Alternatives to Plastic Mulch for Organic Vegetable Production

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Introduction

Weed control is one of the primary concerns in organic farming as it is labor intensive, expensive and time consuming. 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 1999 almost 30 million acres worldwide were covered with plastic mulch, with more than 185,000 of those acres in the United States (American Plastics Council, 2004; Takakura and Fang, 2001). However, each year farmers must dispose of their plastic, and although agricultural plastic recycling has begun, the disposal option that most choose is the landfill (Garthe, 2002). Many organic farmers, especially those who are small-scale, choose not to use plastic mulch because of the waste disposal issues. An effective, affordable, degradable alternative to the now-standard plastic mulch would contribute the same production benefits as plastic mulch and in addition would reduce non-recyclable waste.

Previous work. In 2003, we conducted a preliminary study at Washington State University Vancouver Research and Extension Unit (WSU VREU) to evaluate paper and cornstarch mulches as alternatives to plastic mulch. We used 81 lb Kraft paper with and without oil application. We evaluated three oils (soybean, linseed and tung) applied before and after laying the paper. ARS chemist Randal L. Shogren (2000) at the National Center for Agricultural Utilization Research found that Kraft paper treated with a combination of epoxidized soybean oil and citric acid was effective for 13 weeks in the field and withstood wind and rain better than untreated Kraft paper. A field evaluation by R. C. Hochmuth (2001) of the University of Florida found that watermelon grown on paper mulch coated with polymerized vegetable oil yielded on par with black plastic mulch. In our study at WSU VREU, the 81 lb Kraft paper mulch with and without oil proved as high in quality as the plastic mulch (Miles *et al.*, 2003). To follow up on these promising preliminary results, we conducted further studies in 2004 and 2005 to test different quality papers, additional mulch products and a diversity of vegetable crops.

Objectives

The purpose of this study is to identify and test degradable mulch products that can be used as effective and affordable alternatives to standard plastic mulch. We tested degradable mulches with four different vegetable crops in an organic 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 5 alternative mulches in 2004 and 8 in 2005 (Table 1). Two of the products included both years were degradable plastic mulch that contain TDPA™ (Billingham, 2005). The 2 paper products that were tested in 2004 were eliminated because they were not suitable for organic systems. Five new paper products were added in 2005. Both years, mulch products were compared to black plastic (control) and were evaluated for durability, and effects on soil temperature and crop yield. In 2004, this study was conducted on a certified organic field, and in 2005 it was conducted on a non-certified field that was managed organically. Some of the products tested are not currently allowed in certified organic systems, and research such as this study is needed to determine their suitability.

Table 1. Descriptions of mulch products evaluated in 2004 and 2005 at WSU Vancouver REU.

Product	Description	Year Tested
42 lb Coated Kraft Paper	Brown paper coated with transparent polyethylene	2004
81 lb Kraft Paper	Brown paper bonded with cement	2004
Garden Biofilm	Cornstarch-based black film; 100% degradable	2004 & 2005
Envirocare 1	Black plastic w/ Ciba Envirocare TDPA (Totally Degradable Plastic Additive); 75 days to degredation	2004 & 2005
Envirocare 2	Black plastic w/ Ciba Envirocare TDPA (Totally Degradable Plastic Additive); 140 days to degredation	2004 & 2005
Black plastic (control)	1.0 mil embossed black polyethylene plastic film	2004 & 2005
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
Planters Paper	Kraft paper with black pigment; 100% recycled fiber	2005

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. It is important to note that all these crops are summer crops, two of them are simply short season (short) and two of them are heat loving (warm). Plants were seeded in the greenhouse mid-April both years, and transplanted into the field June 24 2004, and June 8 2005. “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). Mulches were laid using a mulch layer tractor attachment, except for the Garden Biofilm, which was laid by hand. Drip tape was laid at the same time as the mulch, and plots were drip irrigated. After laying the mulches, holes were manually punched for each plant using a bulb setter. Vegetables were transplanted by hand, and were fertilized 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 through the irrigation system at a rate of 5 lb/A and 3 lb/A, respectively. Using Hobo field temperature monitors, we measured temperatures beneath each mulch product at the soil surface and at a 2-inch depth. Temperatures under the mulch were compared to bare soil.

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 total yield, marketable (trimmed) yield, number of marketable fruits/heads, and number of days to harvest. In 2004, black plastic and the paper coated with polyethylene were removed from the field following the final harvest and all other products were tilled into the soil. In 2005, black plastic was again removed from the field following the final harvest and all degradable products were tilled into the soil. However, only 2 plots each of the 2 Envirocare products were tilled and 2 plots were removed and were composted in separate on-farm compost piles.

Results and Discussion

Mulch products evaluated in this study showed significant differences in quality (durability) over time in both 2004 and 2005 (Figures 1 and 2). Black plastic was the most durable, with quality declining only slightly over the course of the growing season both years. Quality of Envirocare 2 and Envirocare 1 mulches was comparable to black plastic throughout both growing seasons. In 2004, Kraft 81-lb and Kraft 43-lb paper mulches exhibited fair quality at the end of the season, but were significantly less durable than black plastic and Envirocare mulches. However, both these paper products are unsuitable for organic systems and so they were not included in this study in 2005. The Kraft 81-lb was laminated with cement, a prohibited substance for organic farming, and the Kraft 43-lb polyethylene coated paper was extremely difficult to remove at the end of the season. In 2005, 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 and was the major cause of their decline in quality. Weeds grew large enough to push the paper mulches off the ground, causing them to tear and eventually blow away. Weed growth under the paper mulch indicates there was significant light penetration through these products. Oil application to these paper mulch products may reduce light penetration and may be worth evaluation. Garden BioFilm was the least durable mulch in 2004, steadily declining to a final quality rating of 2 (20-29% cover), indicating that it was nearly gone at the end of the growing season. In 2005, 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.

In 2004, different mulch products significantly affected broccoli and watermelon yields, but not yields of lettuce and pepper. In 2005, yields of all crops were significantly affected by mulch products, and yields in all paper plots were significantly lower due to their general degradation and the subsequent weed growth in those plots. Yield of lettuce was least impacted by mulch product due to its short time to harvest, and paper or cornstarch products may be most suitable for similar short season crops (Table 2). Envirocare 1 and 2 and Garden BioFilm resulted in the highest overall yield of lettuce both years. In general, there was very little variability in number of heads produced by the different mulch products.

Black plastic mulch resulted in high broccoli yield both years while Envirocare 1 and Envirocare 2 produced the lowest yields in 2004 and were high yielding in 2005 (Table 3). Paper products in 2005 resulted in the lowest broccoli yields. There was no significant difference in average broccoli head weight in 2004, but in 2005, all paper products resulted in lower head weight.

There were no significant differences in pepper yield in 2004, however in 2005, all paper products resulted in significantly lower yields (Table 4). Only average fruit weight of peppers due to LF3 was equivalent to plastic. Watermelon yield and number of fruit were significantly greater due to Envirocare 1 and Envirocare 2 both years (Table 5). Paper products resulted in significantly lower watermelon yields and fruit number than all other mulch treatments both years. Yield differences were primarily due to the number of fruit harvested.

Mulch quality was significantly correlated to crop yield in 2005 and as quality of mulch declined, yield declined (Table 6). Weed growth under the paper mulch products was the primary cause of their ripping which caused them to decline in quality. Weeds pushed up the mulches, causing them to rip along the edges where they were buried in the soil. Garden Biofilm began to degrade in longitudinal rips and weeds then grew in the exposed areas of the beds.

Harvest of all crops was 10-20 days later in 2005 than in 2004, due to cooler temperatures throughout the summer. In 2004, days to maturity from transplanting of broccoli was significantly affected by mulch product, and in 2005, broccoli and pepper were significantly affected (Table 7). In 2004, broccoli was harvested earliest from plots treated with Garden BioFilm, and latest from plots treated with black plastic. In 2005, broccoli was harvested earliest from Envirocare 1 and 2 plots and latest from paper plots except LF4, which was comparable to black plastic. Pepper was harvested earliest from black plastic plots and latest from paper plots except LF 3, which was comparable to black plastic.

In 2004, black plastic mulch showed an insulating effect on underlying soil. That is, minimum and maximum temperature beneath the mulch were less extreme than above it (Figure 3). Temperatures under all of the mulch products appeared similar to black plastic in their insulating effect, except for Kraft 81-lb paper, which showed greater extremes of both high and low temperatures. In 2005, maximum and minimum temperatures under all products differed significantly from black plastic. Minimum temperatures under LF1, LF2, LF3, LF4, and Planters Paper were lower than under black plastic. Maximum temperatures under LF1 and Planters Paper were greater than under black plastic. Maximum temperatures under Envirocare 1, Envirocare 2 and Garden Biofilm were less than black plastic, while minimum temperature under Envirocare 1 was higher, under Envirocare 2 was lower, and under Garden Biofilm was the same as under black plastic.

Approximate costs per acre were calculated for 80% mulch cover. Black plastic costs $252 - $281 per acre, and may differ depending on the source. Envirocare films are similar in price to black plastic, ranging from $215 to $243 per acre, and the cost of Garden Bio-Film is higher, ranging from $695 to $1087. The cost of the LF paper products can vary over the year and the relatively heavy weight of paper makes shipping costs higher for paper mulches.

Both years, degradable mulch products were tilled into the soil following the final harvest, and by the following spring, the paper and cornstarch products had completely degraded while the 2 Envirocare products had not. In 2005, in addition to plowing down 2 plots each of both Envirocare products, we also removed both products from 2 plots each prior to plow-down and added the products to 2 separate on-farm compost piles (feedstock: fresh horse manure with bedding). We monitored temperatures in both compost piles throughout the winter/spring

(Figures 12 and 13) and by April 28 found that both Envirocare products had not degraded in this composting environment.

Conclusions

Envirocare 1 and Envirocare 2 are as durable as black plastic in the field and result in similar crop yield. However, in this study results indicate that Envirocare products did not degrade when they were incorporated into the field or when they were incorporated into on-farm compost piles. Garden Biofilm degrades completely in the soil, but it does not retain its quality long enough to be useful for long season crops. LF and Planters Paper products were suitable for a short season crop such as lettuce, but did not retain their quality for a long season crop such as watermelon. Once mulch cover fell below 50% (a quality rating of 5 or below), the product was ineffective for weed control or temperature modification. The extensive weed growth under all the paper mulch products indicates there was significant light penetration through these products.

The Kraft 81-lb and Kraft 43-lb paper mulches that were tested in 2004 were unsuitable for organic systems because the first was laminated with cement, a prohibited substance in organic farming, and the polyethylene coating on the second made it extremely difficult to remove (and removal is required by organic standards).

We plan to repeat this trial in 2006, using reformulated paper LF products and new additional cornstarch biofilms.

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Hochmuth, R.C. 2001. Field evaluation of watermelon produced on paper mulch coated with polymerized vegetable oil. North Florida Research and Education Center. Suwanee Valley, FL. <http://nfrec-sv.ifas.ufl.edu/reports_mulch.htm>

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Shogren, R.L. 2000. Biodegradable mulches from renewable resources. Journal of Sustainable Agriculture. 16:33-47.

Takakura, T., and W. Fang. 2001. Climate under cover. Kluwer Academic Publishers p 1-10 <http://ecaaser3.ecaa.ntu.edu.tw/weifang/Bio-ctrl/cuc-chap1.pdf>

Mulch Sources:

LF Paper products 1-4: Longview Fibre Company; 300 Fibre Way, P. O. Box 639, Longview, WA 98632; (360) 425-1550; www.longviewfibre.com
Planters Paper: Ken-Bar, Inc.; 25 Walkers Brook Drive, Reading, MA 01867-0704; 781-944-0003; www.ken-bar.com
Envirocare 1 and 2: Pliant Corporation; 1475 Woodfield Road, Suite 700, Schaumberg, IL, 60173; 866-878-6188; www.pliantcorp.com
Garden Bio-Film: BIOgroupUSA, Inc., 107 Regents PI., Ponte Vedra Beach, FL 32082; 904-280-5094; www.biogroupusa.com
Kraft 81-lb Paper: Newark Paperboard Products; 620 11th Ave., Longview, WA, 98632; 360-423-3420; www.newarkgroup.com (*No longer available from this source)*
Kraft 42-lb Polyethylene-coated Paper: Graphic Packaging; 814 Livingston Court, Marietta, GA, 30067; 770-644-3000; www.graphicpkg.com

Black plastic: Peaceful Valley Farm Supply P.O. Box 2209, Grass Valley, CA 95945; (530) 272-4769; www.groworganic.com

Seed Sources:

Lettuce: Variety: Pirat, from Wild Garden Seed www.wildgardenseed.com
Broccoli: 2004 Varieties: Gypsy and Green Goliath from Burpee, www.burpee.com
2005 Variety: Gypsy, from Sakata, distributed by Snow Seed Organic; www.snowseedco.com/organic.html
Watermelon: Variety: Smile, from America Takii Seeds, www.takii.com
Peppers: Variety: California Wonder, from Terra Organics; www.terraorganics.com

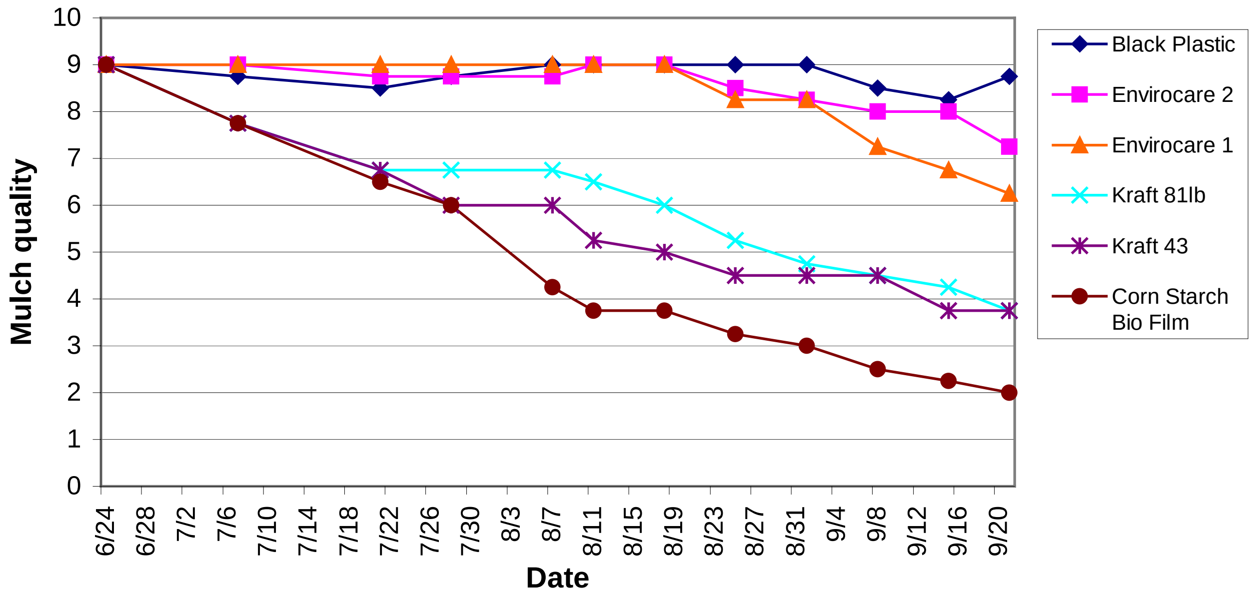

Figure 1: Mulch durability (quality over time) on a scale 0-9, where 0 is 0-9% mulch cover and 9 is 90-100% cover, in 2004 at WSU Vancouver REU.

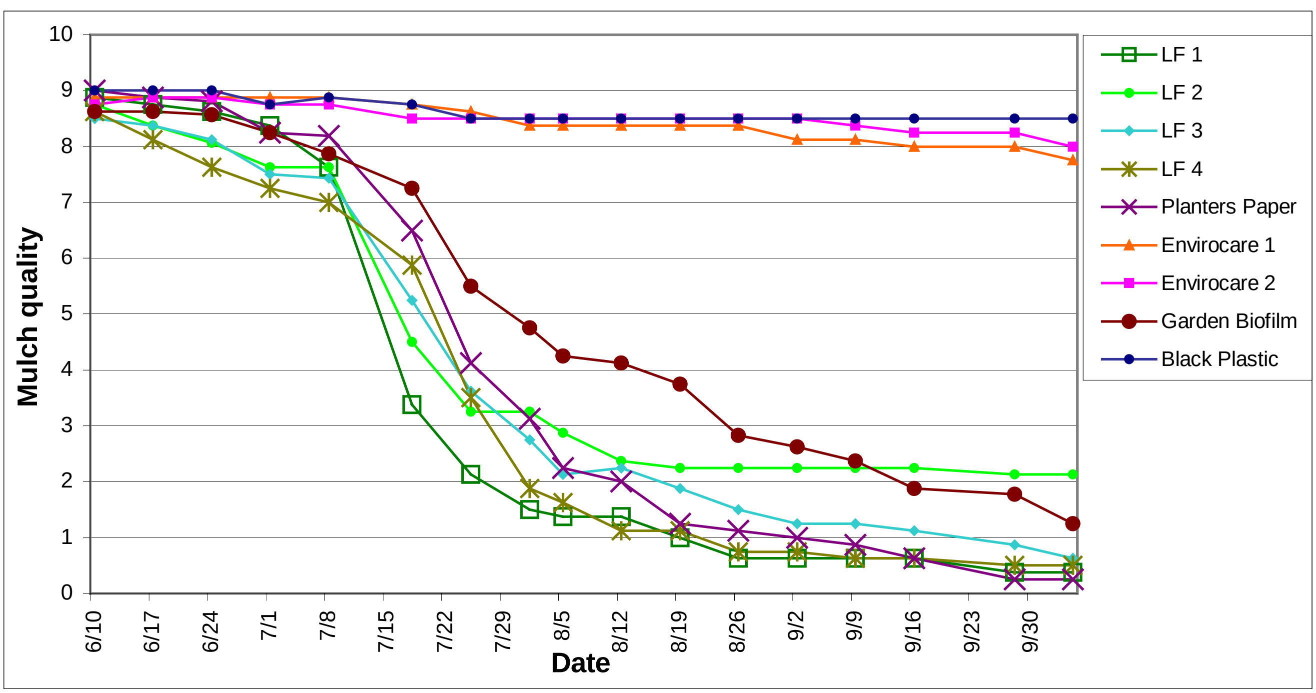

Figure 2. Mulch durability (quality over time) on a scale 0-9, where 0 is 0-9% mulch cover and 9 is 90-100% cover, in 2005 at WSU Vancouver REU.

Table 2. Mean marketable yield (kg) of lettuce, number of marketable heads per plot, and weight per head (g) in 2004 and 2005.

	Yield (kg)		No. Heads		Head Wt. (g)	
Mulch Product	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Black plastic	4.98 a	4.77 abc	18 a	19 a	276 a	202 abc
Envirocare 1	6.05 a	5.06 ab	20 a	19 a	306 a	211 ab
Envirocare 2	4.63 a	5.58 a	18 a	18 a	251 a	259 a
Garden BioFilm	5.03 a	5.55 a	20 a	19 a	252 a	245 a
Kraft 42	4.91 a		20 a		246 a	
Kraft 81lb	4.47 a		19 a		232 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		18 a		180 bcd
Planters Paper		3.71 bcd		19 a		155 bcde
P Value	**0.4588**	**0.0000**	**0.5945**	**0.0000**	**0.2225**	**0.0006**

Table 3. Mean marketable yield (kg) of broccoli, number of marketable heads per plot, and weight per head (g) in 2004 and 2005.

	Yield (kg)		No. Heads		Head Wt. (g)	
Mulch	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Black plastic	7.28 a	3.08 abc	12.8 a	11.0 ab	655 a	280 ab
Envirocare 1	4.01 b	4.19 a	6.8 b	11.5 ab	651 a	370 a
Envirocare 2	3.22 b	3.96 ab	5.3 b	11.0 ab	573 a	360 a
Garden BioFilm	4.78 ab	2.98 bc	6.3 b	11.0 ab	762 a	270 ab
Kraft 42	3.95 b		6.0 b		641 a	
Kraft 81lb	4.68 ab		7.0 b		684 a	
LF 1		1.57 d		9.8 b		150 c
LF 2		2.29 cd		11.8 ab		190 bc
LF 3		2.18 cd		9.8 b		210 bc
LF 4		2.59 cd		11.3 ab		230 bc
Planters Paper		2.03 cd		12.0 a		170 c
P Value	**0.1046**	**0.0061**	**0.0910**	**0.5566**	**0.8605**	**0.0008**

Table 4. Mean marketable yield (kg) of pepper, number of marketable fruit per plot, and weight per fruit (g) in 2004 and 2005.

Mulch	Yield (kg)		No. Fruit		Fruit Wt. (g)	
	2004	2005	2004	2005	2004	2005
Black plastic	19.48 a	3.56 a	79 a	38.75 b	253 a	90 a
Envirocare 1	14.60 a	4.76 a	82 a	56.75 a	178 a	90 a
Envirocare 2	13.44 a	3.89 a	77.3 a	45.75 ab	175 a	80 a
Garden BioFilm	22.11 a	3.68 a	80.5 a	41.5 ab	270 a	90 a
Kraft 42	15.90 a		62.8 a		227 a	
Kraft 81lb	11.23 a		70.5 a		164 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		3.75 c		30 d
Planters Paper		0.06 b		1.25 c		50 cd
P Value	**0.6797**	**0.0000**	**0.5653**	**0.0000**	**0.7115**	**0.0000**

Table 5. Mean marketable yield (kg) of watermelon, number of marketable fruit per plot, and weight per fruit (g) in 2004 and 2005.

Mulch	Yield (kg)		No. Fruit		Fruit Wt. (kg)	
	2004	2005	2004	2005	2004	2005
Black plastic	55.1 a	16.2 c	18.8 ab	9.0 c	3.1 a	1.8 b
Envirocare 1	71.2 a	37.7 a	24.0 a	15.5 a	2.9 a	2.4 a
Envirocare 2	50.4 ab	26.9 b	17.5 ab	10.8 bc	2.8 a	2.4 a
Garden BioFilm	47.5 ab	20.0 bc	16.3 abc	12.5 ab	3.0 a	1.5 bc
Kraft 42	44.9 ab		13.8 bc		3.2 a	
Kraft 81lb	19.6 b		7.0 c		2.7 a	
LF 1		1.0 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		3.0 d		3.5 d		0.8 d
Planters Paper		2.0 d		2.3 d		0.8 d
P Value	**0.0650**	**0.0000**	**0.0307**	**0.0000**	**0.5727**	**0.0000**

Table 6. Correlation between mulch quality and yield in 2005.

Correlation of mean mulch quality and total yield		
	r-value	p-value
Broccoli	0.8733	0.0021
Peppers	0.8907	0.0013
Watermelons	0.8594	0.0030
Lettuce		

Correlation of final mulch quality and total yield		
	r-value	p-value
Broccoli	0.835	0.0051
Peppers	0.8253	0.0062
Watermelons	0.804	0.009
Lettuce		

Table 7. Days after transplanting to maturity of lettuce, broccoli, pepper and watermelon in 2004 and 2005.

	Lettuce		Broccoli		Pepper		Watermelon	
Mulch	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Black plastic	34	46	76	84 cd	91	102 d	85	106 ab
Envirocare 1	33	46	67	80 d	89	106 bcd	80	103 ab
Envirocare 2	35	46	71	80 d	89	109 bc	83	104 ab
Garden BioFilm	34	46	67	85 bcd	85	105 cd	83	96 b
Kraft 42	34		68		87		83	
Kraft 81lb	33		68		86		88	
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		88 bc		114 a		106 ab
Planters Paper		46		91 ab		117 a		111 a
P Value	**0.5875**	**n/a**	**0.0687**	**0.0001**	**0.3536**	**0.0002**	**0.5414**	**0.3405**

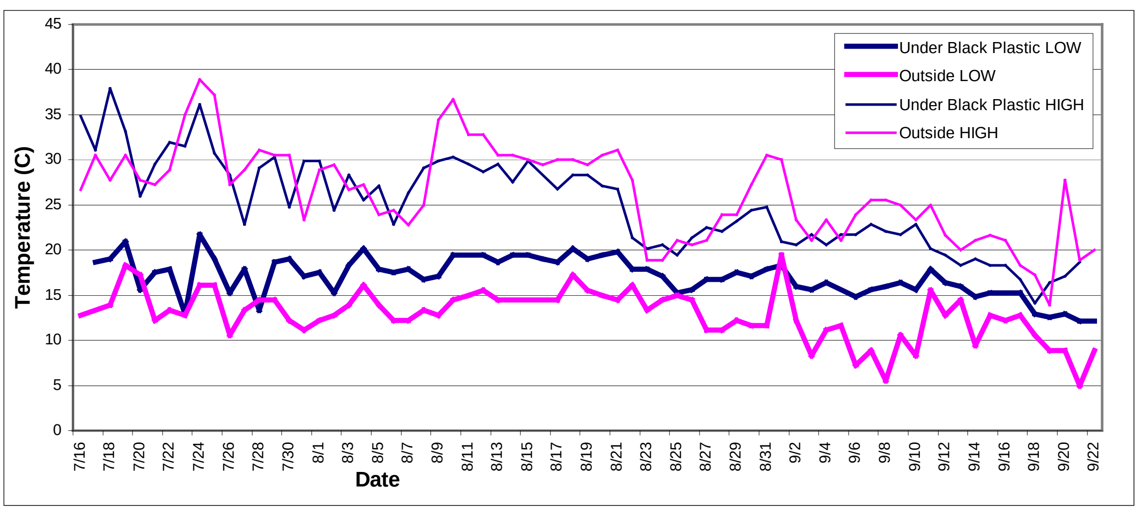

Figure 3. Maximum and minimum temperatures under black plastic and at the soil surface on bare ground in 2004.

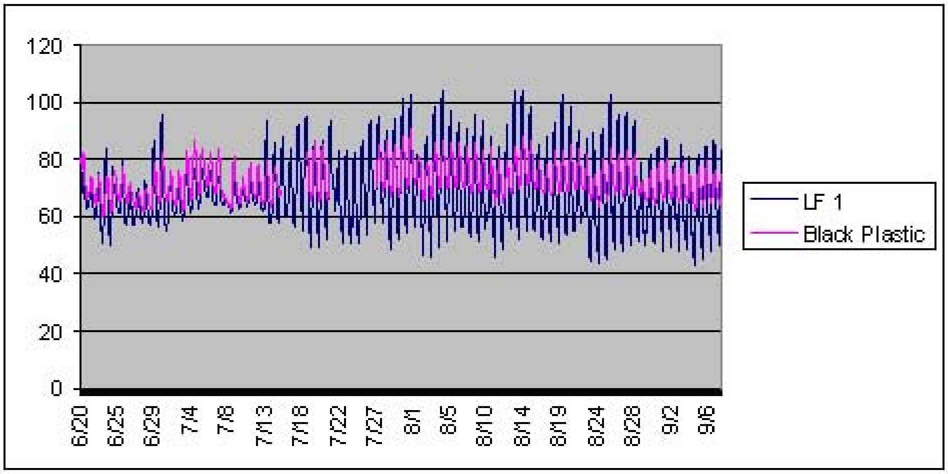

Figure 4. Temperatures under black plastic and under LF 1 paper mulch in 2005.

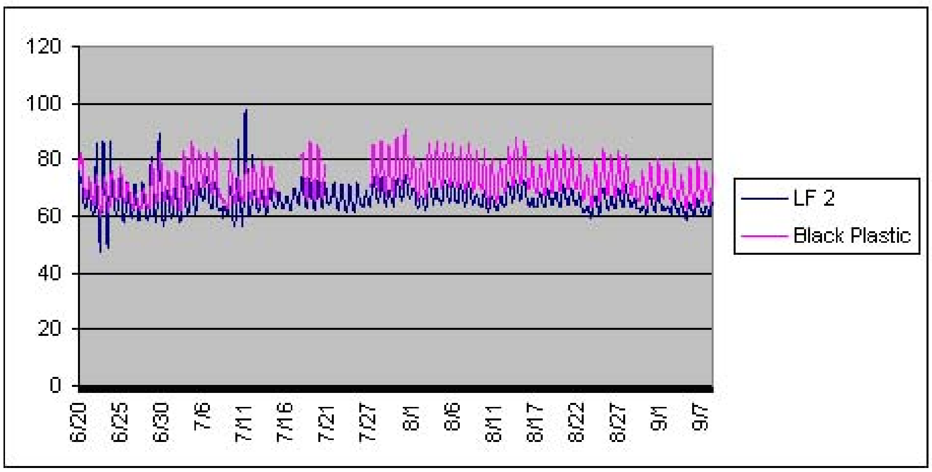

Figure 5. Temperatures under black plastic and under LF 2 paper mulch in 2005.

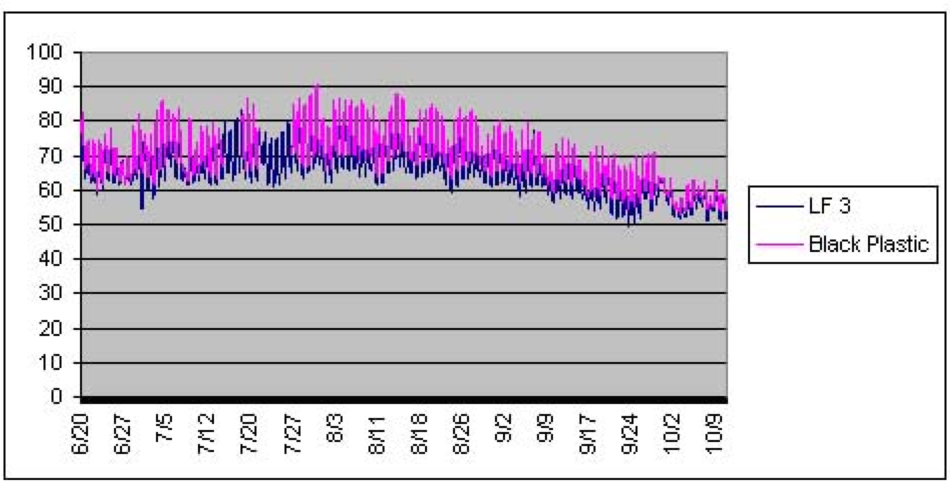

Figure 6. Temperatures under black plastic and under LF 3 paper mulch in 2005.

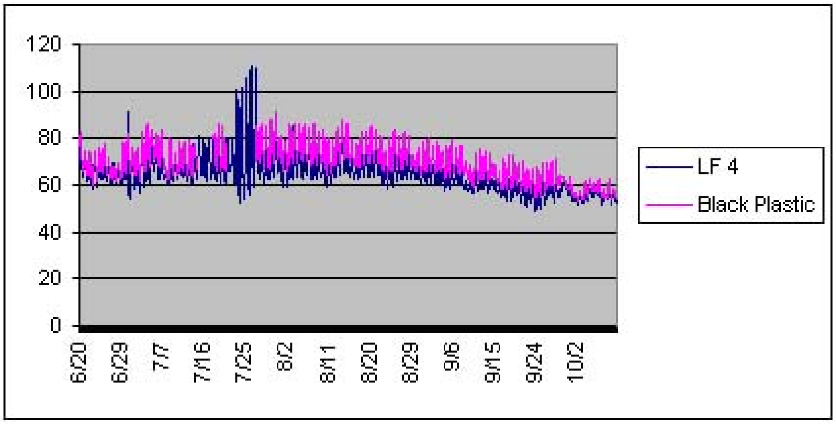

Figure 7. Temperatures under black plastic and under LF 4 paper mulch in 2005.

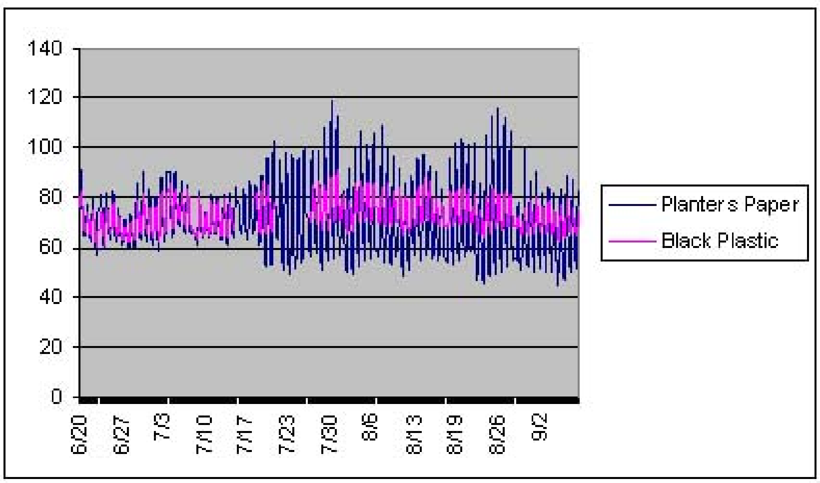

Figure 8. Temperatures under black plastic and under Planters Paper mulch in 2005.

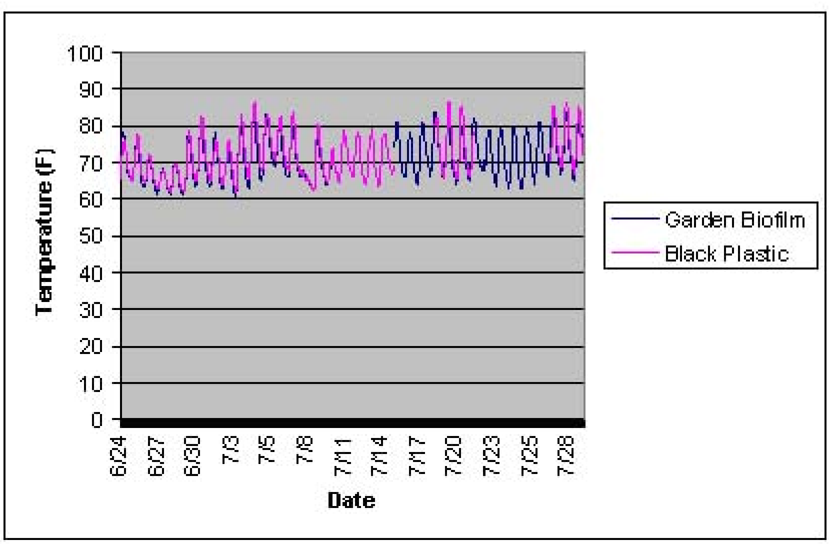

Figure 9. Temperatures under black plastic and under Garden Biofilm mulch in 2005.

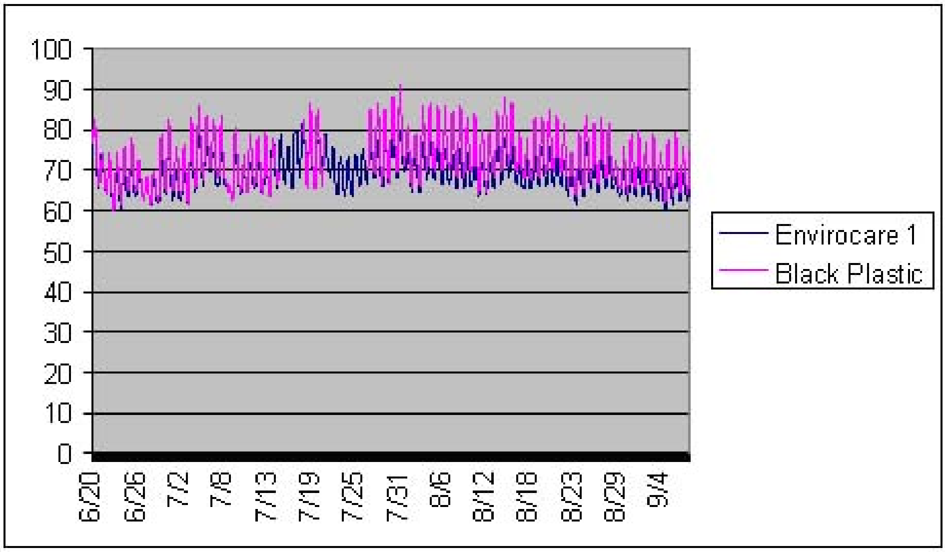

Figure 10. Temperatures under black plastic and under Envirocare 1 mulch in 2005.

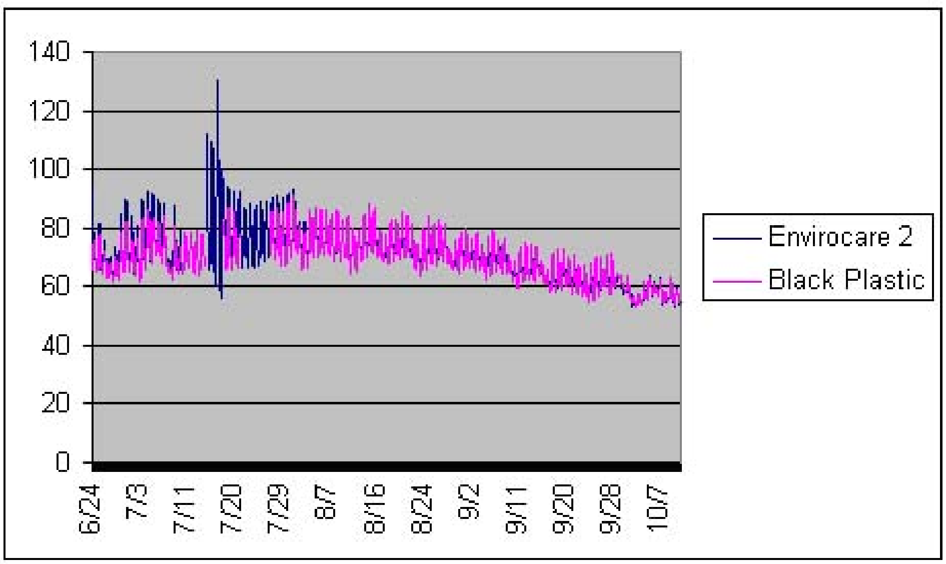

Figure 11. Temperatures under black plastic and under Envirocare 2 mulch in 2005.

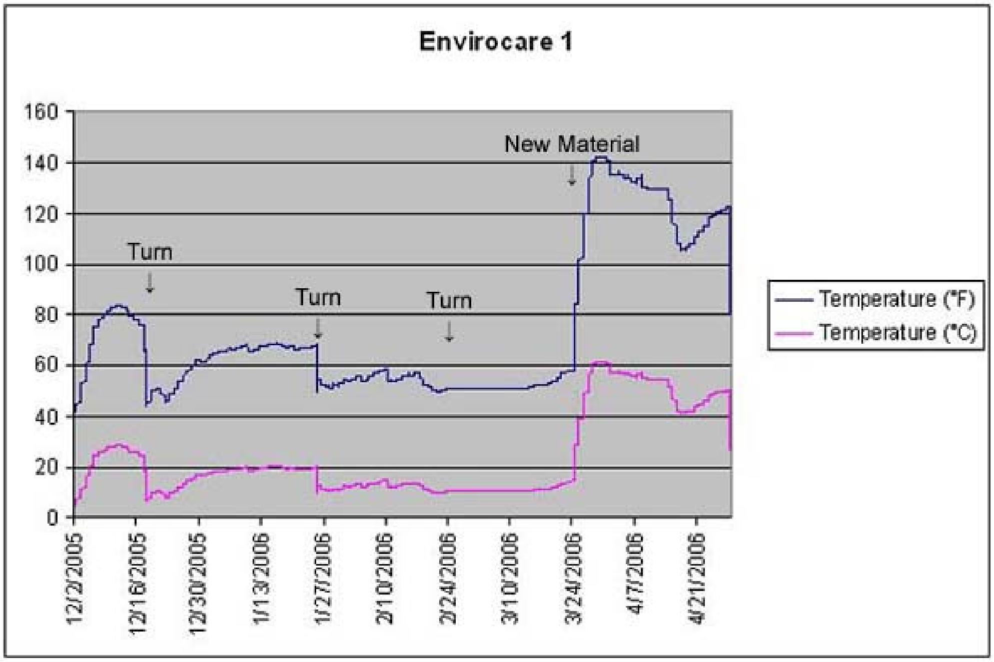

Figure 12. Temperatures in on-farm compost pile from December through April that included Envirocare 1 mulch product.

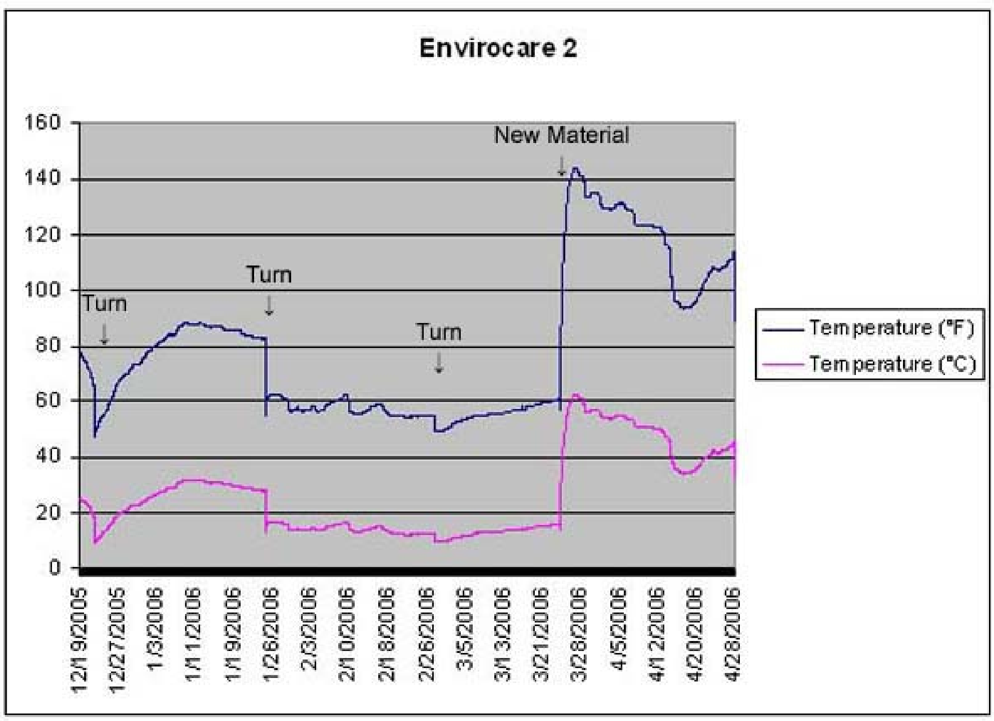

Figure 13. Temperatures in on-farm compost pile from December through April that included Envirocare 2 mulch product.