Journal of Applied Horticulture, 8(1): 12-14, January-June, 2006

Biodegradable paper/polymerized vegetable oil mulches for tomato and pepper production

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Abstract

This project was undertaken to compare the efficacy of a biodegradable paper/cured vegetable oil mulch with newspaper/straw and bare soil for reducing weed growth and promoting vegetable yields. There were no significant differences in total tomato (*Lycopersicon esculentum*) or pepper (*Capsicum annum*) yields between the different mulch types. The coated paper and newspaper/straw mulches were effective in preventing weed growth around the plants while hand weeding was required for the bare soil plots. After 3 months, there was slight degradation (a few cracks, holes) of the coated paper mulches but not enough to allow noticeable weed penetration or detachment of the buried edge. Paper/cured oil mulch rolls appear to be a convenient and effective alternative to laborious hand weeding or spreading of newspaper and straw for vegetable gardening.

Key words: Degradable mulch, soybean oil, sustainable agriculture, vegetable production

Introduction

There has been growing interest recently in the use of biodegradable mulch films for suppression of weeds, increasing soil temperatures and yields of vegetables and fruits (Greer and Dole, 2003; Halley *et al.*, 2001; Weber, 2003). A biodegradable mulch allows growers to till the mulch into the field at the end of the growing season rather than having to remove and dispose of non-degradable polyethylene mulches, often at considerable cost (Anderson *et al.*, 1995).

Various types of biodegradable mulches have been considered including starch-based films (Halley *et al.*, 2001), polyester films (Dever *et al.*, 1998), fiber slurries (Olsen and Gounder, 2001) and coated paper. Paper alone begins to tear and blow away within 2-3 weeks after field application due to rapid biodegradation and loss of strength when wet (Anderson *et al.*, 1995; Shogren, 2000). Therefore, a number of coatings or laminates on paper have been examined to increase wet strength and slow biodegradation. These include tar (Rivise, 1929), wax, polyethylene (Vandenberg and Tiessen, 1972), latexes (Brault *et al.*, 2002), polyesters (Rangarajan, 2000) and vegetable oils (Anderson *et al.*, 1995).

Vegetable oil coatings are attractive because they are inexpensive, renewable, produced in large quantity in the U.S. and can be polymerized (cured) into water resistant, biodegradable films (Shogren, 1999). Previous studies have shown that kraft paper coated with soybean or linseed oils then allowed to cure via sun and air in the field were effective as polyethylene mulches for growing watermelon (Shogren and Hochmuth, 2004) and cottonwood trees (Shogren and Rousseau, 2005). One disadvantage of these oil saturated paper mulches was the messiness associated with handling oily paper in the field (Shogren and Hochmuth, 2004). In order to avoid this problem, kraft paper was coated with a resin made from epoxidized soybean oil (ESO) and citric acid and then thermally cured (Shogren, 1999; Shogren, 2000). Previous work has shown these compositions to be fully biodegradable in soil but over a longer time span than uncoated paper (several months) (Shogren *et al.*, 2004).

The objective of this study was to assess whether mulches made from paper coated with ESO/citric acid resins would serve as effective weed barriers, promote the growth of tomato and pepper plants and sustain good yields when compared to other weed control methods commonly used in a garden or small farm setting.

Materials and methods

Materials: Brown kraft paper, 30 and 40 lb weights (3000 ft^{-2}), made from 100% recycled fiber was obtained from Carter Paper and Packaging, Peoria, IL. Epoxidized soybean oil (ESO, Paraplex G-62) was from C. P. Hall, Bedford Park, IL. Citric acid (99%) was from Aldrich, Milwaukee, WI. Straw was a mixture of wheat (*Triticum aestivum*) and rye (*Secale cereale*) stems from a local farm. Tomato (*Lycopersicon esculentum*) and sweet green pepper (*Capsicum annum*) plants were donated by Greenview Nursery, Peoria, IL.

Preparation of coated paper: ESO (2950 g) was heated to 100 ^oC in a 11.5 l stainless steel beaker and 110 g of carbon black (colorant) was added with a motorized propeller stirrer. Carbon black was added to reduce light transmission through the paper mulches. A hot (102 ^oC) solution of 850 g citric acid in 280 g deionized water was next added to the ESO with stirring. After the mixture reached 105 ^oC, the beaker was removed from heat and placed in an ice bath to cool to 40 ^oC.

*Product names are necessary to report factually on available data; however the USDA neither guarantees nor warrants the standard of the product, and the use of the name. USDA implies no approval of the product to the exclusion of others that may also be suitable.

Paper coating and heat curing was accomplished using a simple in-house design. This consisted of a stainless steel table with supply and motorized take-up rolls on the lower shelf, a flat aluminum sheet on the top shelf for coating, and an attached flow-through sheet oven for heat-curing. The oven consisted of 2 x 4.5 ft. aluminum sheets separated by 1 in. heated by electrical resistance mats and insulated with 2 in. of fiberglass top and bottom. ESO/citric coatings were dripped onto one side of the paper and were spread into a thin layer by a neoprene rubber blade clamped between 2 aluminum bars. Temperatures and residence times in the oven were 150-180 ^{o}C and ~1 min, respectively at coating speeds of 2-3 ft./min. Coating weights were 37 and 42% of paper weight for the 30 and 40 lb papers, respectively.

Field studies: There were four different mulch treatments (30 lb coated paper, 40 lb coated paper, newspaper/straw, bare soil). The field site was located in Peoria, IL and run by the University of Illinois Master Gardeners of Peoria County as part of the Plant-a-Row-for-the-Hungry program. Tomato and bell pepper plants were planted in adjacent 75 ft. long rows with spacings of approximately 1.5 ft. between plants and 4 ft. between row centers. Planting took place on 26 May and mulches were laid on 3 June 2003. Coated paper mulch samples were cut into 6 x 2 ft. lengths then cut from the side with scissors to allow the mulch to be placed around the plants (coated side up). Edges of the mulches were then weighted down with soil (pepper) or held in place by steel cages (tomato). For the newspaper/straw treatment, 3 layers of newspaper were placed around the plants followed by approximately 2 inches of straw on top on the newspaper to help hold the newspaper in place. There were 3 replications for each treatment and were arranged in randomised order. The bare soil plots were hand weeded once per week over the summer. Vegetables were harvested weekly beginning 21 July until 15 September. Total number as well as weight of vegetables deemed marketable were measured weekly.

Soil temperatures were measured in duplicate on 18 June, 24 June, 7 July and 26 August at 8 AM and 2 PM using a digital temperature probe model 4045 (Control Co., Friendswood, TX). Measurements were taken at a depth of approximately 4 in. (10.2 cm) below the surface. Soil samples for moisture determination were collected on 18 June, 24 June, 7 July and 26 August. Mulches were carefully lifted from the edge and the top 3-4 in. of soil (~100 g) was scooped into plastic zip lock bags. Edges of the mulches were reburied after sample collection. Soil samples were then transported to the lab where water content was measured gravimetrically after heating 10 g soil to 105 ^{o}C for 20 min. using an Ohaus moisture analyzer, model MB200 (Ohaus Co., Florham Park, NJ). Counts of weeds growing through the mulches were made from detailed photographs of the plots taken on 24 June, 24 July, 4 August and 18 September.

Statistical analyses: A Levene's homogeneity of variance test was carried out to determine if transformation of the vegetable number and weight data were necessary. Four, single-factor Analyses of Variance (ANOVA) were performed comparing the four mulch treatments for number and weight of harvested tomatoes and green peppers at the end of each week and for the season. In case significant F-test was obtained in ANOVA, Duncan's multiple range test was used for multiple comparison procedure, at the P=0.05 level, for determining pairwise differences between the mulch treatments.

Results and discussion

As shown in Table 1, there were no significant differences in the total number or weight of tomatoes or peppers between plants grown on the different mulch types. Soil temperatures for the different mulch treatments are shown in Table 2. Soil temperatures underneath the newspaper/straw were less than the coated paper or bare soil, especially during the hottest part of the day (afternoon). This is probably due to the thick, insulative properties of the straw as well as its light colour which tends to reflect solar radiation. There was a noticeable lightening in colour (bleaching) of the coated papers over the summer and this would likely tend to lessen the soil warming later on. This lightening effect has been noted previously for coated paper mulches (Brault *et al*., 2002). Soil moisture, as shown in Table 2, was generally higher under the newspaper/straw mulch than under the bare soil or coated paper. This is likely due to the lower soil temperature under the newspaper/straw and hence lower evaporation rates. Water permeability of the coated paper mulches has not been measured but a simple test of a drop of water placed on the mulch shows it will pass through within an

Table 1. Total mean yields of tomato and pepper

Mulch	Total mean tomato yield		Total mean pepper yield	
	Number (number/plot)	Weight (kg/plot)	Number (number/plot)	Weight (kg/plot)
30 lb paper/oil	59 a^{z}	12.5 a	48 a	3.7 a
40 lb paper/oil	66 a	12.6 a	44 a	3.3 a
Newspaper/straw	58 a	17.0 a	38 a	3.0 a
Bare soil	57 a	12.0 a	41 a	3.2 a

^{z}Means with the same letter within a column are not significantly different at P=0.05.

Table 2. Mean soil temperatures and moistures on 7 July

Mulch	8 AM		2 PM	
	Temperature (^{o}C)	Moisture (%)	Temperature (^{o}C)	Moisture (%)
30 lb paper/oil	25.4 a^{z}	-	32.2 a	12.1 a
40 lb paper/oil	24.9 a	-	33.0 a	12.9 a
Newspaper/straw	24.0 b	-	27.7 b	17.9 b
Bare soil	25.2 a	-	33.3 a	11.8 a

^{z}Means with the same letter within a column are not significantly different at P=0.05.
Ambient air temperatures were 30 and 34.8 ^{o}C at 8 AM and 2 PM, respectively

Table 3. Mean[y] number of weeds from six 1.8 x 0.6 m plots

Mulch	Days post-planting			
	29	59	70	114
30 lb paper/oil	0 a[z]	0 a	1 a	1 a
40 lb paper/oil	0 a	0 a	0 a	1 a
Newspaper/straw	0 a	0 a	1 a	1 a
Bare soil	4 b	6 b	14 b	11 b

[y]Mean of six replications (data from tomato and pepper replicates combined)
[z]Means with the same letter within a column are not significantly different at *P*=0.05.

hour or so, indicating some permeability.

Mean number of weeds penetrating different mulch treatments are given in Table 3. Even after almost 4 months, there was only an average of 1 weed per 6 ft plot penetrating the coated paper mulches. The exposed and buried tuck areas of the coated paper mulches were largely intact, with a few holes. In contrast, there were >10 weeds per plot in the bare soil treatments, even with weekly hand pulling of weeds. There was no significant difference between the 30 and 40 lb coated paper so the thinner paper could be used for better economics. Manual weed removal required about 1 hour per week for the six 6-ft bare ground plots or 16 hours total for the 16 week growing season. The time required for the initial coated paper mulch laying was about 1 hour for six 6-ft plots.

Thus, paper/ESO/citric acid mulches were effective in preventing weed growth and plants grown on these gave yields of tomatoes and green peppers similar to the newspaper/straw mulch or hand-weeded control plots. For many home or community gardeners, hand-weeding is a tedious and difficult task so use of a weed-blocking mulch would be desirable. Application of the paper/oil mulch would be a little easier than newspaper/straw since the former is in a roll form. It could be unrolled first then seedlings planted in cut holes or placed around existing plants as in this study. For larger-scale vegetable growers, the paper/oil rolls would work with conventional plastic mulch-laying equipment, as has been shown previously (Shogren and Hochmuth, 2004). The ESO/citric acid coated paper used here might be more readily accepted commercially since it has been heat cured to give a hard surface rather than the oily paper described previously (Shogren and Hochmuth, 2004).

Paper coated with other types of biodegradable polymers, especially polyesters, have been tested recently (Rangarajan, 2000). These biodegradable polyesters, such as polycaprolactone, polylactic acid, poly(butylene succinate-adipate), are currently rather expensive ($1.5-3/lb.) Epoxidized soybean oil and citric acid are less expensive ($0.30-0.60/lb.), making them more economically attractive. Paper, on an area basis, is however more expensive than polyethylene mulch due to the greater thickness of the paper. Thus the coated paper mulches would be more suited to higher value applications such as home gardening or small farmers or where a biodegradable, water permeable mulch is required.

Acknowledgements

We thank Elizabeth Krietemeyer, Lynn Webb, Helen Nixon and Patrise Swanson for help in field work. We also thank Debra Palmquist, USDA/ARS Midwest area statistician for statistical analyses.

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