Alternatives to Plastic Mulch in Vegetable Production Systems

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Introduction

Since its introduction in the 1950s, plastic mulch has become a standard practice used by many farmers to control weeds, increase crop yield, and shorten time to harvest (Lamont, 1991). Plastic mulch has contributed significantly to the economic viability of farmers worldwide, and by 2006 it was estimated that 400,000 acres were covered with plastic mulch in the United States (American Plastics Council, 2004; Takakura and Fang, 2001; Bergholtz, 2006). Due to tracking difficulties it is currently impossible to determine the true number of acres in the U.S. (Garthe, 2006). Each year farmers must dispose of their plastic and the disposal option that most choose is the landfill (Garthe, 2002). Many small-scale and organic farmers choose not to use plastic mulch because of the waste disposal issues. Ideally, farmers would like to plow down the mulch at the end of the season, thereby eliminating removal as well as disposal costs (Sorkin, 2006). Degradable plastics were introduced in the 1980's; however, there remains many questions regarding their efficacy, degradability and potential residues (Vert *et al*., 1992; Riggle, 1998; Shogren, 2000; Hockmuth, 2001). For organic farming, degradable mulches would need to meet National Organic Program (NOP) standards.

The purpose of this study was to identify and test degradable mulch products that can be used as effective and affordable alternatives to standard plastic mulch (Miles, *et.al*., 2005) We tested degradable mulches with four different vegetable crops in an organic vegetable production system to evaluate mulch durability and effects on soil temperature and crop yields. Different vegetable crops have different temperature needs, and it is possible each crop may perform best with a different mulch product.

Materials and Methods

We evaluated 8 alternative mulches in a field study in 2005 and 10 in 2006 (Table 1). This study was conducted on a field that was managed organically but was not certified organic. Some of the products tested may not currently be allowed in organic systems, and research such as this study is needed to determine their suitability.

The experimental design both years was a randomized complete block with four replications. Main plots were 55 feet long by 3 feet wide and each included 4 subplots, one for each of 4 vegetable crops. Vegetable crops were selected to represent 2 growing periods (short vs. long) and 2 temperature regimes (cool vs. warm): lettuce – short growing season, cool temperature; broccoli – long growing season, cool temperature; bell pepper – short growing season, warm temperature; and icebox watermelon – long growing season, warm temperature. Plants were seeded in the greenhouse mid-April both years, and transplanted into the field June 8, 2005 and June 9, 2006. "Pirat" lettuce, "Gypsy" broccoli, and "California Wonder" bell peppers were planted in double 10-foot-long rows, while "Smile" icebox watermelon was planted in a single 21-foot long row. Spacing in the row was 12 inches for lettuce (20 plants per plot), 20 inches for broccoli and peppers (12 plants per plot), and 3 feet for watermelon (7 plants per plot) (Figure 1).

Mulches were laid using a mulch layer tractor attachment, except for the Garden Biofilm in 2005, which was laid by hand. Drip tape was laid at the same time as the mulch. After laying the mulches, holes were manually punched using a bulb setter and vegetables were transplanted by hand. Plots were drip irrigated once a week at the rate of 1 inch. Plants were fertigated immediately after transplanting and every 3 weeks thereafter. Fertilizer was soluble BioLink (5-5-5) and soluble seaweed extract powder (Acadian 1-0-4 w/ trace minerals) applied at a rate of 5 lb/A and 3 lb/A, respectively. Temperatures were measured with Hobo field monitors beneath each mulch product at the soil surface and at a 2-inch depth in the neighboring bare soil.

Table 1. Descriptions of mulch products evaluated in 2005 and 2006 at Washington State University Vancouver REU. This table is not intended to be used to promote any products listed or detract from any products not included in this field study.

Product	Description	Year Tested
Black plastic (control)	1.0 mil embossed black polyethylene plastic film	2005, 2006
Envirocare 1	Black plastic w/ Ciba Envirocare TDPA (Totally Degradable Plastic Additive); 75 days to degradation	2005, 2006
Envirocare 2	Black plastic w/ Ciba Envirocare TDPA (Totally Degradable Plastic Additive); 140 days to degradation	2005, 2006
Garden Biofilm	Cornstarch-based black film, 100% degradable;	2005, 2006
Garden Biofilm NF01U/P 15 mic	Cornstarch-based black film, 100% degradable; developed for short cycle crops	2006
Garden Biofilm NF803/P 12 mic	Cornstarch-based black film, 100% degradable; developed for longer cycle crops	2006
Garden Biofilm NF803/P 15 mic	Cornstarch-based black film, 100% degradable; developed for longer cycle crops	2006
Planters Paper	Kraft paper with black pigment; 100% recycled fiber	2005, 2006
Longview Fibre Paper (LF) 1	Raisin Tray Paper - highly sized, high wet strength; 15% recycled fiber	2005
LF 2	Leaf Bag Paper - normally sized, high wet strength; 28% recycled fiber	2005
LF 3	Raisin Tray Paper - highly sized, no wet strength; 12% recycled fiber	2005
LF 4	Bag Paper - normally sized, no wet strength; 40% recycled fiber	2005, 2006
LF 5	Hi STFI Liner (Hi Performance Liner) - medium sized, medium wet strength, 18% recycled fiber	2006

Mulch quality was rated weekly on a scale of 0 to 9 where 0 was 0-9% mulch cover and 9 was 90-100% cover. Vegetables in each plot were harvested when they reached peak maturity, and yield measurements included marketable yield, number of marketable fruits/heads, and number of days to first harvest. In 2005, black plastic was removed from the field following the final harvest and all products except Envirocare 1 and Envirocare 2 were incorporated into the soil using a rototiller/rotovator. Two plots of each Envirocare 1 and Envirocare 2 were rototilled into the soil while 2 plots were removed and composted in separate on-farm compost piles. In 2006, Envirocare 1 and Envirocare 2 were removed from the field at the same time as black plastic and all other products were tilled into the soil.

Figure 1. Field trial of alternatives to plastic mulch at WSU Vancouver REU in 2006.

Results and Discussion

Mulch products evaluated in this study showed significant differences in quality (durability) over time (Figure 2). In 2005, black plastic, Envirocare 2 and Envirocare 1 were the most durable, with quality declining only slightly over the course of the growing season. The 5 paper mulch products declined in quality relatively quickly, and were rated 5 or below (50% cover or less) only 5-6 weeks after field application. Weed growth occurred under all the paper mulches, indicating there was significant light penetration, and was the major cause of their decline in quality. Weeds grew large enough to push the paper mulches off the ground, causing the mulches to rip along the edges where they were buried in the soil, and eventually blow away. Garden BioFilm quality dropped below 50% after 7 weeks in the field, and it's quality rating remained slightly better than the paper mulches until 12 weeks after application, at which point it dropped below a rating of 2. Garden Biofilm began to degrade in longitudinal rips and weeds then grew in the exposed areas of the beds.

In 2006, black plastic, Envirocare 1, Envirocare 2 and LF 5 were the most durable products, with quality declining by less than 20% over the course of the growing season. Paper mulch LF 4 declined in quality in a similar fashion as in 2005 while Planters Paper was considerably more durable in 2006 than in 2005, indicating a significant variation in performance. In 2006 just as in 2005, weed growth occurred under the LF 4 paper mulch, and this was the primary cause of its decline in quality. The 4 cornstarch mulch products varied from each other in quality over the season, with Garden Biofilm NF01U/P15 being the most durable followed by Garden Biofilm NF803/P15. Garden Biofilm declined in quality in 2006 in a similar fashion as in 2005.

Yields differed significantly between years and were lower for all crops in 2006 than in 2005. Both years, yields with paper mulches tended to be lower than with other mulch products, and these differences were significant for some crops. In general, yield of lettuce and broccoli (both cool season crops) were least impacted by paper mulch whereas yield of pepper and watermelon (both warm season crops) were more greatly impacted. In 2005, all paper mulches exhibited a general degradation early in the season and weeds subsequently grew throughout those plots, resulting in low yields. In 2006, only LF 4 degraded early and yields were consequently lower than for other products.

In 2005, Envirocare 1 and 2 and Garden Biofilm resulted in the highest overall yield of lettuce but there was little variability in the number of lettuce heads (Table 2). Black plastic mulch resulted in high broccoli yield, followed closely by Envirocare 1 and Envirocare 2. Paper products resulted in the lowest broccoli yields. All paper products resulted in significantly lower pepper yields while only LF3 resulted in mean fruit weight equivalent to plastic (Table 3). Watermelon yield and number of fruit were significantly greater due to Envirocare 1 and Envirocare 2, and paper products resulted in significantly lower watermelon yields and fruit number than all other mulch treatments. Watermelon yield differences were primarily due to the number of fruit harvested.

In 2006, lettuce yield and number of heads tended to be greatest with Envirocare 2, LF 5, and Garden Biofilm NF803/12 and lowest with black plastic, Garden Biofilm, and LF 4, however these differences were not significant (Table 2). Broccoli yield tended to be greatest with Garden Biofilm NF803/15, Envirocare 2, and Garden Biofilm NF803/12, and lowest with LF 5, Planters Paper and black plastic, however these differences were not significant (Table 3). Numbers of broccoli heads were greatest with Envirocare 2 and Garden Biofilm, and lowest with Garden Biofilm NF01U/P15. The average head weight of broccoli was greatest with Garden Biofilm NF803/15 and Garden Biofilm NF803/12, and lowest with black plastic and Garden Biofilm. Pepper yield and number of fruit were greatest with Garden Biofilm NF803/15, Envirocare 2 and Envirocare 1, and lowest with LF 4, Planters Paper and black plastic (Table 4). Watermelon yield and fruit number were greatest with Envirocare 1, Envirocare 2 and Garden Biofilm NF803/15, and lowest with LF 4 and LF 5 (Table 5). The average fruit weight of watermelon was greatest with Envirocare 1 and Envirocare 2, and lowest with LF 5.

Mulch products had a significant effect on days to maturity for all crops both in 2005 or 2006, however these effects were generally not consistent (Table 6). However, Envirocare 1 and Envirocare 2 resulted in earlier yields of broccoli both years and of watermelon in 2006.

Both years, maximum and minimum temperatures under all products differed significantly from black plastic (Figures 3-10). Minimum temperatures under LF1, LF2, LF4, and Planters Paper were lower than under black plastic, and minimum temperatures under LF3 and LF5 were the same as under black plastic. Maximum temperatures under LF1 and Planters Paper were greater, under LF2 and LF3 were lower, and under LF4 and LF5 were the same as under black plastic. Maximum temperatures under Envirocare 1 varied substantially by year, but minimum temperatures were the same as under black plastic both years. Maximum and minimum temperatures under Envirocare 2 were lower than under black plastic. Maximum and minimum temperatures under Garden Biofilm NF01U/P15, Garden Biofilm NF803/P12, and Garden Biofilm NF803/P15were the same as under black plastic.

In 2005, paper, cornstarch and 2 plots each of Envirocare 1 and Envirocare 2 mulch products were tilled into the soil in October following the final harvest. By spring 2006, the paper and cornstarch products had completely degraded in the field while Envirocare 1 and Envirocare 2 had not. Also in 2005, two plots each of Envirocare 1 and Envirocare 2 were added to two separate on-farm compost piles (feedstock: fresh horse manure with bedding). By April 28 2006, Envirocare 1 and Envirocare 2 had not degraded in on-farm composting. In 2006, Envirocare 1 and Envirocare 2 were removed from the field at the same time as black plastic and all other mulch products were tilled into the soil.

Conclusions

In this study, once mulch cover fell below 50% (a quality rating of 5 or below), the product was ineffective for weed control. The extensive weed growth under all the paper mulch products in 2005 was the primary reason for yield decline with those mulch products.

Envirocare 1 and Envirocare 2 were as durable as black plastic in the field and resulted in similar crop yield. Preliminary results indicate that LF 5 is almost as durable as black plastic however it may be more suitable for cool season crops and not as well suited for warm season crops. Temperatures under LF 5 were greater than or equal to temperatures under black plastic so it is not clear why crop yields tended to be lower. The new cornstarch product Garden Biofilm NF803/P15 appeared somewhat durable in the field and had the added benefit of resulting in higher crop yields than black plastic, likely due to the higher maximum temperatures that occurred under this mulch as compared to black plastic. Garden Biofilm NF01U/P15 was more durable in the field than Garden Biofilm NF803/P15 but did not result in greatly increased yields. Garden Biofilm and Garden Biofilm NF803/P12 did not retain their mulch quality beyond mid August, however yields were comparable to or better than with black plastic. Planters Paper had poor quality the first year and good quality the second year of this study, perhaps indicating variability in batch quality. In addition, yields of all crops with Planters Paper tended to be lower than for other mulch products.

In this study Envirocare products did not degrade when they were incorporated into the field or when they were incorporated into on-farm compost piles. Therefore these products did not provide reduced farm labor costs or disposal fees. Ideally, degradable mulch would degrade in the soil, eliminating the removal and disposal costs.

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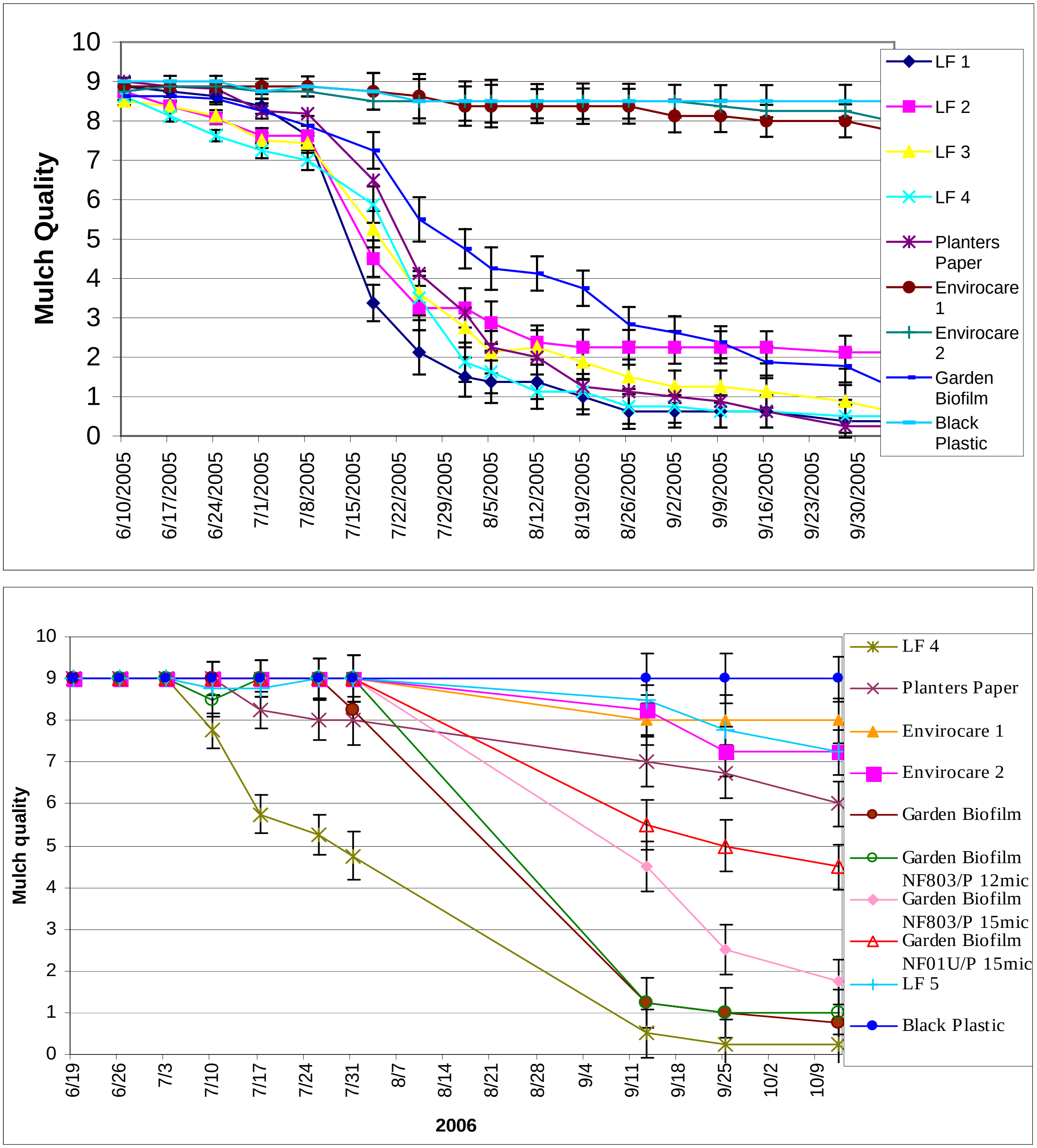


Figure 2. Mulch durability (quality over time) on a scale 0-9, where 0 is 0-9% mulch cover and 9 is 90-100% cover, in 2005 and 2006 at WSU Vancouver REU.

Table 2. Mean marketable yield (kg) of lettuce, number of marketable heads per plot, and weight per head (g) in 2005 and 2006.

	Yield (kg)		No. Heads		Head Wt. (g)	
Mulch Product	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**
Black plastic	4.77 abc	2.14 a	19 a	16 a	202 abc	135 a
Envirocare 1	5.06 ab	2.59 a	19 a	16 a	211 ab	162 a
Envirocare 2	5.58 a	2.86 a	18 a	17 a	259 a	171 a
LF 1	1.11 e		6 b		92 e	
LF 2	3.04 d		20 a		127 de	
LF 3	3.36 cd		17 a		141 cde	
LF 4	3.83 bcd	2.31 a	18 a	16 a	180 bcd	142 a
LF 5		2.73 a		17 a		162 a
Planters Paper	3.71 bcd	2.43 a	19 a	16 a	155 bcde	154 a
Garden Biofilm	5.55 a	2.20 a	19 a	20 a	245 a	125 a
Garden Biofilm NF803/12		2.62 a		17 a		154 a
Garden Biofilm NF01U/P15		2.33 a		18 a		131 a
Garden Biofilm NF803/15		2.33 a		16 a		144 a
P Value	**0.0000**	**0.6475**	**0.0000**	**0.8960**	**0.0006**	**0.2336**

Table 3. Mean marketable yield (kg) of broccoli, number of marketable heads per plot, and weight per head (g) in 2005 and 2006

	Yield (kg)		No. Heads		Head Wt. (g)	
Mulch	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**
Black plastic	3.08 abc	1.18 a	11.0 a	8.3 abc	280 ab	137 d
Envirocare 1	4.19 a	1.50 a	11.5 a	8.8 ab	370 a	164 cd
Envirocare 2	3.96 ab	1.78 a	11.0 a	9.8 a	360 a	183 bcd
LF 1	1.57 d		9.8 a		150 c	
LF 2	2.29 cd		11.8 a		190 bc	
LF 3	2.18 cd		9.8 a		210 bc	
LF 4	2.59 cd	1.25 a	11.3 a	7.8 abcd	230 bc	162 cd
LF 5		1.14 a		6.3 cd		188 bcd
Planters Paper	2.03 cd	1.15 a	12.0 a	7.8 abcd	170 c	150 cd
Garden Biofilm	2.98 bc	1.29 a	11.0 a	9.5 a	270 ab	137 d
Garden Biofilm NF803/12		1.66 a		6.5 bcd		258 ab
Garden Biofilm NF01U/P15		1.36 a		5.8 d		234 abc
Garden Biofilm NF803/15		2.03 a		6.5 bcd		318 a
P Value	**0.0061**	**0.2506**	**0.5566**	**0.0167**	**0.0008**	**0.0032**

Table 4. Mean marketable yield (kg) of pepper, number of marketable fruit per plot, and weight per fruit (g) in 2005 and 2006.

Mulch	Yield (kg) 2005	Yield (kg) 2006	No. Fruit 2005	No. Fruit 2006	Fruit Wt. (g) 2005	Fruit Wt. (g) 2006
Black plastic	3.56 a	1.86 abc	38.75 b	15.8 abc	90 a	114 a
Envirocare 1	4.76 a	3.31 ab	56.75 a	27.8 ab	90 a	118 a
Envirocare 2	3.89 a	3.70 ab	45.75 ab	29.5 ab	80 a	126 a
LF 1	0.2 b		5.25 c		40 d	
LF 2	0.51 b		9.5 c		60 bc	
LF 3	0.68 b		8.5 c		80 ab	
LF 4	0.15 b	0.40 c	3.75 c	3.8 c	30 d	107 a
LF 5		2.11 abc		19.0 abc		111 a
Planters Paper	0.06 b	1.51 bc	1.25 c	13.8 bc	50 cd	113 a
Garden Biofilm	3.68 a	2.67 abc	41.5 ab	21.0 abc	90 a	129 a
Garden Biofilm NF803/12		2.52 abc		18.8 abc		159 a
Garden Biofilm NF01U/P15		3.01 ab		27.8 ab		108 a
Garden Biofilm NF803/15		4.09 a		34.0 a		119 a
P Value	**0.0000**	**0.0002**	**0.0000**	**0.0003**	**0.0000**	**0.4957**

Table 5. Mean marketable yield (kg) of watermelon, number of marketable fruit per plot, and weight per fruit (g) in 2005 and 2006

Mulch	Yield (kg) 2005	Yield (kg) 2006	No. Fruit 2005	No. Fruit 2006	Fruit Wt. (kg) 2005	Fruit Wt. (kg) 2006
Black plastic	16.2 c	11.4 ab	9 c	6.5 ab	1.8 b	1.7 ab
Envirocare 1	37.7 a	27.3 a	15.5 a	12.8 a	2.4 a	2.2 a
Envirocare 2	26.9 b	20.2 ab	10.8 bc	10.8 ab	2.4 a	2 ab
LF 1	1 d		1.3 d		0.6 d	
LF 2	4.4 d		4.5 d		1.1 cd	
LF 3	0.6 d		1.3 d		0.5 d	
LF 4	3 d	1.9 b	3.5 d	1.5 b	0.8 d	1.3 ab
LF 5		6.6 b		6.5 ab		1.1 b
Planters Paper	2 d	10.5 ab	2.3 d	6.8 ab	0.8 d	1.4 ab
Garden Biofilm	20 bc	14.6 ab	12.5 ab	8.3 ab	1.5 bc	1.8 ab
Garden Biofilm NF803/12		12.7 ab		8.5 ab		1.5 ab
Garden Biofilm NF01U/P15		18 ab		13.8 a		1.3 ab
Garden Biofilm NF803/15		18.7 ab		11 ab		1.7 ab
P Value	**0.0000**	**0.0023**	**0.0000**	**0.0077**	**0.0000**	**0.0471**

Table 6. Days after transplanting to first harvest of lettuce, broccoli, pepper and watermelon at WSU Vancouver REU in 2005 and 2006.

	Lettuce		Broccoli		Pepper		Watermelon	
Mulch	2005	2006	2005	2006	2005	2006	2005	2006
Black plastic	46	39 a	84 cd	71 bc	102 d	109 a	106 ab	72 abcd
Envirocare 1	46	39 a	80 d	67 c	106 bcd	109 a	103 ab	65 d
Envirocare 2	46	39 a	80 d	67 c	109 bc	109 a	104 ab	67 cd
LF 1	46		97 a		115 a		115 a	
LF 2	46		91 ab		111 ab		105 ab	
LF 3	46		97 a		106 bcd		103 ab	
LF 4	46	40 a	88 bc	69 bc	114 a	113 a	106 ab	81 a
LF 5		38 a		70 bc		109 a		78 a
Planters Paper	46	39 a	91 ab	70 bc	117 a	109 a	111 a	69 bcd
Garden Biofilm	46	38 a	85 bcd	68 c	105 cd	109 a	96 b	65 d
Garden BiofilmNF803/12		34 b		74 bc		112 a		77 ab
Garden BiofilmNF01U/P15		35 b		84 a		109 a		68 cd
GardenBiofilmNF803/15		34 b		84 a		109 a		74 abcd
P Value	**n/a**	**0.0000**	**0.0001**	**0.0000**	**0.0002**	**0.124**	**0.3405**	**0.0100**

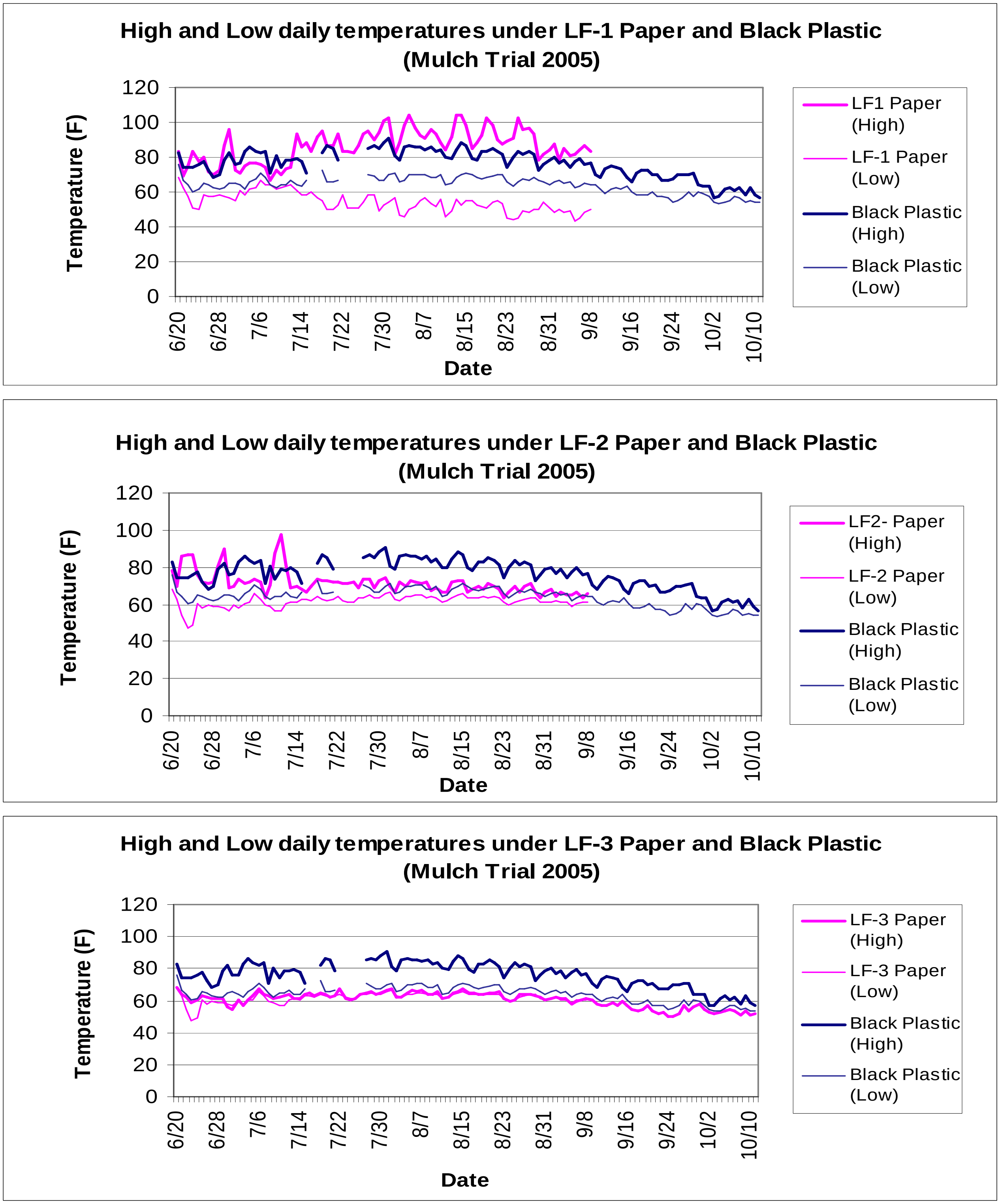
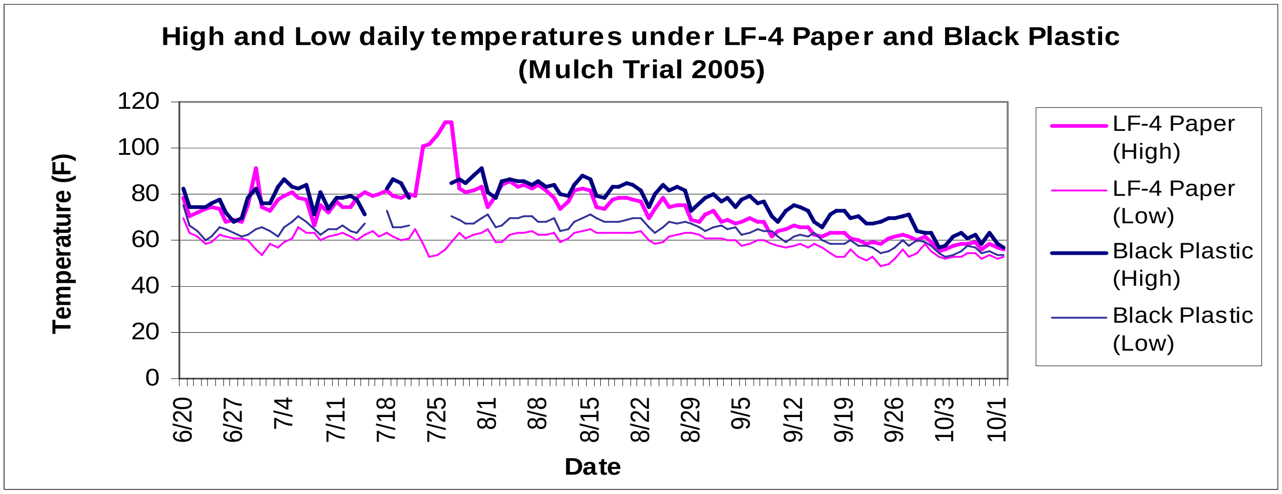


Figure 3. Temperatures (^{o}F) measured under black plastic and under LF 1, LF 2, and LF 3 paper mulches in 2005.



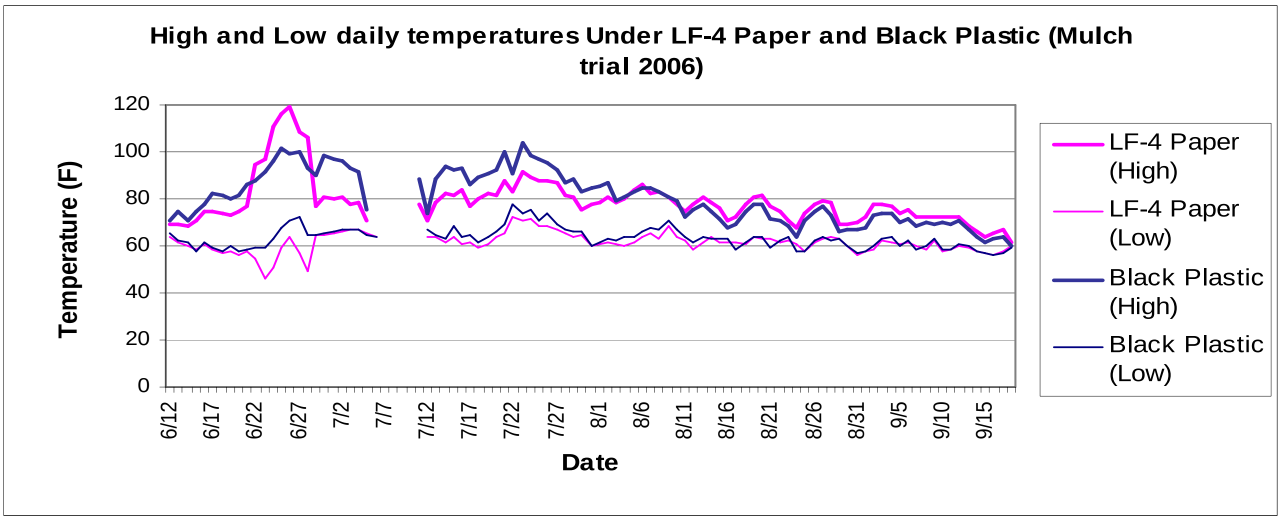


Figure 4. Temperatures (°F) measured under black plastic and under LF 4 paper mulch in 2005 and 2006.

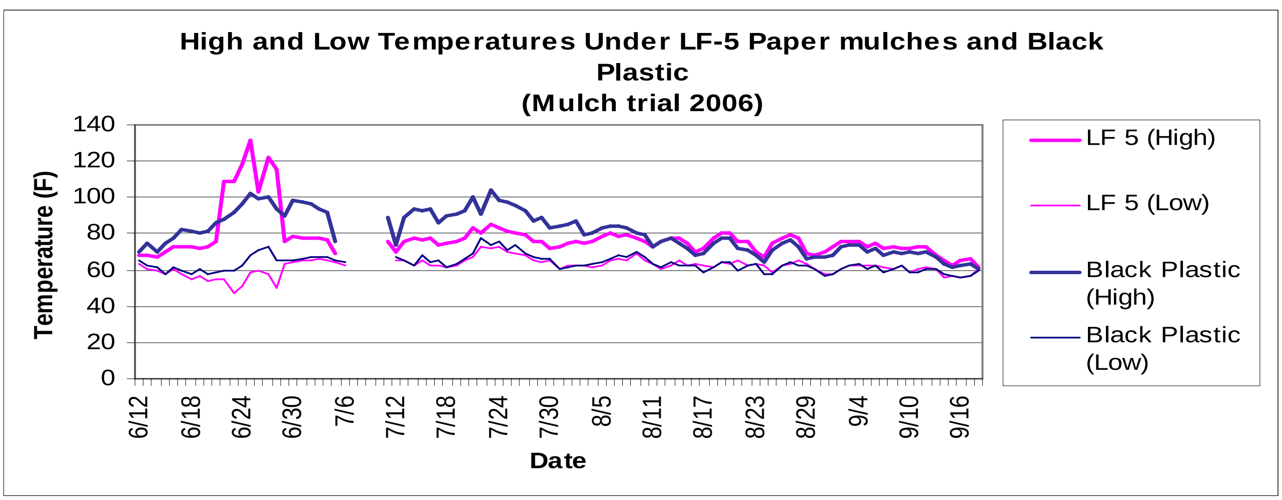
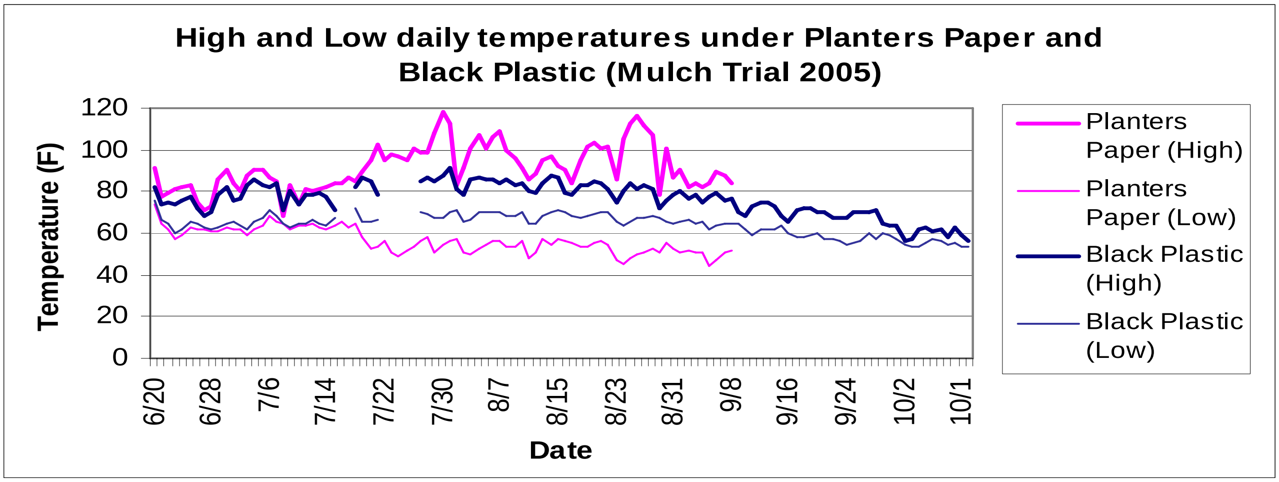


Figure 5. Temperatures (°F) measured under black plastic and under LF 5 paper mulch in 2006.



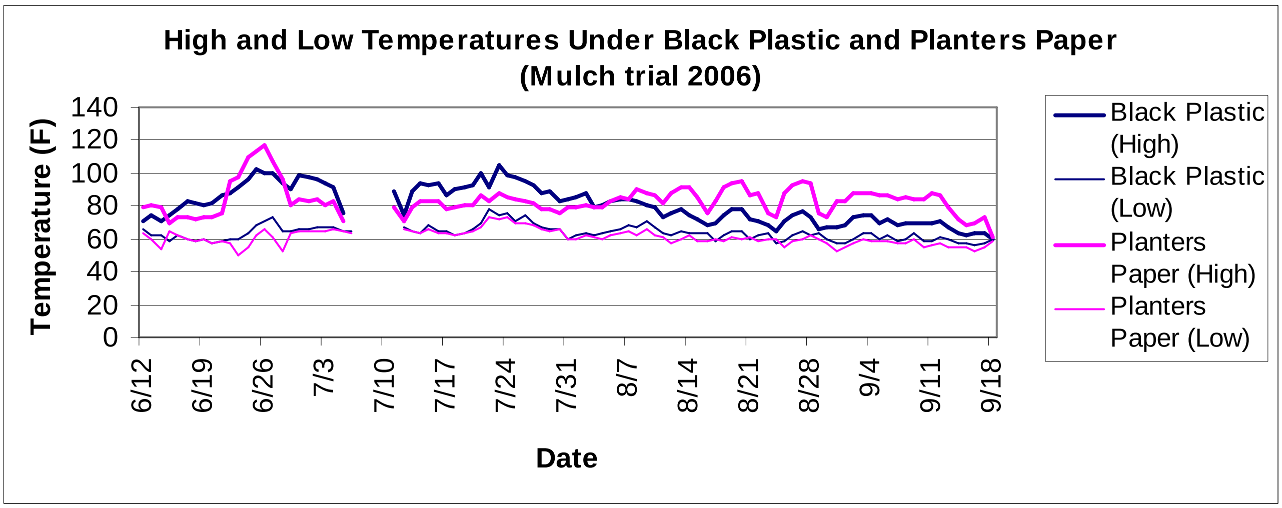
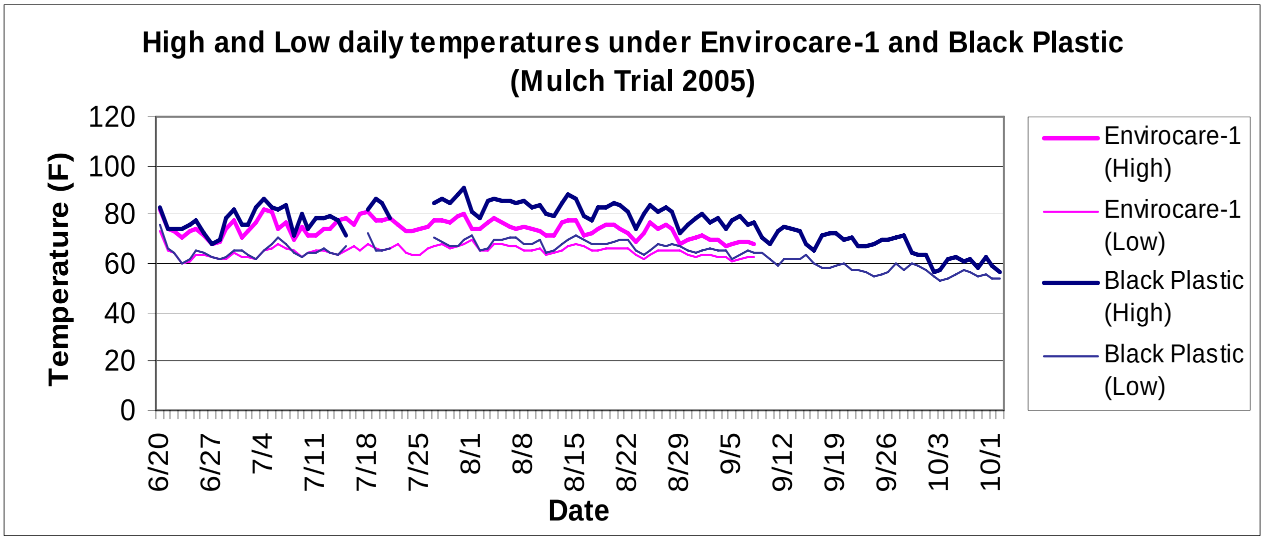


Figure 6. Temperatures (°F) measured under black plastic and under Planters Paper mulch in 2005 and 2006.



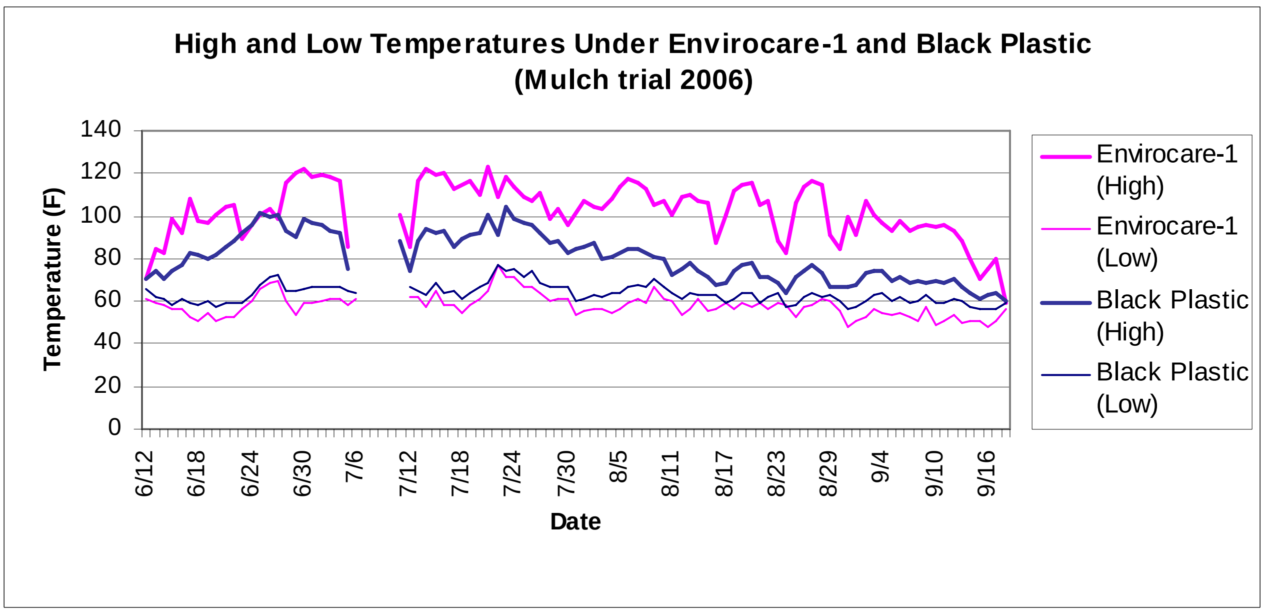
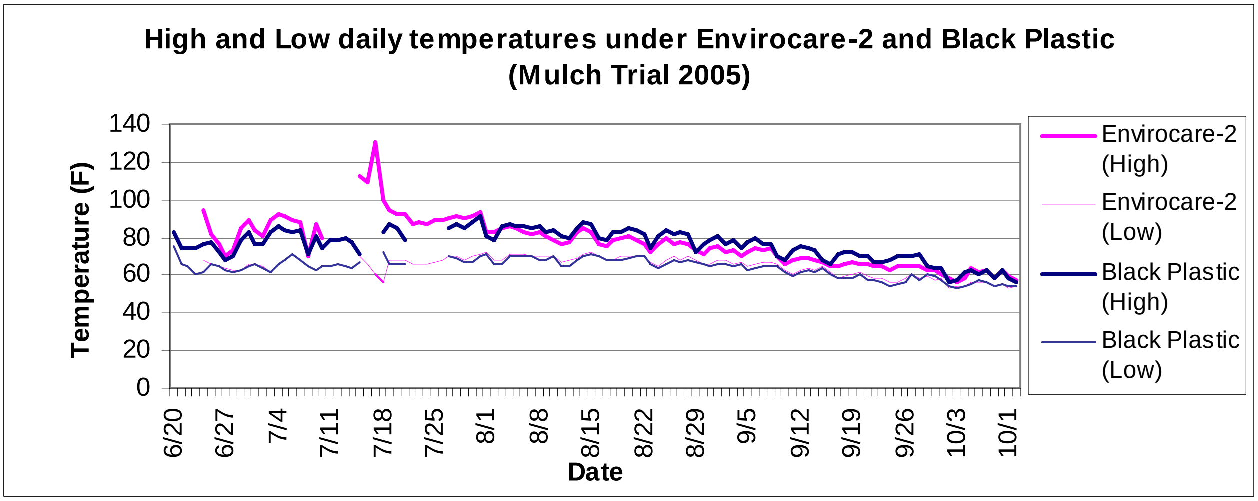


Figure 7. Temperatures (^{o}F) measured under black plastic and under Envirocare 1 mulch in 2005 and 2006.



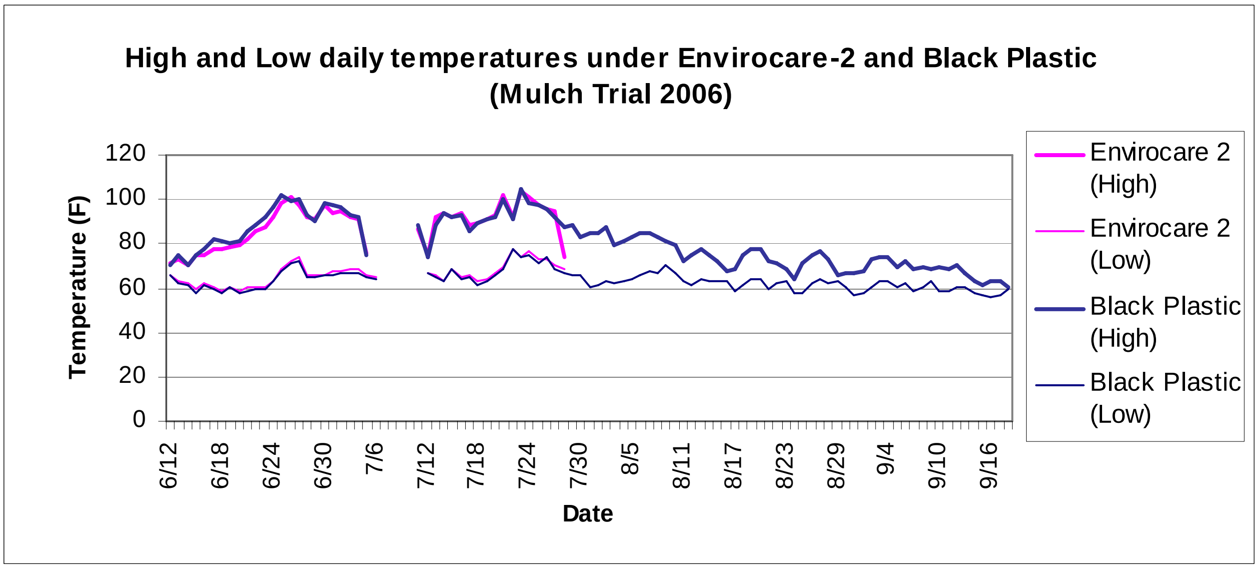
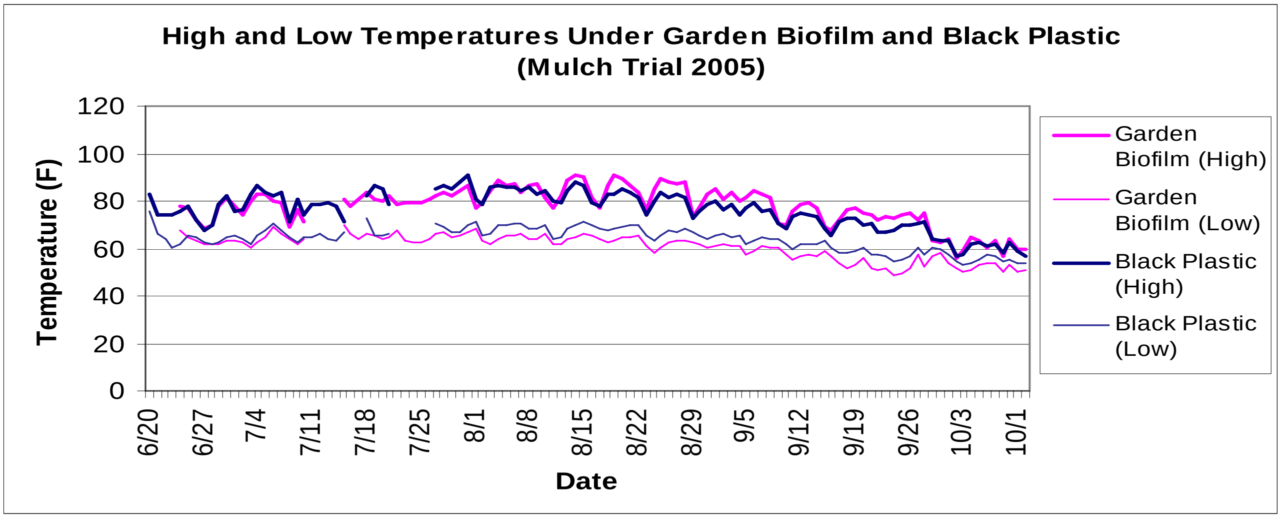


Figure 8. Temperatures (^{o}F) measured under black plastic and under Envirocare 2 mulch in 2005 and 2006.



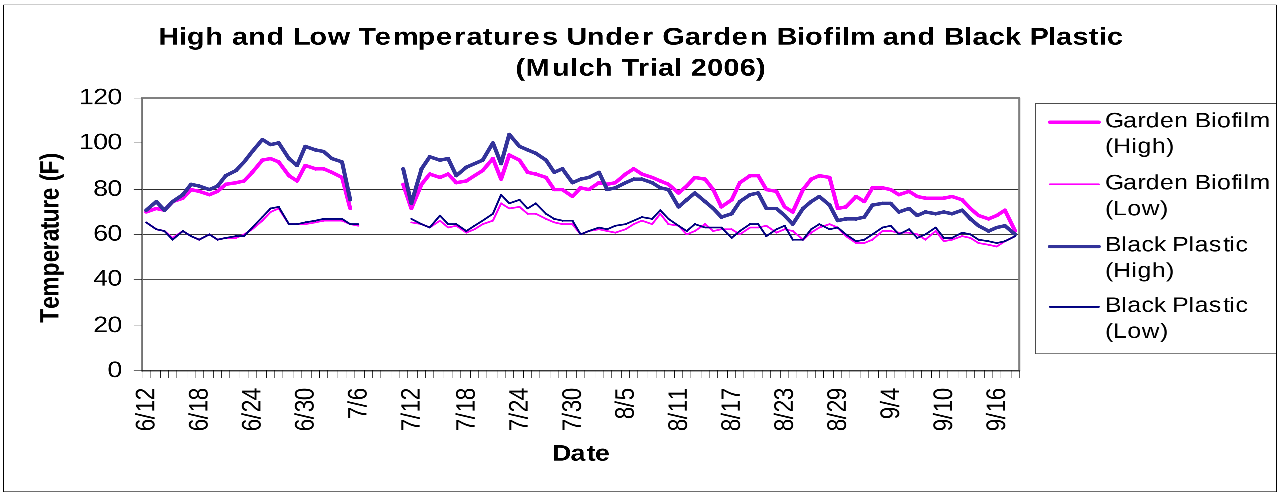
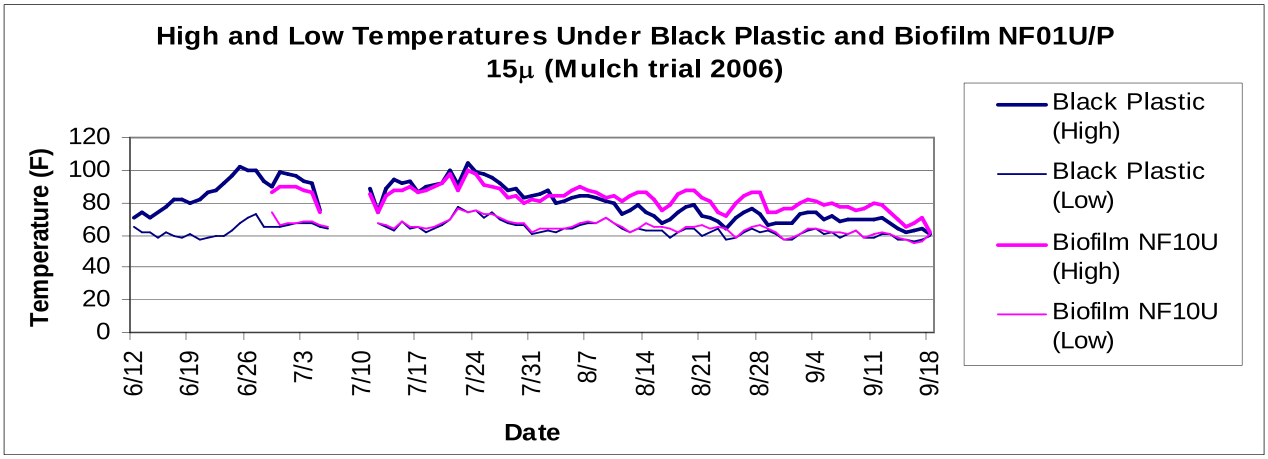
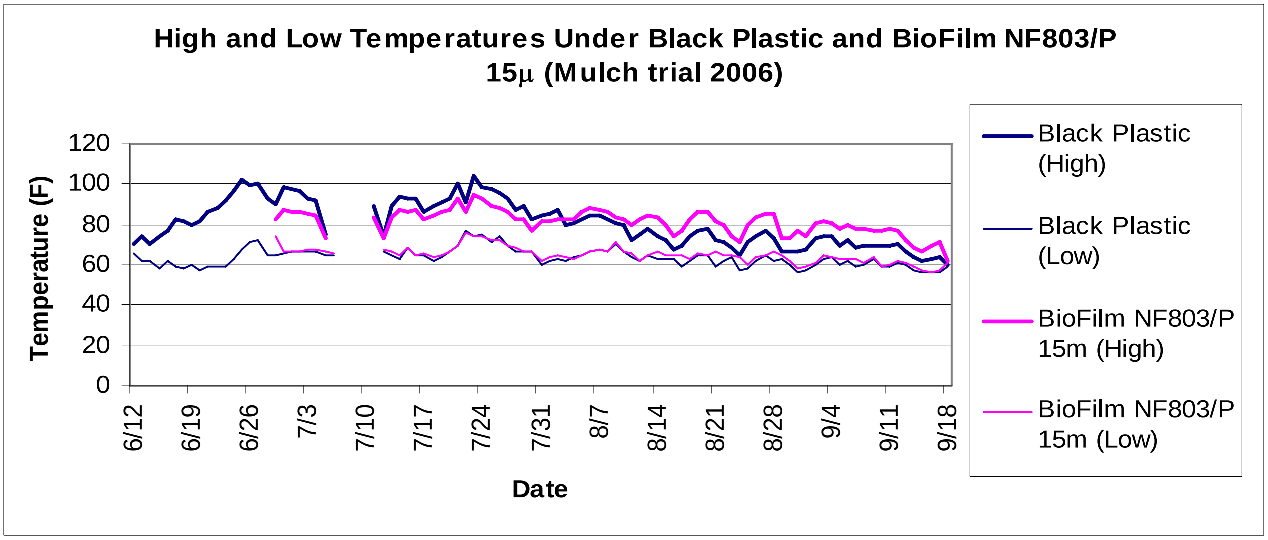


Figure 9. Temperatures (^{o}F) measured under black plastic and under Garden Biofilm mulch in 2005 and 2006.





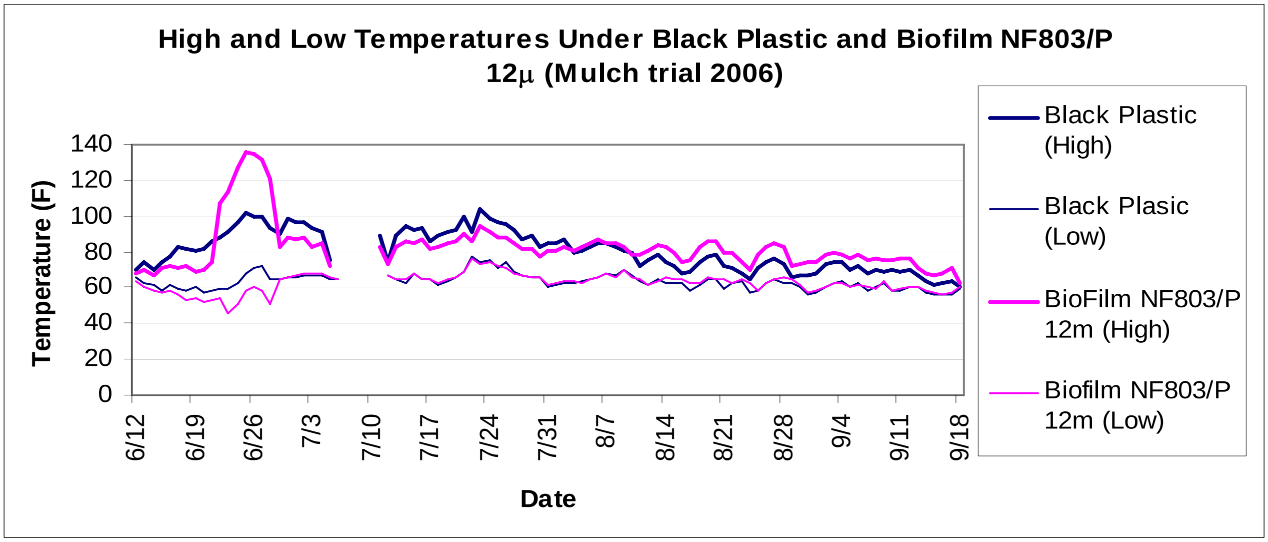


Figure 10. Temperatures (^oF) measured under three new Garden Biofilm products and compared to Black plastic in 2006.