, at 130 DAT, with subsequent evaluation of total yield (TY). TY was determined by the ratio between all the fruit weights harvested from the eight plants in the central row of each and the area occupied by the eight plants mentioned above. Subsequently, the TY (t ha^{-1}) was obtained by extrapolation according to the plant stand per hectare.

The collected data were submitted to analysis of variance (Fisher's F test) at 0.01 and 0.05 probability levels. The parameters that showed a significant effect of treatments had their means grouped by the Scott-Knott test at 0.05 probability.

Results and Discussion

At 55 DAT, the "use of non-woven fabric" and "types of irrigation" did not present a significant difference for any of the evaluated parameters (Table 2). This fact infers that 55 DAT was an insufficient period to express any statistically significant difference, mainly due to the delay in the crop cycle in the present experiment caused by the temperature reduction in the previous days (Figure 2). At 55 DAT, the plants did not have the maximum photosynthetic potential, which was more pronounced around 60 to 80 days.

Although the average temperatures that occurred over the evaluated period in the present study followed the historical averages of the region, in 2019, there was a decrease in temperature up to 80 DAT of 5.8% in average temperatures and 8% in minimum temperatures when compared to previous years. This fact promoted a delay in the crop cycle, possibly related to reduced plant metabolic activity.

The localized irrigation systems did not present a significant difference in any of the parameters evaluated at 80 DAT; however, the plant cover strategies with non-woven fabric significantly influenced E ($p<0.01$) and gs ($p<0.05$) (Table 2). The similarity of the two systems can explain the non-difference between the two irrigation systems since they used the same brands and models of emitters, the same design conditions (pipes, service pressure, flow, etc.), being differentiated only by the location of the drippers in the soil profile. The fact that dripping is a very efficient method of irrigation in the application of water, with very little loss (Guimarães et al., 2019), and the cover with non-woven fabric tends to reduce evapotranspiration, almost all the water supplied to the soil by irrigation was used by the plant, regardless of the place of application, which are very close (20 cm).

The highest E values were obtained in the white uninterrupted (10.38 mmol m^{-2} s^{-1}) and white (30-60 DAT) (10.03 mmol m^{-2} s^{-1}) plant cover strategies with non-woven fabric, while the other strategies obtained lower values and they did not differ from each other, statistically (Figure 3A). For gs, the plant cover strategies with non-woven "white", "white (30-60 DAT)", and "red" had the highest means, 0.733, 0.702, and 0.668 mol m^{-2} s^{-1}, respectively (Figure 3B).

The use of red color non-woven fabric allows greater transmittance only for wavelengths greater than 590 nm (Taiz et al., 2017), which reduces the quality of light received by the plant and the characteristics of interest (E, gs, and yield), also observed in the present study (Figure 3A, B, and C), especially, in red (30-60 DAT). This causes the photosynthetic apparatus of the plants covered with the red non-woven fabric to come into contact with the red (620-700 nm) and far red (710-850 nm) bands up to 30 DAT, mostly. These colorations are generally abundant under shade conditions (Taiz et al., 2017). Furthermore, according to the same authors, the low transmittance of blue light (350-500 nm) is another characteristic of these red-colored coverings, as opposed to the white-colored one, allowing the homogeneous passage of the entire visible spectrum.

Thus, from the moment the cover was removed, in the period from 30 to 60 DAT, all the photosynthetic apparatus adapted to a certain level of shade had to readapt. This reaction probably occurred more intensely in the plants under the red non-woven fabric when compared to those under the white non-woven fabric since the white color allows more light to

Table 2. Summary of ANOVA for transpiration rate (E), photosynthetic rate (A), water use efficiency (WUE), internal and external carbon concentration ratio ([Ci/Ca]), stomatal conductance (gs), and electron transport rate (ETR), at 55 and 80 days after transplanting (DAT), total yield (TY), after harvesting, according to the different localized irrigation systems (I) and colors of non-woven (NW) fabric used as coverings for tomato plants (hybrid Heinz 9553)

Source of variation	DF	Mean squares					
		E	A	WUE	[Ci/Ca]	gs	ETR
				55 DAT			
Irrigation (I)	1	24.186 ns	19.429 ns	0.701 ns	0.016 ns	0.301 ns	380.904 ns
Block	3	2.745 ns	31.534 ns	0.327 ns	1.100 ns	0.007 ns	2201.962 ns
Residue 1	3	13.741	7.664	0.774	0.006	0.089	1043.964
Non-woven (NW)	4	2.546 ns	30.004 ns	0.268 ns	0.002 ns	0.029 ns	2108.110 ns
I × NW	4	7.728 ns	24.508 ns	0.282 ns	0.002 ns	0.063 ns	164.041 ns
Residue 2	24	5.197	13.177	0.285	0.002	0.045	1667.806
Total	39	239.472	671.331	13.157	0.109	2.046	59234.649
CV 1 (%)		38.40	10.26	30.18	10.24	45.94	20.36
CV 2 (%)		23.61	13.45	18.33	6.49	32.65	25.74
Overall average		9.654	26.994	2.915	0.759	0.651	158.661
				80 DAT			
Irrigation (I)	1	0.320 ns	1.193 ns	0.099 ns	0.001 ns	0.002 ns	74.307 ns
Block	3	3.152 ns	0.633 ns	0.397 ns	0.001 ns	0.008 ns	188.477 ns
Residue 1	3	4.072	11.957	0.464	0.003	0.032	677.608
Non-woven (NW)	4	5.326 **	24.354 ns	0.057 ns	0.001 ns	0.053 *	569.091 ns
I x NW	4	0.867 ns	4.104 ns	0.143 ns	0.001 ns	0.005 ns	305.036 ns
Residue 2	24	1.241	16.423	0.257	0.002	0.010	1089.091
Total	39	76.562	548.158	9.653	0.060	0.606	32307.251
CV 1 (%)		21.35	13.02	23.86	7.27	27.94	16.96
CV 2 (%)		11.79	15.26	17.76	5.42	15.88	21.50
Overall average		9.453	26.554	2.855	0.769	0.644	153.468

After harvesting		
Source of variation	DF	Mean squares Total yield (TY)
Irrigation (I)	1	2077.31 ns
Block	3	48.34 ns
Residue 1	3	1538.49
Non-woven (NW)	4	1850.93 *
I x NW	4	116.13 ns
Residue 2	24	566.27
Total	39	28296.56
CV 1 (%)		26.06
CV 2 (%)		15.81
Overall average		150.53

** - Significant at 0.01 probability, using the F test; *: Significant at 0.05 probability, using the F test; ns: Not significant; DF- Degrees of freedom; MS- Mean squares; CV- Coefficient of variation. Units for overall average: E (mmol m^{-2} s^{-1}), A (μmol m^{-2} s^{-1}), WUE [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$], [Ci/Ca] (unidimensional), gs (mol m^{-2} s^{-1}), ETR (μmol m^{-2} s^{-1}), and TY (t ha^{-1})

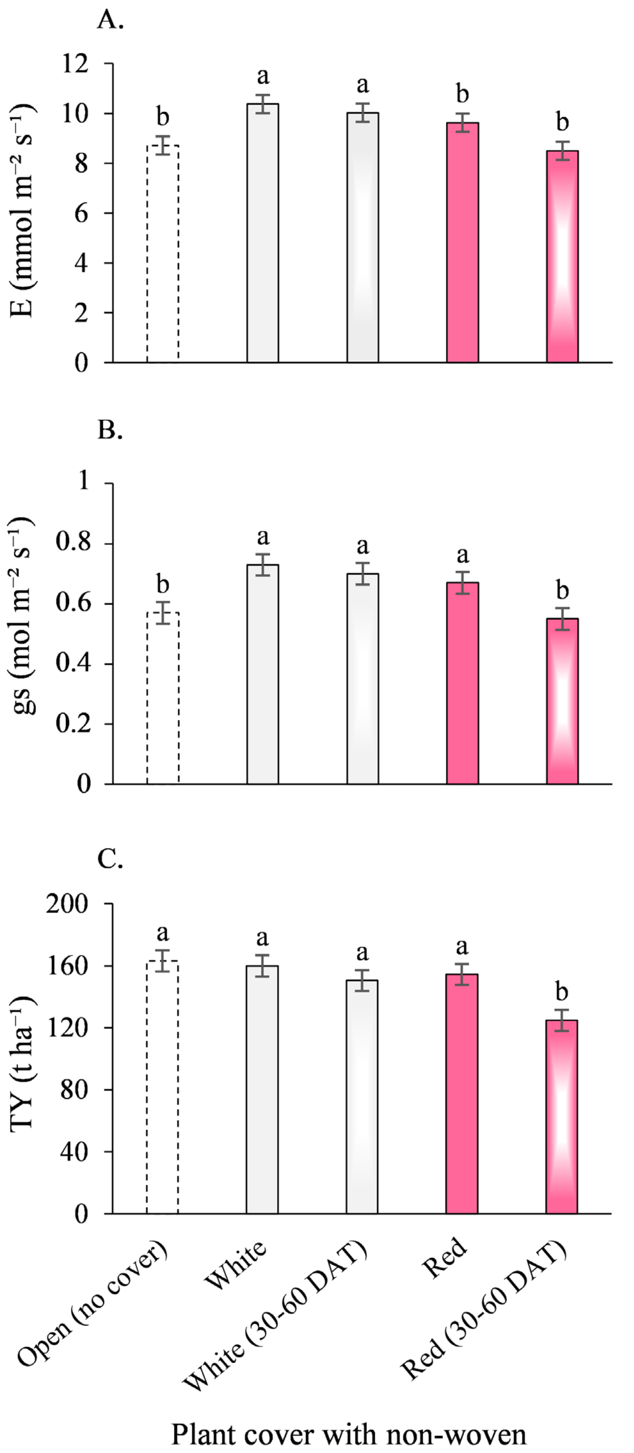
pass through. Oliveira et al. (2021) also noticed that plants under cover of more intense colors had to adapt to the shading condition by increasing the leaf area to compensate for the lower radiation intensity. Thus, the sudden removal of cover, which occurred in the present study for the red non-woven fabric (30-60 DAT), possibly caused greater stress in the plants, which had to reduce stomatal conductance and transpiration to reduce water losses from the plant to the environment (Taiz et al., 2017), with a consequent drop in the yield of tomato fruits (Figure 3C).

This way, one of the possible reasons for the absence of significant differences in the assessments measured at 55 DAT may be closely related to the readaptation process made possible by the plant's phenotypic plasticity. This characteristic allows plants to adapt to the environment in which they are inserted through gene expression changes that occur due to changes in their physiology or morphology, according to the imposed conditions (Oliveira et al., 2021).

When the covers were removed at 30 DAT, the plants under the red non-woven fabric possibly invested in greater carotenoid production to protect their photosynthetic structures from the high light incidence. However, when the plants were covered at 60 DAT, the return condition to the red non-woven fabric demanded a new adaptation to the partial shading condition from this cover. In addition, it is possible that, when exposed again to an unfavorable situation of light capture in an advanced phase of their cycle, the plants have found greater barriers to physiological readjustment since, in this period, almost all energy expenditure is focused on the fruit filling (Dalastra et al., 2020).

In this context, Taiz et al. (2017) state that the increased incidence of direct sunlight on plant leaves induces the production of carotenoids, whose main function is photoprotective agents. Carotenoids act to dissipate excess energy through the release of heat. As photosynthetic membranes can be easily damaged by the large amounts of energy absorbed by pigments, if the plant does not eliminate this unused energy excess, it will be subjected to the formation of reactive oxygen species, which are extremely harmful to almost all life forms.

Given the above, the return to the condition of lower incidence of blue light, generated by the red cover reapplication



Bars with the same letter do not differ from each other statistically according to the Scott-Knott test ($p<0.05$); White – plant cover with white non-woven; White (30-60 DAT) – plant cover with white non-woven, removed only in the interval between 30 and 60 days after transplanting; Red – plant cover with red non-woven; Red (30-60 DAT) – plant cover with red non-woven, removed only in the interval between 30 and 60 days after transplanting

Figure 3. Mean values of transpiration rate – E (A) and stomatal conductance - gs (B), obtained at 80 days after transplanting the seedlings, and total yield - TY (C), after harvesting, for tomato plants (Heinz 9553 hybrid), according to the plant coverings strategies with non-woven fabric

at 60 DAT, may also be directly related to the lower E and gs values found in the red non-woven fabric (30-60 DAT), at 80 DAT. This is because the stomatal opening is induced by blue light photoreceptors called cryptochromes in the early morning hours. With reduced stomatal opening, there will be a transpiration rate reduction. Thus, the lower the release of water vapor by the stomata, the lower the negative pressure generated to absorb water and nutrients from the soil, which may resemble water deficit conditions (Taiz et al., 2017; Barros et al., 2021).

The differences between the edaphoclimatic conditions found during the evaluations at 55 DAT compared to 80 DAT characterize another factor that justifies the data significance only in the second evaluation (80 DAT). At 55 DAT, mean solar radiation was 16.74 MJ m^{-2} day^{-1}, and relative humidity was 44.8%, while at 80 DAT, these were 18.81 MJ m^{-2} day^{-1} and 59.1%, respectively. For tomatoes, the amount of solar radiation must be greater than 8.4 MJ m^{-2} day^{-1}; that is the trophic limit, which is the minimum limit for normal growth and development of the tomato plant to occur (EMBRAPA, 2023).

The solar radiation intensity is directly related to temperature variations on the earth's surface, which has materials with different levels of radiation reflectance, with the ability to reflect solar radiation inversely proportional to heat absorption (Muniz-Gäal, 2018).

The microclimate difference between plant cover strategies with non-woven fabric may be directly related to the significant results at 80 DAT since the high air temperatures under the red non-woven fabric, associated with high humidity, significantly reduce stomatal opening (Taiz et al., 2017). In general, the white-colored coverings presented greater reflectance than the red-colored coverings, and therefore, the temperature under the white non-woven fabric tends to be lower than under the red non-woven fabric (Oliveira et al., 2021).

The results found in the present research corroborate those found by Oliveira et al. (2021) with melon cultivation, where they state that the use of white non-woven fabric presented less shading and greater efficiency in decreasing leaf temperature, compared to the non-woven fabric in orange, gray, and blue colors. The same work showed less development of the plants' leaf area under white cover, up to 24 DAT, compared to the orange cover. This fact was attributed to the greater shading conditions generated by, the more intense colors of the non-woven fabric, demanding a larger interception area of the received light to potentiate its photosynthetic processes.

Furthermore, considering only the plants from the open cultivation strategy (without non-woven), the high wind speed also negatively influenced the stomatal opening and, consequently, the E and gs. At 55 DAT, the maximum wind speed was 4.16 m s^{-1}; at 80 DAT, it reached up to 6.67 m s^{-1} at the data collection time. The direct incidence of wind on the plant's surface removes the humid air close to the leaves, a region known as the boundary layer (Pacheco et al., 2021). This layer plays a key role in regulating the humidity difference between the substomatal chamber and the external environment of the leaves, ensuring less water loss from the plants. On days with a lot of wind, such as 80 DAT, the leaf boundary layer is quite thin; the wind removes the water vapor molecules that escape due to evaporation inside the leaf (Silva et al., 2021). Thus, under these conditions, reducing stomatal opening is essential to control water loss and prevent plant dehydration, which probably happened in the present experiment. Considering this, the lower the stomatal opening rate, the lower the gs and E since they are dependent factors.

Total yield (TY) was significantly influenced ($p < 0.05$) only by the variation in non-woven fabric cover (Table 2). The open cultivation strategy reached the highest TY value (163.07 t ha^{-1}). Still, statistically, it was equal to the white, corroborating with Lemos et al. (2022) and diverging from Factor et al. (2009), white (30-60 DAT) and red plant cover strategy, while the red (30-60 DAT) had the lowest average (124.74 t ha^{-1}). It was statistically the worst condition for tomato TY (Figure 3C). Even with the covering removal during the tomato flowering peak, the presence of coverings with red non-woven fabric interfered with pollination and flower setting.

The lowest means in the red (30-60 DAT) may be related to the lower values of E and gs from the same plant cover strategies with non-woven, at 80 DAT (Figure 3A and B). Gas exchanges, in general, are highly impaired by low stomatal opening, as plants acquire CO_2 and release water in gaseous form through the stomata to enable nutrient absorption by the roots and their movement through the xylem vessels (Sanches et al., 2017). Thus, the less amount of nutrients absorbed from the soil solution, the lower the plant yield potential (Sousa, 2021).

Furthermore, "sun plants" (plants adapted to open field habitats), such as the tomato, activate physiological processes of greater vegetative development when grown in shaded environments with a high incidence of far-red light. This process acts as a survival mechanism, activated by phytochromes, to avoid shading caused by competition for light among plants. When this occurs, plants may stop reallocating resources to fruits and start investing in elongating their internodes (Taiz et al., 2017). This fact certainly contributed to the lower TY in the red (30-60 DAT) plant cover strategies with non-woven.

There was no significant effect for the different types of irrigation systems used, regardless of the evaluated system. Hence, none of the drip forms caused limitations to the water replacement levels of the tomato plants. Consequently, no statistical differences were found for water use efficiency (WUE). It should be noted that the lower the availability of soil water, the lower the degree of stomatal opening to reduce water loss to the environment (Silva et al., 2015).

Conclusions

1. Transpiration is favored by the white non-woven fabric coverings, and the stomatal conductance increases with the use of white and uninterrupted red non-woven fabric covering. However, the tomato yield is not influenced by the coverings, except for the red non-woven fabric, removed only between 30 and 60 days after transplanting, which is the worst condition for industrial tomato production.

2. Surface (conventional) and subsurface (underground) drip irrigation systems are equally efficient in water replacement for tomato plants under conditions similar to those of the present study.

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Literature Cited

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: guidelines for computing crop water requirements. Rome: Food and Agriculture Organization, 1998. 300p. Drainage and Irrigation Paper, 56

Barros, J. R. A.; Guimarães, M. J. M.; Simões, W. L.; Melo, N. F.; Angelotti, F. Water restriction in different phenological stages and increased temperature affect cowpea production. Ciência e Agrotecnologia, v.45, p.1-12, 2021. https://doi.org/10.1590/1413-7054202145022120

Benincasa, P.; Massoli, A.; Polegri, L.; Concezzi, L.; Onofri, A. Optimising the use of plastic protective covers in field grown melon on a farm scale. Italian Journal of Agronomy, v.9, p.8-14, 2014. https://doi.org/10.4081/ija.2014.556

Bernardo, S.; Mantovani, E. C.; Silva, D. D. da; Soares, A. A. Manual de irrigação, 9.ed. Viçosa: UFV, 2019. 545p.

Braga, M. B.; Marouelli, W. A.; Resende, G. M.; Moura, M. S. B.; Costa, N. D.; Calgaro, M; Correia, J. S. Coberturas do solo e uso de manta agrotêxtil (TNT) no cultivo do meloeiro. Horticultura Brasileira, v.35, p.147-153, 2017. https://doi.org/10.1590/S0102-053620170123

Cardoso, M. R. D.; Marcuzzo, F. F. N.; Barros, J. R. Classificação climática de Köppen-Geiger para o Estado de Goiás e o Distrito Federal. ACTA Geográfica: Boa Vista, v.8, p.40-55, 2014. https://doi.org/10.5654/actageo2014.0004.0016

CFSGO - Comissão de Fertilidade de Solos de Goiás. Recomendações de corretivos e fertilizantes para Goiás. Goiânia: UFG/EMGOPA. 1988. 10p.

Dalastra, G. M.; Echer, M. M.; Guimarães, V. F.; Brito, T. S.; Inagaki, A. M. Trocas gasosas e produtividade de tomateiro com diferentes hastes por planta. Iheringia, Série Botânica, v.75, p.1-7, 2020. https://doi.org/10.21826/2446-82312020v75e2020020

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Como plantar tomate de mesa. Available on: https://www.embrapa.br/hortalicas/tomate-de-mesa/cultivares2. Accessed on: Aug. 2023.

Factor, T. L.; Lima Jr, S.; Purquerio, L. F. V.; Branco, R. F.; Blat, S. F.; Araújo, J. A. C. Produtividade e qualidade de tomate em função da cobertura do solo e planta com agrotêxtil. Horticultura Brasileira, v.27, p.606-612, 2009.

Guimarães, C. M.; Cunha, F. F. d.; Silva, F. C. da S.; Araújo, E. D.; Guimarães, A. B. F.; Mantovani, E. C.; Silva, D. J. H. da. Agronomic performance of lettuce cultivars submitted to different irrigation depths. Plos One, v.14, p.1-19, 2019. https://doi.org/10.1371/journal.pone.0224264

Kosterna, E. The effect of covering and mulching on the soil temperature, growth and yield of tomato. Folia Horticulturae, v.26, p.91-101, 2014. https://doi.org/10.2478/fhort-2014-0009

Lemos, O. L.; Seno, S.; Seleguini, A.; Santiago, K.; Ladeia, C. A. Type of protection in hybrid tomato plant conducted in protected environment, with and without application of insecticides. Modern Concepts & Developments in Agronomy, v.12, p.1-10, 2022. https://doi.org/10.31031/MCDA.2022.12.000776

Mahmood, A.; Hu, Y.; Tanny, J.; Asante, E. A. Effects of shading and insect-proof screens on crop microclimate and production: A review of recent advances. Scientia Horticulturae, v.241, p.241-251, 2018. https://doi.org/10.1016/j.scienta.2018.06.078

Martínez, J.; Reca, J. Water use efficiency of surface drip irrigation versus an alternative drip irrigation versus an alternative subsurface drip irrigation method. Journal of Irrigation and Drainage Engineering, v.140, p.1-9, 2014. http://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000745

Medeiros, J. F. de; Santos, S. C. L.; Câmara, M. J. T; Negreiros, M. Z. Produção de melão Cantaloupe influenciado por coberturas do solo, agrotêxtil e lâminas de irrigação. Horticultura Brasileira, v.25, p.538-543, 2007. https://doi.org/10.1590/S0102-05362007000400009

Muniz-Gäal, L. P.; Pezzuto, C. C.; Carvalho, M. F. H. de; Mota, L. T. M. Eficiência térmica de materiais de cobertura. Ambiente Construído, v.18, p.503-518, 2018. https://doi.org/10.1590/s1678-86212018000100235

Nascimento, J. M. S.; Silva, A. C. C.; Diotto, A. V.; Lima, L. A.; Oliveira, M. C. Subsuperficial drip irrigation and pulses drip irrigation tomato production. Brazilian Journal of Development, v.6, p.65903-65916, 2020. https://doi.org/10.34117/bjdv6n9-135

Oliveira, O. H. de; Queiroga, R. C. F. de.; Costa, F. B. da.; Mesquita, E. F. de.; Silva, F. A. da.; Silva, H. L. O.; Silva, A. G. F. da. Use of colored agrotextiles and length of stay in the cultivation of yellow melons. Research, Society and Development, v.10, p.1-12, 2021. https://doi.org/10.33448/rsd-v10i6.15951

Pacheco, F.; Lazzarini, L. E.; Alvarenga, I. Metabolismo relacionado com a fisiologia dos estômatos. Enciclopédia Biosfera, v.18, p.186-206, 2021. https://doi.org/10.18677/EnciBio_2021B14

Sanches, R. F. E.; Catarino, I. C. A.; Braga, M. R.; Silva, E. A. D. Influência da alta concentração atmosférica de CO_2 (↑[CO_2] atm)× disponibilidade hídrica nas relações hídricas, trocas gasosas e acúmulo de carboidratos em *Coffea arabica* L. Hoehnea, v.44, p.635-643, 2017. https://doi.org/10.1590/2236-8906-33/2017

Santos, F. G. B.; Negreiros, M. Z.; Medeiros, J. F.; Lopes, W. A. R.; Soares, A. M.; Nunes, G. H. S.; Freitas, F. C. L. Growth and yield of Cantaloupe melon 'Acclaim' in protected cultivation using agrotextile. Horticultura Brasileira, v.32, p.55-62, 2014. https://doi.org/10.1590/S0102-05362014000100009

Sentelhas, P. C.; Folegatti, M. V. Class-A pan coefficients (Kp) to estimate daily reference evapotranspiration (ETo). Revista Brasileira de Engenharia Agrícola e Ambiental, v.7, p.111-115, 2003. https://doi.org/10.1590/S1415-43662003000100018

Silva, C. J. da; Frizzone, J. A.; Silva, D. A. da; Golynski, A.; Silva, F. M. da; Megguer, C. A. Tomato yield as a function of water depths and irrigation suspension periods. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.591-597, 2019a. https://doi.org/10.1590/1807-1929/agriambi.v23n8p591-597

Silva, F. A.; Queiroga, R. C. F.; Pereira, F. H. F.; Santos, E. N.; Silva, Z. L. da; Silva, H. L. O.; Sousa, F. F.; Assis, L. E. Crescimento e acúmulo de fitomassa em alface com cobertura de solo e sombreado com agrotêxtil. Brazilian Journal of Development, v.5, p.11506-11520, 2019b. https://doi.org/10.34117/bjdv5n8-025

Silva, F. G.; Dutra, W. F.; Dutra, A. F.; Oliveira, I. M.; Filgueiras, L. M. B.; Melo, A. S. Trocas gasosas e fluorescência da clorofila em plantas de berinjela sob lâminas de irrigação. Revista Brasileira de Engenharia Agrícola e Ambiental, v.9, p.946-952, 2015. https://doi.org/10.1590/1807-1929/agriambi.v19n10p946-952

Silva, T. R. G.; Costa, M. L. A.; Farias, L. R. A.; Santos, M. A.; Rocha, J. J. L.; Silva, J. V. Abiotic factors in plant growth and flowering. Research, Society and Development, v.10, p.1-9, 2021. https://doi.org/10.33448/rsd-v10i4.13817

Sousa, F. G. G.; Carvalho, R. D. S. C.; Melo, M. R. M.; Grassi, F. H. Absorção de macronutrientes e sódio pelo tomateiro submetido a irrigação com e sem déficit hídrico, utilizando diferentes concentrações de água residuária. Irriga, v.26, p.65-76, 2021. https://doi.org/10.15809/irriga.2021v26n1p65-76

Taiz, L.; Zeiger, E.; Moller, I.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: Artmed, 2017. 888p.

USDA - United States Department of Agriculture. Soil taxonomy. 2.ed. Lincoln: USDA, 1999. 886p.