Weed Control Efficacy of Organic Mulches in Two Organically Managed Bell Pepper Production Systems

Derek M. Law, A. Brent Rowell, John C. Snyder, and Mark A. Williams[1]

ADDITIONAL INDEX WORDS. compost, straw, wood chips, living mulch, corn gluten, *Capsicum annuum*, shallow cultivation, drip irrigation, raised beds, *Trichogramma ostriniae*

SUMMARY. A 2-year field study in Lexington, Ky., evaluated weed control efficacy and influence on yields of several organic mulches in two organically managed bell pepper (*Capsicum annuum*) production systems. Five weed control treatments [straw, compost, wood chips, undersown white dutch clover (*Trifolium repens*) "living mulch," and the organically approved herbicide corn gluten] were applied to two production systems consisting of peppers planted in double rows in either flat, bare ground or on black polyethylene-covered raised beds. In the first year, treatments were applied at transplanting and no treatment was found to provide acceptable season-long weed control. As a result, bell pepper yields in both production systems were very low due to extensive weed competition. First year failures in weed control required a modification of the experimental protocol in the second year such that treatment application was delayed for 6 weeks, during which time three shallow cultivations were used to reduce early weed pressure and extend the control provided by the mulches. This approach increased the average weed control rating provided by the mulches from 45% in 2003 to 86% in 2004, and resulted in greatly improved yields. In both years, polyethylene-covered raised beds produced higher yields than the flat, bare ground system (8310 lb/acre compared to 1012 lb/acre in 2003 and 42,900 lb/acre compared to 29,700 lb/acre in 2004). In the second year, the polyethylene-covered bed system coupled with mulching in-between beds with compost or wood chips provided excellent weed control and yields. When using the wood chip mulch, which was obtained at no cost, net returns were $5587/acre, which is similar to typical returns for conventionally grown peppers in Kentucky. Net returns were substantially decreased when using compost due to the purchase cost. Results from this study indicate that shallow cultivation following transplanting, combined with midseason mulch application, resulted in high yields in an organically managed bell pepper system that were comparable to yields of most varieties grown conventionally in a variety trial conducted on the same farm.

Production losses from weed competition are among the most important crop management concerns for organic growers, and the ability to control weeds is considered a major limiting factor for farmers wishing to transition to organic production systems (Bond and Grundy, 2001; Walz, 2004). As farmers in Kentucky and other states move away from tobacco (*Nicotiana tabacum*) as a result of the federal government's ending of the tobacco price-stabilization program, production of alternative crops such as vegetables has increased. In this region, as in many parts of the country, growers have expressed interest in organic vegetable production in response to the ever-increasing demand for organic products (Organic Trade Association, 2004). A major constraint for these growers is the lack of research-based information on organic production practices, particularly regarding weed management. There are many weed management techniques used by organic farmers, such as mechanical cultivation and the use of polyethylene and organic mulches; the most effective and economically sustainable organic production systems integrate a combination of practices into a whole-farm management approach. Cover crops, crop rotations, and balanced nutrient availability are all important elements in an organic farm's weed management plan, and when combined with well-timed cultural practices, successful nonchemical weed control is possible (Bond and Grundy, 2001; Grubinger, 1999).

The use of polyethylene mulch with drip irrigation is an important and widespread practice in commercial vegetable production systems, and although polyethylene mulch is allowed in organic vegetable production, the identification of alternatives is important to many organic producers (Lamont, 1993; Schonbeck, 1998; Wittwer, 1993). Despite advantages such as increased weed control, earlier and higher yields, reduction of nutrient leaching, and increased soil moisture retention, polyethylene mulch has disadvantages, such as difficulty of removal, cost of disposal, increased soil erosion, and increased agricultural chemical runoff (Brown and Channell-Butcher, 2001; Hochmuth, 1998; Lamont, 1993; Rice et al., 2001). Organic mulches such as straw, wood chips, or compost can conserve soil moisture, reduce soil erosion, suppress weeds, and may also have advantages of low cost, with no removal requirement (Aparbal-Singh et al., 1985; Davis, 1994; Feldman et al., 2000; Isenberg and Odland, 1950; Roe et al., 1992; Singh, 1992). Organic mulches have also been shown to improve soil quality

University of Kentucky, Department of Horticulture, N-318 Agricultural Sciences North, Lexington, KY 40546-0091.

This research was partially funded by the New Crop Opportunities Center at the University of Kentucky through a USDA Special Grant. Experiment Station manuscript number: 05-11-042

[1]To whom reprint requests should be addressed; e-mail address: mawillia@uky.edu

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
1	cbar	kPa	1
7.8125	fl oz/gal	$mL \cdot L^{-1}$	0.1280
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	ppm	$mg \cdot L^{-1}$	1
1.8893	$yard^3$/acre	$m^3 \cdot ha^{-1}$	0.5293

and stimulate soil microbial communities due to the addition of organic matter (Lalande et al., 1998; Olsen and Gounder, 2001; Ozores-Hampton, 1998). Possible disadvantages of organic mulches include nutrient tie-up and lowering of soil temperatures to sub-optimum levels (Hill et al., 1982; Schonbeck and Evanylo, 1998). Living mulches planted during the growth of the cash crop have been shown in some cases to compete well with weeds and provide soil cover (Paine and Harrison, 1993). In addition to organic mulches, there are a limited number of organically approved products, such as corn gluten meal, that have been shown to exhibit herbicidal properties (McDade and Christians, 2000).

Although research on the benefit and use of mulches is extensive, little is known about how to optimize their use in organically managed systems. Applications of straw, compost, wood chips, living mulch, and corn gluten are all allowed under U.S. Department of Agriculture organic certification standards. Many farmers in Kentucky converting from tobacco to vegetable production have adopted the polyethylene mulched raised bed (plasticulture) system with drip irrigation for bell pepper production. As a result, bell peppers have become one of the most popular and profitable vegetable crops grown in the state. In this study, four organic mulches (wood chips, straw, compost, and undersown clover "living mulch") and the organically approved herbicide corn gluten were evaluated for weed suppression and effects on yield when incorporated into organically managed flat, bare ground and plasticulture production systems. Our objective was to determine which treatments could be effectively used for weed management in two organically managed bell pepper production systems.

Materials and methods

2003 EXPERIMENT. Six weed control treatments in two bell pepper production systems were compared for their weed control efficacy and influence on yields. The weed control treatments were straw mulch, wood chip mulch, compost mulch, corn gluten, a "living mulch" of undersown dutch clover, and an untreated control (weedy check). The bell pepper variety Aristotle (Seminis, Oxnard, Calif.) was chosen for its high yields, high quality, and resistance to bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*). Seeds were sown in Sunshine Organic Gro-mix (Sun Gro Horticulture, Bellevue, Wash.) on 23 Mar. and transferred on 14 Apr. to individual cells (Styrofoam, 72 cells/tray; Speedling, Sun City, Fla.) containing the same media. While in the greenhouse plants were fertigated nine times with Omega 6–6–6 (6N–2.6P–5K), (Peaceful Valley Farm Supply, Grass Valley, Calif.) at a rate of 25 fl oz/gal of water. The experimental field had been planted in a winter wheat (*Triticum aestivum*) cover crop (80 lb/acre; Southern States, Lexington, Ky.) on 21 Oct. 2002. Following plowing and disking on 15 May 2003, but prior to transplanting, a pelleted organic fertilizer, Nature Safe Fine 10–2–8 (10N–0.9P–6.6K) (Griffin Industries, Cold Spring, Ky.), was spread and incorporated at a rate of 60 lb/acre of nitrogen (N). An additional total of 55 lb/acre of N was fertigated in six weekly doses through drip irrigation using liquid Phytamin 7–0–0 (7N–0P–0K) (California Organic Fertilizers, Fresno, Calif.). Trichogramma wasps (*Trichogramma ostriniae*) (IPM Laboratories, Locke, N.Y.) were released for european corn borer (*Ostrinia nubilalis*) control on 18 and 25 July, and on 1 Aug., at a rate of 150,000/acre per release (Friley et al., 2003).

The experimental design was a randomized complete block with four replications with a split plot arrangement of treatments. Main plots were the production systems: 1) flat, bare ground and 2) raised beds covered with black polyethylene mulch. Subplots consisted of five weed control treatments and an untreated control applied to two double-row beds. Main plots consisted of two double-row beds 75 ft long spaced on 6-ft centers. Peppers were spaced 12 inches apart within rows with 18 inches between the double rows. Subplots were 12 ft long and 12 ft wide and mulch treatments were applied to bare ground in both production systems. For the flat, bare ground system, mulches were spread evenly within 1 inch of the transplants. For the polyethylene-covered raised bed system, mulch treatments were applied only to exposed soil between beds (row middles). Drip irrigation was used on all plots. Tensiometers were placed in black polyethylene and flat ground main plots and water was applied when readings of 30 cbar were reached.

Mulch treatments were applied at transplanting on 5 June, except for the living mulch treatment. Wood chips and compost were applied to a depth of 3 inches (408 yard^3/acre) while the wheat straw was spread to a depth of 6 inches (817 yard^3/acre). Compost (0.01N–0.006P–0.35K) was obtained from Creech Compost Co., Lexington, Ky., a local producer of compost derived from horse muck. Baled wheat straw was obtained from a local farm supply store and wood chips were obtained without charge from a regional tree trimming businesses. Corn gluten meal (Bioscape, Petaluma, Calif.) was applied at a rate of 2178 lb/acre four times at approximately 2-week intervals during July and Aug. All mulch treatments and the corn gluten were applied by hand. The living mulch treatment consisted of white dutch clover, (Southern States) sown on newly cultivated soil at a rate of 20 lb/acre, 11 d after pepper transplanting (after transplant recovery). Following mulch applications, weeds were not managed in any other way for the remainder of the season. Weed control was rated on 10 July and 4 Aug. using visual estimation on a 0 to 100% scale with 0% equaling no observable control and 100% equaling complete weed control. Weed ratings for the flat, bare ground system included the entire subplot covered by organic mulch, while only the row middles in between the black polyethylene-covered raised beds were evaluated in the plasticulture system. Areas immediately adjacent to the experimental plots that had also been plowed and disked, but were otherwise undisturbed for the entire season, were also rated for weed growth and used as a 0% control for comparison. Weed species were identified throughout the season and an inventory was compiled. Peppers were harvested on 4 and 24 Aug., and after grading into marketable fruits or culls, were counted and weighed. The weights of marketable peppers were used in the marketable yield determinations.

2004 EXPERIMENT. Because none of the 2003 treatments resulted in acceptable weed control, all plots in 2004 were shallow cultivated (<1 inch deep) by hand hoeing three times at 2-week intervals after transplanting but prior to mulch application. These cultivations were intended to simulate mechanical cultivation and to potentially shift the period of weed control provided by the mulch treatments to later in the growing season. The corn gluten treatment was eliminated due to ineffective weed control and low marketable yields in 2003. The "living mulch" dutch clover was also eliminated because of its slow germination and growth, which substantially reduced its ability to compete with weeds. A treatment utilizing shallow cultivation at approximately2-week intervals throughout the season was included for comparison.

Untreated seeds of the bell pepper 'Red Knight' (Seminis) were sown 29 Mar. and young seedlings transferred to individual cells (Styrofoam, 253 cells/tray; Speedling) containing organic potting media Sunshine Organic Gro-mix (Sun Gro Horticulture) on 16 Apr. 'Red Knight' was chosen for its high yields, resistance to bacterial spot, and because untreated seed of 'Aristotle' was unavailable. Fish emulsion [Maxicrop Liquid Fish Fertilizer 5–1–1 (5N–0.4P–0.8K), Elk Grove Village, Ill.] was used as the primary N source for the transplants. However, repeated use of this product resulted in a crust on the soil surface that limited water penetration and delivery of nutrients to the roots. Threatened with the loss of these transplants and the entire 2004 field trial, conventional 20–10–20 (20N–4.4P–16.6K, 150 ppm) soluble fertilizer was applied twice as a rescue treatment. Although synthetic fertilizers are unacceptable for certified organic production, it was necessary in this case to ensure transplant survival. All other production practices in this study were consistent with organic certification guidelines.

Peppers were transplanted in a field on 8 June that had been cover cropped with two consecutive plantings. During the preceding summer, plots had been planted with sorghum-sudangrass (*Sorghum bicolor* x *S. bicolor* var. *sudanese*), (60 lb/acre; NC+ Organics, Grand Junction, Iowa) and cowpeas (*Vigna unguiculata*), (20 lb/acre; Southern States) that was plowed in the fall. That cover crop was followed by rye (*Secale cereale*), (80 lb/acre; NC+ Organics) and hairy vetch (*Vicia villosa*), (40 lb/acre; NC+ Organics) as a winter cover crop. This was plowed on 23 May and was estimated to provide at least 40–50 lb/acre of total N using the technique described in Bowman et al. (1998). On 7 June an additional 45 lb/acre of N in the form of Nature Safe Fine 10–2–8 fertilizer was surface-applied and incorporated with a shallow cultivation. An additional total of 30 lb/acre of N was fertigated in two doses at mid-season through the drip irrigation system using Phytamin 7–0–0 as in 2003. Trichograma wasps were released on 16 July and 14 Aug., at a rate of 150,000/acre per release for european corn borer control.

As in 2003, the experimental design was a randomized complete block with four replications with a split plot arrangement of treatments. Main plots were the same while subplots consisted of three mulch treatments from 2003 (compost, wood chips, and straw), a control (weedy check), and a cultivated treatment. The main and subplot dimensions, as well as pepper spacings, were as in 2003. Mulch treatments were applied after shallow cultivation (described previously). Drip irrigation was used on all plots. Tensiometers were used to determine water application as in 2003.

Mulches were obtained from the same sources as in 2003 and were applied by hand on 20 July. After 20 July, cultivated plots were shallow cultivated (<1 inch deep) by hand hoeing five times at approximately 2-week intervals. For the control plots (weedy checks) cultivation ceased after 20 July. Wood chips and compost were applied as in 2003. Weed control was evaluated on 30 Aug. and 8 Oct. using the visual scale as in 2003. A weed inventory was also compiled. Peppers were harvested on 5, 16, and 30 Aug.; 16 Sept.; and 11 Oct. Fruits were graded and weighed as in 2003. To determine the mid-harvest date as a measure of earliness, yields for each date were multiplied by the serial value of the harvest date (days after 1 Jan. 1900). These products were summed, and then divided by total weight harvested. The resulting quotients were then converted to Julian dates.

Analysis of variance of all data was conducted using the PROC GLM procedure of SAS (SAS Institute , Cary, N.C.). Main effect means (production systems) were separated by a single degree-of-freedom F-tests, while subplot means (weed control treatments) were separated by Waller–Duncan K-ratio *t* tests. When the F-test for the interaction between production system and weed control treatment was significant, means were separated by *t* test, using the LSMeans options of PROC GLM. Weed control data for the three mulch treatments that were common to both years were combined and analyzed. Year was assumed to be a random variable in the analysis conducted by use of PROC GLM.

Economic analysis. A partial budget analysis was used to compare costs and returns among organic weed control treatments for the two production systems (polyethylene/raised beds and flat, bare ground) in 2004. The partial budget itemizes only costs and returns that are directly affected by changes in treatments; it includes (but does not show) all itemized costs as in a complete crop budget. Production costs not affected by treatments were based on estimates published by the University of Kentucky (Isaacs et al., 2004). Costs associated with organic mulch and other treatments were determined as follows.

The "mulch application charge" was calculated for hand application. An average of 15 min was required for one worker to apply mulch to one plot (about 20 min for 144-ft^2 plots on flat ground, about 10 min for 72-ft^2 in the polyethylene-mulched plots). A labor rate of $8/h was used. Mulch transportation costs were not included.

"Cultivation costs" were estimated using the same fuel and oil costs from the University of Kentucky conventional bell pepper crop budget ($2.55/h). It was estimated that it would take approximately 2 h to cultivate 1 acre of peppers, resulting in a cost of $5.10/cultivation. Repair costs in the conventional pepper budget were $30/acre; since there was additional use of the equipment for cultivation in the organic system, we added $15/acre for repairs for three cultivations and $45/acre for six cultivations.

"Total production costs" included production inputs, some of which are not itemized in the partial budgets. Total production costs included seed, flats, organic potting media, lime, preplant fertilizer, soluble fertilizer, black polyethylene mulch, drip tape, trichogramma wasps, mulch, mulch application charges, cultivation, oil and fuel, repairs, transplanting labor, and irrigation labor.

"Total harvesting and marketing costs" included boxes, polyethylene mulch disposal labor, a polyethylene mulch disposal fee, marketing costs, fuel and oil, and labor for harvest, packing and grading. All except the disposal labor and fee, and fuel/oil were dependent on yield.

"Total variable costs" were the sum of total production costs and total harvesting and marketing costs. In addition, an interest charge was included that took into account the opportunity cost for money spent rather than saved. The following formula was used to calculate interest:

$$\text{Interest} = [(A \times B \times (4/12)] + [(C \times D \times (2/12)]$$

where A = total production cost; B = 0.06%; 4 months/12 months = portion of a year that money was unavailable; C = total harvesting and marketing cost; D = 0.06%; and 2 months/12 months = portion of a year that money was unavailable.

Total fixed costs (not shown in the partial budgets) were the same for all treatments and included depreciation on machinery, depreciation on irrigation equipment, taxes and insurance. "Total expenses" are the sum of all variable and fixed costs.

Results

WEED CONTROL. For the 10 July 2003 weed control rating, the mean square for weed control treatments was highly significant, while the mean squares for production systems and interaction of production systems with weed control treatments were nonsignificant. The lack of significant interaction between production systems and weed control treatments was not surprising because weed control ratings were made only on the areas covered by the treatments, and did not include the weed control provided by the polyethylene mulch. With regard to differences among weed control treatments, only the straw and wood chip mulch treatments gave acceptable levels (>70% of control), while corn gluten and the untreated control gave the worst (Table 1).

The 4 Aug. 2003 weed control rating was consistent with the 10 July 2003 rating in that the only significant source of variance was the weed control treatments. As the season progressed, weeds grew in all treatments, overwhelming the crop by harvest time. In the polyethylene mulched system, weeds grew in between the beds to the point that they substantially shaded the pepper plants. Straw mulch gave the highest level of weed control, followed by wood chips, but their respective ratings of 34% and 20% control were not adequate for commercial production (Table 1); the other treatments (compost, clover, and corn gluten) were even less effective. These results indicated that a single mulch application at planting did not provide effective season-long weed control.

In 2004, when weed control was first assessed on 20 Aug., the mean square for weed control treatments was again significant, while that for production system was not. The three mulch treatments provided weed control similar to that in the cultivated treatment and considerably better than the weedy check (Table 2). At this date, there also was a significant interaction between production systems and treatments, mainly caused by the weedy checks, which had an average of 50% weed control on flat, bare ground but 60% in the plasticulture system (data not shown).

For the 4 Oct. 2004 assessment date, the mean square for weed control treatments was again significant while that for production systems was not. Also, there was a significant interaction between production systems and weed control treatments, mainly caused by the straw mulch which unexplainably performed poorly in the plasticulture system (45% control) compared to the flat, bare ground system (83% control). Differences in weed control efficacy were apparent among the treatments, with compost being the most effective weed suppressor, followed by wood chips and straw (Table 2). The cultivation treatment provided effective weed control, although by the end of the season there was no significant difference between this labor-intensive technique and the compost treatment.

Three treatments (compost, wood chips, straw) were common to both years of the study. When the data for the 2 years were combined and analyzed, there was a highly significant year effect ($P < 0.0001$), with an average weed control rating of 45% in 2003 and 86% in 2004, indicating that the cultivations in 2004 likely improved overall weed control.

Weed diversity in both years of the study was essentially the same, and included many horticulturally significant species such as velvetleaf (*Abutilon theophrasti*), lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia*), ivy leaf morning glory (*Ipomea hederacea*), field bindweed (*Ipomea purpurea*), pigweed (*Amaranthus retroflexus*), pennsylvania smartweed (*Persicaria pensylvanica*), galinsoga (*Galinsoga parviflora*), prickly sida (*Sida spinosa*), foxtail (*Setaria glauca, S. viridis*), johnsongrass (*Sorghum halapense*), yellow nutsedge (*Cyperus esculentus*), and crabgrass (*Digitaria* spp.). The weed distribution was consistent with that on the rest of the research farm and

Table 1. Efficacy of weed control treatments averaged over flat ground and polyethylene-mulched raised bed organic bell pepper production systems on two assessment dates in 2003.

Weed control treatment	Assessment dates: 10 July 2003	4 Aug. 2003
	Control (%)[z]	
Straw	83 a	34 a
Wood chips	73 b	20 b
Compost	54 c	9 c
Clover	54 c	8 c
Corn gluten	13 d	3 c
Control	13 d	3 c

[z]Means in a column and year followed by the same letter(s) are not significantly different (Waller–Duncan K-ratio *t* test, $P = 0.05$).

Table 2. Efficacy of weed control treatments averaged over flat ground and polyethylene-mulched raised bed organic bell pepper production systems on two assessment dates in 2004.

Weed control treatment	Assessment dates: 20 Aug. 2004	4 Oct. 2004
	Control (%)[z]	
Compost	95 a	92 a
Cultivated	93 a	90 a
Wood chips	92 a	77 b
Straw	95 a	63 c
Control	55 b	17 d

[z]Means in a column and year followed by the same letter(s) are not significantly different (Waller–Duncan K-ratio *t* test, $P = 0.05$).

individual species appeared throughout the plots with no treatment providing better control of a particular species (data not shown).

Marketable yields and earliness. For the 2003 marketable yield, the mean squares for production systems, weed control treatments, and the interaction of production systems with weed control treatments were significant. The overall average marketable yield for the plasticulture system (8310 lb/acre) was considerably greater than the average yield for the flat, bare ground system (1012 lb/acre). On average, corn gluten resulted in the poorest yield (Table 3). The yields for the straw, compost and woodchips were significantly greater than that for the control (Table 3). The significant interaction between production system and treatments (P<0.001) resulted mainly from a difference in magnitude of response among the weed control treatments in the two production systems (Table 4). For example, yield from the compost treatment in the plasticulture system was 2.6 times that of the same treatment in the bare ground system; for clover, yield from the plasticulture system was 53 times that of the clover treatment in the bare ground system. As an extreme example, the ratio between the two systems was infinite for the corn gluten treatment because the bare ground system treated with gluten had no marketable yield.

Similar to 2003 marketable yield, in 2004 the mean square for production systems was significant, while the interaction of production systems with weed control treatments was not significant (Table 4). Unlike 2003, the mean square for production systems was not significant, but nearly so (P=0.07). The average marketable yield from the plasticulture system was more than 42,900 lb/acre and from the bare, flat ground system, more than 29,700 lb/acre. Although, as mentioned previously, the underlying mean square for production systems was not significant (P = 0.07), separation by t test indicated differences among means; compost resulted in the highest overall yield, while the lowest yields resulted from the straw mulch and uncultivated control (Table 3).

Production systems and mulches, but not their interaction, had a significant impact on earliness in 2004 (2003 data were not analyzed because of extensive weed pressure and low yields). The average 2004 harvest midpoint date was 28 Aug. for raised beds and black polyethylene mulch, and 5 Sept. for flat, bare ground plots. This 8 d difference in midpoint harvest dates was highly significant (P < 0.01). Among treatments, use of any mulch tended to delay harvest midpoint by 4–7 d (Table 5). The longest delay was associated with compost, which was significantly different than the cultivated and control treatments (Table 5).

Table 3. Yield of marketable bell peppers[z] as affected by weed control treatments on both flat ground and polyethylene-mulched raised bed organic bell pepper production systems in 2003 and 2004.

Weed control treatment	Marketable yield[y] (lb/acre) 2003	2004
Straw	6373 a	33380 b
Wood chips	5548 ab	36946 ab
Compost	5746 ab	40204 a
Clover	4273 bc	---
Control	3696 c	33256 b
Corn gluten	1824 d	---
Cultivated	---	37768 ab

[z]Marketable bell peppers included extra-large, large, medium, and choppers in 2003; extra-large, large, and medium in 2004.
[y]Means in a column followed by the same letter(s) are not significantly different (Waller–Duncan K-ratio t test, P < 0.05); 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.

Table 4. Yield of marketable bell peppers[z] as affected by weed control treatments applied as mulches on flat ground or polyethylene-mulched raised beds in 2003 and 2004.

Production system	Weed control treatment	Marketable yield[y] (lb/acre) 2003	2004
Polyethylene mulch	Straw	12424 a	38511
	Wood chips	10162 ab	42516
	Clover	8387 b	---
	Compost	8300 bc	46345
	Control	6938 c	40949
	Corn gluten	3648 d	---
	Cultivated	---	46258
Flat ground	Compost	3192 d	34062
	Wood chips	933 ef	31375
	Control	453 f	25562
	Straw	322 f	28249
	Clover	158 f	---
	Corn gluten	0 f	---
	Cultivated	---	29278
Interaction[x]	PS[w] × WCT[v]	***	NS

[z]Marketable bell peppers included extra-large, large, medium, and choppers in 2003; extra-large, large, and medium in 2004.
[y]Means followed by the same letter are not significantly different (P < 0.05), (1 lb/acre = 1.1209 $kg \cdot ha^{-1}$).
[x]Interaction refers to the interaction of main effects, production systems, and weed control treatments.
[w]PS = Production system.
[v]WCT = Weed control treatment.
NS, ***Nonsignificant or significant at P < 0.001, respectively.

Table 5. Dates at which 50% of the total pepper harvest was completed for five weed control treatments on flat ground and polyethylene-mulched raised bed organic bell pepper production systems in 2004. The average harvest midpoint for polyethylene-mulched raised beds was 28 Aug., and 5 Sept. for flat ground.

Weed control treatment	Harvest midpoint[z]	Time after transplanting (d)
Straw	6 Sept. ab	91
Wood chips	6 Sept. ab	91
Compost	9 Sept. a	94
Cultivated	2 Sept. b	87
Control	2 Sept. b	87

[z]Means in a column followed by the same letter(s) are not significantly different (Waller–Duncan K-ratio t test, P < 0.05).

Table 6. Partial budget analyses for four weed control treatments used in two organic bell pepper production systems (flat ground and polyethylene-mulched raised beds), 2004. All data except yields are reported in dollars per acre.

	Flat ground					Polyethylene-mulched raised beds				
Associated expenses/returns	Compost mulch	Straw mulch	Wood chip mulch	Cultivated	Control	Compost mulch	Straw mulch	Wood chip mulch	Cultivated	Control
Black polyethylene mulch/drip	---	---	---	---	---	300	300	300	300	300
Organic mulch	10830	1513	0	---	---	5041	756	0	---	---
Organic mulch application charge	600	600	600	---	---	300	300	300	---	---
Cultivation costs	15	15	15	31	15	15	15	15	31	15
Machinery repairs	45	45	45	75	45	45	45	45	75	45
Weed control, total costs	11516	2198	686	131	86	5727	1442	686	431	386
Total production cost	13028	3711	2198	1644	1598	7239	2955	2198	1944	1898
Total harvesting and marketing cost	4546	3772	4189	3910	3415	6269	5227	5759	6258	5555
Total variable cost	17880	7595	6473	5625	5079	13716	8293	8059	8303	7546
Total expenses	18200	7915	6793	5945	5399	14036	8613	8379	8623	7866
Yield (no. boxes harvested)[z]	1216	1008	1120	1045	912	1655	1375	1518	1652	1463
Gross returns[y]	9728	8064	8960	8360	7296	13240	11000	12144	13216	11704
Gross returns (with premium)[x]	11187	9274	10304	9614	8390	15226	12650	13966	15198	13460
Net Return (loss)[w]	(8472)	149	2167	2415	1897	(796)	2387	3765	4593	3838
Net Return (loss) with premium[v]	(7013)	1359	3511	3669	2991	1190	4037	5587	6575	5594

[z]1 bushel box = 28 lb (12.7 kg).
[y]Wholesale price used = $8.00/box ($1.00/box = $0.0787/kg).
[x]Wholesale price used = $8.00/box plus a theoretical 15% premium for organic = $9.20/box.
[w]Return to operator labor, land, capital, and management at $8.00/box.
[v]Return to operator labor, land, capital, and management at $9.20/box (includes 15% premium for organic).

ECONOMIC ANALYSIS. Yield data from 2004 reflect an overall improvement in weed control and other management practices over 2003. The 2004 data were considered more typical of an optimized organic production system and were therefore used in the partial budget analysis (Table 6). Due to hand application (labor) costs, use of any additional mulch treatment in either the bare ground or plasticulture system increased weed control costs substantially ($300–600/acre) over the control and cultivated treatments, even if the mulch material could be obtained without cost. Purchase of mulch as an off-farm input dramatically drove up costs, and in the case of purchased compost, resulted in a net loss in either system (Table 6). Using a relatively low wholesale price of $8/box, which is typical for growers in Kentucky, and without any premium for organic produce, net returns were considered moderate for wood chip mulch and cultivated treatments on bare ground when compared to average net returns from conventional growers in the state (about $3000/acre). Net returns were roughly doubled in all but the compost and straw mulch treatments when the plasticulture system was used (Table 6). In both of these treatments the cost of mulch, accompanied by reduced weed control efficacy, substantially reduced net returns in the bare ground system. If a theoretical (but realistic) 15% price premium was received for organic bell peppers, moderate profits were possible even on bare ground from wood chip and cultivated treatments although the highest net returns were obtained from the cultivated treatment on raised beds with black polyethylene ($6575/acre, Table 6). The analysis indicated no economic benefit from straw mulch or wood chip treatments compared to the control in the plasticulture system.

Discussion

Our primary goal was to determine if surface-applied organic mulches would effectively suppress weeds in a commercial organic production system for bell peppers. While weed control was the main focus of this study, it is only one component of a system that relies on the integration of many important parts, each contributing to the overall enhancement of the crop. These include the use of mixed leguminous and grass cover crops as N and carbon sources, planting disease-resistant varieties, releasing biocontrol agents as part of an insect management program, and using shallow cultivation for early weed control. Although each of these components was used in the experiment, the focus was on evaluating how mulches fit into this system to provide economical and effective weed control.

In 2003, straw and wood chip mulch treatments provided the best weed control and high yields (Table 1, Table 4). Although the compost treatment did not provide adequate weed control in 2003, it also had high yields and was retested in 2004 due to its documented positive effects as a surface-applied mulch in bell peppers (Roe et al., 1992). In 2004, cultivation was integrated with straw, wood chip, and compost mulches in a way that maximized weed control and yields. Most of the mulches provided very good to excellent weed control in 2004 from the time they were applied until final harvest (Table 2); however, for reasons unknown, straw mulch was less effective in row middles in the plasticulture system by the end of the season and therefore its control rating was lower than the other treatments when averaged over the two systems.

Marketable pepper yields from the organic plasticulture production system were higher than those on the flat, bare ground system in both years of the study (8310 vs. 1012 lb/acre in 2003; 42,800 vs. 29,700 lb/acre in 2004). This is consistent with many studies in conventional production systems showing that polyethylene mulch increases bell pepper yields (Abdul-Baki et al., 1999; Roe and Stoffella, 1994; VanDerwerken and Wilcox-Lee, 1988) compared to bare ground systems. Simply using black polyethylene and raised beds ensured higher and earlier yields. The addition of organic mulches to control weeds between beds did not significantly enhance yields (Table 4). Polyethylene mulch has been shown to increase soil temperatures (Janick, 1986) and it is possible that this accounted for some of the increased yield in 2004 (Table 4), as well as the increase in earliness (Table 5); however, the elimination of weed competition directly around the plants provided by the polyethylene mulch probably had a greater impact on yield.

Consistent with the level of weed control provided by each treatment (Table 1), straw, compost and wood chip mulches resulted in the highest overall total yields in 2003 (Table 3). In 2004, when these treatments were applied after three shallow cultivations, compost gave the highest marketable pepper yields, although these were not significantly different from yields in the cultivated control and wood chip treatments (Table 3). Although adequate N was provided, it is possible that the slightly higher yields observed with compost mulch resulted from a small amount of additional N and other nutrients provided to the crop; however, given the very low nutrient levels in the compost (0.01N–0.006P–0.35K) and its surface application, it is unlikely that nutrient levels were appreciably increased. It is also possible that the compost may have had a higher water holding capacity than the other mulches which could have contributed to the increased yield. In general, yields were consistent with the level of weed control provided by the individual treatments; that is, treatments with the highest weed control ratings were the highest yielding.

Any of the organic mulches (compost, straw, or wood chips) could be used in a large field production operation via mechanical application; however, given the increased yields in 2004 (Table 3), it is clear that post-transplanting cultivation is required to ensure good yields. Soil tests from both years indicated that potassium and phosphorous levels were adequate (data not shown). Although N sources differed between the 2 years, similar rates were applied (115 lb/acre N in 2003 and 115–125 lb/acre N in 2004), based on recommended rates for pepper production in Kentucky. Therefore, the overall increase in marketable yield in 2004 was likely caused by the increased level of weed control resulting from the addition of the shallow cultivations. While the three cultivations in this experiment were necessary to provide acceptable weed control for the treatments applied to the flat ground system, it seems likely two would be sufficient between raised beds in the plasticulture system because of the weed control provided by the plastic mulch.

No single mulch application at planting provided season-long weed control. The combination of shallow cultivation following transplanting coupled with midseason mulch application was capable of producing good yields in two organically managed bell pepper production systems. Excellent economic returns were possible, particularly with the use of polyethylene mulch and raised beds; however, profits in both systems were reduced substantially if mulch was purchased (Table 6). In addition, application costs should be considered and mechanization used where possible, to lower the amount of time and associated costs required for mulch application. As reduction of off-farm inputs is highly desirable on organic farms, applying purchased mulching material solely for weed control should be limited. However, other benefits that organic mulches provide, such as the addition of organic matter and reduced erosion/runoff, which were not factored into the economic analysis, could help justify the mulch and application costs on a site-specific, case-by-case basis. If organic mulches can be acquired at no charge, as with the wood chips in this study, justification for their use would be substantially increased.

Although this study was not designed to compare conventional and organic production systems, returns from the compost mulch and cultivated treatments in the plasticulture system with the organic premium were only slightly lower than those for the same variety (Red Knight) grown in a conventional bell pepper variety trial approximately 1500 ft away with no price premium applied (data not shown). This variety was one of the two highest yielding varieties in that trial (Rowell et al., 2004).

In conclusion, integrating early-season shallow cultivation with mid-season mulch applications could provide organic growers with a sustainable way to minimize yield losses from weed competition. Organic growers who choose to use polyethylene mulch-covered raised beds could use these same techniques to increase soil organic matter while optimizing bell pepper production.

Literature cited

Abdul-Baki, A.A., R.D. Morse, and J.R. Teasdale. 1999. Tillage and mulch effects on yield and fruit fresh mass of bell pepper (*Capsicum annum* L.). J. Veg. Crop Prod. 5(1):43–58.

Aparbal-Singh, Man-Singh, D.V. Singh, A. Singh, and M. Singh. 1985. Relative efficacy of organic mulch and herbicides for weed control in *Cymbopogon* species. Annu. Conf. Indian Soc. Weed Sci. p. 77 (Abstr.).

Bowman, G., C. Shirley, and C. Cramer. 1998. Managing cover crops profitably. 2nd ed. Sustainable Agr. Network, Beltsville, Md.

Bond, W. and A.C. Grundy. 2001. Non-chemical weed management in organic farming systems. Weed Res. 41(5):383–405.

Brown, J.E. and C. Channell-Butcher. 2001. Black plastic mulch and drip irrigation affect growth and performance of bell pepper. J. Veg. Crop Prod. 7(2):109–112.

Davis, J.M. 1994. Comparison of mulches for fresh-market basil production. HortScience 29(4):267–268.

Feldman, R.S., C.E. Holmes, and T.A. Blomgren. 2000. Use of fabric and compost mulches for vegetable production in a low tillage, permanent bed system: Effects on crop yield and labor. Amer. J. Alternative Agr. 15(4):146–153.

Friley, K., B. Rowell, and R. Bessin. 2003. Biological control of European corn borer in bell peppers, p. 91–94. In: J. Snyder and C. Smigell (eds.). 2003 Fruit and Vegetable Crops Research Report (PR488). Univ. of Kentucky, Lexington.

Grubinger, V. 1999. Sustainable vegetable production from start-up to market. Natural Resource, Agr., and Eng. Serv., Ithaca, N.Y.

Hill, D.E., L. Hankin, and G.R. Stephens. 1982. Mulches: Their effect on fruit set, timing, and yields of vegetables. Conn. Agr. Expt. Sta. Bul. 805, Storrs.

Hochmuth, G. 1998. What to do with all that mulch? Amer. Veg. Grower 46(4):45.

Isenberg, F.M. and M.L. Odland. 1950. Comparative effects of various organic mulches and clean cultivation on yields of certain vegetable crops. Pa. State Prog. Rpt. No. 35. State College.

Isaacs, S., S. Goode, R. Trimble, T. Woods, M. Ernst, J. Strang, B. Rowell, T. Jones, D. Spaulding, and W. Dunwell. 2004. Vegetable and melon enterprise budgets for Kentucky. Univ. of Kentucky, College of Agr.; Dept. of Agr. Econ., Lexington. 5 Jan 2005. <http://www.uky.edu/Ag/AgEcon/pubs/software/budgets_veg_melon.html>.

Janick, J. 1986. Horticultural science. 4th ed. Freeman, New York.

Lalande, R., V. Furlan, D.A. Angers, and G. Lemieux. 1998. Soil improvement following addition of chipped wood from twigs. Amer. J. Alternative Agr. 13(3):132–137.

Lamont, W.J., Jr. 1993. Plastic mulches for the production of vegetable crops. HortTechnology 3(1): 35–39.

McDade, M.C. and N.E. Christians. 2000. Corn gluten meal—A natural herbicide: Effect on vegetable seedling survival and weed cover. Amer. J. Alternative Agr. 15(4):189–191.

Olsen, J.K. and R.K. Gounder. 2001. Alternatives to polyethylene mulch film-field assessment of transported materials in capsicum (*Capsicum annuum* L.). Austral. J. Expt. Agr. 41(1):93–103.

Organic Trade Association. 2004. Organic Trade Association survey: US organics reach $10.8 billion. What's New in Organic 28:1–4.

Ozores-Hampton, M. 1998. Compost as an alternative weed control method. HortScience 33(6):938–940.

Paine, L.K. and H. Harrison. 1993. The historical roots of living mulch and related practices. HortTechnology 3(2):137–143.

Rice, P.J., L.L. McConnell, L.P. Heighton, A.M. Sadeghi, A.R. Isensee, J.R. Teasdale, A.A. Abdul-Baki, J.A. Harmen-Fetcho, and C.J. Hapeman. 2001. Runoff loss of pesticides and soil: A comparison between vegetative mulch and plastic mulch in vegetable production systems. J. Environ. Qual. 30(5):1808–1821.

Roe, N.E., H.H. Bryan, P.J. Stoffella, and T.W. Winsberg. 1992. Use of compost as mulch on bell peppers. Proc. Fla. State Hort. Soc. 105:336–338.

Roe, N.E. and P.J. Stoffella. 1994. Growth and yields of bell pepper and winter squash grown with organic and living mulches. J. Amer. Soc. Hort. Sci. 119(6):1193–1199.

Rowell, B., A. Satanek, and J.C. Snyder. 2004. Bell and jalapeno pepper evaluations for yield and quality in central Kentucky. p. 45–46. In: B. Rowell, J. Snyder, and C. Smigell (eds.). 2004 Fruit and Vegetable Crops Research Report (PR 504). Univ. of Kentucky, Lexington.

Schonbeck, M.W. 1998. Weed suppression and labor costs associated with organic, plastic, and paper mulches in small-scale vegetable production. J. Sustainable Agr. 13(2):13–33.

Schonbeck, M.W. and G.K. Evanylo. 1998. Effects of mulches on soil properties and tomato production I. Soil temperature, soil moisture, and marketable yield. J. Sustainable Agr. 13(1):55–81.

Singh, S.P. 1992. Studies on mulching of vegetable crops—A review, p. 115–143. In: S.P. Singh (ed.). Advances in horticulture and forestry 2. Scientific Publ., Jodhpur, India.

VanDerwerken, J.E. and D. Wilcox-Lee. 1988. Influence of plastic mulch and type and frequency of irrigation on growth and yield of bell pepper. HortScience 23(6):985–988.

Walz, E. 2004. Fourth national organic farmers' survey. Organic Farming Res. Foundation, Santa Cruz, Calif.

Wittwer, S.H. 1993. World-wide use of plastics in horticultural production. HortTechnology 3(1):6–19.