

Color of Plastic Mulch Affects Lateral Root Development But Not Root System Architecture in Pepper

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Abstract. In 1999, ‘Sweet Banana’ pepper [*Capsicum annuum* L. (Grossum Group)] plants were grown under clean cultivation or with red, silver, or black polyethylene selective reflecting (SMR) mulches over the soil surface. Plants in each of three replications per treatment were field-set on 15 June. On 22 Sept., the plants were excavated and their root systems examined using a trench profile method and a succession of trench wall slices. The total numbers of roots of each plant at depths of 5, 10, 15, 20, and 25 cm and 10, 20, 30, 40, 50, and 60 cm from the plant stem were recorded. Distribution and architecture of the root systems were also examined. Plants grown under clean cultivation developed 50 to 60 adventitious roots each, while those grown under red mulch developed ≈20 and those under black and silver mulch about nine adventitious roots each. In all treatments, the adventitious roots radiated downward from the stem at an angle of 35° from the horizontal. No plants had vertical roots. Root system architecture was similar among treatments, with 40% of the roots in the upper 5 cm of soil and 70% in the upper 10 cm. Thirty percent of the roots were within 10 cm, 50% within 20 cm, and nearly 100% within 40 cm of the stem. Root numbers decreased with increasing depth and distance from the stem. The greatest number of lateral roots were produced under silver mulch, intermediate numbers under clean cultivation and black mulch, and the fewest roots under red mulch. Colored mulches influenced the total number of adventitious and lateral roots but not the root system architecture of pepper plants.

The root systems of sweet pepper have been studied recently in vitro by Stoffella et al. (1988, 1991, 1992), who described seedling root morphology and the influence of medium pH on root growth. Little work has been done to describe the mature root systems of these plants under field conditions, especially when plants are grown under polyethylene (PE) mulch. Weaver and Bruner (1927) used the open trench method to examine the architecture and distribution of pepper root systems on plants grown in a fine sandy loam. They reported that most roots spread horizontally to a distance of 75 cm from the crown and that some roots reached depths of 90 to 120 cm. Up to ≈90 lateral roots developed from the original taproot and gave rise to the entire root system. Using injection of ³²P, Hammes and Bartz (1963) found that roots on transplanted pepper plants were shallower and more branched than those on direct-seeded, field-grown plants and that 80% of the active root system was located in the upper 75 cm of soil. Wein (1997) speculated that root growth and distribution was significantly influenced by soil structure and man-

agement, including cultivation, irrigation, and the use of PE mulch.

Knave and Mohr (1967) reported that pepper plants grown with black polyethylene or black paper mulch developed more roots than those grown under clear PE or on bare soil, but they did not examine root system architecture. Gosselin and Trudel (1986) found that varying root zone temperatures affected shoot dry weight and leaf area in sweet pepper, but reported no influence of soil temperature on root growth. Wein et al. (1993) reported that tomato roots were significantly longer 1 week after transplanting on plants grown under clear PE than on those grown without mulch. They attributed this finding to an increase in soil temperature, consistent with arguments presented by others (Miller, 1986; Tindall et al., 1991; Waggoner et al., 1960).

The purpose of this study was to determine the root system distribution of transplanted sweet peppers under the new colored PE film mulches.

Materials and Methods

One hundred forty-six kg·ha⁻¹ of actual nitrogen per acre were broadcast and incorporated prior to transplanting. Strips of colored plastic mulch 1.2 m wide and 3 m long were placed on the prepared soil and held in place with soil banked along the strip edges. The plastics consisted of 1 mil red (“red”),

0.75 mil silver on black (“silver”) and 4 mil black polyethylene (“black”) SMR mulch. The red and silver plastics were supplied by Ken-Bar Co., Reading, Mass., and the black was purchased locally. Three bare-soil plots were used for comparison.

Eight-week-old sweet pepper plants, cv. Sweet Banana, were purchased from a local greenhouse and field set manually in Bozeman (lat. 111°6′W, long. 45°40′N) on 15 June 1999 into a silt loam soil (fine-silty, mixed, frigid argic pachic cryoboroll) with pH 7.5. Plants were set into bare soil or through the plastic and spaced 60 cm apart within rows and 3 m between rows. There were three plants per replication with three replications per treatment arranged in a randomized complete-block design. Bare soil plots were kept weed-free by hand hoeing. Plots received 25 mm of water each week applied in three applications using overhead sprinklers. Irrigation was supplemental to sparse rainfall during the growing season. Soil moisture was recorded 1 d after irrigation at varying depths and distances from the plants in six replications per treatment using a portable soil moisture probe.

At the end of the growing season (22 Sept.), root architecture was described using a trench profile method (Russel 1977; Weaver and Bruner, 1927). Trenches 60 cm long and 25 cm deep were hand dug parallel to and on one side of three plants in each treatment. A plow pan limited trench and rooting depth. Initial trenches were dug 60 cm distant from the stem so as not to sever roots inadvertently. A succession of trench wall slices were made moving toward the plants at 10 cm intervals until the final slice was made 10 cm from the plant stem. In each slice, the trench wall was scarified with a small piece of pointed lath to break the scoured soil and expose the pepper roots. The numbers of roots exposed at depths of 5, 10, 15, 20, and 25 cm in each slice were recorded.

Near the completion of the study, three plants in each treatment were completely excavated to determine the extent of vertical root penetration and the regularity and relative density with which roots radiated from the crown.

Air temperatures, surface temperatures of the mulch and soil, and temperatures on the soil surface beneath the mulch and 5 cm beneath bare and mulched soils were recorded nine times throughout the growing season using a hand-held digital Traceable Universal thermometer with an 11-mm needle probe (Control Co., Friendswood, Texas).

Where appropriate, data were analyzed by analysis of variance with mean separation by least significant difference ($P \leq 0.05$) using Statistix for Windows 2.0 Analytical Software (Analytical Software, Tallahassee, Fla.).

Results and Discussion

The soil surface beneath red PE had the highest mean temperature, followed by surface soil on bare plots and beneath the black

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Table 1. Mean temperatures (°C) over nine dates and four treatments during the 1999 growing season.

Temperature	Air	Mulch Color							
		Bare		Black		Red		Silver	
		Surface	5 cm ^z	Surface ^y	5 cm	Surface	5 cm	Surface	5 cm
Mean	26.0	33.0	25.5	31.5	24.0	35.0	26.0	29.5	24.0
SE	1.5	2.6	1.7	1.7	1.3	3.5	2.1	1.9	1.7
Minimum	18.5	20.0	16.5	26.5	19.0	23.5	17.0	23.5	17.0
Maximum	34.0	44.4	31.5	41.0	32.0	57.8	36.0	40.0	31.5

^zTemperature 5 cm beneath the soil surface.^ySurface of the soil beneath mulch.

and silver mulches respectively (Table 1). Temperatures 5 cm beneath the surface of all treatments averaged $\approx 7^\circ\text{C}$ cooler than at the surface, with the greatest difference occurring beneath the red mulch and the least beneath the silver. The highest surface temperature was recorded beneath the red mulch and the lowest on the bare soil. Red mulch had the highest subsurface soil temperature and bare soil and silver mulch had the lowest. Averaging the surface and subsurface mean temperatures, the red mulch provided the warmest and silver the coolest soil environment, with bare soil and black mulch being intermediate. There appeared to be no direct correlation among the different soil temperature regimes and pepper root growth.

While there were no substantial differences among treatments in total amounts of soil moisture, the surface 5 cm were drier than lower levels (Table 2). Since overhead irrigation was used, moisture entered the root zone through the planting holes, all of which were of similar size. Measured at the stem, soil moisture levels were $\approx 60\%$ of saturation in the surface 5 cm of soil but near 100% at the lower depths. This suggests that moisture was adequate in most of the root zone and that it evaporated from the soil surface through the planting hole. Water content of the upper 10 cm of soil generally decreased with distance from the planting hole. This trend was also displayed, but to a lesser degree, beneath the black and red mulches at the 18-cm depth. Moisture therefore was more restricted beneath the mulch than under clean cultivation.

Using the terminology of Leskovar and Stoffella (1995), plants grown under clean cultivation developed 50 to 60 adventitious roots from the subsurface proximal end of the damaged taproot. These averaged 3.75 mm in diameter at their point of origin and generally radiated from the stem in four indistinct ranks. The number and thickness of adventitious roots and their origins were similar to those described by Weaver and Bruner (1927). Those authors, calling these roots "laterals," described most of them as spreading horizon-

tally from the stem; in this study all spread obliquely downward at $\approx 35\%$ from the horizontal. In concert with the findings of Weaver and Bruner (1927), there were few or no roots penetrating vertically into the soil.

Plants grown under mulch had fewer but thicker adventitious roots. As in control plants, all radiated in four indistinct ranks from the stem at angles of $\approx 35\%$. Plants on silver and black mulches produced about nine adventitious roots, each with mean diameters of 6.5 and 7.5 mm, respectively. Plants on red mulch produced ≈ 20 adventitious roots with mean diameters of 7 mm. Thus, plants grown on the slightly warmer soils produced greater numbers of adventitious roots.

In general, root numbers decreased with increasing soil depth and distance from the stem, regardless of treatment (Table 3). This is consistent with the findings of Greenwood et al. (1982) and Weaver and Bruner (1927). While these data generally agree with those findings regarding the width of the pepper root system, the depth of the system was abbreviated in our study by the presence of a plowpan at a depth of 25 cm. The total number of roots observed varied significantly with treatment. Plants grown under silver mulch had the most lateral roots (a mean of 687 per plant) in the soil profile studied, whereas plants grown on bare soil averaged 616, and those under black and red mulch averaged 458 and 367 roots, respectively. All differences were significant. This disagrees with Knavel and Mohr (1967) who reported that plants grown under black PE had more roots than those grown under clean cultivation. Soil beneath the red mulch was warmest and most moist of any mulched soil, both of which may have restricted lateral root growth. Soil beneath the silver mulch registered one of the lowest mean temperatures and moisture contents, but apparently provided good conditions for development of many lateral roots.

The general architecture of the pepper root system was similar among treatments. In the control (bare soil) the percentage of roots

decreased from 34% to 3% as distance from the stem increased from 10 to 60 cm, and from 40% to 1% as soil depth increased from 5 to 20 cm. About 70% of pepper roots were located in the upper 10 cm of soil; proportionally fewer roots were found at lower depths where soil moisture approached saturation. Higher moisture levels and greater depth may result in lower oxygen levels and cooler temperatures, both of which restrict growth.

About 30% of the roots were located within 10 cm, 50% within 20 cm, and nearly all within 40 cm from the stem.

Knavel and Mohr (1967) reported that soil temperature did not directly influence root distribution but did not report its influence on root numbers. They also reported that soil temperatures near 35°C may interfere with nitrification and restrict root growth. Soil temperatures beneath the red mulch approached this upper limit. However, Gosselin and Trudel (1986) reported that increasing pepper root zone temperatures, presumably to 36°C , improved production, but they did not directly address root growth. Miller (1986) reported that the temperature range for most rapid root growth in warm season vegetables was $\approx 28^\circ\text{C}$ but did not report the optimum temperature for pepper root growth. The temperature of the soil within 5 cm of the surface under the red mulch most closely approached this temperature, while that beneath the silver and black mulches were coolest. However, plants mulched with red PE had the fewest roots while those mulched with silver PE had the most. Miller (1986) addressed the influence of soil temperature on the speed of root growth but not on total root growth.

Based on the findings of this study, colored PE mulches alter the number of adventitious roots but not the root system architecture of the pepper plant. Silver mulch stimulated root growth most and red mulch least.

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Table 2. Percentage of soil saturation at three soil depths under four mulch treatments and four linear distances from the stem of the pepper plant.

Depth (cm)	Bare 0 ^z	Mulch color											
		Black				Silver				Red			
		0	10	20	30	0	10	20	30	0	10	20	30
5	59 $\pm$ 02 ^y	68 $\pm$ 15 ^x	33 $\pm$ 11	17 $\pm$ 05	12 $\pm$ 02	48 $\pm$ 10	12 $\pm$ 02	21 $\pm$ 10	12 $\pm$ 06	63 $\pm$ 12	62 $\pm$ 13	16 $\pm$ 05	10 $\pm$ 02
10	100 $\pm$ 00	100 $\pm$ 00	92 $\pm$ 04	70 $\pm$ 12	52 $\pm$ 11	100 $\pm$ 00	83 $\pm$ 06	80 $\pm$ 05	75 $\pm$ 07	100 $\pm$ 00	93 $\pm$ 04	77 $\pm$ 08	48 $\pm$ 08
15	100 $\pm$ 00	100 $\pm$ 00	100 $\pm$ 00	95 $\pm$ 03	92 $\pm$ 06	100 $\pm$ 00	100 $\pm$ 00	100 $\pm$ 00	100 $\pm$ 00	100 $\pm$ 00	100 $\pm$ 00	98 $\pm$ 02	95 $\pm$ 05

^zDistance from stem in cm.^yMoisture distribution remained similar to that under mulch at corresponding depths and distances from the stem.^xMean SE.

Table 3. Root frequency and distribution of 'Sweet Banana' pepper plants grown on a silt loam soil under four plastic mulch regimes.^z

Distance from stem (cm)	Depth (cm)	Mean no. of roots in profile			
		Bare	Silver	Red	Black
10	5	74.0 ± 7.0	70.0 ± 7.0	47.0 ± 3.0	55.0 ± 5.0
	10	67.0 ± 1.0	58.0 ± 5.0	32.0 ± 3.0	49.0 ± 11.0
	15	39.0 ± 6.0	49.0 ± 10.0	14.0 ± 8.0	23.0 ± 3.0
	20	25.0 ± 12.0	16.0 ± 7.0	1.0 ± 1.0	13.0 ± 3.0
20	25	7.0 ± 4.0	2.0 ± 1.0	0.0 ± 0.0	2.0 ± 0.5
	5	68.0 ± 10.0	80.0 ± 9.0	32.0 ± 2.0	42.0 ± 3.0
	10	40.0 ± 7.0	56.0 ± 6.0	27.0 ± 3.0	36.0 ± 2.0
	15	27.0 ± 3.0	39.0 ± 6.0	16.0 ± 3.0	32.0 ± 1.0
30	20	18.0 ± 6.0	6.0 ± 3.0	2.0 ± 1.0	19.0 ± 6.0
	25	3.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.3
	5	57.0 ± 10.0	70.0 ± 9.0	29.0 ± 3.0	40.0 ± 4.0
	10	32.0 ± 3.0	43.0 ± 7.0	22.0 ± 3.0	27.0 ± 10.0
40 ^y	15	20.0 ± 3.0	23.0 ± 7.0	14.0 ± 6.0	21.0 ± 2.0
	20	11.0 ± 5.0	8.0 ± 4.0	5.0 ± 4.0	13.0 ± 3.0
	25	1.0 ± 1.0	1.0 ± 1.0	0.0 ± 0.0	1.0 ± 0.0
	5	22.0 ± 9.0	51.0 ± 3.0	41.0 ± 6.0	27.0 ± 3.0
50	10	18.0 ± 5.0	25.0 ± 3.0	19.0 ± 5.0	16.0 ± 1.0
	15	18.0 ± 6.0	31.0 ± 7.0	9.0 ± 2.0	10.0 ± 1.0
	20	5.0 ± 2.0	8.0 ± 6.0	1.0 ± 0.3	8.0 ± 1.0
	25	2.0 ± 2.0	1.0 ± 0.6	0.0 ± 0.0	0.3 ± 0.3
60	5	12.0 ± 10.0	14.0 ± 9.0	11.0 ± 2.0	1.0 ± 1.0
	10	12.0 ± 6.0	14.0 ± 6.0	12.0 ± 4.0	5.0 ± 1.0
	15	6.0 ± 2.0	4.0 ± 1.0	6.0 ± 2.0	4.0 ± 1.0
	20	4.0 ± 1.0	2.0 ± 1.0	3.0 ± 3.0	3.0 ± 1.0
	25	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	5	12.0 ± 11.0	4.0 ± 3.0	2.0 ± 2.0	1.0 ± 1.0
	10	8.0 ± 6.0	8.0 ± 2.0	3.0 ± 3.0	5.0 ± 2.0
	15	3.0 ± 3.0	3.0 ± 1.3	4.0 ± 4.0	3.0 ± 1.0
	20	1.0 ± 1.0	0.3 ± 0.3	1.0 ± 1.0	2.0 ± 0.3
	25	1.0 ± 1.0	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0

^zMeans and SE of three plants per treatment.

^yLocation of outer edge of mulch.

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