Strategies to reduce supraoptimal temperatures in the root zone during field and containerized production of highbush blueberry in warm climates

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Abstract

The roots of highbush blueberry (*Vaccinium* sp.) are sensitive to high temperatures and tend to grow poorly in warm soils or warm soilless media. Three experiments were conducted to evaluate strategies for reducing temperatures in the root zone in Évora, Portugal, where soil can reach temperatures >45°C. The first experiment was conducted in a small planting of 'Ozarkblue' blueberry. Treatments included bare soil, a 10-cm-deep layer of aged pine bark mulch, and black, green, or white geotextile landscape fabric. Bark mulch and green landscape fabric resulted in the lowest mid-day soil temperatures among the treatments, which improved canopy development and survival of the plants during establishment. White geotextile fabric also reduced soil temperature but resulted in a considerable amount of weed growth under the fabric. The second experiment was likewise conducted on 'Ozarkblue', but, in this case, the plants were grown in 40-L pots filled with a soilless mix of three parts peat, two parts pine bark, and one part humus, by volume. Treatments included black pots and black pots covered with white geotextile landscape fabric. After a year, canopy volume of the plants was greater in black pots than in white pots; however, yield was not affected by pot color. The third experiment was conducted in a 2-year-old planting of 'Legacy' blueberry. Treatments included no shade and 60% green shade netting. The netting had no effect on soil temperature in the root zone because: 1) the canopy of the plants intercepted the majority of the radiation at midday, and 2) frequent irrigation mitigated changes in soil temperature. Based on these results, bark mulch and green landscape fabric appear to be the best options for reducing temperatures in the root zone of blueberry in warm climates.

Keywords: landscape fabric, mulch, shade netting, soilless media, *Vaccinium* sp.

INTRODUCTION

Highbush blueberry production has increased considerably over the past decade in Portugal and Spain. The plants grow well in the region but often struggle with high temperatures during the summer. Under these conditions, soil temperatures often exceed 40°C near the soil surface. Like many members of the *Ericaceae* family, highbush blueberry (*Vaccinium* sp.) has extremely fine roots that mostly average <100 µm in diameter (Valenzuela-Estrada et al., 2008) and are largely concentrated near the soil surface (Bryla and Strik, 2007). The roots tend to be sensitive to extreme soil conditions, especially high soil temperatures (Erez, 2013). Consequently, highbush blueberry plants often respond favorably to the use of woody mulches and other cultural practices that reduce soil temperatures in the root zone (Cox, 2009; Spiers, 1995).

Currently, most blueberry fields in Portugal and Spain are mulched with geotextile landscape fabric. Geotextile permits the passage of water and air but can also influence soil temperature due to alterations in soil conduction and convection of heat (Lamont, 2005; Tarara, 2000). The color of the landscape fabric, which is usually black, also has decisive influence on soil temperature (Lamont, 2005; Tarara, 2000), as well as the quality and intensity of light in the canopy (Tarara, 2000; Retamales and Hancock, 2012). We hypothesize

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that lighter colored fabrics such as white or green would result in lower soil temperatures than black geotextile landscape fabric and, therefore, would be better for growing blueberry in warmer climates.

The production of blueberries in containers filled with soilless media is also becoming a popular practice in Portugal and Spain. The practice maximizes the use of available growing space and allows for better control of growing environment, particularly in areas where soil conditions are not well suited for blueberry. However, much like in soil, a major concern with growing the plants in containers is substrate temperature. In containers, extreme temperatures can influence root development negatively (Ingram et al., 2015; Markham et al., 2011; Mathers et al., 2007; Miralles et al., 2012). Most growers are using black plastic pots, but the color absorbs heat from the large influx of solar radiation in the region, which increases temperature of the substrate (Ingram et al., 2015; Mathers et al., 2007; Nambuthiri et al., 2015; Ruter, 2000; Wright et al., 2001). One way to reduce substrate temperature is by using white containers, which increases the albedo. Brown (1982) observed that changing the color of containers from black to white reduced the temperature of the growing media by 7°C.

Another potential method of reducing temperature of soil and potting media is the use of shade netting (Stamps, 2009). Shade netting is commonly used to protect agricultural crops from excessive heat and radiation, and in warm climates, has been shown to improve growth and production of highbush blueberry (Lobos et al., 2013; Retamales et al., 2008). The benefit is usually attributed to a reduction of ultraviolet radiation (Lobos and Hancock, 2015), but it could also be related to its effects on air and soil temperature (Díaz-Pérez, 2013; Meena et al., 2014).

The objective of the present study was to identify strategies to reduce the temperature of the root zone during field or container production of highbush blueberry in warmer climates. Specifically, we tested lighter colored mulches, white containers, and the use of shade netting to reduce soil temperature.

MATERIALS AND METHODS

Three experiments were conducted at the Center of Studies and Experimentation of Mitra in Évora, Portugal (38°57'N, 8°32'W, elevation 200 m), including two in the field and one in pots. We designed the first experiment to determine whether green and white colored geotextile landscape fabrics could be used in place of black landscape fabric to improve survival and growth of highbush blueberry in southern Portugal and other regions with warm climates. The second experiment was conducted to determine whether white pots were better than black pots for producing blueberries in substrate in the region. Finally, the third experiment was conducted to determine whether shade netting could also be useful for improving soil and other growing conditions for blueberries in the region.

Experiment 1

This experiment was conducted in 2014 in a small planting of 'Ozarkblue' blueberry. Treatments included bare soil, soil mulched with a 10-cm-deep layer of aged pine bark, and soil covered with black, green, or white geotextile landscape fabric (Guerner; Perosinho, Portugal). Each fabric had a water flow rate of 16 L h^{-1} m^{-2} and weighed 0.1 kg m^{-2}. The treatments were arranged in a randomized block design with four replicates per treatment and 10 plants per replicate. One-year-old plants were obtained from a commercial nursery and spaced 0.8×3.0 m apart on raised beds (0.4 m high × 0.9 m wide). The soil was enriched with 4 t ha^{-1} of a composted mix of horse manure and plant debris at 6 months prior to planting. At that point, the top 40 cm of soil had >250 mg kg^{-1} P_2O_5 and K_2O, 7.6 meq 100 g^{-1} Ca^{2+}, and 1.7 meq 100 g^{-1} Mg^{2+}, and a pH (H_2O) of 7.0. The soil was then adjusted to pH 5.5 with 200 kg ha^{-1} of H_2SO_4 and 100 kg ha^{-1} of elemental sulfur. Furthermore, each planting hole was filled with a 4-kg mixture containing three parts sphagnum peat, two parts pine bark (1-15 mm particle size), and one part humus, by volume, and supplemented with 75-150 mg L^{-1} N, 200-300 mg L^{-1} P_2O_5, 50-70 mg L^{-1} K_2O, and fulvic and humic acids (Siro, Mira, Portugal). The mix of soil and organic matter in the planting hole had a pH ($CaCl_2$) of 4.5-5.0 and an EC of 40-100 µS cm^{-1}. The planting was irrigated using two lines of drip tubing per row (placed at 10 cm on each side of the plants) with 2 L h^{-1} in-line, pressure-compensating emitters located at every 40 cm. The tubing was covered with the pine bark or landscape fabric after planting. A 20-cm-diameter hole was cut in the landscape fabric for each plant. Flowers were removed from the plants during the first growing season to encourage shoot growth.

Soil temperature was measured using steel-head sensors (EN Robotics, Rio de Mouro, Portugal) and recorded every 30 min using a data logger (model CR10X; Campbell Scientific, Logan, UT, USA). The temperature sensors were installed next to and at 12 cm from the crown of the plants at depths of 5 and 15 cm below the soil surface. Air temperature was measured using sensors installed above the plant canopy. Plant survival and growth were evaluated in early September. Measurements included plant height, width, and depth, the number of new shoots on each plant, and the number of dead plants. Canopy volume was calculated using the ellipsoid volume formula recommended by Thorne et al. (2002).

Experiment 2

This experiment was conducted in 2015 during the second year after planting in 40-L (42 cm diameter × 29 cm high) pots of 'Ozarkblue' blueberry. The pots were filled with a 1:2:3 (v/v/v) mixture of humus, pine bark (1-15 mm particle size between) and blond peat (Siro, Mira, Portugal). Treatments included black pots and black pots covered with white geotextile landscape fabric, referred to as "white pots". The treatments were arranged in a randomized complete block design with 40 replicates per treatment. Each pot was irrigated using four, 8 L h^{-1} pressure-compensating drip emitters placed evenly around the plant at a distance of 12 cm from the center. Irrigation was scheduled four to eight times per day using a timer and averaged 20 to 30% drainage (leaching fraction) at each application. Temperature of the irrigation water ranged from 17 to 20°C. Nutrient solution was injected continuously into the irrigation system throughout the growing season. Initially, the solution contained 6.43 mmol L^{-1} NH_4-N, 4.28 mmol L^{-1} NO_3-N, 0.80 mmol L^{-1} P, 3.59 mmol L^{-1} K, 1.20 mmol L^{-1} Ca, 0.99 mmol L^{-1} Mg, 0.78 mmol L^{-1} S, 46 µmol L^{-1} B, 3 µmol L^{-1} Cu, 7 µmol L^{-1} Fe, 18 µmol L^{-1} Mn, 2 µmol L^{-1} Zn, and 1 µmol L^{-1} Mo. However, NH_4- and NO_3-N were reduced to 2.85 and 4.28 mmol L^{-1}, respectively, from the pink-blue stage of berry development to harvest and to 1.71 and 2.57 mmol L^{-1}, respectively, after harvest. Furthermore, K were increased to 4.36 mmol L^{-1} from the pink-blue stage of berry development to harvest and reduced to 2.56 mmol L^{-1} after harvest. Each pot was also treated with 40 g of slow-release fertilizer (7-5-20 plus 8.1% $CaCO_3$, 1.9% Mg, 19.5% SO_4-S, and 0.56% Mn enriched with amino acids and organic acids) in early February. To encourage flowering and fruit production, the plants were top-pruned to 1.2 m in August 2015.

Temperature of the substrate was recorded every 30 min using the same steel-head sensors and CR10X data logger used in the first experiment. The sensors were installed next to and at 12 cm from the crown of the plants to a depth of 5 cm below the surface of the substrate in the pots. Plant growth and yield were also measured in early September. The measurements included canopy height and width in the direction of the crop row and between rows, number of shoots, and yield.

Experiment 3

This experiment was conducted in 2015 in a 2-year-old planting of 'Legacy' blueberry. Treatments included no shade and 60% green shade netting. The netting was installed in May and centered over the plants using a 1.7-m high by 1.0-m wide (each side) frame. The treatments were arranged in a randomized block design with four replicates and 10 plants per treatment plot. These plants were also 1-year-old when they were obtained from the nursery and spaced 0.8×3.0 m apart on raised beds (0.25-m high and 0.8-m wide). Each plant was irrigated by four 2 L h^{-1} pressure-compensating drip emitters placed around the base of the plants at a distance of 12 cm. The methodology to make the raised bed and to acidify the soil was similar to the first experiment. Based on the results of the first experiment, the raised beds were covered with green geotextile landscape fabric.

Air temperature and photosynthetic photon flux density (PPFD) were measured in each treatment using a steel-head temperature sensor and a PAR sensor (Tranzflo Quantum QPAR-

02, Tranzflo NZ Ltd., New Zealand). The sensors were installed in the center of the row at height of 1.25-m above the canopy. Soil temperature was also measured in each treatment using steel-head sensors installed next to and at 12 cm from the crown of the plants at a depth of 5 cm below the soil surface. In each case, the measurements were recorded every 30 min with the CR10X data logger. Plant survival, growth, and production were evaluated in early September on four plants in the center of each treatment plot. The measurements included plant height, width, and depth, the number of new shoots, the number of dead plants, and yield.

RESULTS AND DISCUSSION

Impacts of mulching with bark and different colored geotextile landscape fabrics

At 5 cm, soil temperature during the day was lowest with bark or white geotextile landscape fabric and highest with bare soil or black landscape fabric (Figure 1A). This was expected given that white reflects incoming solar radiation while black absorbs it (Tarara, 2000). However, white geotextile resulted in excessive weed growth underneath due to transmittance of light through the fabric. Green geotextile landscape fabric also reduced soil temperature, but unlike white, it did not promote weed growth. Relative to the black fabric, green landscape fabric reduced the maximum soil temperature at 5 cm by an average 4.5°C and daily variation in temperature by 5.0°C. Recently, Strik et al. (2020) also investigated the use of different mulches in a new planting of northern highbush blueberry in Oregon, USA and found no significant difference in soil temperature in beds with black or green landscape fabric. In their case, air temperature averaged a daily high of only 23 to 28°C in June through September. Daily highs during these same months in the present trial averaged 30 to 33°C. The soil was also sandier at our site. Thermal diffusivity is often higher in sandy soils, which will amplify the positive or negative effects of a given mulch on soil temperature (Villalobos et al., 2016). We did not find much difference in soil temperature among the treatments at 15 cm (Figure 1B). This was not the case in Oregon, where average maximum soil temperature at 15 cm was consistently higher with black or green landscape fabric than with sawdust mulch (Strik et al., 2020).

Plant survival was 90% with pine bark or green landscape fabric but only 70% with bare soil and black or white landscape fabric (Table 1). Furthermore, the plants produced fewer new shoots with black landscape fabric than with bare soil or any other mulch. Thus, despite their effectiveness in controlling weeds and reducing soil temperatures, respectively, the use black or white landscape fabric alone does not seem advisable, particularly in warmer climates. Green landscape fabric, on the other hand, was quite effective at reducing both weeds and soil temperature, and over the long-term, may be less costly than bark. Alternatively, Strik and others determined that the use sawdust under black landscape fabric was an effective means of reducing soil temperature and resulted in more growth and production in northern highbush blueberry than either sawdust or black landscape fabric alone (Strik et al., 2020; Strik and Davis, 2021).

Table 1. Effects of different mulches on plant survival and growth of 'Ozarkblue' blueberry.

Mulch treatment	Survival (%)	Canopy volume (m^3)	New shoots (no. $plant^{-1}$)
Bare soil	70 b	0.11 a	5.0 a
Pine bark	90 a	0.12 a	4.5 a
Geotextile (black)	70 b	0.11 a	3.6 b
Geotextile (green)	90 a	0.13 a	4.5 a
Geotextile (white)	70 b	0.11 a	4.5 a

Means followed by a different letter within a column are significantly different at $P \leq 0.05$, according to Tukey's test.

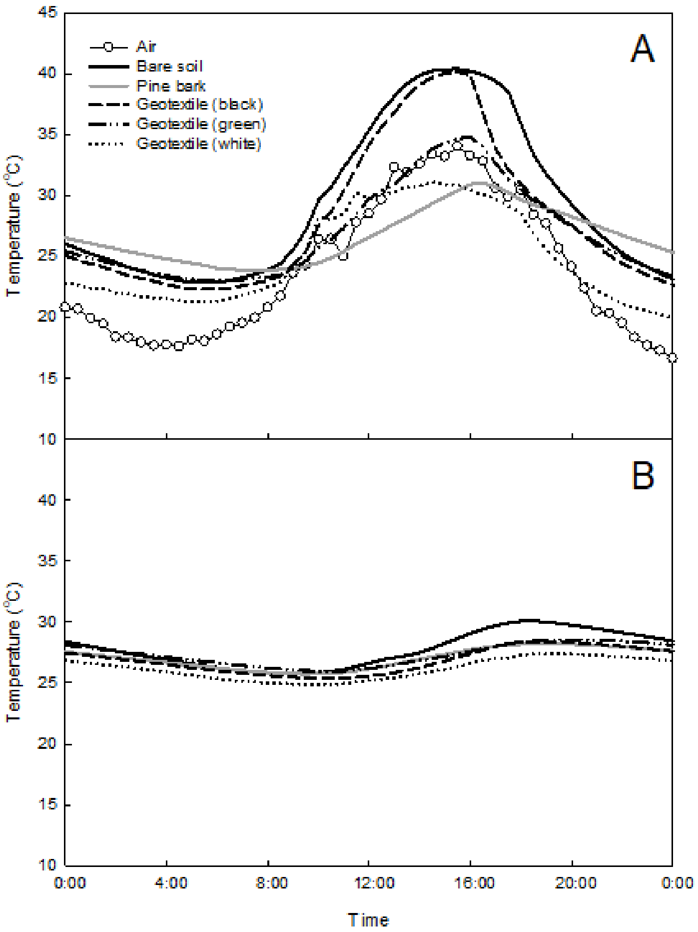

Figure 1. Diurnal changes in (A) air and soil temperature at a depth of 5 cm and (B) soil temperature at a depth of 15 cm in plots of 'Ozarkblue' blueberry with bare soil, pine bark mulch, or black, green, or white geotextile landscape fabric.

Black vs. white pots for substrate production

An example of diurnal changes in temperature measured in the black and white pots is illustrated in Figure 2. Substrate temperature was clearly cooler and more stable throughout the day in white pots than in black pots. During the day, maximum temperature of the substrate was higher in black pots than in white pots by an average of 1.5°C near the crown and 2.3°C at 12 cm from the crown; however, nighttime minimum temperatures were lower in black pots than in white pots by an average of 3.1°C near the crown and 0.9°C at 12 cm from the crown. Consequently, mean temperature over the course of a 24-h period was also lower in black pots than in white pots near the crown but higher at 12 cm from the crown. Miralles et al. (2012) found that white pots reduced both mean and maximum temperatures by 3 and 6°C, respectively, in *Rhamnus alaternus*, commonly known as Mediterranean buckthorn, but had no effect on the minimum temperature.

Regardless of location or pot color, maximum temperature was 6-9°C lower in the substrate than in the air; this differs from many of the published reports on the topic (Ingram et al., 2015). Usually, heat energy enters the pots from direct and reflected solar radiation and results in daytime root zone temperature significantly above ambient (Ingram et al., 2015). Frequent irrigation may have helped reduce the temperature of substrate (Figure 2). Temperature differentials between the water and substrate creates a gradient for the flow of heat energy via conduction and convection, until temperature equilibrium is established (Martin and Ingram, 1991). However, this is only true when: 1) water temperature is lower than the substrate temperature, and 2) a sufficient volume of water is applied to physically disperse the thermal energy (Keever and Cobb, 1985). Both of these conditions were met in the present study. Specifically, water temperature ranged from 17 to 20°C, and the leached fraction after each irrigation event averaged 20 to 30% of the total water applied.

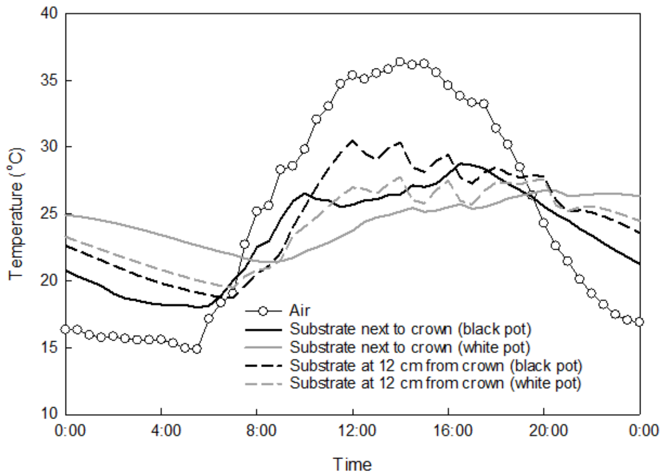

Figure 2. Diurnal changes in air and substrate temperature in black and white pots planted with 'Ozarkblue' blueberry. Peaks and valleys in the temperature curves at 12 cm from the crown coincide with irrigation events during the day (12:00-20:00 HR).

Canopy volume was greater when the plants were grown in black pots than in white pots; however, pot color had no effect on the number of new shoots plant^{-1} or on yield (Table 2). Yield was reasonable given the young age of the plants.

Table 2. Effects of pot color on growth and yield of 'Ozarkblue' blueberry.

Pot color	Canopy volume (m^3)	New shoots (no. plant^{-1})	Yield (kg plant^{-1})
Black pot	0.84 a	14 a	0.90 a
White pot	0.55 b	12 a	0.87 a

Means followed by a different letter within a column are significantly different at $P \leq 0.05$.

Shade netting

Shade netting dramatically affected incident PPFD between 08:30 and 16:30 HR and reduced it by average of 77% at midday (Figure 3A). However, the netting only affected air temperature between 11:30 and 16:00 HR and had nearly no effect on soil temperature (Figure 3B). On average, shade netting reduced maximum air temperature by 1.3°C and reduced the daily range of air temperature by 1.8°C. Retamales et al. (2008) likewise reported shade netting had little to no effect on air and soil temperature in highbush blueberry. Others, on the other hand, observed that shade netting reduced air and soil temperature in crops such as spinach (Meena et al., 2014) and bell pepper (Díaz-Pérez, 2013). The limited effects of shading on temperature in the present study could have been related to the relatively small size of the shading structures, which probably provided enough air circulation underneath to limit temperature gradients. Lack of any differences in soil temperature may have also been due to the fact that the canopy of the plants intercepted the majority of the radiation at midday. Root zone temperature increases with light interception but decreases with increased shading caused by greater canopy cover (Díaz-Pérez, 2013). With or without shade, maximum soil temperature in both treatments varied between 27.3 and 29.4°C and was lower than air temperature by ≈6-8°C.

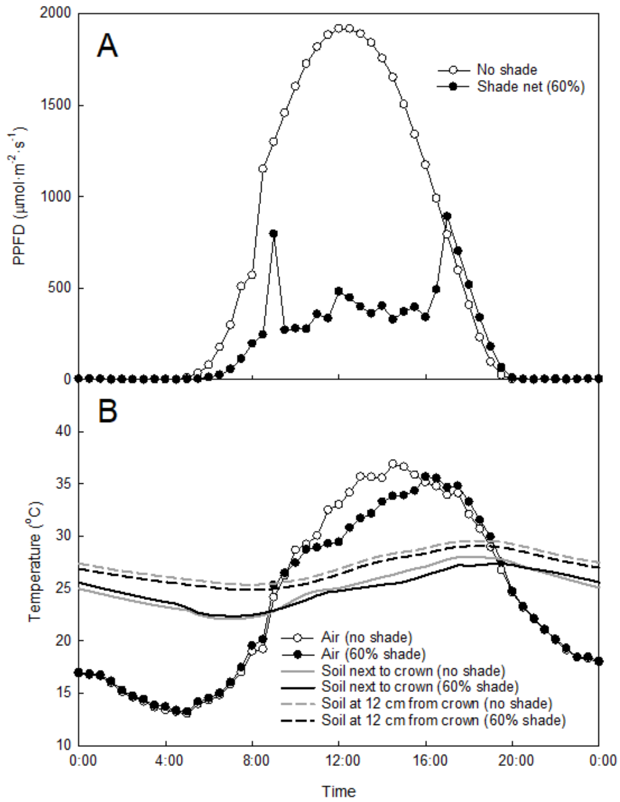

Figure 3. Diurnal changes in (A) photosynthetic photon flux density (PPFD) and (B) air and soil temperature (5 cm depth) in unshaded and shaded plots of 'Legacy' blueberry.

The plants had vigorous growth throughout the study, but they were largely unaffected by shade netting (Table 3). Others have observed that the effects of shade netting on blueberry depend on the color of the net and the percentage of the shading (Kim et al., 2011; Lobos et al., 2013; Retamales et al., 2008). A lack of yield response with shading in the present study was not surprising given that we installed the shade nets in mid-May, less than 2 months prior to the first harvest. However, we noticed that some of the upper leaves on plants without shading had reddish stains on the adaxial surface, which was probably due to accumulation of anthocyanins. Generally, induction of anthocyanin synthesis requires high light intensities (Steyn et al., 2002; Albert et al., 2009). Additional work is needed to determine whether plant growth and production in the region would be affected by multiple years of shading in blueberry.

Table 3. Effects of shading on growth and yield in a 2-year-old planting of 'Legacy' blueberry.

Shade treatment	Canopy volume (m^3)	New shoots (no. $plant^{-1}$)	Yield (kg $plant^{-1}$)
No shade	0.72 a	7.5 a	0.13 a
Shade net (60%)	0.92 a	6.4 a	0.14 a

Means followed by a different letter within a column are significantly different at $P \leq 0.05$.

CONCLUSIONS

The results indicate that bark mulch and green landscape fabric appear to be the best options for reducing temperatures in the root zone of highbush blueberry in warm climates. Pot color had less influence on soil temperature in soilless growing medium, primarily due to irrigation scheduling and the cool temperature of the irrigation water. Shade netting had no influence on soil temperature but can reduce abiotic stress caused by high light intensity and high air temperature; however, further studies with larger shade structures are needed to verify the finding.

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