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Winter Cover Crops and Vinegar for Early-Season Weed Control in Sustainable Cotton

P. J. Moran
S. M. Greenberg

ABSTRACT. Weeds may be suppressed by winter cover crops and the use of organic herbicides such as vinegar. Black oat (*Avena strigosa*) and hairy vetch (*Vicia villosa*) winter cover crops were planted for 2 years as part of a sustainable production system for cotton in the Lower Rio Grande Valley of Texas, and were till-killed each spring prior to cotton planting. Palmer amaranth (*Amaranthus palmeri*), common purslane (*Portulaca oleracea*), and sunflower (*Helianthus annuus*) were frequently-encountered winter and spring weeds. Both cover crops controlled winter weeds as well as did winter tillage without cover. Black oats plots had 8% and 17% more total winter weed cover than no-cover and hairy vetch plots, respectively. Seven weeks after cotton planting, cotton cover was 10% to 15% less in former winter hairy vetch and no-cover sustainable plots than in former black oats plots, but cotton height did not vary by winter cover crop. Total spring weed, pigweed, and purslane cover did not vary between former hairy vetch, black oats, and no-cover plots. All sustainable plots had higher spring weed cover than did conventional plots maintained with cultivation and synthetic herbicides. Breakdowns in the sustainable spring weed management system (withholding of spring cultivation) or insect pest

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management system (failure of alfalfa strips) led to increases of 60% or more in weed cover in sustainable plots. Cotton lint yield (kg/ha) did not differ between sustainable and conventional weed management systems. When evaluated as a cover crop and weed management tool, vinegar containing 9% acid (1,550 L/ha) reduced live hairy vetch cover to less than 5% in one of two trials, but was not effective as a burndown herbicide on black oats. Vinegar at this concentration (2,980 L/ha) killed >80% of 30-day-old or younger cotton and sunflower and 10-day-old Palmer amaranth and purslane in field trials, but caused <50% mortality to mature Palmer amaranth and purslane. More dilute vinegar solutions (0.9% to 4.5% acid) caused little or no mortality. Black oats and hairy vetch covers controlled winter but not spring weeds in this production system. With more prolonged use, winter covers could become a key spring weed control component in sustainable cotton production. Vinegar could be useful in controlling young weed seedlings in non-crop areas, or as a follow-up to cultivation.

KEYWORDS. Acetic acid, black oats, cotton, hairy vetch, pigweed, purslane, Rio Grande Valley, sunflower, Texas, weed cover

INTRODUCTION

Sustainable agriculture encompasses a wide range of physical, cultural, biological, and chemical weed control techniques and seeks to minimize off-farm inputs in all phases of crop production (Labrada, 2006; Mohler, 2001a). Organic crop production specifically excludes synthetic inputs (Kuepper, 2002). In cotton, weeds are an important obstacle to production, and can reduce yield in the absence of control (Griffith et al., 2006; Rowland et al., 1999; Showler and Greenberg, 2003), usually requiring the use of synthetic herbicides (Burgos et al., 2006). Only 0.03% of total U.S. cotton acreage was grown organically in 2001, but consumer demand for organic cotton products is growing (Guerena and Sullivan, 2003). In the subtropical Lower Rio Grande Valley (LRGV) of Texas, over 200,000 acres of cotton are planted annually (Norman, 2004). Weeds grow and produce seed year-round in the absence of control. Information on sustainable weed control in cotton, as a component of multiple pest, fertilizer, and crop growth management systems, is limited in this region and nationally (Liebman, 2001).

Many crop production techniques are compatible with sustainable and organic weed control, including various tillage regimes (Mohler, 2001b), inter-row cultivation, mulching, weed flaming, the coating of seed with deleterious rhizobacteria (Kremer, 2002), the application of plant pathogenic

fungi as bioherbicides (Ortiz-Ribbing and Williams, 2006), crop rotation, and cover cropping (Guerena and Sullivan, 2003). For example, alfalfa strips support beneficial predators and parasites of insect pests (DeBach, 1964; Ellington et al., 2003; Guerena and Sullivan, 2003) but may also affect weed populations. Winter cover crops, including black oats (*Avena strigosa* Schreb.) and hairy vetch (*Vicia villosa* Roth) suppress weeds via chemical allelopathy (Batish et al., 2006; Hill et al., 2006; Nava-Rodriguez et al., 2005), physical blockage and shading (Teasdale and Mohler, 2000) and by increasing seed predator abundance (Clark et al., 2006). Leguminous covers such as hairy vetch increase plant-accessible soil nitrogen (Sainju et al., 2005). Cover crops also improve soil composition; conserve soil carbon, nitrogen, and moisture content; and enhance microbial activity (Hoffman and Regnier 2006; Yenish et al. 1996), leading to increases in the growth and yield of cotton (Bauer and Reeves, 1999; Sainju et al., 2005) and other crops (Burgos et al., 2006; Fisk et al., 2001; Nagabhushana et al., 2001). Questions remain about the benefits of live *versus* killed covers in no-till crop production (Teasdale and Daughtry, 1993) and the importance of soil incorporation of residue (Mohler, 2001b; Schomberg et al., 2006). This study examined the effects of black oat and hairy vetch winter covers on winter and spring weeds in the LRGV of Texas, in the context of a sustainable weed, pest, and soil management system for cotton.

A limited number of chemical substances, including vinegar (Garrett and Beck, 1999; Webber et al., 2005) have been approved for specific uses in organic production under the USDA National Organic Program (Kuepper, 2002, OMRI, 2007). Vinegar has herbicidal effects on broadleaf and grass weeds (Fausey, 2003; Spencer et al., 2003; Webber et al., 2005; Young, 2004), and the high acetic acid content of immature mulches contributes to weed control (Ozores-Hampton et al., 2002). In the absence of synthetic herbicides, vinegar applications could kill cover crops before crop production begins, and reduce the need for frequent cultivation and hand-weeding during production. The effects of vinegar on hairy vetch, black oats, and several abundant broadleaf weeds were therefore evaluated.

MATERIALS AND METHODS

Cover Crops and Sustainable Cotton Production

Winter cover crop and sustainable early-season cotton production involved a 2 ha field of Hidalgo fine sandy loam (fine-loamy mixed,

hyperthermic Typic Calciustolls, 543 g/kg sand, 205 g/kg silt, 252 g/kg clay, pH 7.9, organic C 10.3 g/kg, organic N 0.95 g/kg, P 6.4 mg/kg, K 25.4 mg/kg) (Zibilske and Bradford, 2003) divided into 0.2 ha (0.5 acre) plots, 20 m (66 ft) wide by 100 m (328 ft) long, located at the USDA-ARS, Kika de la Garza Subtropical Agricultural Research Center (KSARC) in Hidalgo County, Texas, USA (26° 13' N, 97° 59' W). In October 2004 and 2005, the field was plowed, disked, and bedded on 0.8 m (2.6 ft) centers. Cover crop experiments used a randomized complete block design with three replications. On 9 November 2004 and 15 December 2005, cover crops were planted in 18 rows per plot using a UFT grain drill (United Farm Tools, South Charleston, WV) with six rows left unseeded in each plot as a turn row. Seeding rates were 50.4 kg/ha (45 lb/acre) for black oats (*Avena strigosa*, cv. Soilsaver) (BO) and 28 kg/ha (25 lb/acre) for hairy vetch (*Vicia villosa*) (HV). One plot per block was designated as a no-cover plot (NC). Before planting, BO and HV plots received 201 kg/ha (179 lb/acre) granular sulfur and NC plots received 1120 kg/ha (1000 lb/acre) poultry litter, incorporated with a six-row Lilliston cultivator (Bigham Brothers, Lubbock, TX). All plots were irrigated at the time of planting and 3 wk after planting (WAP). Total precipitation from November 2004 through February 2005 was 7.4 cm (2.9 in), and from November 2005 to February 2006 it was 5.4 cm (2.1 in); the 30-year normal for this period at this location is 17.2 cm (6.8 in). NC plots were tilled 4 wk after planting.

Seven WAP covers, all plots were tilled, killing the cover crops. In 2005 only, sorghum (*Sorghum vulgare* L.) was planted in six buffer rows between plots at a rate of 400,000 seeds/ha (162,000 seeds/acre) using a Max-Emerge® planter (John Deere, Moline, IL). In 2005 and 2006, six rows of alfalfa (*Medicago sativa* L.) were hand-seeded (28 kg/ha, 25 lb/acre) into HV and BO plots as a green manure, with two rows on each inner edge of the plots and two rows in the center, placed between six planned cotton rows. Alfalfa seed was incorporated with a two-row Lilliston cultivator. Cotton (*Gossypium hirsutum* L., variety Fiber Max 960RR, non-Bt, glyphosate-tolerant) (Bayer Crop Science, Research Triangle Park, NC) was planted on 7 March 2005 and 20 March 2006 at a rate of 124,000 seeds/ha (50,200 seeds/acre) to a soil depth of 2 to 3 cm (0.75 to 1.2 in), in 12 rows in HV and BO plots and 18 rows in NC plots. Seedlings emerged within 1 wk. All sustainable plots were furrow-irrigated 2 and 6 WAP, and the soil between rows was sweep-cultivated 4 WAP. Compost tea was added 3.5 WAP cotton to promote positive soil-microbial-plant interactions (Carpenter-Boggs, 2005) and improve pest resistance

(Litterick et al., 2004). Compost tea was brewed in a Worm-Gold[®] Extractor (California Vermiculture, Cardiff-by-the-Sea, CA), according to the manufacturer's instructions and Ingham (2005), from 3.0 g/L (0.4 oz/ gallon) bat guano, 6.0 g/L (0.8 oz/gallon) worm castings, 3.0 g/L (0.4 oz/gallon) standard compost, 1.2 g/L (0.16 oz/gallon) kelp meal, and 2.6 ml/L (0.3 fluid oz/gallon) each of humic acid and molasses, and was applied using a tractor-mounted sprayer with Lurmark DT20 (Hypro Inc., New Brighton, MN) horizontal fan spray tips calibrated to deliver 187 L/ha (20 gallon/acre) at 345 kPa (50 psi) moving at 0.9 m/sec (2 miles/hr). In the first 7 WAP, azadirachtin (72 g ai/ha or 1.0 oz ai/acre) (Neemix[®], Certis USA, Columbia, MD), rosemary oil (210 ml ai/ha or 2.87 fl oz ai/acre) (Sporan[®], Ecosmart Technologies, Franklin, TN), and spinosad (66 g ai/ha or 0.94 oz ai/acre) (Spintor[®], Dow Agrosiences, Indianapolis, IN) were applied to control insect pests using the same equipment. Rainfall in March-April 2005 was 1.1 cm (0.5 in) and in the same period in 2006 it was 1.8 cm (0.7 in). Normal (30-year) precipitation for this period at this location is 5.2 cm (2.0 in).

In 0.2 ha (0.5 acre) plots in separate fields, cotton (variety DP 541 BGII/RR, glyphosate-tolerant and Bt-transgenic) (Monsanto, St. Louis, MO) was cultivated using conventional chemical tools. Pre- and post-planting tillage, planting date, cotton seeding rate and irrigation in these plots were similar to sustainable plots. Synthetic fertilizer (22.4 kg/ha or 19.9 lb/acre N, 56 kg/ha (50 lb/acre) P, no potassium), glyphosate (0.95 kg ai/ha or 0.85 lb ai/acre) (RoundUp[®], Monsanto, St. Louis, MO) and dicamba methylamine salt (1.13 kg ai/ha or 1 lb ai/acre) (Banvel[®], Micro Flo LLC, Memphis, TN) were applied to conventional fields before cotton planting. Insects were controlled with acephate (75.6 g ai/ha or 1.1 oz ai/acre) (Orthene 90S[®], Valent Co., Walnut Creek, CA) and oxamyl (1.0 kg ai/ha or 0.89 lb ai/acre) (Vydate CLV[®], Dupont Inc., Wilmington, DE) within the first 7 WAP. Liquid applications used an 18-row sprayer (John Deere 6500) with Teejet 8002 vertical fan nozzles (Teejet Mid Tech, Wheaton, IL) and a Raven SCS440 control system.

Winter and Spring Weed Sampling

Winter weeds in sustainable cotton plots were sampled 6 WAP cover crops (20 December 2004, 31 January 2006) in one linear transect per plot using five 1 m² (10.76 ft²) subplots spaced 20 m (66 ft) apart in 2005, and in eight subplots per transect in 2006. Hairy vetch plants were mature and flowering at the time of sampling (mean \pm SE; 55 \pm 4 cm breadth of

prostrate stems per plant, 16 ± 1 shoots/m²), while black oat plants were pre-reproductive (32.8 ± 7.5 cm height, 82.3 ± 4.5 shoots/m²). Based on shoot counts and visual coverage estimates, each hairy vetch stem occupied 0.02 m² area, and each black oat shoot occupied 0.0089 m². Spring weeds were sampled 7 WAP cotton (29 April 2005, 10 May 2006) in the nine sustainable plots and in three conventional plots. Cotton plants were approximately 23 cm (9 in) tall and had 8 to 10 nodes at the time of sampling. Spring weeds and cotton were also sampled in each of three conventional cotton plots using one transect containing five subplots. Within the sustainable field, one additional spring transect was sampled in each of six alfalfa strips that were planted without cotton in the middle of the BO and HV plots (five subplots per transect in 2005, three in 2006). In the spring of 2006, one small strip (5 m long \times 1 m wide, or 16.4 ft \times 3.3 ft) within eight of the nine sustainable cotton plots was left uncultivated when the rest of the plots were cultivated 4 WAP. Three 1 m² subplots were sampled within each of these strips 7 WAP.

In 2005 and 2006 winter and spring subplots, total percent plant cover, cover crop or cotton cover, and Palmer amaranth (*Amaranthus palmeri* Wats.) and common purslane (*Portulaca oleracea* L.) cover were visually estimated. Total weed cover was calculated by subtracting cover crop or cotton cover from total plant cover. In spring subplots, the proportions of total percent plant cover consisting of weeds, cotton, Palmer amaranth and purslane were determined. In 2006 subplots only, the presence or absence and cover occupied by all broadleaf weeds and sedges that could be identified with Richardson (1995), and unidentified grasses (winter subplots) or identified common grasses (spring subplots) were also determined. Numbers of Palmer amaranth and purslane shoots were determined in winter 2005 subplots. The number of Palmer amaranth shoots was determined in spring 2006 subplots. In spring subplots in cotton rows, the shoot heights of two cotton plants per subplot were measured and averaged.

Winter 2005 and 2006 data were combined because there were no significant differences between years in preliminary analyses. In spring sampling, total weed cover in the sustainable plots was significantly higher in 2006 (18% to 29%) than in 2005 (2–9%) ($F = 73.9$, $df = 1,2$, $p < 0.05$). Only data from 2006 are presented. Differences in the frequency of occurrence (presence/absence) of weed species were examined with likelihood-ratio Chi-square tests (SAS Institute, 1999). Cover estimates were arcsine-square root transformed. Shoot counts of Palmer amaranth and purslane were $\log(x + 1)$ transformed. Means derived from untransformed

data (\pm SE) are presented. All winter and spring cover estimates, weed shoot count and cotton height data from the sustainable field were analyzed with SAS PROC MIXED (SAS Institute, 1999) with cover crop as the fixed effect and block, subplot nested within block, and the block-cover crop interaction as random effects. Differences among cover crops were examined via least-squares means, *t*-tests, and Tukey-Kramer adjusted *p* values. A similar approach was used to compare uncultivated strips to cultivated areas within sustainable plots in spring 2006 samples, but in this case winter cover crop, cultivation and their interaction were included as fixed effects. Follow-up tests examined the effects of withholding cultivation separately for each winter cover crop treatment. Differences between 2005 and 2006 in alfalfa and spring weed cover in the alfalfa strips were examined by combining data from HV and BO plots and specifying year as the only fixed effect.

Cotton Yield Determination

The effects of sustainable (HV, BO, or NC treatments combined) and conventional weed control on cotton yield was assessed by hand-weeding the sustainable plots 8 WAP, cultivating all plots 9 WAP, continuing the insect control techniques noted above, applying mepiquat chloride (1.3 g ai/ha or 0.03 oz ai/acre) (Mepichlor[®], Micro Flow LLC., Memphis, TN) to all plots 12 WAP to control cotton height, and applying ethephon (8.2 g ai/ha or 0.1 oz ai/acre) (Prep[®], Bayer Crop Science) and thidiazuron (20.8 g ai/ha or 0.3 oz ai/acre) (Dropp[®] SC, Bayer Crop Science) defoliants to all plots 17 WAP. A prior application of organic defoliant (163.7 L/ha or 17.5 gallons/acre 20% vinegar and 11.7 L/ha or 1.3 gallons/acre each of orange oil and molasses) to the sustainable plots did not produce sufficient plant mortality. Seed cotton was hand-collected 18 WAP in 9 or 10 4 m (14 ft) sampling rows each in the sustainable and conventional fields. Lint was separated with an Eagle laboratory gin (Continental Gin Co., Birmingham, AL) and weighed. The difference in yield between sustainable and conventional production systems was analyzed with a *t*-test.

Vinegar Burndown Treatment of Cover Crops

All vinegar studies used household distilled white vinegar (9% acetic acid content) (HEB Inc., San Antonio, TX). All vinegar solutions were mixed with 1% (v/v) surfactant (potassium salts of fatty acids) (Safer Soap[®] concentrate containing 49.5% ai, Woodstream Inc., Lititz, PA). This product has been approved for use in organic agriculture (OMRI,

2005). All vinegar applications were made with a 3.8 L (1 gallon) hand-held sprayer with a cone fan nozzle pressurized to 276 KPa (40 psi) (Model 2751E, Chapin Inc., Batavia, NY). Applications were made between 0900 and 1100 in full sun, and in windspeeds < 5 m/sec (10 mph). To test the ability of vinegar to kill cover crops, 9%, 4.5%, 0.9% vinegar solutions were applied [1550 L/ha (166 gallons/acre) solution, containing 138 L ai/ha (14.8 gallons ai/acre) for 9%, 69.1 L ai/ha (7.4 gallons ai/acre) for 4.5%, 13.8 L ai/ha (1.48 gallons ai/acre) for 0.9%, or 15.5 L ai/ha (1.7 gallons ai/acre) surfactant for the 0% control solution] 7 WAP to 1-m² (10.76 ft²) subplots inside HV, BO, or NC plots (two subplots per vinegar concentration per plot, six total subplots per cover crop per vinegar concentration). In a separate field (Willacy fine sandy loam [fine-loamy, mixed hyperthermic Udic Argiustolls]) an application to hairy vetch was performed 8 WAP covers (six subplots per vinegar concentration). Percent live cover crop coverage was visually estimated before and one week after vinegar application. The overall effect of vinegar on the change in live cover was analyzed using Kruskal-Wallis χ^2 tests, and asymptotic Wilcoxon tests were used to determine differences between each vinegar concentration and the control solution (PROC NPAR1WAY) (SAS Institute, 1999).

Vinegar Treatment to Control Weeds

The effect of 9% vinegar or control solution on mortality of purslane shoots (82 ± 19 shoots/m² density before application, 7 ± 1 cm breadth of prostrate stems on the ground, 21 ± 2 leaves, 25 plants measured) was examined in 1 m² plots located on the edge of the sustainable cotton field, (six plots per treatment), using the same application rates and equipment as for cover crops. The effects of 0%, 0.9%, 4.5%, or 9% vinegar on mortality of winter Palmer amaranth and sunflower (*Helianthus annuus* L.) were examined by spraying individual shoots (30 mL/plant solution [1 fl oz/plant]) (10 plants per weed species per vinegar concentration) with the hand-held pressure sprayer. Palmer amaranth plants were mature and flowering (mean \pm SE; 21 ± 3 cm tall, 47 ± 10 leaves, 28 plants measured), while sunflower plants were pre-reproductive (16 ± 4 cm tall, 34 ± 9 leaves, 12 plants measured). In May 2006, individual common purslane, Palmer amaranth and sunflower shoots were sprayed with 9% vinegar [40 mL solution/plant (1.4 fl oz/plant)] (26 to 27 plants per weed species; no control treatment). Palmer amaranth plants were mature and flowering (29 ± 3 cm tall, 63 ± 16 leaves) as were purslane plants (38 ± 4 cm

breadth of prostrate stems), while sunflower plants were pre-reproductive (20 ± 3 cm tall, 22 ± 4 leaves). Shoot mortality was determined 1 week after application.

In a field experiment in August 2005, the effects of 9%, 4.5%, 0.9%, and 0% vinegar on mortality of young, vegetative Palmer amaranth shoots (8 ± 0.2 cm tall, 13 ± 0.4 leaves) and mature, flowering shoots (42 ± 2 cm tall, 40 ± 2 leaves) were examined in 1 m^2 plots in fallow fields adjacent to the sustainable cotton field. Young volunteer cotton (9 ± 0.3 cm tall, 3 ± 0.2 leaves) was also present in the plots containing young Palmer amaranth. Vinegar was applied with the hand-held pressure sprayer to five plots per vinegar concentration per Palmer amaranth age, delivering 900 ml (30.4 fl oz) solution to each mature plot (for 9%, 4.5%, and 0.9% vinegar solutions, this volume equals 801, 405, and 81 L ai/ha, or 85.7, 43.3, and 8.7 gallons ai/acre), respectively) and 380 mL (12.8 fl oz) to each young plot (338, 169, and 34 L ai/ha, or 36, 18, and 3.6 gallons ai/acre, respectively). Shoot mortality was determined, and damaged leaves on six shoots (young cotton and Palmer amaranth) or 10 shoots (mature Palmer amaranth) per plot were counted 72 hr (young cotton and Palmer amaranth) or one week (mature pigweed) after application.

To examine the influence of weed and cotton age on vinegar efficacy, a field experiment was conducted in July 2006 at the USDA-ARS KSARC Rio Delta Experimental Farm ($26^\circ 26' \text{ N}$, $97^\circ 57' \text{ W}$) in fine sandy-loamy soil similar to that of the January 2006 hairy vetch vinegar experiment. Plots (1 m^2) were fertilized with 40 g (1.4 oz) Osmocote[®] (Scotts-Sierra, Marysville, OH) (15-9-12 N-P-K plus micronutrients). Seeds of Palmer amaranth (1.0 g/m^2), purslane (0.7 g/m^2), and cotton (10 seeds) (Fibermax 960RR) were hand-sown into plots. Sunflower and additional cotton seedlings were grown until they had cotyledons plus one true leaf in a greenhouse and then transplanted to field plots (15 plants per plot). A total of 20 plots of each plant species were established. Shoot height (or breadth of prostrate stems in purslane) and number of leaves were determined for five plants in each control plot at each application time, 10, 16, 23, and 30 days after emergence. Plots (four per plant species per vinegar treatment per application time) received 9% vinegar and surfactant solution at a rate of 300 mL/plot (2,980 L/ha or 319 gallons/acre solution) containing 266 L ai/ha (28.4 gallons ai/acre). Separate groups of four plots per plant species were sprayed with the surfactant-only control solution. Mortality was assessed 1 wk after application.

The effects of vinegar on arcsine-square root-transformed percent mortality of weeds and cotton were examined using PROC NPAR1WAY

(SAS Institute, 1999) and methods similar to those used to assess changes in live cover crop cover. One-way analysis of variance (ANOVA) using SAS PROC GLM and Tukey mean separation were used to analyze the effects of vinegar dose on proportions of Palmer amaranth and cotton leaves per shoot that were damaged in field plots.

Effect of Vinegar on Soil Surface pH

One wk after the winter 2006 application of 0%, 0.9%, 4.5%, and 9% vinegar to cover crops within the sustainable field, one 20 g (0.7 oz) sample from the top 1 cm (0.4 in) of bare soil, free from plant residue, was collected inside each 1m² subplot. Soil samples were suspended in 40 mL (1.4 fl oz) deionized water, agitated for 15 min and allowed to settle for 1 hr at 25°C. The pH was determined with a Model 300729.1 wet electrode connected to a Model 215 pH meter (Denver Instruments, Denver, CO). Effects on pH were analyzed with one-way ANOVA.

RESULTS AND DISCUSSION

Cover Crops and Winter Weeds

Common purslane was the most common winter weed (88% of 117 subplots sampled in 2005 and 2006) and was equally likely to be present in all three cover crop treatments. Palmer amaranth occurred in 54% of all subplots, but was found more often in subplots containing hairy vetch (67%) or no cover (59%) than in black oat subplots (36%) ($\chi^2 = 8.1$, $p < 0.05$), as was wild lettuce, *Lactuca ludoviciana* (Nutt.) Ridd which occurred in 42% of all winter 2006 subplots (75% in HV, 38% in NC, 13% in BO; $\chi^2 = 21$, $p < 0.001$). Grasses occurred in 39% of 2006 samples and were less common (4%) in BO subplots than in HV (50%) and NC subplots (63%) ($\chi^2 = 23$, $p < 0.001$). Other winter weeds encountered in winter 2006 sampling were rocket mustard, *Sisymbrium irio* L. (15%), henbit, *Lamium amplexicaule* L. (6%), common sunflower, *Helianthus annuus* L. (4%), purple sedge, *Cyperus rotundus* L. (3%), camphor weed, *Heterotheca latifolia* Buckl. (< 1%) and cowpen daisy, *Verbesina encelioides* (Cav.) Gray (< 1%). Volunteer cotton and alfalfa were also observed (11% and 4%, respectively). BO and HV plots had 61% and 52% more total plant cover than did NC plots, respectively (Table 1). BO plots had 8 and 17% less total weed cover, respectively, than did NC and HV plots, and purslane coverage was 5% lower in BO plots than in HV

and NC plots, while Palmer amaranth cover did not vary among cover treatments (Table 1). In winter 2005 samples, common purslane seedling density was 3.6-fold higher in BO plots (mean \pm SE; 30 ± 9 shoots/m²) and 2.5-fold higher in HV plots (21 ± 6 shoots/m²) than in NC plots (8.3 ± 3 shoots/m²) ($F = 25.9$, $df = 2, 4$, $p < 0.01$), while Palmer amaranth shoot density did not vary significantly among cover crops (BO, 1.9 ± 0.8 ; HV, 3.5 ± 1.2 ; NC, 0.4 ± 0.2 shoots/m², $p = 0.249$).

The results concur with past findings that winter cover crops vary in their weed suppressive abilities. Grasses such as black oats can suppress weeds to a greater extent than legumes like hairy vetch (Yenish et al., 1996). In this study, black oats suppressed total weed and purslane cover more than either hairy vetch or tillage without cover cropping. Several factors may have promoted greater weed suppression by black oats, including the two fold higher seeding rate and the higher coverage attained by this crop (Table 1) (Hoffman and Regnier, 2006) compared to hairy vetch, even though hairy vetch inhibited weed seed germination and seedling establishment through both chemical allelopathy (Bauer and Reeves, 1999; Kamo et al., 2003; Nava-Rodriguez et al., 2005; Teasdale and Pillai, 2005) and physical obstruction of space and light. Physical factors may have been more important in this experiment. Non-living materials like plastic and non-allelopathic plant residues can physically suppress

TABLE 1. Percent total plant, cover crop, total winter weed, Palmer amaranth, and purslane cover as influenced by winter cover crops in 2005 and 2006, in a field being prepared for sustainable cotton cultivation.^a

Cover Crop ^b	Total	Cover crop	Total weed	Palmer amaranth	Purslane
BO	78.7 \pm 1.7 ^a	69.8 \pm 2.2 ^a	8.9 \pm 1.5 ^b	1.6 \pm 0.5 ^a	5.9 \pm 1.4 ^b
HV	68.9 \pm 2.5 ^a	43.2 \pm 2.8 ^b	25.7 \pm 1.7 ^a	8.3 \pm 1.4 ^a	11.3 \pm 1.7 ^a
NC	17.3 \pm 2.0 ^b	0 ^c	17.3 \pm 2.0 ^a	3.9 \pm 0.8 ^a	10.4 \pm 1.4 ^a
F, p ^c	456.6, < 0.001	402.8, < 0.001	24.3, < 0.01	2.4, > 0.05	12.0, < 0.05

^aValues (mean \pm SE) represent the average of 39 1 m² subplots sampled in 2005 and 2006 for each treatment.

^bAbbreviations: BO, black oats; HV, hairy vetch; NC, no cover.

^cF and p values reflect the effect of cover crop in analyses of variance ($df = 2, 4$). Differing letters within columns denote significant differences among cover crops in Tukey-Kramer tests ($p < 0.05$).

redroot pigweed (*Amaranthus retroflexus* L.) and other weeds (Hill et al., 2006; Teasdale and Mohler, 2000). The higher numbers of purslane seedlings in BO and HV plots are suggestive of a transient physical benefit of cover, such as increased moisture retention under drought conditions (Teasdale and Mohler, 2000), which were present throughout winter and spring sampling in 2005 and 2006. Alternatively, stimulation by low concentrations of exudates or nutritive leachates (Hill et al., 2006; Teasdale and Pillai, 2005), promoted seed germination and seedling establishment, but not shoot growth. The reduced occurrence of Palmer amaranth, wild lettuce, and grasses in BO plots illustrate the ability of cover crops to alter the composition of weed communities (Barberi and Mazzoncini, 2001).

Cover Crops and Spring Weeds

Seven WAP, purslane was the most common weed (58% of 114 total subplots in the sustainable field sampled in 2005 and 2006), and occurrence did not vary according to winter cover. Palmer amaranth was found in 52% of all subplots, and, as in winter samples, was more likely to occur in HV (72%) than in BO (42%) or NC (41%) subplots ($\chi^2 = 9.8$, $p < 0.01$). At least one type of grass occurred in 46% of all 2006 subplots. Johnsongrass (*Sorghum halapense* (L.) Pers) occurred in 23% of subplots, but was found more frequently in BO (28%) and HV (36%) than in NC (5%) subplots ($\chi^2 = 13$, $p < 0.005$), possibly reflecting an increased susceptibility of johnsongrass to winter tillage and spring cultivation in NC plots, because of its tendency to grow in inter-row spaces (S. Greenberg, personal observation). At least one composite (Family Asteraceae) was found in 24% of samples, with no differences between winter covers. Sunflower was the most common species in this group (21%), with other species (sow thistle, *Sonchus oleraceus* L. and cowpen daisy) occurring in less than 1% of subplots. Other weeds observed in 5% or less of subplots included purple nutgrass (*Cyperus rotundus* L.), goosefoot (*Chenopodium murale* L. and *C. berlanderi* Moq.), croton (*Croton leucophyllus* Muell. Arg.), spurge (*Euphorbia* spp.), powderpuff (*Mimosa strigillosa* T. and G.), American nightshade (*Solanum americanum* Mill.), netted globe berry (*Margaranthus solanaceus* Schlecht), and rocket mustard. Volunteer hairy vetch, black oats, alfalfa, and beets (*Beta vulgaris* L.) were also observed.

Seven WAP (3 weeks after sweep cultivation), total plant, total weed, Palmer amaranth and purslane cover did not differ according to winter cover within the sustainable cotton field (Table 2), nor did the density of

TABLE 2. Percent total plant, cotton, total spring weed, Palmer amaranth, and purslane cover as influenced by prior-tilled winter cover crops in sustainable cotton cultivation in 2006^a

Cover Crop ^b	Total	Cotton	Total weed	Palmer amaranth	Purslane
	% cover				
BO	44.7 ± 2.1 ^a	26.7 ± 2.6 ^a	18.0 ± 2.2 ^a	2.8 ± 1.0 ^a	12.4 ± 1.7 ^a
HV	42.7 ± 3.6 ^a	14.0 ± 1.5 ^b	28.7 ± 4.0 ^a	15.9 ± 4.6 ^a	8.5 ± 3.0 ^a
NC	41.3 ± 3.0 ^a	20.8 ± 1.9 ^b	20.5 ± 3.4 ^a	12.0 ± 3.8 ^a	8.0 ± 2.2 ^a
F, p ^c	0.3, > 0.05	9.8, < 0.05	2.6, > 0.05	2.5, > 0.05	2.0, > 0.05

^aValues (mean ± SE) represent the average of 15 1 m² subplots per cover crop treatment.

^bAbbreviations: BO, black oats; HV, hairy vetch; NC, no-cover.

^cF and p values reflect the effect of cover crop in analyses of variance (df = 2, 4). Differing letters denote significant differences among plots in Tukey-Kramer tests (p < 0.05).

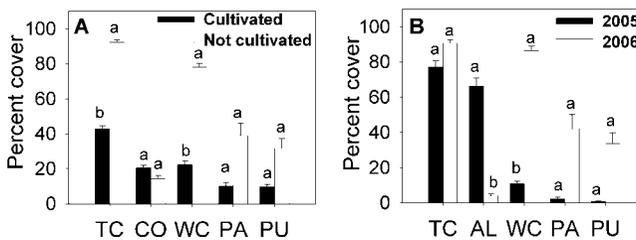
Palmer amaranth shoots, which varied greatly among subplots (mean ± SE; BO, 1 ± 0.5; HV, 160 ± 40; NC, 77 ± 31 shoots/m²) (p = 0.189). However, more of the total plant cover consisted of weeds in former HV plots (64 ± 5%), than in former BO (41 ± 5%) or NC plots (46 ± 6%) (F = 5.3; df = 2, 4; p = 0.07). Cotton occupied 13% and 6% more cover in BO plots than in HV and NC plots, respectively (Table 2). Cotton height, however, did not vary according to past winter cover (BO, 27.1 ± 2.0 cm; HV, 21.3 ± 2.1 cm; NC, 19.4 ± 2.2 cm) (p = 0.295). By comparison, weed cover in conventional plots was 3.7 ± 1.0%, cotton cover was 31.1 ± 1.5%, and cotton heights were 23.1 ± 1 cm.

Cover crop residues on the soil surface can reduce weed establishment and growth (Bauer and Reeves, 1999, Fisk et al., 2001; Teasdale and Rosecrance, 2003), but this study examined the effects of soil-incorporated cover residues. The beneficial effects of black oats on the soil (Bauer and Reeves, 1999) and modestly reduced Palmer amaranth seedling occurrence, cover and density in former BO plots, may have allowed cotton in former BO plots to develop and expand leaves more rapidly than did cotton in former HV and NC plots, without influencing seedling height. In tests in the state of Georgia, black oats enhanced early-season cotton height more than did hairy vetch or five other cover crops (Schomberg et al., 2006). Hairy vetch can enhance cotton height either with or without residue incorporation (Boquet et al., 2004), but hairy vetch plots in this study had higher winter weed cover than black oats plots and possibly enhanced

weed seed production. Cultivation can stimulate weed seed germination (Mohler, 2001a), and in HV plots, residue incorporation and subsequent inter-row cultivation may have reduced the potential benefits of prior vetch cover for crop growth. The efficacy of spring weed suppression by incorporated cover residues did not vary greatly between winter cover species, in contrast to the variable efficacy of surface cover residues (Burgos et al., 2006; Hoffman and Regnier, 2006; Teasdale and Mohler, 2000).

Subplots from which cultivation was withheld for 4 weeks had 50% more total plant cover ($p = 0.009$) and 55% more total weed cover ($p = 0.004$) than cultivated areas across winter cover treatments (Figure 1A), and within treatments (BO, $p = 0.059$; HV, $P = 0.014$; NC, $p = 0.012$). Total spring weed cover was roughly similar in reduced-cultivation strips within all sustainable treatments (BO, $75 \pm 4\%$; HV, $84 \pm 3\%$; NC, $74 \pm 3\%$). Palmer amaranth, purslane and cotton cover (Figure 1A), Palmer amaranth shoot density (cultivated, 77 ± 19 shoots/m²; not cultivated, 40.0 ± 10 shoots/m²; $p = 0.460$), and 7-week-old cotton height (cultivated, 22.6 ± 1.3 ; not cultivated, 21.6 ± 1.9) were not affected by withholding cultivation ($p > 0.05$). Adverse effects on young cotton may have been ameliorated by abundant soil resources (Mohler, 2001a), but full-season cotton growth and yield would have likely been affected, either with (Griffith et al., 2006) or without (Rowland et al., 1999) mechanical weed removal.

FIGURE 1. Percent total (TC), crop (cotton [CO] in Figure 1A; alfalfa [AL] in Figure 1B), total weed (WC), Palmer amaranth (PA), and purslane (PU) cover in early-season sustainable cotton production. **A.** Cover in cultivated plots of all three winter cover treatments (average \pm SE of 45 1 m² subplots) and in strips left uncultivated for 4 wk (average \pm SE of 24 subplots). **B.** Cover in alfalfa strips in 2005 (mean \pm SE of 30 subplots) and 2006 (mean \pm SE of 18 subplots). Bars with different letters vary significantly (Tukey-Kramer tests, $p < 0.05$) in cover between cultivation treatment (**A**) or year (**B**).



Failure of the alfalfa strips in 2006 led to 75% higher total weed cover in these strips than in 2005 (Figure 1B) ($p = 0.006$), with similar trends for Palmer amaranth ($P = 0.081$) and purslane ($P = 0.094$), which occurred in 94% and 100% of alfalfa subplots in 2006, respectively, compared to 30% and 13% in 2005 ($\chi^2 = 22$ and $\chi^2 = 43$, respectively, $p < 0.001$). The results show that two years of hairy vetch and black oat covers were not sufficient to obviate the need for cultivation and alfalfa strips as spring weed management strategies.

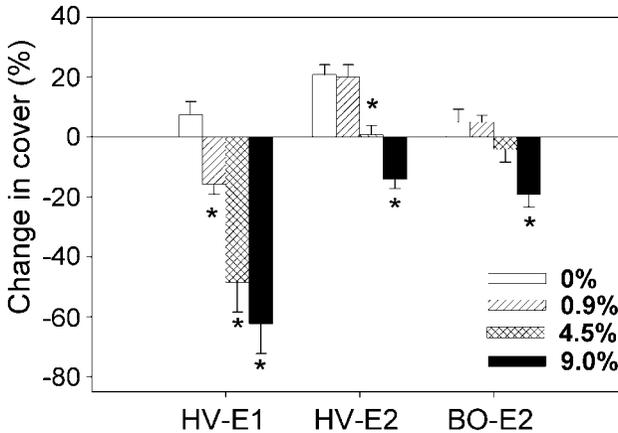
Sustainable Production and Yield

The use of winter cover crops and avoidance of herbicides incurred a penalty in increased spring weed cover relative to conventional weed control, and slightly influenced early-season cotton size. However, cotton yields were similar in sustainable and conventional plots, in both 2005 (mean \pm SE; sustainable, $1,065 \pm 60$ kg/ha or 1.98 ± 0.11 bales/acre; conventional $1,232 \pm 72$ kg/ha or 2.29 ± 0.14 bales/acre; $t = 0.72$, $df = 19$, $p = 0.510$) and 2006 (sustainable, 580 ± 68 kg/ha or 1.08 ± 0.13 bales/acre; conventional 665 ± 95 kg/ha or 1.24 ± 0.18 bales/acre; $t = 1.8$, $df = 5$, $p = 0.094$). The results suggest that weed control with winter cover cropping and spring cultivation, augmented with hand-weeding in the first 8 WAP, generated yields similar to conventional production, when used in concert with sustainable insect pest and fertilization techniques and conventional height control and defoliation techniques. Past studies have shown economically viable cotton yields in systems involving hairy vetch cover despite increased weed densities (Boquet et al., 2004).

Vinegar for Cover Crop Control

In two experiments, application of full-strength (9% acid) vinegar solution was necessary to consistently lower live hairy vetch and black oat winter coverage below levels associated with the control solution (Figure 2). Final live vetch cover in 1 m^2 plots one week after treatment was $4 \pm 1\%$, in the first experiment and $50 \pm 2\%$ in the second experiment, suggesting variation in either environmental conditions or cover crop phenology. Vetch is easier to kill with synthetic herbicides in the mid- to late-flowering stage than in the early flower bud stage (Hoffman and Regnier, 2006), and hairy vetch was 1 to 2 weeks older in the more successful vinegar trial. In contrast to some past data (Burgos et al., 2006), vinegar was less effective in reducing live black oats cover than hairy vetch cover (Figure 2), with $57 \pm 8\%$ live black oats still remaining. One application of 9% vinegar did not

FIGURE 2. Change in estimated coverage of hairy vetch (HV) or black oats (BO) in 1 m² plots 1 week after application of 0%, 0.9%, 4.5%, or 9.0% vinegar solution in two trials (E1, E2). Bars represent the mean \pm SE of six plots per cover crop per experiment. Asterisks (*) indicate changes in cover that are significantly different (Wilcoxon χ^2 tests, $p < 0.05$) from the change caused by control solution.



significantly alter soil surface pH ($p = 0.473$) (control solution, 7.63 ± 0.07 ; 9.0% vinegar, 7.47 ± 0.03). The use of acetic acid does not inhibit soil microbiological activities and may generate additional organic carbon (Malkomes, 2006). However, the overall level of cover crop kill provided by vinegar was inferior to that of glyphosate at 1 to 3 kg/ha (0.9 to 2.7 lbs/acre) (Hoffman and Regnier, 2006). Similarly, repeated applications of 5% to 7% acid vinegar provided only 60% to 80% control of hairy vetch (Young, 2004). At least 95% kill is needed in no-till systems, which, although not used in this study, are common in both sustainable and conventional crop production. Repeated application or the use of vinegar concentrations higher than 9% acid may have increased cover crop mortality, but the amount or concentration of vinegar required may have been impractical.

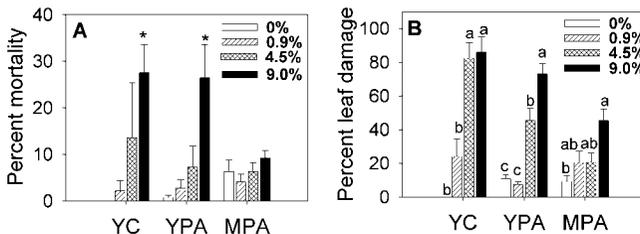
Vinegar for Weed Control in Cotton

Because of its potential as a non-selective contact herbicide (Webber et al., 2005; Young, 2004), vinegar was evaluated as an alternative to synthetic herbicides, cultivation and hand-weeding. Past work (Showler and Greenberg, 2003) and this study found that Palmer amaranth, common

purslane, and composites such as sunflower are the most common winter and early spring broadleaf weeds in cotton fields in the LRGV of Texas. In 1 m² winter plots containing purslane, only 17 ± 6 % of shoots were killed by 9% vinegar, compared to 12 ± 5% in plots that received surfactant only (*p* = 0.629). In winter applications to individual plants, vinegar was ineffective in killing individual Palmer amaranth and sunflower shoots (0 and 10% mortality, respectively). In similar spring tests, 38% of Palmer amaranth, 19% of purslane, and 67% of sunflower plants were killed when sprayed with 9.0% vinegar. Warmer spring temperatures may have enhanced vinegar efficacy, consistent with recommendations to apply under full sunlight (Garrett, 1999), but even these mortality levels do not compare favorably with those associated with synthetic contact herbicides (Heap, 2005).

In August 2005 tests, young volunteer cotton and Palmer amaranth in 1 m² plots in fallow areas showed near-equal levels of mortality (28% and 26%, respectively) in response to 9% vinegar, significantly greater than the response to surfactant only (cotton, $\chi^2 = 11.7$, *p* = 0.008; Palmer amaranth, $\chi^2 = 10.1$, *p* = 0.02) (Figure 3A). Lower vinegar doses did not cause mortality greater than the control. Mature, flowering Palmer amaranth shoots were not killed by vinegar (Figure 3A). The 9% vinegar application damaged 86% of the leaves on small cotton seedlings (*F* = 23.3, *df* = 3, 16, *p* < 0.001), 73% of leaves on small Palmer amaranth plants (*F* = 40.2 *df* = 3, 16, *p* < 0.001) and 45% of leaves on large, reproductive pigweed plants (*F* = 6.7, *df* = 3, 16, *P* = 0.004) (Figure 3B). Because of leaf

FIGURE 3. Percent mortality (A) and leaf damage (B) after application of 0%, 0.9%, 4.5%, or 9.0% vinegar solution to young cotton (YC) and young (YPA) and mature (MPA) Palmer amaranth. Each bar represents the mean ± SE of five 1 m² plots. Asterisks in Figure 3A indicate mortality levels significantly higher than the control application (Wilcoxon χ^2 tests, *p* < 0.05). Bars with different letters in Figure 3B are significantly different from each other (Tukey tests, *p* < 0.05).



damage, it is possible that Palmer amaranth mortality would have increased after a waiting period longer than 1 week, but this delay would likely be impractical for sustainable weed control.

The trials on volunteer field weeds supported past findings that it is difficult to achieve mortality on mature weeds using vinegar, in part because of insufficient vinegar contact (Young, 2004). The fallow cotton field results suggest that vinegar efficacy varied with weed age, as did our own prior greenhouse results (Moran and Greenberg, 2006), in which 4.5% or 9.0% vinegar killed 100% of 1.5 week-old Palmer amaranth, purslane, and sunflower, while 9.0% vinegar killed only 12% to 68% of 3.5 and 5.5-week-old Palmer amaranth and purslane, and 28% to 90% of sunflower. Young (1.5-week-old) cotton plants sprayed with 0.9% vinegar survived and replaced damaged leaves within two weeks, while plants exposed to higher concentrations died (Moran and Greenberg, 2006). Most 3.5 and 5.5-week-old cotton (90–100%) survived application of 9.0% vinegar, but failed to replace damaged leaves.

In a 2006 field experiment to examine the effects of weed age on vinegar efficacy, full-strength (9% acid) solution was used because this dose was the only one capable of causing mortality in prior field trials. Field-sown cotton seedlings sprayed 10 days after emergence were etiolated at the time of application, explaining why they were taller than greenhouse-grown and transplanted seedlings sprayed 16 and 23 days after emergence (Table 3). Variation in vinegar-induced mortality according to plant age followed two trends. Cotton and sunflower sprayed any time within the first month after emergence showed 84% or greater mortality, with the exception of 16-day-old cotton (Table 3). Satisfactory ($\geq 95\%$) Palmer amaranth and purslane mortality occurred only in plants that were 10 days old (Table 3). Re-application of vinegar to 16- and 23-day-old Palmer amaranth and purslane increased mortality by only 10% and 0%, respectively, after an additional week.

As with some synthetic herbicides (Sellers et al., 2003; Griffith et al., 2006), and physical control methods like electrocution (Mohler, 2001b), the efficacy of vinegar declined sharply with age in the two most common early-season cotton weeds in the LRGV, Palmer amaranth and purslane. In contrast, sunflower and the cotton crop remained susceptible throughout the first month of field growth. Leaf contact times may be greater on pubescent cotton and sunflower leaves than on smooth, waxy Palmer amaranth and purslane leaves. Declines in efficacy with increasing plant age could be related to lignin accumulation and cell wall strengthening (Boerjan et al., 2003), since the acid likely exerts its effects by rupturing cell walls and

TABLE 3. Height and number of leaves in field cotton, Palmer amaranth, purslane, and sunflower seedlings 10, 16, 23, and 30 days after emergence, and mortality after vinegar application.*†

Age	Measure	Cotton	Palmer amaranth	Purslane	Sunflower
10 days	Height (cm)	8.0 ± 0.6	6.4 ± 0.3	2.8 ± 0.4	ND
	Leaves	0.2 ± 0.1	7.8 ± 0.9	11.7 ± 3.7	ND
	Mortality (%)	90 ± 6 [‡]	96 ± 2 [‡]	98 ± 2 [‡]	ND
16 days	Height (cm)	4.2 ± 1.0	14.9 ± 1.2	24.1 ± 5.4	6.3 ± 0.3
	Leaves	2.0 ± 0.0	27.1 ± 2.5	70.0 ± 17.5	4.0 ± 0.1
	Mortality (%)	59 ± 11 [‡]	62 ± 8 [‡]	26 ± 3 [‡]	100 ± 0 [‡]
23 days	Height (cm)	7.2 ± 0.3	51.7 ± 3.9	50.1 ± 5.5	8.7 ± 0.7
	Leaves	4.3 ± 0.1	36.1 ± 2.8	170 ± 38.6	8.7 ± 0.4
	Mortality (%)	98 ± 2 [‡]	9 ± 7	7 ± 7	100 ± 0 [‡]
30 days	Height (cm)	10.9 ± 0.5	86.6 ± 10.5	61.1 ± 2.2	11.4 ± 1.0
	Leaves	6.5 ± 0.3	27.8 ± 2.4	239 ± 38.8	12.0 ± 0.5
	Mortality (%)	84 ± 7 [‡]	49 ± 5 [‡]	6 ± 6	100 ± 0 [‡]

*Each number represents the mean ± SE of four 1 m² plots. Mortality was measured one week after application of 9% vinegar or control solution (2,980 L/ha volume, 266 L ai/ha). Mortality means within a column and plant age followed by a double dagger

‡are significantly higher than the mortality associated with control solution (0% acid) (Wilcoxon χ^2 tests, $p < 0.05$). ND, not determined.

†Control mortality was 1% to 6% in cotton, 1% to 31% in Palmer amaranth, 0% to 13% in purslane, and 0% to 6% in sunflower.

membranes. Wind-induced lignin deposition (Cipollini, 1997) could also increase the resistance of field weed seedlings as they age.

CONCLUSIONS

Black oats and hairy vetch winter cover crops suppressed winter weeds to the same extent or more than did winter tillage in no-cover plots, although black oats favored initial establishment of purslane, and hairy vetch tended to have the same effect on Palmer amaranth, composites and grasses. In the spring, soil-incorporated black oats cover was slightly more beneficial to cotton than incorporated hairy vetch, but neither cover controlled spring weeds. Two years of winter cover cropping did not obviate the need for cultivation, alfalfa strips, and hand-weeding for sustainable spring weed management in cotton in the LRGV of Texas. Among seven cover crops tested in Georgia, U.S.A., black oats in

combination with strip tillage and limited herbicide use at planting maximized cotton yield and economic returns (Schomberg et al., 2006). The sustainable weed control system used in this study did not negatively affect cotton yield. The benefits of winter cover crops to production crops may be enhanced by residue incorporation (Sainju et al., 2005). Untilled cover residues may be more effective in suppressing Palmer amaranth, purslane, and other weeds after crop planting, and can enhance crop growth (Bauer and Reeves, 1999; Boquet et al., 2004; Fisk et al., 2001; Hoffman and Regnier, 2006; Nagabhushana et al., 2001) but involve some risk to crop establishment (Boquet et al., 2004), and herbicide treatments after crop emergence are often still necessary (Teasdale et al., 2005; Teasdale and Rosecrance, 2003). Further studies are needed to examine interactions between winter cover crops and the wide range of physical, chemical, and biological techniques available (Mohler, 2001b) for weed suppression and promotion of cotton growth. Many studies on herbicide efficacy, cover crop growth and weed suppression, and effects of weeds on crops measure cover, crop or weed biomass as key measures of impact (Hoffman et al., 1996; Koger and Reddy, 2005; Rowland et al., 1999; Teasdale et al., 2005). In this study, visual cover estimates were used rather than biomass, but treatment effects were still discernable.

Vinegar has limited potential as an additional component in sustainable weed control in cotton. The risk of mortality or injury to cotton is high at the dose required for consistent impact on field weeds (at least 9% acid content), restricting the use of vinegar to non-crop areas. Applications of 9% vinegar to 10-day-old or younger weeds under conditions of full sun and calm winds could be used to augment tillage before planting and inter-row cultivation after planting. Spot applications to 1 month-old or less volunteer cotton and sunflower should also be effective. Vinegar containing 9% acid is not effective for killing hairy vetch or black oats and associated weed infestations, or for control of mature Palmer amaranth and purslane. Reports of successful weed control with vinegar in nurseries, home gardens and fields involved acetic acid levels as high as 20% (Garrett and Beck 1999, Webber et al., 2005). For field crop production, both vinegar concentrations and application rates must be feasible for producers, and some of the rates used in this study likely exceed what is practical. At sub-lethal levels, vinegar could be used to cause leaf damage in weeds outside of crop rows, which could reduce seed production and mitigate herbicide resistance development, a documented problem for Palmer amaranth pigweed (Heap, 2005; Manley et al., 1999), common purslane (Masabni and Zandstra, 1999), and sunflower (Zelaya and

Owen, 2004). Many resistance delay techniques involving synthetic chemicals focused on weed reproduction, rather than growth (Beckie and Gill, 2006). The judicious and repeated use of cover crops, tillage, soil cultivation and organic control tools such as vinegar could increase the sustainability of weed control in cotton production in the LRGV of Texas.

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