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Degradation of plastic film mulch affects root zone temperature and fruit yield of eggplant (*Solanum melongena* L.)

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Abstract

Eggplant or brinjal (*Solanum melongena* L.) is commonly grown on plastic film mulch. Plastic film mulches, however, may degrade before the end of the growing season. The objectives were to determine the effects of plastic film mulch degradation on root zone temperature (RZT) and fruit yield in eggplant. Eggplant ('Santana') plants were grown according to the recommendations of the Extension Service of the Univeristy of Georgia (USA). The experimental design was a randomized complete block with four replications and 20 treatments [plastic mulches (black, transparent, and white)]. Film mulches showed significant differences in their degradation during the season. Some films showed degradation as early as 30 d after being laid. There were differences in degradation rating, RZT, early fruit yield (first four harvests), and total fruit yield among film treatments. The RZT under the film mulch decreased with increasing film degradation. Early fruit yield decreased with increasing mean RZT during the first 42 days after transplanting (DAT). Thus, the differences in early fruit yield among film mulches were associated with differences in RZT and film mulch degradation. Eggplants were negatively affected when exposed to high RZT conditions [mean seasonal RZT (soil depth 10 cm) > 28–29 °C]. In conclusion, black plastic film mulch degradation affected eggplant early fruit yield by influencing the mulch's ability to warm the soil. The present report is based on a single fall trial. It is recommended to conduct further research on the effect of plastic film mulch degradation on crop responses with different plastic mulch colors, seasons, and locations.

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Introduction

Eggplant (*Solanum melongena* L.), brinjal, or aubergine, is a solanaceous vegetable crop highly consumed in Asia and of increasing popularity in the US. Eggplants grow as a bush to a height of 0.5 to 2.5 m[1]. Eggplants thrive under warm conditions and are more affected by low air temperatures than peppers and tomatoes. The optimal temperature range for eggplant plant growth is 22 to 30 °C during the day and 18 to 24 °C at night.

Eggplant in the southeast US is typically grown using plastic film mulch and drip irrigation[2–4]. Plastic film mulches generally increase yield, modify root zone temperature (RZT), suppress weed growth, reduce soil water evaporation, and increase earliness compared to unmulched crops[5]. The effect of plastic film mulch on plant growth and yield in significant proportion depends on the RZT under the film mulch, which is influenced by the film's optical properties, such as color[2,6]. Black film mulches warm the soil and are thus beneficial in cool conditions[7]. In Egypt, under greenhouse conditions (October to April), black mulch had higher eggplant plant growth and yield than bare soil[8].

In contrast, white and silver reflective film mulches maintain cooler soil conditions than black mulch and are typically utilized under warm conditions. In the San Joaquin Valley, California (USA) (June to July), using plastic mulch painted with black, white, red, blue, yellow, or silver oil-based paint, eggplants grown on silver-painted beds produced significantly greater fruit and total fruit weight than eggplants on other mulches. Silver-painted mulch stimulated significantly greater flowering and fruit set numbers before the first harvest at one site[9].

Under certain conditions, the ability of mulches to control weeds may be more important than the ability to modify the RZT. In Nigeria, from May to July, the black film was more effective in controlling weeds and enhancing plant growth and yield and less effective in cooling the soil than several organic mulches.

The physical, optical, and chemical film properties determine how film mulches affect the crop and its microenvironment[3,10]. These properties change with film degradation in the field, mainly when using the film mulches for more than one season[11,12]. Biodegradable film mulches unexpectedly degrade in the field during the growing season, causing enhanced weed growth and decreasing the soil-warming effect of the film mulch[13]. Thus, we must increase our understanding of how film degradation in the field may impact vegetable crop responses. This study aimed to determine the effects of plastic film mulch degradation on root zone temperature and fruit yield in eggplant.

Materials and methods

The study was conducted at the Horticulture Farm (108 m above mean sea level, 31°28' N latitude, and 83°31' W longitude), University of Georgia, Tifton, GA (USA), from June to Nov 2005. The soil was a Tifton Sandy Loam (a fine loamy-siliceous, thermic Plinthic Kandiudults) with a pH of 6.5. The field was

prepared by mold-board plowing and rototilling. Before planting, the soil received an application of 900 kg/ha of 10-10-10 fertilizer (Rainbow). Eggplant transplants 'Santana' (Lewis Taylor Farms, Tifton, GA, USA) were planted into the film mulch on 24 Aug in a single row per raised bed (1.8-m centers), with a 76 cm separation between plants. Plants were drip irrigated and fertilized weekly through the drip system starting three weeks after transplanting. The total amount for each N and K received by the plants after transplanting was 110 kg/ha. Each plot (experimental unit) consisted of a 6.6 m long bed with a 1.5-m alley between plots.

The experimental design was a randomized complete block with four replications and 20 treatments (plastic film mulches). The 20 plastic film mulches (122 cm wide; 25 μm thick; Ampacet, Atlanta, GA, USA) of various colors [black (13), transparent (4), and white (3)] and differing in composition [additives for ultraviolet (UV) protection and durability] were laid in the field on 23 June. By differing in UV additives composition, film degradation in the field was expected to vary among films. Film degradation was evaluated visually on a scale of 0 to 5 (0 = 0% degradation; 1 = 1% to 5% degradation; 2 = 6% to 10% degradation; 3 = 11% to 20% degradation; 4 = 21% to 50% degradation; 5 = > 50% degradation).

Film degradation was evaluated every three weeks, starting immediately after laying the films. The RZT under the films was measured with copper-constantan thermocouples (10 cm deep) connected to a datalogger (CR10X, Campbell Sci., Logan, UT, USA). The data logger was programmed to collect data every 10 min. Weather data (air temperature) were obtained from a nearby (< 300 m) University of Georgia weather station (www.georgiaweather.net).

Plants were harvested nine times (4 Oct to 17 Nov), and the fruit were graded as marketable and cull (USDA grading standards) and weighed. Early marketable fruit yield represents the cumulative yield of the first four harvests (before 17 Oct). Data were analyzed using the General Linear Model and Regression Procedures from SAS (ver. 9.4, SAS Inst. Inc., Cary, NC, USA). The Fischer's Protected Least Significance Range Test procedure separated the data means ($p < 0.05$).

Results

Weather data

Seasonal (24 Aug to 17 Nov) averages for air temperature were 28.3 °C (maximal), 22.6 °C (mean), and 16.8 °C (minimal), and cumulative rainfall was 33.5 mm. For the first 42 DAT, air temperature averages were 31.3 °C (maximal), 26.2 °C (mean), and 21.2 °C (minimal), and cumulative rainfall was 25.1 mm.

Degradation of plastic film mulch

Film degradation differed among treatments and over the season (Table 1). On day 75, films showed degradation ratings ranging from 0 (no degradation) to 5 (severe degradation). On day 75, the degradation ratings varied from 0.75 to 5.0 (black), 0.5 to 5.0 (transparent), and 0.75 to 2.0 (white). Films were already showing signs of degradation as early as 30 days after being laid, with 4637D (degradation rating = 4.25) and 4625A (degradation rating = 5.0) being the most degraded at the end of the season.

Root zone temperature

There were significant differences in the mean seasonal RZT among film mulches (Table 2). The highest RZT (29.93 °C) was in a transparent film (4625D), and the lowest (25.97 °C) was in a black film (4611L). Film color significantly ($p < 0.05$) affected mean seasonal RZT. Mean seasonal RZT was 26.8 (white), 28.4 (black), and 29.4 (transparent). On average, RZT was lower in white than in black films. Black films with ≤ 20% degradation (rating ≤ 3) had similar values of RZT (Fig. 1). However, at

Table 1. Visual degradation of plastic film mulches under field conditions during the eggplant growing season. Plastic film mulches varied in color and chemical composition (laid on 23 June 2005). Tifton, GA, USA.

Mulch	Mulch color	23 June	25 July	5 Aug	24 Aug	8 Sept
4566A	Black	0.00	0.00 d[z,y]	0.5 f	0.25 e	0.75 f
4603M	Black	0.00	0.25 cd	0.75 ef	0.75 cde	0.50 f
4603P	Black	0.00	0.75 cd	0.75 ef	0.50 de	0.75 f
4603Q	Black	0.00	1.00 c	0.75 ef	1.00 cd	1.75 def
4611J	Black	0.00	0.50 cd	2.5 c	3.50 b	4.25 abc
4611L	Black	0.00	2.00 b	4 b	4.50 a	5.00 a
4636A	Black	0.00	0.25 cd	0.25 f	1.00 cd	2.75 cde
4636B	Black	0.00	0.50cd	0.75 ef	0.50 de	1.75 def
4636C	Black	0.00	0.50 cd	0.75 ef	0.75 cde	0.75 f
4637B	Black	0.00	2.25 b	4.25 ab	4.75 a	4.75 ab
4637C	Black	0.00	0.25 cd	0 f	0.75 cde	1.50 def
4637D	Black	0.00	4.25 a	5 a	5.00 a	5.00 a
4637E	Black	0.00	0.75 cd	2.25 cd	3.50 b	4.25 abc
4625A	Transparent	0.00	5.00 a	5 a	5.00 a	5.00 a
4625D	Transparent	0.00	0.75 cd	0.5 f	1.00 cd	3.00 bcd
4626C	Transparent	0.00	0.00 d	0 f	0.50 de	0.50 f
4637A	Transparent	0.00	0.75 cd	0.75 ef	0.50 de	1.00 ef
4636L	White	0.00	1.00 c	1.75 cd	1.25 c	1.50 def
4636M	White	0.00	0.00 d	0.75 ef	0.75 cde	0.75 f
4636N	White	0.00	0.75 cd	1.5 de	1.00 cd	2.00 def
p			<0.0001	<0.0001	<0.0001	<0.0001

[z] Values that are followed by different letters in the same column are significantly different by Fischer's Protected Least Significant Difference test at $p \leq 0.05$.
[y] Film degradation was evaluated visually on a scale of 0 to 5 (0 = 0% degradation; 1 = 1% to 5% degradation; 2 = 6% to 10% degradation; 3 = 11% to 20% degradation; 4 = 21% to 50% degradation; 5 = > 50% degradation).

moderate to severe degradation (rating > 3), RZT decreased with increasing black film degradation.

Fruit yield

The ANOVA showed that film mulches had similar total fruit yields (av. 23.0 t/ha) and cull yields (av. 7.7 t/ha). However, early marketable yields [first four harvests (before 17 Oct)] were highest in plants on white film mulches (Table 2), with the average yields (t/ha) being 6.60 (white), 4.32 (black), and 3.48 (transparent). Early fruit yield decreased with increasing mean RZT during the first 42 DAT (Fig. 2). High RZTs, mainly under black and transparent films, were probably the cause of the reduced early yields. Plants on black and transparent films had increased yields as the RZT decreased with season progress resulting in minor total yield differences among mulches. Total cumulative marketable yields were similar among film mulches, although yields tended to be lowest in plants on black films.

Table 2. Seasonal root zone temperature (RZT) and cumulative fruit yields of eggplant grown on various plastic film mulches. Tifton, GA, USA Fall of 2005.

Mulch film	Film color	Seasonal RZT (°C)	Early marketable (t/ha)	Total marketable (t/ha)	Fruit weight (g)
4566A	Black	28.19 d[z]	4.02 cde	14.6 ab	373 abc
4603M	Black	29.31 b	4.11 cde	16.7 ab	355 bc
4603P	Black	28.27 d	4.62 bcde	16.4 ab	360 bc
4603Q	Black	27.71 e	4.29 cde	15.2 ab	347 bc
4611J	Black	27.73 e	5.07 bcd	15.3 ab	345 bc
4611L	Black	25.97 i	4.20 cde	16.4 ab	346 bc
4636A	Black	28.81 c	2.77 e	10.4 c	430 a
4636B	Black	28.86 c	3.61 cde	14.5 abc	365 bc
4636C	Black	27.60 e	4.84 bcde	14.7 abc	376 ab
4637B	Black	26.79 g	4.58 bcde	12.8 bc	330 bc
4637C	Black	28.65 c	4.39 cde	17.2 ab	352 bc
4637D	Black	26.46 h	4.80 bcde	15.3 abc	352 bc
4637E	Black	27.78 e	4.85 bcde	13.4 abc	325 bc
4625A	Transparent	26.98 fg	4.30 cde	16.3 ab	327 bc
4625D	Transparent	29.93 a	3.64 cde	14.1 abc	351 bc
4626C	Transparent	29.24 b	3.12 de	14.7 abc	328 bc
4637A	Transparent	29.27 b	2.86 de	17.0 ab	320 bc
4636L	White	27.14 f	6.79 ab	16.5 abc	335 bc
4636M	White	26.92 fg	7.50 a	17.5 a	341 bc
4636N	White	26.36 h	5.52 abc	16.1 ab	313 c
p		<0.0001	0.018	0.0431	0.046
LSD		0.51	2.28	4.6	60

[z] Values that are followed by different letters in the same column are significantly different by Fischer's Protected Least Significant Difference test at $p \leq 0.05$.

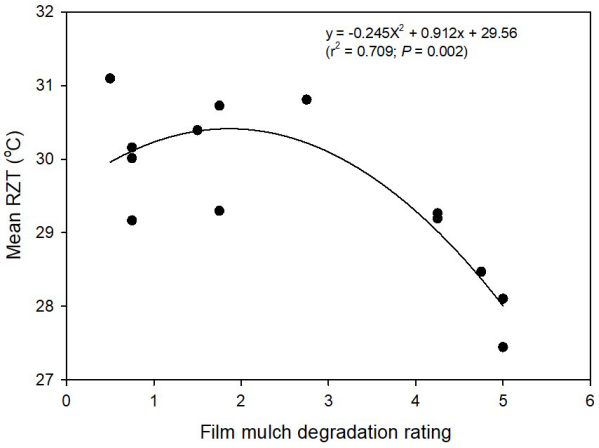

Fig. 1 Relationship between mean daily root zone temperature (RZT) and black plastic film mulch degradation rating during the first 42 d after transplanting (DAT). Transplanting was on 24 Aug. Film degradation rating was evaluated visually on a scale of 0 to 5 (0 = 0% degradation; 1 = 1% to 5% degradation; 2 = 6% to 10% degradation; 3 = 11% to 20% degradation; 4 = 21% to 50% degradation; 5 = > 50% degradation). Tifton, GA, USA.

Discussion

Plastic film mulches may improve plant growth and yield of vegetable crops[5,7]. The benefits of plastic mulches on vegetable crop production arise from the ability of mulches to modify the crop microenvironment[2]. The optical properties determine the mulch's ability to warm the soil, while the mulch's restriction to the passing of solar radiation reduces weed growth[14]. The low film mulch permeability to gas transfer reduces soil water evaporation resulting in improved soil water use efficiencies. Black and white mulches warm the soil primarily by conduction, transmitting the heat energy (visible and infrared) from solar radiation to the soil[5,15]. This energy transfer is most effective when close contact between the film and the soil exists. Cracks in the film mulch and loose soil-mulch contact reduce the film's ability to control weeds and warm the soil[13].

Studies have shown that the RZT under plastic film mulch affects plant growth and fruit yield in various crops[2,15,16]. Plant growth and fruit yield increase with increasing RZT until they reach maximum and decrease with subsequent increases in RZT. The present study showed differences in RZT, fruit yield, and degradation ratings among plastic film mulches. In addition to degradation rating, RZT was influenced by film color, with higher RZTs on black than on white film mulch. Eggplants were negatively affected when exposed to high RZT conditions [mean seasonal RZT (soil depth = 10 cm) > ~28–29 °C] (Fig. 2). Detrimental effects on fruit yield by high RZTs under black film mulch (during warm conditions) have been found in tomato (*Solanum lycopersicum* L.), tomatillo (*Physalis ixocarpa* Brot.), and pepper (*Capsicum annuum* L.)[2,5,7,17]. Tomato plants grown

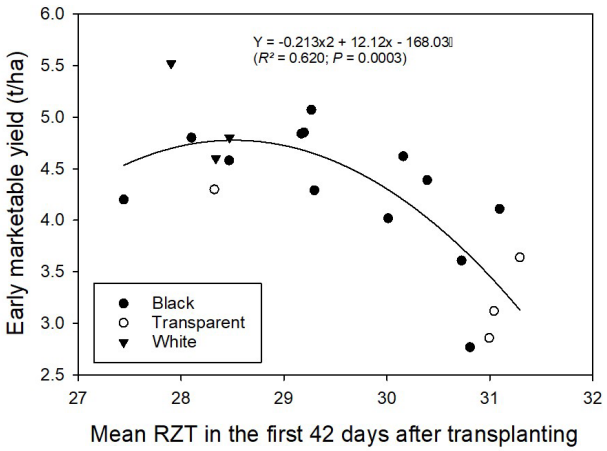

Fig. 2 Eggplant marketable yield as a function of the mean daily root zone temperature (RZT) under colored plastic mulches during the first 42 d after transplanting. Transplanting was on 24 Aug Tifton, GA, USA.

on various colored plastic mulches (and thus exposed to a range of root zone temperatures) during the fall showed that the optimum mean seasonal RZT was 26.3 °C[2].

This one-year study showed that the degree of film mulch degradation affected the film's ability to warm the soil. However, since film mulch color also affects RZT, the effect of film degradation on RZT was evaluated separately for black, transparent, and white films. Black mulches showed a range in RZTs. The RZT variability among black film mulches may be associated with film degradation (Fig. 1). Black film mulches with moderate to high degradation (> 20%) showed decreasing RZTs (mean seasonal) as the degradation increased (Fig. 1).

The differences in RZT among black film mulches may explain, at least partially, the differences in early fruit yield among film mulches (Fig. 2). As in black mulches, RZT decreased with increasing film degradation in transparent mulches. In contrast, it was not possible to determine the impact of mulch degradation on RZT in white films. The reduced range in degradation rating among the white films did not produce a significant regression coefficient.

Personal field observations (spring season in south Georgia) showing poor watermelon plant growth on degraded black plastic mulch are consistent with the relationship between mulch degradation and the reduced mulch's ability to warm the soil. Although this study focused on the effect of film mulch degradation on RZT, film mulch degradation may also influence other factors necessary for crop growth, such as soil, water and weed control[13].

Conclusions

Degradation of black plastic film mulch affected eggplant early fruit yield by influencing the mulch's ability to warm the soil. Practices such as utilizing biodegradable film mulches and using a single mulch for two crops ('double-cropping') or more must consider the possible impact of film mulch degradation on crop response. The present report is based on a single fall trial. It is recommended to conduct further studies on the effect of plastic film mulch degradation on crop responses with different mulch colors (e.g., black, white, silver), seasons, and locations.

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Conflict of interest

The author declares that there is no conflict of interest.

Dates

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