Effects of Silver Reflective Mulch, White Inter-row Mulch, and Plant Density on Yields of Pepper in Maine

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SUMMARY. Bell peppers (*Capsicum annuum*) are an economically important yet difficult to grow crop in northern New England. Yields of bell peppers can be increased through the use of plastic mulches; however, refinements are needed to make bell peppers a more viable crop in regions with short, variable growing seasons. The objectives of this study were to (1) compare the effects of black mulch with white inter-row much, reflective silver mulch, and standard black plastic mulched beds on bell pepper yield and quality and (2) compare the effects of two in-row plant arrangements [single rows at 12-inch within-row spacing (7260 plants/acre) and double rows spaced 18 inches apart with 18-inch in-row spacing (9680 plants/acre)] on pepper yield and quality. Treatments were factorial combinations of three mulch treatments and two within-row planting arrangements. Double rows produced more fruit by number and weight than single rows; however, fruit harvested from the double-row plots tended to be smaller than fruit harvested from the single-row plots. Mulch treatments significantly influenced total marketable yield and yield of cull bell peppers grown in Maine. The plots receiving the inter-row white mulch or reflective silver mulch treatment produced significantly greater yield than standard black plastic mulch treatment. The reflective mulch treatment produced significantly more cull fruit per acre compared with the white inter-row mulch and black plastic.

Bell peppers are economically important yet difficult to grow in northern New England. Bell peppers are recognized to be environmentally sensitive, particularly with respect to flowering and fruit set (Quagliotti, 1979; Wien, 1997). Peppers grow best at soil temperatures between 20 and 30 °C (Gosselin and Trudel, 1986) and stable air temperatures between 18 and 30 °C (Maynard and Hotchmuth, 1997). Techniques are needed to enhance pepper maturity and yield to make this a more viable and profitable crop in northern New England and other regions characterized by short growing seasons and variable temperatures. Early and total yields of bell peppers can be increased through the use of plastic mulches, rowcovers, and low plastic tunnels (Alexander and Clough, 1998; Bowen and Frey, 2002; VanDerwerken and Wilcox-Lee, 1988; Wells and Loy, 1985). The increased yield of peppers and other crops grown on plastic mulch is generally attributed to increased soil temperatures. However, mulches can also effect the plant environment in other ways such as inhibition of weed growth, maintaining soil moisture, insect repellence, and selection of light wavelengths reflected back into the plant canopy (Decoteau et al., 1990; Greer and Dole, 2003; Ham et al., 1993; Tarara, 2000). Plastic mulches are now available in a range of types and colors, providing growers the opportunity to choose a mulch film best suited to a particular crop or growing conditions (Tarara, 2000). Clear mulches elevate soil temperatures more than opaque mulches, while reflective and light-colored mulches tend to keep soil temperatures cooler compared with dark-colored mulches. White and reflective mulches also have the effect of changing the amount and quality of light reflected up into the plant canopy (Ham et al., 1993). Reflective mulches, such as aluminum foil and aluminum-painted plastic mulches, have had mixed results relative to increasing pepper yields compared

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.0731	fl oz/acre	$L\cdot ha^{-1}$	13.6840
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg\cdot ha^{-1}$	0.8922
0.0254	mil	mm	39.3701
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

with black plastic mulch. Reflective mulches appear to lower insect infestations and reduce insect-transmitted diseases, although the overall effect on yield is unclear (Greer and Dole, 2003). Increased yield of bell peppers grown on aluminum-painted mulch was attributed to an increased amount of photosynthetically active radiation (*PAR*) being reflected into the plant canopy (Porter and Etzel, 1982). Mulch surface colors that reflect light affect the growth of bell pepper plants by influencing the amount and quality of upwardly reflected light in addition to modifying soil temperature (Decoteau et al., 1990). To capitalize on the soil-warming characteristics of black mulch, in addition to the beneficial aspects of reflective mulch, agricultural plastic manufacturers have begun making printed or co-extruded aluminum on black films with 8-inch-wide black stripes where the plants are planted (Pliant, Schaumburg, Ill.). The intent of the black planting zone is to warm the soil in the immediate area around the seedlings.

The amount of light reflected into a plant canopy can also be altered with the use of plastic mulches placed between the planting beds. A recent study has shown that a high-density tomato (*Lycopersicon esculentum*) planting, grown on raised, black plastic mulched beds with white mulch covering the inter-row area between the beds had greater yields compared with the same tomato density on similar beds without the white inter-row mulch. In fact, the high-density, 12-inch within-row spacing and white inter-row mulch treatment produced 54% higher yields per unit area compared with the standard system of black mulch and 18-inch within-row plant spacing (Ouellette and Loy, 2000).

The objectives of this study were to (1) compare the effects of black mulch with white inter-row much, reflective silver mulch, and standard black plastic mulched beds on bell pepper yield and quality and (2) compare the effects of two in-row plant arrangements on pepper yield and quality under these different mulch systems.

Materials and methods

The experiment was conducted at three locations in Maine: the University of Maine, Highmoor Farm, Monmouth (lat. 44°14′N, long. 70°04′W), soil type Woodbridge fine sandy loam; a commercial vegetable farm located in Lewiston (lat. 43°55′N, long. 70°07′W), soil type Melrose fine sandy loam; and a commercial vegetable farm was in Readfield (lat. 44°21′N, long. 69°55′W), soil type Paxton-Charlton fine sandy loam.

Treatments were factorial combinations of three mulch treatments and two within-row planting arrangements. The following mulch treatments were applied by machine to 32-inch-wide, 3-inch-high raised beds on 6-ft centers: (1) black-embossed polyethylene mulch 0.07 mil thick, with SRM White mulch 0.07 mil thick (Kenbar, Reading, Mass.) applied after planting to the inter-row area between the black plastic raised beds; (2) reflective silver mulch with one or two 8-inch-wide black stripes (Heat Trap I and Heat Trap II, respectively; Reflectek Foils, Lake Zurich, Ill.); and (3) control treatment, black-embossed polyethylene mulch 0.07 mil thick (Kenbar). Treatments were arranged in a split-plot design with mulch treatments as the main plots and planting arrangement as subplots. The subplot treatments were in-row plant spacing and density treatment: (a) two rows of plants on a bed 16 inches apart and spaced 18 inches within rows (9680 plants/acre) and (b) a single row of plants spaced 12 inches within the row (7260 plants/acre). Plots were arranged in an identical randomized complete-block design with three replications at each site, resulting in a total of nine replications. Plots were 15 ft long with guard rows planted in the beds on each side of treatment plot.

Fertilizer was applied at each site based on soil test recommendations before forming beds and laying the plastic mulch. No herbicides were applied at site one; the weeds were managed through cultivation. At site two, napropamide (2 lb/acre) was incorporated before application of the plastic mulch. Weeds were managed at site three by applying halosulfuron applied at 0.5 fl oz/acre between the rows of plastic.

'King Arthur' pepper transplants were grown by each farm for use in the experiment at that site. Field preparation and planting dates were determined by the growers at the participating farms. Sites one and three were planted on 15 June 2005, while site two was planted 5 June 2005. Each farm followed standard pest management practices recommended in the New England Vegetable Management Guide (Howell, 2004).

Fruit yields from each site were evaluated by harvesting all but the first and last plant on the single-row plots (13 harvested plants) or the first and last pair of plants in the double-row plots (16 harvested plants). Four harvests were made at sites one (19 Aug., 25 Aug., 9 Sept., 21 Sept.) and four at site three (18 Aug., 26 Aug., 2 Sept., 14 Sept.). A total of six harvests were made at site two (4 Aug., 10 Aug., 18 Aug., 26 Aug., 2 Sept., and 19 Sept.). Harvests before 1 Sept. were considered early harvest. All fruit of marketable size were harvested by hand and graded as marketable or cull. Fruit with poor shape, sunscald, blossom end rot, insect damage, and disease were graded as culls. Fruit from each plot were counted and weighed at each harvest. Early marketable yield, marketable yield, and cull yield were summed for all harvests and expressed on a per acre basis.

Soil temperatures were measured using two temperature probes (HOBO U12 and TMC-50HD temperature probes; Onset Computer, Bourne, Mass.) placed in one plot of each mulch treatment plot in the center of each bed ≈10 cm deep. Temperature data were collected hourly beginning 1 June and continued through 23 Sept. Average hourly soil temperature was calculated over the entire growing season.

Results and discussion

Temperature. Small differences were seen in soil temperature among the mulch treatments (Fig. 1). Diurnal soil temperatures were slightly warmer in the beds mulched with reflective mulch compared with black mulch with and without the inter-row mulch. Generally, soil temperatures are cooler under silver mulch compared with black mulch (Ham et al., 1993); in contrast, Gough (2001) found no differences in soil temperature at a depth of 5 cm in beds

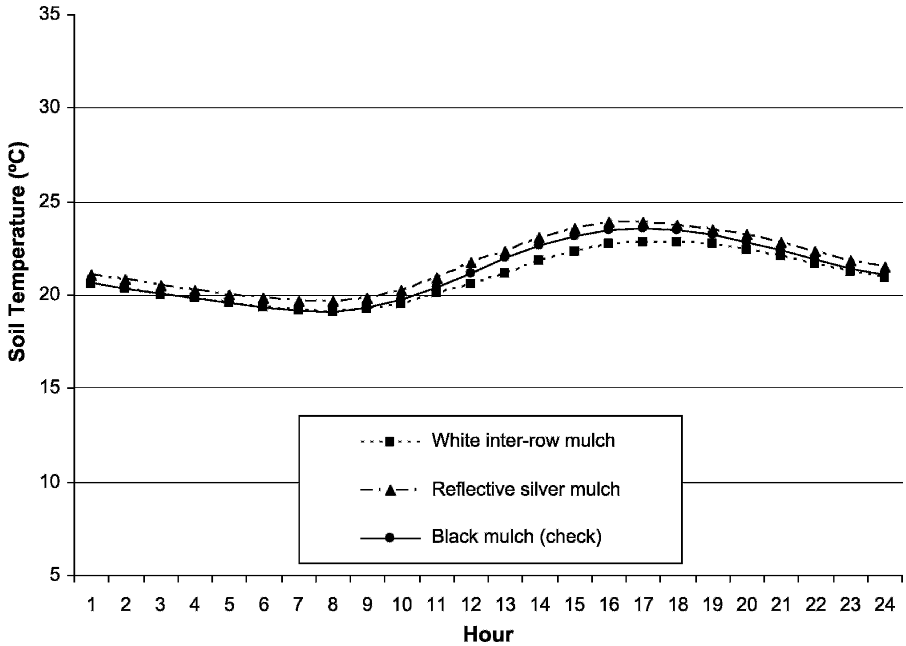

Fig. 1. Average hourly soil temperature measured at 10 cm (3.9 inches) below soil surface. Values are hourly averages from 1 June to 23 Sept. 2005 at University of Maine, Highmoor Farm, Monmouth; (1.8 × °C) + 32 = °F.

covered with either black or silver mulch. Ham et al. (1993) examined the optical properties of several mulches and determined that silver mulch would absorb less shortwave and longwave radiation compared with black, but would also emit less longwave radiation, potentially making it a better insulator, trapping more soil heat compared with black mulch. It is possible the combination of the black stripe on the silver mulch combines the properties of both plastics to achieve the warmer soil temperatures observed.

MARKETABLE YIELD. Pepper yields were significantly different among the three farms in this study (Table 1). This is not surprising given the differences in the farm location, field cropping history, and differences in planting and harvest dates. However, there were no significant interactions between farms and the mulch or plant density treatments. There was a significant interaction between farm and planting density for early yield. However, by the end of the season the interaction was nonsignificant and was probably due to age and size of transplants.

Double plant rows with 18-inch spacing produced significantly more fruit by number and weight than single plant rows at 12-inch spacing for early and total marketable harvest (Table 2). This result agrees with other work in which higher planting densities of pepper increased yields (Locascio and Stall, 1994). The 9% yield increase observed under the higher plant density, however, was not proportional to the 33% increase in plant numbers for the double rows, likely a result of increased interplant competition at the higher density. Higher plant densities also tended to produce smaller fruit and a higher number of culls (Table 3).

There were no significant interactions between mulch treatment and plant density (Table 1). However, it is interesting to note that the yield of single-row peppers in the white inter-row mulch treatment (51,085 fruit/acre and 20,353 lb/acre) was similar to the yield of double-row peppers from the standard black plastic mulch plots (52,345 fruit/acre and 19,913 lb/acre). However, the single-row treatment had 25% fewer plants than the double rows per acre.

Early marketable yield accounted for 25% to 27% of the total marketable yield. Earliness was not significantly affected by the three mulch treatments (Table 1).

The inter-row white and reflective silver mulch treatments produced significantly more marketable fruit than the black mulch control (Table 2). The number of fruit harvested from the inter-row mulch plots was 21% greater than the amount harvested from the control treatment and 18% greater than from the silver mulch treatment. These results agree with results obtained in preliminary experiments (Hutton et al., 2005) and similar research with tomato (Ouellette and Loy, 2000), indicating white inter-row mulch increased yield compared with black plastic mulch alone. We were unsuccessful in measuring light levels within the plant canopy. However, Ouellette reported (2005) a 3× increase in the amount of light reflected back up into the plant canopy in rows with white inter-row mulch compared with black mulched beds without inter-row mulch. It seems reasonable to expect the yield increase observed from the white inter-row mulch and reflective silver mulch treatments could be attributed to the increased amount of light reflected into the plant canopy.

Studies have documented mixed results on the effects of reflective and silver mulch on pepper yield. In some cases, increased yields occurred (Black and Rolston, 1972; Porter and Etzel, 1982); in other cases, no yield increases were detected (Kring and Schuster, 1992). One advantage of reflective mulches is the reduction of aphid-transmitted virus diseases and increased yields due to lower incidence of insect-transmitted virus (Greer and Dole, 2003). However, in northern New England, insect-vectored viruses are not typically a concern. In the study by Porter and Etzel (1982) where insect-vectored viruses were not a problem, aluminum painted plastic mulch resulted in higher yields of bell pepper compared with black plastic. However, in only 1 of 2 years were the differences statistically significant. The authors concluded that the yield increase was probably due to increased light being reflected into the plant canopy.

CULL YIELD. There were no significant differences in cull yield among the mulch treatments. The percentage of harvest fruit culled was generally low. Nineteen percent of the fruit harvested from the silver mulch were culled, followed by 14% for the control treatment and 11%

Table 1. Analysis of variance for marketable and cull yield of 'King Arthur' bell peppers grown on three Maine farms using three mulch treatments and two planting densities during the 2005 growing season.

		Mean square											
		Early marketable yield				Total marketable yield				Cull yield			
Source	df	no./acre		lb/acre		no./acre		lb/acre		no./acre		lb/acre	
Farm	2	1,779,222,106	***	379,315,460	***	2,768,931,852	***	238,020,774	***	265,685,249	***	51,230,773	**
Replication (farm)	6	63,497,980		13,389,433		231,098,561		16,934,933		81,272,797		12,654,898	
Mulch treatment	2	17,460,022		2,626,346		971,650,681	**	150,695,716	**	70,605,320		5,733,758	
Farm × mulch	4	8,378,409		2,443,917		143,442,840		38,549,050		115,774,126		12,236,968	
Error	12	16,557,523		4,708,642		120,662,111		28,479,168		36,227,334		5,189,748	
Density	1	65,505,439	**	13,745,495	**	1,778,252,118	***	192,387,212	**	173,713,029	***	17,053,328	***
Farm × density	2	58,997,331	**	13,956,850	**	21,749,852		6,354,868		28,582,044		3,925,995	
Mulch × density	2	21,521,747		4,209,014		188,923,150		29,918,467		17,847,284		1,488,795	
Farm × mulch × density	4	7,295,127		1,228,096		32,655,776		5,989,354		34,276,008		4,271,099	
Error	18	14,539,579		2,676,428		115,126,462		12,730,804		18,335,733		2,094,184	
Total	53												
CV (%)		26.4		24.9		19.8		16.7		31.2		32.6	

,*Significant at 0.05 or 0.01, respectively.

for the inter-row mulch treatment. The most frequent reason for culling fruit was sunscald. The incidence of sunscald was significantly different among the three mulch treatments. The white inter-row mulch treatment had the highest percentage of sunscald followed by the reflective mulch and the black mulch control. Sunscald occurs when fruit are exposed to high levels of sunlight and the fruit surface heats to the point of damaging the cells (Wien, 1997). Exposure of the fruit to high light levels can result from poor foliage cover (VanDerwerken and Wilcox-Lee, 1988) or exposure to high light levels (Robert and Anderson, 1994). Silver reflective mulch (Ham et al., 1993) and white inter-row mulch (Ouellette, 2005) have been shown to increase light levels within the plant canopy and may have resulted in increased sunscald observed in this study. In this study, we observed significantly fewer insect damaged fruit harvested from the reflective mulch treatments compared with the black mulch control treatment (Table 3). This agrees with the findings of Greer and Dole (2003) demonstrating that reflective mulches have been shown to reduce insect damage. Other defect categories accounted for less than 20% of the cull fruit and are probably unimportant.

Weed control through the use of plastic mulch is an oft-cited benefit of using mulches (Ngouajio and Ernest, 2004). In this study, the use of the white inter-row mulch expanded the benefit of weed control into the row middles. The two growers participating in this study were impressed by the additional benefit of weed control as a result the inter-row mulch treatment covering the area between the raised beds. These preliminary data suggest that white inter-row mulches can be used by bell pepper growers to achieve greater yields compared with the standard practice of using only black plastic. Growers should exercise caution, however, because these results are for 1 year only with only the total numbers of fruit affected. Further research in this area is warranted. Finally, growers should be cautioned that there are potential disadvantages to the system, such as an increase in the amount of sunscald resulting from the reflective mulches.

Table 2. Early, total marketable yield, and fruit size of 'King Arthur' bell peppers grown using different mulch treatments and plant arrangements.

Treatment	Early marketable harvest (no./acre)[z]	Early marketable harvest (lb/acre)[z]	Total marketable harvest (no./acre)	Total marketable harvest (lb/acre)	Avg fruit wt (oz)[z]
Black mulch with white inter-row mulch	15,429	6,836	60,560 a	23,724 a	6.3
Silver mulch	14,500	6,707	55,635 a	21,971 a	6.5
Black mulch (control)	13,461	6,120	46,108 b	18,071 b	6.5
LSD, $P = 0.05$[y]	NS	NS	6,514	3,164	NS
Single-row 12-inch (30.5 cm) spacing	13,362	6,050	48,363	19,363	6.5
Double-row 18-inch (45.7 cm) spacing	15,565	7,059	59,840	21,143	6.3
Significance	**	NS	***	***	NS

[z]1 fruit/acre = 2.4711 fruit/ha, 1 lb/acre = 1.1209 $kg\cdot ha^{-1}$, 1 oz = 28.3495 g.
[y]Means not followed by the same letter are significantly different with least significant difference (LSD) at $P = 0.05$.
NS,**,***Nonsignificant or significant at 0.05 or 0.001, respectively.

Table 3. Cull yield and classification of 'King Arthur' bell peppers grown using different mulch treatments and plant arrangements.

Treatment	Total cull harvest (no./acre)[z]	Total cull harvest (lb/acre)[z]	Classification of cull fruit (% of culls): Poor shape	Blossom end rot	Sunscald	Insect damage	Disease
Black mulch with white inter-row mulch	7,733	2,946	16 b	10 b	49 a	7 b	18
Silver mulch	11,485	3,851	19 a	18 a	35 b	8 b	20
Black mulch (control)	8,510	2,814	14 b	15 b	30 c	18 a	23
LSD, $P = 0.05$[y]	NS	NS	2.7	3.6	3.3	2.6	NS
Single-row 12-inch (30.5 cm) spacing	7,449	2,642	14	14	43	9	20
Double-row 18-inch (45.7 cm) spacing	11,036	3,766	19	15	33	12	21
Significance	***	***	***		***	**	NS

[z]1 fruit/acre = 2.4711 fruit/ha, 1 lb/acre = 1.1209 $kg\cdot ha^{-1}$.
[y]Means not followed by the same letter are significantly different with least significant difference (LSD) at $P = 0.05$.
NS,**,***Nonsignificant or significant at 0.05 or 0.001, respectively.

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