Scientia Horticulturae 275 (2021) 109657

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

The effect of different mulching on tomato development and yield

Sara Raquel Mendonça[a,*], Mylla Crysthyan Ribeiro Ávila[a], Roberto Gomes Vital[a], Zeuxis Rosa Evangelista[a], Nadson de Carvalho Pontes[b], Abadia dos Reis Nascimento[a]

[a] School of Agronomy, Federal University of Goiás, Goiânia, GO, Brazil
[b] Federal Institute of Education, Science and Technology in Goiás, Morrinhos Campus, Brazil

ARTICLE INFO

Keywords:
Solanum lycopersicum L.
Mulching film
Soil temperature
Fruit quality
Post-harvest

ABSTRACT

A study was conducted under field conditions to investigate the effects of different soil mulching on tomato development and yield for fresh consumption. Two experiments were conducted, one in the fall-winter and the other in the spring-summer. The following treatments were evaluated: soil mulching with brown plastic film (1); green plastic film (2); black plastic film (3); silver/black plastic film (4); white/black plastic film (5), yellow/brown plastic film (6); rice straw mulching (7); without mulching and with herbicide application (8); without mulching and with weed hoeing (9); and, without mulching and without weed control (10). Morphometric characteristics of tomato cv. Cordillera were measured at 10, 20, 30, and 40 days after transplanting (DAT). At harvest, yield and number of fruits, total and commercial, were measured, and then physicochemical analyzes were performed. The results reported that colored plastic film mulches affected soil temperature in both growing seasons, with higher temperatures for dark-colored mulching films, which may have compromised plant growth in the spring-summer season. In the fall-winter season, yellow and silver plastic film mulches improved tomato plant growth at 40 DAT, while green and silver plastic film mulches resulted in a 33 and 34 % increase in yield and the total number of fruits, respectively. Thus, it was possible to conclude that soil mulching materials have distinct effects on tomato development and yield, depending on the growing season.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a vegetable of great economic importance worldwide and is commercially cultivated on all continents (Sun et al., 2014). Tomato is an essential component in the diet of the world population because it has high levels of lycopene and minerals, resulting in benefits to human health (Perveen et al., 2015). Brazil is among the top ten tomato producers in the world. In 2018, the country produced more than 4.11 million tons in an area of 57.134 ha (FAOSTAT Database Results, 2020).

Many management practices have been studied, aiming to enhance the yield and quality of agricultural products. Among the technologies used in the cultivation of vegetables in recent years, the soil mulching with plastic films or organic material has stood out (Lopes et al., 2011). In some vegetable species, this practice has been important in improving production and product quality (Zhang et al., 2018).

Soil mulching is a method used in crops grown around the world, especially for vegetables, which can promote numerous advantages (Moreno et al., 2016). Mulching improves soil water retention capacity, contributes to early crop development, changes the soil temperature and reduces weed incidence, and all these factors contribute to increased yield (Mutetwa and Mtaita, 2014; Haque et al., 2018; Zhao et al., 2014; Zangoueinejad et al., 2018). However, these effects may vary according to soil type, climate, and material used for mulching (Ghosh et al., 2006).

The mulching can be done with organic materials such as straw or with inorganic materials such as plastic films. The choice of mulching material depends on the climate, the cost-benefit ratio, and the crop to be grown (Wang et al., 2016). Mulching materials have a direct influence on the microclimate near the plant, which can have positive or negative impacts on plant physiological metabolism (Kader et al., 2017). Beneficial effects of soil mulching have been reported for several crops, including tomato (Kosterna, 2014), potato (Zhao et al., 2014), blueberry (Munner et al., 2019), strawberry (Deschamps et al., 2019), and maize (Wang et al., 2019).

The plastic film has become the main material used for soil mulching in recent years (Steinmetz et al., 2016), especially in vegetable production. The most popular types of plastic mulching films on the market

* Corresponding author.
E-mail address: saramendonca31@hotmail.com (S.R. Mendonça).

https://doi.org/10.1016/j.scienta.2020.109657
Received 13 December 2019; Received in revised form 13 August 2020; Accepted 14 August 2020
Available online 12 September 2020
0304-4238/© 2020 Elsevier B.V. All rights reserved.

are black mulch film and white/black mulch film. Other colors of plastic mulch films that are being studied, include silver, red, blue, yellow, and green films (Decoteau et al., 1988; Caruso et al., 2019). However, the effects of these colored mulch films on plant development and production are still inconclusive.

The coloring of plastic mulch films results in distinct responses due to the ability of each color to absorb, transmit and reflect incident solar radiation, which may influence soil temperature and the plastic mulch surface (Ham et al., 1993). In this context, it is evident that information on the use of different plastic mulching films is still incipient. Thus, the study aimed to determine the effects of different materials used as soil mulches on growth and yield of tomato plants.

2. Material and methods

2.1. Experimental description

Two experiments were conducted under field conditions in the Horticulture Sector of the Faculty of Agronomy of the Federal University of Goiás, in Goiânia, Goiás, Brazil (16°35′12″ S, 49°21′14″ W, and 730 m of altitude). One experiment was carried out during the fall-winter season (from July to October 2018) and the other in the spring-

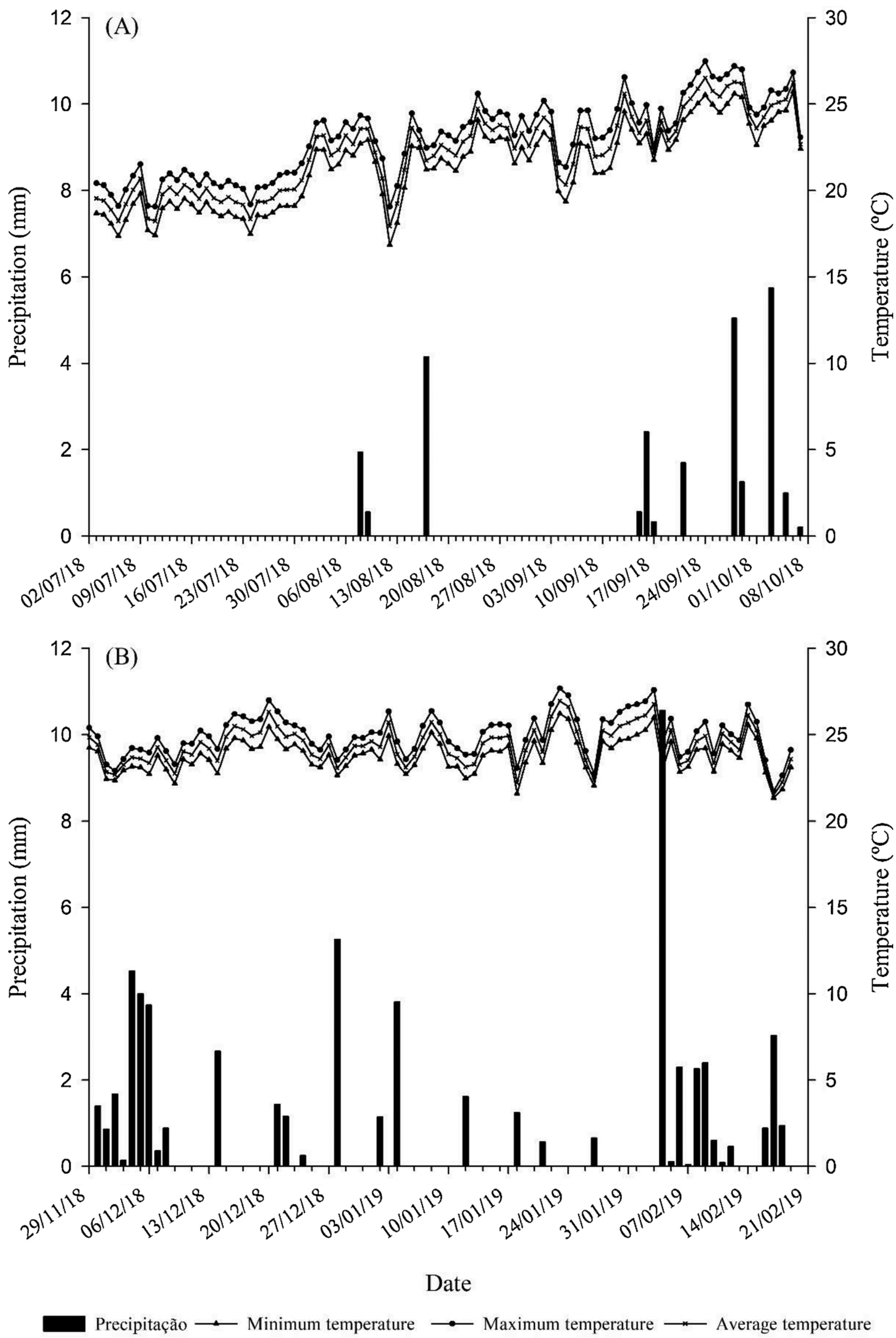

Fig. 1. Daily rainfall, average, minimum, and maximum temperature during fall-winter (A) and spring-summer (B) season.

summer season (from November 2018 to February 2019). In the fall-winter season, lower rainfall rate, lower relative humidity, and mild temperatures were observed (Fig. 1A), while in the summer season, higher rainfall and higher temperatures were recorded (Fig. 1B).

The experiments were carried out in clayey soil (53 % clay, 35 % sand, and 12 % silt) under the conventional tillage system. The soil had the following chemical characteristics: pH in $CaCl_2$ of 5.3; 0.0; 3.9; 2.3; 0.8; and 0.64 $cmol_c\,dm^{-3}$ of Al^{3+}, H + Al, Ca^{2+}, Mg^{2+} and K^{+}, respectively; 30.8 mg dm^{-3} of P, and 21 g dm^{-3} of organic matter.

The experimental design was a randomized block design with ten treatments and four replications. The treatments consisted of different materials for soil mulches: 1) brown plastic film (25 μm thickness), 2) green plastic film (25 μm thickness), 3) black plastic film (18 μm thickness), 4) silver/black plastic film (22 μm thickness), 5) white/black plastic film (22 μm thickness), 6) yellow/brown plastic film (25 μm thickness), both produced from polyethylene films manufactured by Ginegar Polysack; 7) rice straw mulch (10 t ha^{-1}, Ceasa, Goiânia, Brazil), 8) without mulches and with herbicide application, 9) without mulches and with weed hoeing, and 10) without mulches and without weed control. Chemical weed control was performed using 1.0 L ha^{-1} of herbicide metribuzin (Sencor®, Bayer Crop Science S.A.) and 0.5 L ha^{-1} of herbicide fluazifop-p-butyl (Fusilade® 250 EW, Syngenta Proteção de Cultivos Ltda), in two applications at 13 and 21 days after transplanting (DAT). The weed control with hoeing was carried out weekly.

Tomato seedlings were produced in 128 cell expanded polyethylene trays, in a commercial seedling nursery and transplanted at 35 days after sowing. The cultivar Cordillera® (Feltrin, Farroupilha, Brazil) was used, which has an indeterminate growth habit and fruits of saladete type. The plants were grown in four beds of 1.20 m wide, in double rows spaced 0.8 m between rows and 0.5 m between plants. The distance between the beds was 1.20 m, totaling 16.66 thousand plants per hectare.The experimental unit was represented by 16 plants, being considered the eight central plants as a useful plot for the measurements of plant development and fruit yield.

The need for irrigation was determined according to the soil moisture provided by the Irrigás Básico sensor (Embrapa, Brasília, Brazil). Irrigation was carried out following the recommendations of Alvarenga (2013), considering the water requirement of the tomato crop of approximately 600 mm throughout the cycle. Three irrigations were carried out per week, with the application of a 14 mm irrigation depth in each irrigation throughout the 14 weeks of cultivation. This irrigation management was applied to all treatments. Irrigation was not carried out only on days of natural precipitation.

The plants were grown in the vertical system with two stems, trellised with plastic string with ultraviolet protection. Thinning of lateral shoots was performed weekly, and all tomato plants were pruned at the height of 1.8 m. At the time of apical pruning, the plants had from 5 to 6 fruiting trusses. Pest and disease management were performed as needed with products registered for the crop. In the autumn-winter experiment, the plants were grown for 97 days and in the spring-summer for 84 days.

2.2. Soil temperature

Ten measurements of soil temperature were performed, at 7-day intervals, from the beginning of the transplant until 70 DAT. The data collection was performed with a digital thermometer (TE02, Asko, São Leopoldo, Brazil) with a probe 115 mm long stainless steel. Measurements were taken at 7 a.m. and 2 pm in two depths, at 5 and 10 cm below the soil surface.

2.3. Plant development

Developmental evaluations were carried out at 10, 20, 30, and 40 DAT, based on plant height and stem diameter, from 8 plants in the center of the seedbed for each replication. The height of the plants was produced using a 1.5 m ruler, considering the distance between the soil surface and the apical meristem of the main stem. The stem diameter was measured at 1.0 cm from the soil surface with a digital caliper (MTX, China).

2.4. Yield, the total number of fruits and marketable fruits

The harvests were carried out weekly, totaling five harvests. The estimated fruit yield (tons per hectare) and the total number and marketable fruits (fruit per plant) were performed after the final harvest (5^{th} weeks of harvest).

2.5. Physicochemical analysis

The content of soluble solids and titratable acidity were determined with samples composed of the pulps of five fruits per plot, harvested at the ripe stage, and crushed. The titratable acidity content was determined by titrating 5 g of homogenized pulp and diluted to 90 mL of distilled water, with a standardized 0.1 M NaOH solution, using 1% phenolphthalein alcoholic solution as an indicator. The soluble solids content was measured by refractometric reading in ºBrix, at 20 °C, with a refractometer Digital Abbe Refractometer (Quimis, Diadema, Brazil). The results were expressed in g of citric acid per 100 g of pulp. All chemical analyzes were performed in triplicate according to the proposed methodology Instituto Adolfo Lutz (São Paulo) (2008).

2.6. Statistical analysis

Analysis of variance was performed to evaluated the treatments effects on the soil temperatures in each season. The effect of the 'treatments', 'season', and intection 'treatments x season' about developtment and productivity variables was evaluated by analysis of variance. When significant effects of evaluated factor were observed (F test, $P \leq 0.05$), the means were compared by the Tukey test at 5% probability. All analyses were performed using SAS statistical software (SAS Institute, Cary, NC, version 9.4).

3. Results

3.1. Soil temperature

The soil mulch materials had a direct effect on soil temperature in both growing seasons (Table 1). About the two growing seasons, the highest soil temperatures were recorded at both depths (5 and 10 cm) in the spring-summer.

In the fall-winter season, an increase of 2 °C in soil temperature at 7 a.m. was observed with the use of brown, green, black, and silver plastic mulches films compared to treatments without soil mulching at both depths. Similar results were observed at 2 pm for brown, green, and black plastic mulches films, which had the highest temperatures, with an average increment of 2.54 °C compared to treatments without mulches cover. However, during this evaluation, rice straw mulch resulted in a reduction of up to 3 °C in soil temperature when compared to treatments without cover.

In the spring-summer season, all mulch materials provided high soil temperatures at 7 a.m. at both depths. The highest temperature increases (2.27–2.55 °C) were observed with the use of brown and green plastic mulches films. In both depths, the treatments without mulches presented lower soil temperature. At 2 pm, the use of brown and green plastic mulch films provided higher soil temperatures at both depths, with an average increment of 4 °C. The treatments without covering and without weed control and rice straw had the lowest soil temperatures, with 28.20 and 27.88, respectively.

Table 1
Soil temperature at 7 a.m. and 2 p.m. at two depths (5 and 10 cm). in the fall-winter and spring-summer growing seasons.

Mulch material	Temperature 7 am (°C)		Temperature 2 pm (°C)	
	5 cm	10 cm	5 cm	10 cm
Fall-winter season				
Brown plastic	20.04 a	21.33 ab	28.92 a	26.84 a
Green plastic	19.96 a	21.41 a	27.94 ab	26.08 ab
Black plastic	19.84 a	21.25 ab	27.87 ab	26.06 ab
Silver plastic	19.63 ab	21.11 abc	26.87 bc	25.25 bc
White plastic	18.93 abc	20.25 abc	25.52 cd	24.13 cde
Yellow plastic	18.92 abc	19.74 bc	25.98 cd	24.56 cd
Rice straw	19.13 abc	20.02 abc	22.44 e	22.54 f
Without mulches/ herbicide[1]	17.95 bc	19.74 bc	26.28 bcd	24.86 cd
Without mulches/hoeing[2]	17.68 c	19.50 c	25.50 cd	23.94 de
Without mulches/without control[3]	17.81 c	19.68 bc	24.58 d	23.30 ef
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001
CV (%)	10.62	9.51	8.12	5.34
Spring-summer season				
Brown plastic	25.50 a	26.63 a	35.34 a	33.18 a
Green plastic	25.66 a	26.62 a	34.40 ab	33.13 a
Black plastic	25.08 ab	26.32 ab	33.61 abc	31.71 abc
Silver plastic	25.34 a	26.32 ab	32.79 bc	31.22 bcd
White plastic	24.46 b	25.33 c	32.00 c	30.48 bcd
Yellow plastic	25.13 ab	26.04 ab	33.86 abc	31.87 ab
Rice straw	25.17 a	25.81 bc	28.29 d	27.47 e
Without mulches/ herbicide[1]	23.14 c	24.06 d	32.01 c	29.84 d
Without mulches/hoeing[2]	22.73 c	23.70 d	31.69 c	30.00 cd
Without mulches/without control[3]	23.14 c	23.90 d	28.79 d	27.61 e
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001
CV (%)	3.32	2.86	8.04	6.97

Values followed by similar letters under the same column are not significantly different at $p \leq 0.05$ according to Tukey test.
[1] Without mulches and with herbicide application.
[2] Without mulches and with weed hoeing.
[3] Without mulches and without weed control.

3.2. Plant development

About plant height, at ten days after transplanting (DAT), there was a difference only according to the growing season (Table 2), with the highest average observed in autumn-winter cultivation (Table 3). For the other periods evaluated, there was an interaction between the factors (Table 2), with higher plant height in the spring-summer cultivation in all treatments.

In the autumn-winter cultivation, there was a significant difference in plant height only at 40 DAT, a higher average was observed in the yellow and silver plastic coverings. Lower plant height was found in treatments without cover with herbicide application, and without cover and weed control (Table 4).

In the spring-summer cultivation, at 20 DAT, the green plastic cover had a lower average plant height, and the other treatments did not differ from each other. In the subsequent evaluation, at 30 DAT, treatment without soil covering and herbicide showed the highest average plant height, differing from treatments with black, green, and brown plastic cover. At 40 DAT, treatments without covering with herbicide, without cover with weeding, white plastic cover, and straw cover, showed taller plants. The brown and green plastic coverings had the lowest plant height at 30 and 40 DAT.

For stem diameter at 10, 20, 30 and 40 DAT, there was an interaction between the factors 'coverage' 'growing season' (Table 2), with higher

Table 2
Analysis of variance and effects of the treatments with different mulching (T) and season (S) on development, yield and post-harvest quality of fresh market tomato.

Source[a]	DF[b]	ALT10	ALT20	ALT30	ALT40	DIAM10	DIAM20	DIAM30	DIAM40	TYIELD	MYIELD	NFT	NFM	TSS	TA
T	9	0.3695	0.1319	0.0039	0.0007	0.1806	0.2775	0.0145	0.0158	<.0001	0.0020	0.0005	0.0027	0.0638	0.0524
S	1	<0.0001	0.0001	0.0001	0.0001	<0.0001	0.0001	0.0001	0.0001	0.7699	<.0001	<.0001	0.0001	0.0001	0.8662
T x S	9	0.5170	0.0127	0.0001	0.0001	0.0089	0.0290	0.0466	0.0361	0.0067	0.3043	0.0176	0.3568	0.1009	0.3455
CV (%)		6.13	5.10	4.61	3.41	5.50	6.76	7.47	6.73	13.01	14.96	11.32	11.64	8.95	15.43

Abbreviations: ALT10= plant height at 10 DAT; ALT20= plant height at 20 DAT; ALT30= plant height at 30 DAT; ALT40= plant height at 40 DAT; DIAM10= stem diameter at 10 DAT; DIAM20= stem diameter at 20 DAT; DIAM30= stem diameter at 30 DAT; DIAM40= stem diameter at 40 DAT; TYIELD = total yield; MYIELD = marketable yield; NFT = number of total fruits; NFM = number of marketable fruits; TSS = total soluble solids; TA = titratable acidity.
[a] Sources of variation were considered significant when $P \leq 0.05$. CV = coefficient of variation.
[b] Number of degrees of freedom.

Table 3
Average values of plant height at 10 DAT (ALT10), marketable yield (MYIELD), number of marketable fruits (NFM) and post-harvest quality of fresh market tomato, total soluble solids (TSS) and titratable acidity (TA), in response to the growing under different mulching or season.

Mulch material	ALT10	MYIELD	NFM	TSS	TA
Brown plastic	21.14^{NS}	36.19 a	27.95 a	4.16^{NS}	0.32^{NS}
Green plastic	20.69	34.54 ab	27.12 ab	4.27	0.31
Black plastic	20.68	35.95 ab	27.42 a	4.29	0.32
Silver plastic	20.69	37.53 a	28.24 a	4.20	0.33
White plastic	20.94	35.97 ab	27.54 a	4.58	0.37
Yellow plastic	21.25	35.66 ab	27.19 ab	4.47	0.35
Rice straw	20.86	31.91 ab	25.72 ab	4.55	0.38
Without mulches/ herbicide[1]	20.45	36.10 ab	26.84 ab	4.33	0.33
Without mulches/hoeing[2]	20.01	40.39 a	29.84 a	4.25	0.32
Without mulches/without control[3]	19.74	27.48 b	22.11 b	3.95	0.38
Growing season					
Fall-winter	21.63*	28.65*	19.99*	4.13*	0.34^{NS}
Spring-summer	19.66	41.70	34.00	4.48	0.34

Values followed by similar letters under the same column are not significantly different at $p \leq 0.05$ according to Tukey test.
* Significant difference and ^{NS}Not significant difference (F, $p \leq 0.05$).
[1] Without mulches and with herbicide application.
[2] Without mulches and with weed hoeing.
[3] Without mulches and without weed control.

Table 4
Plant height and stem diameter of tomato plants grown under different soil mulch in the fall-winter and spring-summer growing seasons.

Mulch material	Plant height (cm)			Stem diameter (mm)		
	20 DAT	30 DAT	40 DAT	20 DAT	30 DAT	40 DAT
Fall-winter season						
Brown plastic	35.05^{NS}	58.55^{NS}	96.26 ab	7.85^{NS}	10.93 ab	15.09 abc
Green plastic	34.98	56.08	96.28 ab	7.73	10.89 ab	15.32 ab
Black plastic	34.54	58.47	94.40 ab	7.67	10.92 ab	14.70 abc
Silver plastic	33.83	57.91	99.57 a	8.02	11.55 ab	15.85 ab
White plastic	34.66	56.28	95.31 ab	7.71	10.84 ab	14.65 abc
Yellow plastic	36.03	59.18	100.98 a	8.02	11.91 a	16.08 a
Rice straw	35.07	56.16	93.03 ab	7.31	10.37 ab	14.15 abc
Without mulches/ herbicide[1]	32.82	52.61	89.46 b	6.82	9.95 ab	13.82 abc
Without mulches/ hoeing[2]	33.64	54.50	94.72 ab	7.01	10.29 ab	13.39 bc
Without mulches/ without control[3]	32.38	53.38	88.56 b	6.77	9.42 b	12.76 c
Pr > F	0.4079	0.1138	0.0003	0.0844	0.0453	0.0009
Spring-summer season						
Brown plastic	49.73 ab	82.91 bc	120.50 bc	13.09^{NS}	17.02 ab	17.86^{NS}
Green plastic	47.84 b	77.31 c	116.66 c	13.04	15.84 ab	17.35
Black plastic	50.03 ab	84.41 bc	124.37 abc	12.97	16.96 ab	18.36
Silver plastic	49.81 ab	86.53 ab	123.67 abc	13.30	15.39 b	17.25
White plastic	52.78 ab	89.75 ab	130.50 a	14.54	18.01 a	18.94
Yellow plastic	53.13 a	88.72 ab	127.50 ab	13.38	16.53 ab	18.17
Rice straw	50.61 ab	88.70 ab	130.09 a	13.81	16.23 ab	18.24
Without mulches/ herbicide[1]	53.94 a	93.16 a	129.31 a	13.68	16.30 ab	17.87
Without mulches/ hoeing[2]	53.03 a	90.28 ab	129.81 a	13.70	16.20 ab	17.62
Without mulches/ without control[3]	51.53 ab	87.47 ab	125.16 abc	13.52	15.63 b	17.38
Pr > F	0.0034	0.0001	0.0001	0.1037	0.0281	0.4902
CV (%)	5.10	4.60	3.41	6.76	7.47	6.73

Values followed by similar letters under the same column are not significantly different at $p \leq 0.05$ according to Tukey test. ^{NS} Not significant difference (F, $p \leq 0.05$).
[1] Without mulches and with herbicide application.
[2] Without mulches and with weed hoeing.
[3] Without mulches and without weed control.

averages in spring-summer cultivation in all treatments, except for the silver plastic cover at 40 DAT (Table 4). In the autumn-winter cultivation, there was a significant difference only at 30 and 40 DAT, where the yellow cover presented plants with a larger diameter, differing from the treatment without cover and weed control.

In the spring-summer cultivation, there was a statistical difference only for the evaluations at 10 and 30 DAT for the stem diameter variable. At 10 DAT, green and straw coverings presented lower averages, and the other treatments did not differ from each other. At 30 DAT, the white plastic cover had a higher average stem diameter, differing from treatments without cover and weed control and with a silver cover.

3.3. *Total yield, marketable yield, the total number of fruits and marketable fruits*

Regarding total yield, there was a significant interaction between the factors evaluated (Table 2). Regarding silver and green cover, higher averages were found in the autumn-winter cultivation, unlike the treatment without cover and without weed control, which presented higher averages in the spring-summer cultivation. In the autumn-winter cultivation, all treatments showed total yield superior to that without cover and without weed control. The highest averages were found in green and silver coverings. In the spring-summer crop, there were no differences between treatments (Table 5).

Marketable production was not influenced by the interaction between the factors evaluated (Table 2). Treatments without weeding, silver, and the brown plastic cover showed higher averages of commercial production. The treatment without cover and weed control showed a lower average of commercial production compared to the others. Regarding the growing season, the highest average was observed in spring-summer (Table 3).

For the total number of fruits, there was an interaction between the factors evaluated (Table 2). The treatments with a white cover, rice straw, without cover using herbicides, without cover with weeding, and without cover and without weed control had the highest averages of the number of fruits in spring-summer cultivation. In autumn-winter cultivation, treatments without cover and weeding and green, silver, yellow, brown, and black coverings presented the highest averages, differing from treatment without cover and weed control. In the spring-summer cultivation, there were no differences between treatments (Table 5).

About marketable fruits, there was no effect of the interaction between growing seasons and coverages (Table 2). The treatments without cover and with weeding and plastic coverings in silver, brown, white,

Table 5
Total yield (TYIELD) and number of total fruits (NFT) of tomato crop grown under different soil mulch in the fall-winter and spring-summer growing seasons.

Mulch material	TYIELD (t ha^{-1})	NFT (number plant^{-1})
Fall-winter season		
Brown plastic	49.22 a	35 a
Green plastic	52.60 a	36 a
Black plastic	46.17 a	33 a
Silver plastic	53.18 a	36 a
White plastic	42.71 a	30 ab
Yellow plastic	51.41 a	36 a
Rice straw	41.16 ab	29 ab
Without mulches/herbicide[1]	43.47 a	30 ab
Without mulches/hoeing[2]	47.23 a	32 a
Without mulches/without control[3]	27.98 b	22 b
Pr > F	<0.0001	<0.0001
Spring-summer season		
Brown plastic	46.75^{NS}	38^{NS}
Green plastic	41.88	36
Black plastic	45.88	37
Silver plastic	44.67	37
White plastic	48.93	40
Yellow plastic	46.35	38
Rice straw	43.66	39
Without mulches/herbicide[1]	47.69	38
Without mulches/hoeing[2]	53.07	42
Without mulches/without control[3]	40.14	33
Pr > F	0.1644	0.2487
CV (%)	13.01	11.32

Values followed by similar letters under the same column are not significantly different at $p \leq 0.05$ according to Tukey test. ^{NS} Not significant difference (F, $p \leq 0.05$).
[1] Without mulches and with herbicide application.
[2] Without mulches and with weed hoeing.
[3] Without mulches and without weed control.

and black showed the highest average number of fruits, and the treatment without cover and weed control showed the lowest average of commercial fruits. About the cultivation period, the highest average was observed in the spring-summer (Table 3).

3.4. Physicochemical quality of fruits

About soluble solids, there was a significant difference only between periods of cultivation (Table 2), with the highest content in spring-summer cultivation (Table 3). For titratable acidity, no significant difference was observed for all factors evaluated (Table 2).

4. Discussion

The temperature increase occurred with the use of all plastic mulches films, but with higher intensity during the spring-summer growing season in darker mulches films. Similar behavior was observed by Zhang et al. (2019), where there was an increase in soil temperature with plastic coverings in all growing seasons, especially in the summer.The results showed that dark-colored plastic mulches films (black, brown, and green) provided a higher increase in soil temperature when compared to the soil without mulches. Similar results were reported by Filipović et al. (2016) and Majumder et al. (2016).

The soil temperature under mulching depends on the specific thermal properties of the material used and the incident solar radiation (Pramanik et al., 2015). The color of the plastic mulch film determines the behavior of the radiant energy and its influence on the microclimate, which may affect soil temperature. The black plastic mulch film tends to absorb and transmit more shortwave radiation, resulting in increased soil profile temperature (Job et al., 2016). According to Díaz-Pérez and Batal (2002), the ideal soil temperature near the root system for tomato cropping ranges from 24.5–29.3 °C, with a maximum of 30.3 °C, above which tomato development can be inhibited.

The rice straw mulching contributed to the reduction of soil temperature, especially at 2 pm, in both growing seasons. This is because this mulch material has a higher albedo and lower thermal conductivity than soil without mulches, which reduces the amount of radiation reaching the soil surface, resulting in less surface energy available to heat the soil (Horton et al., 1996; Jabran, 2019). Similar results have been reported for okra (Adekiya et al., 2017) and maize (Haque et al., 2018; Yin et al., 2019) crops.

Tomato plants showed greater development in spring-summer cultivation. This period of the year is characterized by a higher incidence of sunlight and higher temperatures than in winter (Karvatte Junior et al., 2020). According to He et al. (2019), among the environmental factors, air and soil temperature play a fundamental role in the growth of tomato plants.

In the autumn-winter cultivation, the plants in the yellow and silver cover presented higher plant heights and stem diameter. Research on yellow coverage is still scarce, but the efficiency of the silver coverage in plant growth has already been found in studies by Jha et al. (2018) in the okra crop and Torres-Olivar et al. (2017) in cucumber crop. The plants on the cover with rice straw showed lower mean stem diameter, a result similar to treatments without cover and without weed control. A similar result was found by Moursy et al. (2015) in tomato, showing that plants grown in rice straw cover had stem diameter lower than the plastic cover.

The brown, green, black, and silver plastic cover reached higher soil temperatures and, consequently, lower plant height in spring-summer cultivation. According to Szymańska et al. (2017), photosynthesis is directly affected by the temperature conditions of the production environment, as some physiological processes are more sensitive to high temperatures. Thus, extreme temperatures above the optimum for the crop can cause several negative impacts on plant growth. A study carried out with tomatoes showed that root growth was strongly restricted by heat stress induced by black plastic mulch (Zhang et al., 2019).

The positive effect of plastic mulches films on tomato yield was significant only in the fall-winter growing season. In the spring-summer season, the use or not of soil mulches resulted in similar tomato fruit yield, indicating that mulches will not always increase crop yield (Ibarra-Jiménez et al., 2012). Adamczewska-Sowińska and Turczuk (2018) reported that the use of soil mulches did not significantly increase tomato fruit yield.

In the fall-winter growing season, the highest tomato fruit yield was observed with the use of green and silver plastic mulches film with an increase of 33 % and 34 %, respectively, when compared to treatments without mulches. Many studies have reported that plastic mulch increases the yield of many vegetables, such as eggplant (Adamczewska-Sowińska et al., 2016), potatoes (Li et al., 2018), and tomatoes (Rahman et al., 2016; Kundu et al., 2019).

Plastic coverings were effective for a greater amount of total and marketable fruits, similar to those found by Ogundare et al. (2015). According to Ansary et al. (2017), the increase in the number of fruits per plant may be related to an improved microclimate, below and above the soil surface, using plastic coverings.

The plants grown in the treatment without mulches and without weed control presented the lowest total yield, marketable yield, the number of fruits and marketable fruits, certainly due to the presence and competition of weeds with tomato plants. Weeds can cause direct and indirect damage to the tomato crop. Weeds act directly in reducing fruit yield by competing for production factors such as water, light, nutrients, and carbon dioxide (CO_2). They act indirectly by creating a microclimate favorable to disease occurrence and may have an allelopathic effect or host pest insects (Castro et al., 2016).

The highest content of soluble solids was found in spring-summer cultivation, possibly due to higher irradiance and ambient temperature. Solar radiation and temperature have a great influence on the accumulation of sugar in fruits, with an increase in the content of soluble solids in periods with higher temperatures and greater irradiance, and it is unlikely that the sugar production of winter fruits will be the same as that produced in the summer (Beckles, 2012). The soil cover did not alter the titratable acidity of tomato fruits, similar to that found by Compagnol et al. (2014).

5. Conclusions

Plastic film mulches affect soil temperature in both growing seasons, with higher temperatures using dark-colored mulches films, which may have compromised plant growth during the spring-summer growing season. In the fall-winter growing season, yellow and silver plastic film mulches improved tomato plant growth, while green and silver plastic film mulches resulted in a 33 % and 34 % increase in fruit yield and the total number of fruits, respectively. Therefore, soil mulches materials have distinct effects on plant development and tomato yield, which is dependent on the growing season.

CRediT authorship contribution statement

Sara Raquel Mendonça: Conceptualization, Investigation, Writing - original draft, Visualization, Methodology. **Mylla Crysthyan Ribeiro Ávila:** Investigation, Writing - original draft, Methodology. **Roberto Gomes Vital:** Writing - original draft, Writing - review & editing. **Zeuxis Rosa Evangelista:** Visualization, Writing - original draft. **Nadson de Carvalho Pontes:** Formal analysis, Writing - original draft, Writing - review & editing. **Abadia dos Reis Nascimento:** Writing - original draft, Writing - review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

The research was funded by the Research Support Foundation of the State of Goiás (FAPEG), grant no 201510267001478/2015.

References

Adamczewska-Sowińska, K., Turczuk, J., 2018. Effects of plastic and biodegradable mulch films in field tomato cultivation. Acta Sci. Pol. Hortorum Cultus 17, 123–133. https://doi.org/10.24326/asphc.2018.5.11.

Adamczewska-Sowińska, K., Krygier, M., Turczuk, J., 2016. The yield of eggplant depending on climate conditions and mulching. Folia Hortic. 28, 19–24. https://doi.org/10.1515/fhort-2016-0003.

Adekiya, A.O., Agbede, T.M., Aboyeji, C.M., Dunsin, O., 2017. Response of okra (Abelmoschus esculentus (L.) Moench) and soil properties to different mulch materials in different cropping seasons. Sci. Hortic. 217, 209–216. https://doi.org/10.1016/j.scienta.2017.01.053.

Alvarenga, M.A.R., 2013. Tomate: produção em campo, casa de vegetação e hidroponia, 2 ed. UFLA, Lavras.

Ansary, S.H., Manna, A., Barui, K., Mudi, N., Gayen, N., Chowdhury, A.K., 2017. Evaluation of different mulch materials on growth and yield of summer tomato (Solunum lycopersicum L.). Int. J. Trop. Agric. 35, 47–55.

Beckles, D.M., 2012. Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. Postharvest Biol. Technol. 63, 129–140. https://doi.org/10.1016/j.postharvbio.2011.05.016.

Caruso, G., Stoleru, V., De Pascale, S., Cozzolino, E., Pannico, A., Giordano, M., Teliban, G., Cuciniello, A., Rouphael, Y., 2019. Production, leaf quality and antioxidants of perennial wall rocket as affected by crop cycle and mulching type. Agronomy 9, 194. https://doi.org/10.3390/agronomy9040194.

Castro, Y.O., Cavalieri, S.D., Santos, M.P., Galynski, A., Nascimento, A.R., 2016. Manejo integrado de plantas daninhas na cultura do tomate para processamento industrial e para consumo in natura. Sci. Electron. Arch. 9, 11–17. http://www.seasinop.com.br/revista/index.php?journal=SEA&page=article&op=view&path%5B%5D=285&path%5B%5D=pdf.

Compagnol, R., Abrahão, C., Mello, S.C., Oviedo, V.R.S., Minami, K., 2014. Impactos do nível de irrigação e da cobertura do solo na cultura do tomateiro. Irrigation 19, 345–357. https://doi.org/10.15809/irriga.2014v19n3p345.

Decoteau, D.R., Kasperbauer, M.J., Daniels, D.D., Hunt, P.G., 1988. Plastic mulch color effects on reflected light and tomato plant growth. Sci. Hortic. 34, 169–175. https://doi.org/10.1016/0304-4238(88)90089-1.

Deschamps, S.S., Whitaker, V.M., Agehara, S., 2019. White-striped plastic mulch reduces root-zone temperatures during establishment and increases early season yields of annual winter strawberry. Sci. Hortic. 243, 602–608. https://doi.org/10.1016/j.scienta.2018.09.018.

Díaz-Pérez, J.C., Batal, K.D., 2002. Colored plastic film mulches affect tomato growth and yield via changes in root-zone temperature. J. Am. Soc. Hortic. Sci. 127, 127–135. https://doi.org/10.21273/JASHS.127.1.127.

FAOSTAT Database Results, 2020. Crop Statistics. Disponível em: http://www.fao.org/faostat/en/#data/QC. Acesso em 13 de agosto de 2020.

Filipović, V., Romić, D., Romić, M., Borošić, J., Filipović, L., Mallmann, F.J.K., Robinson, D.A., 2016. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: experimental results and a modeling study. Agric. Water Manag. 176, 100–110. https://doi.org/10.1016/j.agwat.2016.04.020.

Ghosh, P.K., Dayal, D., Bandyopadhyay, K.K., Mohanty, M., 2006. Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. Field Crops Res. 99, 76–86. https://doi.org/10.1016/j.fcr.2006.03.004.

Ham, J.M., Kluitenberg, G.J., Lamont, W.J., 1993. Optical properties of plastic mulches affect the field temperature regime. J. Am. Soc. Hortic. Sci. 118, 188–193. https://doi.org/10.21273/jashs.118.2.188.

Haque, M.A., Jahiruddin, M., Clarke, D., 2018. Effect of plastic mulch on crop yield and land degradation in south coastal saline soils of Bangladesh. Int. Soil Water Conserv. Res. 6, 317–324. https://doi.org/10.1016/j.iswcr.2018.07.001.

He, F., Thiele, B., Watt, M., Kraska, T., Ulbrich, A., Kuhn, A.J., 2019. Effects of root cooling on plant growth and fruit quality of cocktail tomato during two consecutive seasons. J. Food Qual. 1–15. https://doi.org/10.1155/2019/3598172.

Horton, R., Bristow, K.L., Kluitenberg, G.J., Sauer, T.J., 1996. Crop residue effects on surface radiation and energy balance- review. Theor. Appl. Climatol. 54, 27–37. https://doi.org/10.1007/bf00863556.

Ibarra-Jiménez, L., Valdez-Aguilar, L.A., Cárdenas-Flores, A., Lira-Saldivar, H., Lozano-del Río, J., Lozano Cavazos, C., 2012. Influence of double cropping on growth and yield of dry beans with colored plastic mulches. Chil. J. Agric. Res. 72, 470–475. https://doi.org/10.4067/s0718-58392012000400002.

Instituto Adolfo Lutz (São Paulo), 2008. Métodos físico-químicos para análise de alimentos/coordenadores Odair Zenebon. Neus Sadocco Pascuet e Paulo Tiglea – São Paulo: Instituto Adolfo Lutz, p. 1020.

Jabran, K., 2019. Mulching in Pest Management and Agricultural Sustainability. Springer, Switzerland.

Jha, R.K., Neupane, R.B., Khatiwada, A., Pandit, S., Dahal, B.R., 2018. Effect of different spacing and mulching on growth and yield of Okra (Abelmoschus esculentus L.) in Chitwan, Nepal. J. Agric. Nat. Resour. 1, 168–178. https://orcid.org/0000-0003-4837-6392.

Job, M., Bhakar, S.R., Sing, P.K., Tiwari, G.S., Sharma, R.K., Lakhawat, S.S., Sharma, D., 2016. Evaluation of plastic mulch for changes in mechanical properties during onion cultivation M. Int. J. Sci. Environ. Technol. 5, 575–584.

Kader, M.A., Senge, M., Mojid, M.A., Ito, K., 2017. Recent advances in mulching materials and methods for modifying soil environment. Soil Tillage Res. 168, 155–166. https://doi.org/10.1016/j.still.2017.01.001.

Karvatte Junior, N., Miyagi, E.S., de Oliveira, C.C., Barreto, C.D., Mastelaro, A.P., Bungenstab, D.J., Alves, F.V., 2020. Infrared thermography for microclimate assessment in agroforestry systems. Sci. Total Environ. 731, 139252. https://doi.org/10.1016/j.scitotenv.2020.139252.

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

Kundu, P., Adhikary, N.K., Saha, M., Ghosal, A., Sahu, N.C., 2019. The effects of mulches on tomato (Lycopersicon esculentum L.) in respect of yield attribute in ecosystem of Coastal Bengal. Curr. J. Appl. Sci. Technol. 5, 1–8. https://doi.org/10.9734/CJAST/2019/v35i430190.

Li, Q., Li, H., Zhang, L., Zhang, S., Chen, Y., 2018. Mulching improves yield and water-use efficiency of potato cropping in China: a meta-analysis. Field Crops Res. 221, 50–60. https://doi.org/10.1016/j.fcr.2018.02.017.

Lopes, W.A.R., Negreiros, M.Z., Dombroski, J.L.D., Rodrigues, G.S.O., Soares, A.M., Araújo, A.P., 2011. Análise do crescimento de tomate 'SM-16' cultivado sob diferentes coberturas de solo. Hortic. Bras. 29, 554–561. https://doi.org/10.1590/s0102-05362011000400019.

Majumder, D.A.N., Nath, S.C., Kabir, M.A., Majumder, S., 2016. Short Communication: effect of mulching materials on mini-tuber production of potato fromin vitroplantlets. N Usantara Bioscience 8, 123–127. https://doi.org/10.13057/nusbiosci/n080121.

Moreno, M.M., Cirujeda, A., Aibar, J., Moreno, C., 2016. Soil thermal and productive responses of biodegradable mulch materials in a processing tomato (*Lycopersicon esculentum* Mill.) crop. Soil Res. 54, 207–2015. https://doi.org/10.1071/sr15065.

Moursy, F.S., Mostafa, F.A., Solieman, N.Y., 2015. Polyethylene and rice straw as soil mulching: reflection of soil mulch type on soil temperature, soilborne diseases, plant growth and yield of tomato. Glob. J. Adv. Res. 2, 1497–1519.

Munner, S., Kim, J.H., Shin, M.H., Cha, G.H., Kim, H.L., Ban, T., Kumarihami, P.C., Kim, S.H., Jeong, G., Kim, J.G., 2019. Reflective plastic film mulches enhance light intensity, floral induction, and bioactive compounds in 'O'Neal' southern highbush blueberry. Sci. Hortic. 246, 448–452. https://doi.org/10.1016/j.scienta.2018.10.042.

Mutetwa, M., Mtaita, T., 2014. Effects of mulching and fertilizer sources on growth and Yield of onion. J. Glob. Innov. Agric. Soc. Sci. 2, 102–106. https://doi.org/10.17957/JGIASS/2.3.561.

Ogundare, S.K., Babatunde, I.J., Etukudo, O.O., 2015. Response of Tomato Variety (Roma F) Yield to Different Mulch Materials and Staking in Kabba, Kogi State, Nigeria. J. Agric. Stud. 3, 61–70. https://doi.org/10.5296/jas.v3i2.7568.

Perveen, R., Suleria, H.A.R., Anjum, F.M., Butt, M.S., Pasha, I., Ahmad, S., 2015. Tomato (Solanum lycopersicum) carotenoids and lycopenes chemistry; metabolism, absorption, nutrition, and allied health claims—a comprehensive review. Crit. Rev. Food Sci. Nutr. 55, 919–929. https://doi.org/10.1080/10408398.2012.657809.

Pramanik, P., Bandyopadhyay, K.K., Bhanduri, D., Acharyyal, R.B., Aggarwal, P., 2015. Effect of mulch on soil thermal regimes - A review. IJAEB 8, 645–658. https://doi.org/10.5958/2230-732X.2015.00072.8.

Rahman, M.J., Quamruzzaman, M., Samsuddin, M., 2016. Effect of different mulch materials on growth and yield of tomato. Bangladesh Hort. 2, 29–37.

Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O., Schaumann, G.E., 2016. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? Sci. Total Environ. 550, 690–705. https://doi.org/10.1016/j.scitotenv.2016.01.153.

Sun, Y., Holm, P.E., Liu, F., 2014. Alternate partial root-zone drying irrigation improves fruit quality in tomatoes. Hortic. Sci. 41, 185–191. https://doi.org/10.17221/259/2013-HORTSCI.

Szymańska, R., Ślesak, I., Orzechowska, A., Kruk, J., 2017. Physiological and biochemical responses to high light and temperature stress in plants. Environ. Exp. Bot. 139, 165–177. https://doi.org/10.1016/j.envexpbot.2017.05.002.

Torres-Olivar, V., Ibarra-Jiménez, L., Cárdenas-Flores, A., Lira-Saldivar, R.H., Valenzuela-Soto, J.H., Castillo-Campohermoso, M.A., 2017. Changes induced by plastic film mulches on soil temperature and their relevance in growth and fruit yield of pickling cucumber. Acta Agric. Scand. B 68, 97–103. https://doi.org/10.1080/09064710.2017.1367836.

Wang, X., Jia, Z., Liang, L., Yang, B., Ding, R., Nie, J., Wang, J., 2016. Impacts of manure application on soil environment, rainfall use efficiency and crop biomass under dryland farming. Sci. Rep. 6, 1–8. https://doi.org/10.1038/srep20994.

Wang, F., Wang, Z., Zhang, J., Li, W., 2019. Combined effect of different amounts of irrigation and mulch films on physiological indexes and yield of drip-irrigated maize (Zea mays L.). Water 11, 1–15. https://doi.org/10.3390/w11030472.

Yin, W., Fan, Z., Hu, F., Yu, A., Zhao, C., Chai, Q., Coulter, J.A., 2019. Innovation in alternate mulch with straw and plastic management bolsters yield and water use efficiency in wheat-maize intercropping in arid conditions. Sci. Rep. 9, 1–14. https://doi.org/10.1038/s41598-019-42790-x.

Zangoueinejad, R., Kazemeini, S.A., Ghadiri, H., Javanmardi, J., 2018. Effects of non-living mulches and metribuzin on yield and yield components of tomato (*Lycopersicon escolentum* cv. CH). Iran Agric. Res. 37, 43–48. https://doi.org/10.22099/IAR.2018.4678.

Zhang, F., Zhang, W., Qi, J., Li, F.M., 2018. A regional evaluation of plastic film mulching for improving crop yields on the Loess Plateau of China. Agric. For. Meteorol. 248, 458–468. https://doi.org/10.1016/j.agrformet.2017.10.030.

Zhang, X., You, S., Tian, Y., Li, J., 2019. Comparison of plastic film, biodegradable paper and bio-based film mulching for summer tomato production: soil properties, plant growth, fruit yield and fruit quality. Sci. Hortic. 249, 38–48. https://doi.org/10.1016/j.scienta.2019.01.037.

Zhao, H., Wang, R.Y., Ma, B.L., Xiong, Y.C., Qiang, S.C., Wang, C.L., 2014. Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rainfed ecosystem. Field Crop. Res. 161, 137–148. https://doi.org/10.1016/j.fcr.2014.02.013.