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Cover Crop Residue and Organic Mulches Provide Weed Control during Limited-Input No-Till Collard Production

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*Limited input producers may adopt no-till production if sufficient weed suppression can be achieved. High-biomass producing cover crops used in conjunction with organic mulches may provide sufficient weed control in no-till vegetable production. Our objective was to quantify weed suppression from a forage soybean summer cover crop and three types of organic mulches applied after collard (*Brassica oleracea *L.) planting. Forage soybean residue did not suppress weeds, but mulches were generally effective. Broadleaf and sedge weeds decreased in population size over the three-year period, but grass weed management remained problematic until three years after conversion to no-till. Grass suppression was greater when mulches were applied after the first year. Collard yield, averaging 17,863 kg ha^{-1}, was not affected by any cover crop or mulch treatment.*

KEYWORDS *conservation tillage, weed control,* Brassica oleracae *L., vegetable, mulch, forage soybean, double cover cropping*

INTRODUCTION

Systems involving conservation tillage (CT) with cover crops, mulch, and rotations have been identified as a soil management strategy with potential

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to improve food security for millions of hungry people, as well as contribute to political stability (Lal, 2008). However, adequate weed suppression in CT systems remains problematic without herbicides. Reduced herbicide weed management in conjunction with high-biomass producing cover crops and organic mulches may maintain weeds at manageable levels while simultaneously improving soil quality.

Weed control in CT systems usually depends on herbicides, so producers interested in growing herbicide-free vegetables are generally excluded from adopting CT. However, there is a growing body of literature devoted to the establishment of CT vegetable production, often utilizing high-biomass cover crops, as a feasible technology for herbicide-free olericulture. Used in conjunction with organic mulches, sufficient weed control in CT vegetable production may be achieved.

CT is defined as agricultural production that leaves at least 30% residue on the soil surface after planting, and may include no-till, ridge till, mulch-till, and strip-till (Uri, 1999). CT is known to reduce soil erosion (Langdale et al., 1992a; McGregor and Greer, 1982; Moldenhauer et al., 1983) and increase soil organic matter (SOM) content (Edwards et al., 1992; Langdale et al., 1992b; West and Post, 2002). Associated benefits, such as limiting phosphorus (P) runoff and improving soil infiltration (Uri, 1999), soil structure and aggregate stability (Riley et al., 2008) are beneficial to producers and the environment alike. Other benefits of CT include reduced energy and labor costs (Siemans and Doster, 1992) and increased soil moisture retention (Li et al., 2008). Disadvantages of CT may include reduced weed control, delayed planting dates due to lower soil temperatures in spring, equipment costs (Gupta et al., 1988; Rutledge, 1999) and potential delayed N availability to the crop due to N immobilization (Blevins et al., 1983). Agricultural production in the USA has seen a marked increase in adoption of CT in recent decades. Between 1998 and 2005, no-till corn (*Zea mays*) acreage in the U.S. increased from 3.7 million to 7.5 million hectares, while conventionally tilled corn acreage decreased from 9.9 million to 8.3 million hectares over the same period (USDA, 2008).

Among vegetable producers, there is a perceived increase in insect, disease and weed pressure and potential yield reductions with the adoption of CT. Although no data are available for CT adoption among vegetable producers, it is likely that vegetable producers may be willing to adopt CT if sufficient pest management can be achieved without reducing yields. Vegetable producers, including organic producers, farmers participating in community supported agriculture (CSA) programs, and direct market producers may be willing to adopt CT if sufficient weed management can be achieved due to public interest in obtaining local pesticide-free produce. Conventional vegetable producers should be able to adopt CT more readily than organic producers because of the allowance for herbicides and chemical fertilizers. However, much of the research conducted on herbicide-free weed control in CT olericulture has centered on organic production because of the reliance on soil organic matter provided by cover crop residues and other organic materials, while avoiding the use of chemical herbicides.

CT tends to shift weed populations toward both annual and perennial grasses, while conventional tillage tends to shift populations toward broadleaved weeds (Teasdale et al., 1991; El Titi, 2003). Under CT, germination and emergence of small, old, and deep weed seeds can be reduced (Bond and Grundy, 2001; El Titi, 2003), which may shift weed populations in favor of those with high seed production rates such as grasses (El Titi, 2003) or those with rhizomes (Torresen et al., 2003). Additional perennial grass control may be obtained mechanically by cutting before seeds become viable (Peigne et al., 2007).

The goal of herbicide-free vegetable production is to maintain weed populations at manageable levels, not to eliminate weeds altogether (Bond and Grundy, 2001), though weed control is vital to maintain pressures below yield reducing threshold levels. Traditionally, organic vegetable producers utilize cultivation or hand weeding for weed control, though feasible methods of weed control in organic CT systems include hand-weeding, brush weeding, mowing, cutting, flaming (Bond and Grundy, 2001; Peigne et al., 2007), and the use of plastic, fabric or organic mulches (Feldman et al., 2000).

The use of cover crops during fallow periods can suppress weeds via rapid growth, providing a thick ground cover after termination (Nelson et al., 1991), competing with weeds during growth, and releasing allelopathic compounds during residue decomposition (Grundy et al., 1999). Termination of cover crops without the use of herbicides can be as effective as chemical termination using mechanical crimp and roll methods after the soft dough stage of grain development (Ashford and Reeves, 2003). The killed residue acts as a mulch, thereby suppressing weeds by reducing light transmittance and soil temperature amplitude (Teasdale and Mohler, 1993). During organic sweet potato (*Ipomoea batatas* (L.) Lam.) production in North Carolina, Treadwell et al. (2007) found that a cover crop mixture of rye (*Secale cereale* L. 'Wrens Abruzzi') and hairy vetch (*Vicia villosa* Roth) with reduced tillage was as effective as tillage for the suppression of dicot weeds but not monocot weeds, although CT suppressed yields by at least 45%, due to the increase in monocot weeds.

The quantity of organic mulch needed to suppress weeds may be cost-prohibitive if purchased and transported to the production area, but may be economically feasible if produced *in situ* (Merwin et al., 1995). During tomato (*Lycopersicon esculentum* Mill.) and pepper (*Capsicum annuum* L.) production, weed control using ryegrass (*Lolium* spp.) mulch was found to be more economical than cultivation (Edwards et al., 1995). Ensuring the application of weed seed-free straw is required in order to circumvent volunteer weed infestation (Yordanova and Shaban, 2007).

During echinacea (*Echinacea purpurea* Moench. [L.]) production in Australia, hay mulch exhibited >90% greater weed control compared to a non-weeded control and was comparable to hand-weeding (Kristiansen et al., 2008). The same experiment showed 85% weed control by hay mulch for lettuce production, compared with 96% control by hand-weeding and 66% by tillage. Plots with straw mulch applied to a 10 cm depth exhibited 2.0% weed coverage 38 days after transplanting Chinese cabbage (*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt) in the UK, compared to 0.2% for hand-weeding, 0.8% for black polyethylene, and 76.3% for a non-weeded control (Runham and Town, 1995). Yordanova and Shaban (2007) showed that wheat straw mulch suppressed dicotyledonous weeds more effectively than monocotyledonous, but did not suppress perennial weeds during broccoli (*Brassica oleracea* L. var. *italica* Plenck) production.

Application of mulch several weeks after transplanting can improve weed suppression later into the growing season (Law et al., 2006). Mulch application should be done with care to prevent stem breakage of the main crop (Boyhan et al., 2006) as well as shading of prostrate crops (Pedreros et al., 2008).

The ability of limited-input vegetable producers to adopt CT is currently limited by adequate weed control measures. Adequate weed suppression may be achieved through the use of high-biomass winter and summer cover crops for fall vegetable production. Such a system may find utility for those producers who seek to bring new land into full production two or three years into the future, and wish to begin weed suppression and improve organic matter content now. Weed emergence is limited through the inhibition of light transmittance (Steinmaus et al., 2008) by high biomass cover crops and organic matter is increased as they decompose on the soil surface. Additional late season weed suppression may be achieved by the application of organic mulches over cover crop residues after vegetable crop establishment. Mulches may be produced on the farm in order to reduce purchase and transportation costs, and may even utilize invasive or weedy perennial leguminous species, such as mimosa (*Albizia julibrissin* Durazz.) or lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don) cuttings, as long as those mulches are applied before their seeds become viable. If summer and winter cover crops, as well as organic mulches, are chosen carefully with regard to persistence and nutrient content, the dual purpose of increasing agricultural productivity while simultaneously improving soil quality may be achieved. The persistence and C and N mineralization rates of mimosa, lespedeza, and oat (*Avena sativa* L.) straw under conservation and conventional tillage have been described elsewhere (Mulvaney et al., 2010). The double cover cropping system described in this paper represents a novel, innovative practice for short-term SOM increase and weed suppression on an agriculturally productive field, while simultaneously removing *in situ* invasive, perennial leguminous species.

The objective of this experiment was to quantify weed suppression effects of a summer cover crop and organic mulches under no-till collard (*Brassica oleracea* L. acepahala group cv. Champion) production during the first three years of conversion from CT. This data should enable vegetable producers to make more informed decisions regarding cover crop and mulch residue management during the adoption of CT practices.

MATERIALS AND METHODS

Studies were conducted at the E.V. Smith Research Center in near Tallassee, AL (N 32°29.29' W85°53.26, 66 m elevation) between 2005 and 2008 on a Wickham fine sandy loam soil, 0% to 2% slopes (Wickham fine-loamy, mixed, semiactive, thermic Typic Hapludults). The experiment was a 2 by 4 factorial randomized complete block design replicated four times. Each block was 24.4 m long and 9.1 m wide, with experimental units measuring 9.1 m long and 3.0 m wide, accommodating four collard rows, including two border rows. The two main treatments consisted of a 'Derry' forage soybean (*Glycine max* (L.) Merr. cv. Derry, group VI, Shoffner Farm Research, Inc., Newport, AR) summer cover crop and a no summer cover crop (weed fallow) control. Four sub-treatments consisted of *in situ* organic mulches: fresh mimosa prunings $\leq$1 cm in diameter, fresh lespedeza (cv. AU Grazer) cuttings, wheat straw (*Triticum aestivum* L.), and a no-mulch control. Treatments remained the same on each plot from year to year.

The plots were disked at the initiation of the experiment in October 2005. Before experimental plots were established, soil tests (on Oct. 10, 2005) indicated initial plant available nutrient levels of 41 kg ha^{-1} P_2O_5 (medium), 141 kg ha^{-1} K_2O (high), 205 kg ha^{-1} Mg (high), and 810 kg ha^{-1} Ca with a pH of 6.4 (Table 1). No tillage was used after the experiment was initiated, and the field was not subsoiled at any time. Each year, a winter cover of rye (cv. Elbon) was established and fertilized with 67 kg N ha^{-1}. The rye was mechanically terminated using a roller-crimper (Ashford and Reeves, 2003) or chemically terminated if an adequate kill was not obtained in late April. Two weeks after termination, the forage soybean summer cover crop treatment was planted at 101 kg ha^{-1} on 20 cm rows using a Marliss^{TM} no-till drill. During the second and third years, the amount of residue on

TABLE 1 Field Operations during the Experiment

Date	Operation	Notes
5-Oct-2005	Disked	John Deere 3.7 m leveling disk harrow
10-Oct-2005	Soil sample	pH: 6.4, P_2O_5: 41 kg ha^{-1} (med), K_2O: 141 kg ha^{-1} (high), Mg: 205 kg ha^{-1} (high), Ca: 810 kg ha^{-1} (high)
20-Oct-2005	Disked	John Deere 3.7 m leveling disk harrow
20-Oct-2005	Broadcast 45 kg P_2O_5 ha^{-1}	Granular, John Deere 4030
20-Oct-2005	Chisel plow after fertilizer	7 shank Mohawk chisel plow
26-Oct-2005	Disked	John Deere 3.7 m leveling disk harrow
27-Oct-2005	Broadcast 67 kg N ha^{-1}	Ammonium nitrate, John Deere 4030
27-Oct-2005	Incorporated fertilizer	KMC 3.7 m field cultivator
27-Oct-2005	Cultipacked	2.4 m Lily Roterra Cultipacker
27-Oct-2005	Plant rye winter cover crop	18 cm rows, 101 kg ha^{-1}, 2.4 m grain drill
15-Nov-2005	Cultivate and plant border area	18 cm rows, 101 kg ha^{-1}, 2.4 m grain drill
4-May-2006	Crimped and rolled rye cover	1.8 m crimper roller
31-May-2006	Plant soybean summer cover	Innoculated, 20 cm rows, 11 seeds per m row, 101 kg ha^{-1}
21-Jun-2006	Irrigate	0.8 ha-cm, reel with gun
30-Jun-2006	Irrigate	1.3 ha-cm, reel with gun
13-Jul-2006	Irrigate	1.4 ha-cm, reel with gun
20-Jul-2006	Irrigate	0.7 ha-cm, reel with gun
4-Aug-2006	Herbicide application	Glyphosate, Round-up, 1.9 l ha^{-1}
10-Aug-2006	Crimp/roll (poor kill)	1.8 m crimper roller
14-Aug-2006	Crimp/roll	1.8 m crimper roller
15,16-Aug-2006	Transplant collards	76 cm rows, 42 cm in-row, RJV 600 no-till transplanter
16-Aug-2006	Irrigate	0.5 ha-cm, reel with gun
21-Aug-2006	Replace transplant mortalities	Hand plant
30-Aug-2006	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
1-Sep-2006	Insecticide application	Bt, Dipel DF, 1.1 kg ha^{-1}
1-Sep-2006	Insecticide application	Carbaryl, Sevin 80S, 1.1 kg ha^{-1}
11,12-Sep-2006	Mulch application	6.7 Mg ha^{-1} (oven-dry basis), hand mulched
14-Sep-2006	Insecticide application	Bt, Dipel DF, 0.6 kg ha^{-1}
20-Sep-2006	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
20-Sep-2006	Insecticide application	Bt, Dipel DF, 1.1 kg ha^{-1}
25-Sep-2006	Insecticide application	Zeta-cypermethrin, Mustang Max, 0.2 l ha^{-1}
16-Oct-2006	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
23-Oct-2006	Harvest collards	Hand harvest
14-Nov-2006	Plant rye winter cover crop	18 cm rows, 101 kg ha^{-1}, 2.4 m grain drill
11-Dec-2006	Broadcast 67 kg N ha^{-1}	Ammonium nitrate, John Deere 4030
2-Feb-2007	Soil test	pH: 6.2, P_2O_5: 61 kg ha^{-1} (high), K_2O: 157 kg ha^{-1} (high), Mg: 175 kg ha^{-1} (high), Ca: 763 kg ha^{-1} (high)
17-Apr-2007	Crimp/roll rye cover	USDA 4.6 m roller/crimper
10-May-2007	Herbicide application	Paraquat, Gramoxone Max, 1.755 l ha^{-1}
16-May-2007	Irrigate	1.5 ha-cm, reel with gun
22-May-2007	Plant soybean summer cover	Innoculated, 20 cm rows, 11 seeds per m row, 101 kg ha^{-1}

(*Continued*)

TABLE 1 (Continued)

Date	Operation	Notes
22-May-2007	Irrigate	1.2 ha-cm, reel with gun
4-Jun-2007	Irrigate	1.3 ha-cm, reel with gun
29-Jun-2007	Irrigate	1.2 ha-cm, reel with gun
13-Aug-2007	Herbicide application	Glyphosate, Round-up, 3.5 l ha^{-1}
22-Aug-2007	Herbicide application	Glyphosate, Round-up, 4.7 l ha^{-1}
24-Aug-2007	Crimp/roll summer cover	USDA 4.6 m roller/crimper
10-Sep-2007	Irrigate	3.3 ha-cm, reel with gun
11-Sep-2007	Row cleaners pre-transplant	Kenzie 4 row no-till planter
11-Sep-2007	Transplant collards	76 cm rows, 42 cm in-row, RJV 600 no-till transplanter
11-Sep-2007	Insecticide application	Zeta-cypermethrin, Mustang Max, 0.3 l ha^{-1}
19-Sep-2007	Replace transplant mortalities	Hand plant
20-Sep-2007	Irrigate	1.2 ha-cm, reel with gun
2-Oct-2007	Mulch application	6.7 Mg ha^{-1} (oven-dry basis), hand mulched
2-Oct-2007	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
2-Oct-2007	Irrigate	1.5 ha-cm, reel with gun
16-Oct-2007	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
16-Oct-2007	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, John Deere 950
16-Oct-2007	Irrigate	1.0 ha-cm, reel with gun
8-Nov-2007	Broadcast 45 kg N ha^{-1}	Ammonium nitrate, hand-spread
8-Nov-2007	Irrigate	0.7 ha-cm, reel with gun
15-Nov-2007	Harvest collards	Hand harvest
28-Nov-2007	Plant winter rye	18 cm rows, 101 kg ha^{-1}, 2.4 m grain drill
28-Nov-2007	Broadcast 67 kg N ha^{-1}	Ammonium nitrate, John Deere 4030
28-Nov-2007	Herbicide application	Glyphosate, Eraser, 4.7 l ha^{-1}
29-Apr-2008	Crimp/roll rye cover	USDA 4.6 m roller/crimper
14-May-2008	Lime application	Dolomitic, 3.4 Mg ha^{-1}
23-May-2008	Plant soybean summer cover	Innoculated, 20 cm rows, 11 seeds per m row, 101 kg ha^{-1}
28-May-2008	Irrigate	1.0 ha-cm, reel with gun
3-Jun-2008	Irrigate	0.9 ha-cm, reel with gun
3-Sep-2008	Herbicide application	Glyphosate, Round-up, 3.5 l ha^{-1}
8-Sep-2008	Crimp/roll summer cover	USDA 4.6 m roller/crimper
10-Sep-2008	Row cleaners pre-transplant	Kenzie 4 row no-till planter
10-Sep-2008	Mow plots	Thick biomass necessitated mowing
10-Sep-2008	Row cleaners pre-transplant	Kenzie 4 row no-till planter
10-Sep-2008	Transplant collards	76 cm rows, 42 cm in-row, RJV 600 no-till transplanter
11-Sep-2008	Insecticide application	Zeta-cypermethrin, Mustang Max, 0.3 l ha^{-1}
11-Sep-2008	Irrigate	0.8 ha-cm, reel with gun
15-Sep-2008	Broadcast 45 kg N ha^{-1}	Ammonium sulfate, John Deere 950
23-Sep-2008	Irrigate	1.0 ha-cm, reel with gun
25-Sep-2008	Insecticide application	Zeta-cypermethrin, Mustang Max, 0.3 l ha^{-1}
30-Sep-2008	Mulch application	6.7 Mg ha^{-1} (oven-dry basis), hand mulched
1-Oct-2008	Broadcast 45 kg N ha^{-1}	Ammonium sulfate, John Deere 950
1-Oct-2008	Irrigate	1.0 ha-cm, reel with gun
15-Oct-2008	Broadcast 45 kg N ha^{-1}	Ammonium sulfate, John Deere 950
16-Oct-2008	Irrigate	0.8 ha-cm, reel with gun
17-Nov-2008	Harvest collards	Hand harvest

the soil necessitated the use of row cleaners using a Kinze™ 4-row no-till planter immediately prior to collard transplanting. In mid- to late August, summer cover crops were mechanically terminated using a roller-crimper or chemically terminated if an adequate kill was not obtained. Two weeks after summer cover crop termination, rows were cleared using row cleaners on a Kinze™ no-till planter and collards (cv. Champion; Source: 2006–2007, Abbott & Cobb, Feasterville, PA; 2008, Reimer Seeds, Mount Holly, NC). Seedlings were transplanted 43 cm apart using a single row RJV 600 no-till transplanter (R.J. Equipment, Blenheim, Ontario, Canada) on 76 cm rows. Fresh mimosa was hand cut using branches ≤1 cm in diameter. Fresh lespedeza was cut using a Carter forage harvester. Straw mulch was obtained locally. The dry weight of mulches was determined by oven-drying a sample several days before mulch application. Mulches were hand-applied at a rate of 6.7 Mg ha^{-1} (oven-dry basis) 21 days after transplanting, at which time the collards were approximately 10 to 15 cm tall. Collards were fertilized at a rate of 135 kg N ha^{-1} in three split applications and irrigated using a traveling gun as needed. Hand-harvest operations were conducted 65 to 69 days after transplanting by cutting the base of the plant. Two 2 m rows from the center of each experimental unit were weighed immediately after harvest to determine fresh weight collard yield. Following harvest, a winter cover crop of rye was planted at a rate of 101 kg seed ha^{-1} on 18 cm rows. Weed coverage was determined using line-transect methodology. A marked line with 50 points was laid at a 45 degree angle across the rows, and points that touched weeds were counted. The count was repeated after moving the line 90 degrees (so that the line lay at 45 degrees in the opposite direction), such that two 50-point counts were obtained for each experimental unit during each sampling period. Fifty points along a marked line were counted twice per plot per sampling period. Weeds were classified as broadleaves, grasses or sedges. Twice during 2008, weeds were identified to the species level.

Significant effects were identified by analyses of variance as implemented in SAS 9.1.3 using PROC GLIMMIX procedures and maintaining blocks as a random effect (SAS, 2003). Reduced models were obtained via backward elimination for variable selection using $p > 0.15$ as the criteria for elimination from the model. Since P values change as variables are removed during backwards elimination, the relatively high P value was chosen so as to not reject variables that may have been significant. Variables were considered significant if $p < 0.10$ unless otherwise stated. Inflated Type I error rates associated with the covariance structure in the model were limited by adjusting the denominator degrees of freedom using Kenward-Roger correction in the MODEL statement (Littell et al., 2002). Means and standard errors of significant effects of the reduced models were obtained using PROC MEANS.

RESULTS AND DISCUSSION

The average (± standard error) of winter rye biomass obtained during 2006–2008 was 8.48 ± 0.37 Mg ha^{-1}, 10.48 ± 0.57 Mg ha^{-1}, and 5.89 ± 0.53 Mg ha^{-1}, respectively. The average forage soybean yield during 2007 was 2.32 ± 0.18 Mg ha^{-1}, and 6.72 ± 0.41 Mg ha^{-1}. The 2007 forage soybean biomass was low because of drought conditions. Reliable forage soybean biomass data during 2006 was not available. Mulching provided weed suppression of broadleaves, grasses and sedges. The forage soybean summer cover crop did not suppress weeds (Table 2), likely due to the fact that soybean residue decomposes too quickly to have a lasting mulching effect (Mulvaney et al., 2010).

In all cases, days after mulching (DAM) were significant within each year of the study ($p < 0.0001$). A time by mulch interaction within each year (DAM*Mulch [Year]) was due to both the effect of mulch application and the growth of weeds as the season progressed. Evidence of a mulch by year interaction suggested that weed populations were affected by mulching for three consecutive years. This effect was most apparent on broadleaf weed control (Figure 1). Mulching the first year was effective for suppression of broadleaf weeds. Suppression of broadleaf weeds during the first year appeared to lower broadleaf infestation during subsequent years, although mulching in 2007–2008 did not provide the same level of weed suppression compared with the non-mulched control. Since CT tends to reduce broadleaf populations (Teasdale et al., 1991; El Titi, 2003), it was not surprising that broadleaf control was enhanced with mulch application during the first year after conversion to no-till.

The population shift toward grasses under CT made grass control more difficult (El Titi, 2003). During the first year of no-till, mulching did not improve control of grasses (Figure 2), but in subsequent years, improved grass suppression was observed with mulches compared with the

TABLE 2 Probability of greater F values for the effect of mulch, cover crop (CC), days after mulching (DAM), and year on weed coverage

	P > F		
Effect	Broadleaf	Grass	Sedge
Mulch	0.0913	0.0315	0.0043
Mulch*Year	0.0054	0.1077	0.1046
DAM(Year)	<.0001	<.0001	<.0001
DAM*Mulch(Year)	0.1128	0.0014	0.0008
Year	n/s	n/s	0.0154
CC*Mulch	n/s	n/s	0.0924
CC*Mulch*Year	n/s	n/s	0.1074

Treatments not shown or not significant (n/s) were excluded after backward elimination variable selection for the reduced model if $p > 0.15$.

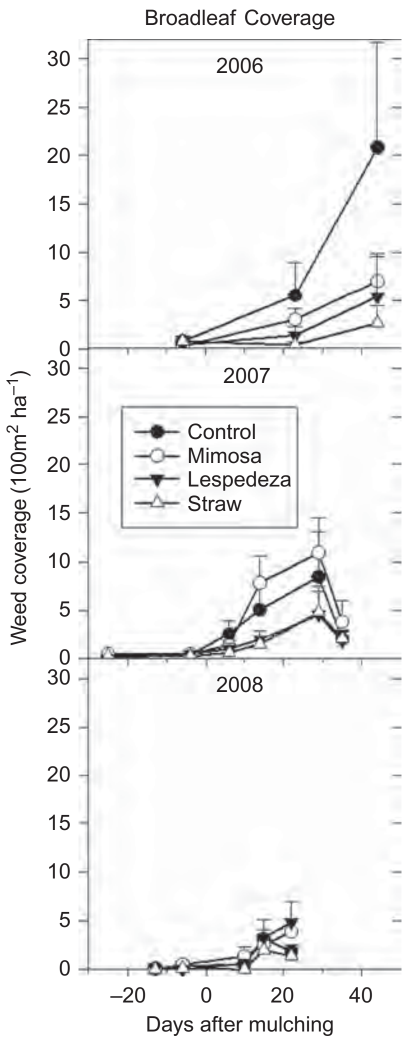

FIGURE 1 Broadleaf weed coverage after conversion to no-till during 2006–2008 with mulches applied at 6.7 Mg ha^{-1} three weeks after transplanting. Bars represent standard errors of the means.

non-mulched control. Grass infestation remained below 10% through the application of all mulching materials in 2007 (compared with 17% for the non-mulched control), and below 6% in 2008. Our results showed that grass populations under no-till are highly variable, with populations increasing dramatically during the second year of conversion from conventional tillage, but decreasing in the third year. Mowing grasses before seed heads become viable may reduce the grass populations to manageable levels during the transition from conventional to CT.

During the first year of the experiment, yellow nutsedge (*Cyperus esculentus* L.) control was highly problematic, with total plot coverage by

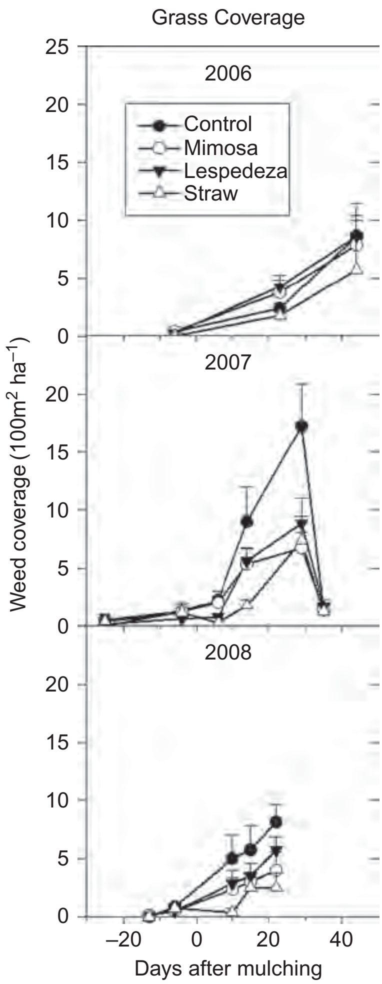

FIGURE 2 Grass weed coverage after conversion to no-till during 2006–2008 with mulches applied at 6.7 Mg ha^{-1} three weeks after transplanting. Bars represent standard errors of the means.

nutsedge ranging from 7% to 21% (Figure 3). However, subsequent years of high residue no-till improved sedge suppression, generally below 5% plot coverage, although differences between mulching treatments and the control were minimal. Bangarwa et al. (2008) showed that straw mulch applied at 7300 kg ha^{-1} (7 cm depth) was effective at reducing medium (0.26 to 0.50 g) purple nutsedge (*Cyperus rotundus* L.) tuber density, but did not reduce large (>0.50 g) or small (0.10 to 0.25 g) tuber density for bell pepper (*Capsicum annum* L. 'Heritage') production in Clemson, SC. They also found generally comparable tuber density when tilled plots were either straw-mulched at transplanting or hand-weeded every 1 to 2 weeks. There was a cover crop by mulch interaction with sedge coverage in our experiment

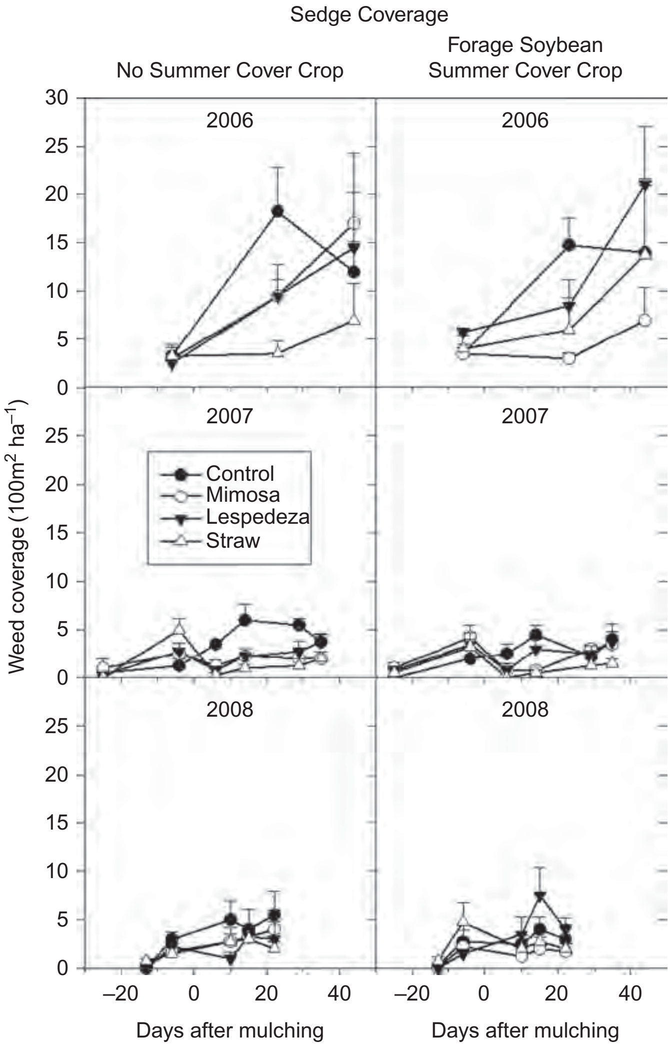

FIGURE 3 Sedge coverage after conversion to no-till during 2006–2008 with mulches applied at 6.7 Mg ha^{-1} three weeks after transplanting. Bars represent standard error of a mean.

(Table 1), resulting from increased sedge suppression by mimosa prunings after the forage soybean summer cover crop in 2006 and increased sedge suppression in control plots with forage soybean in 2007 and 2008 (Figure 3). Although mechanisms are unclear, it was apparent that sedge suppression was improved during subsequent years of no-till using high-biomass cover crops with or without the application of mulches. Yellow nutsedge was the only perennial weed species present after three years (Figure 4).

Weed infestation by species averaged over all plots in 2008 showed no individual weed species averaged more than 4% of plot surface 15 days

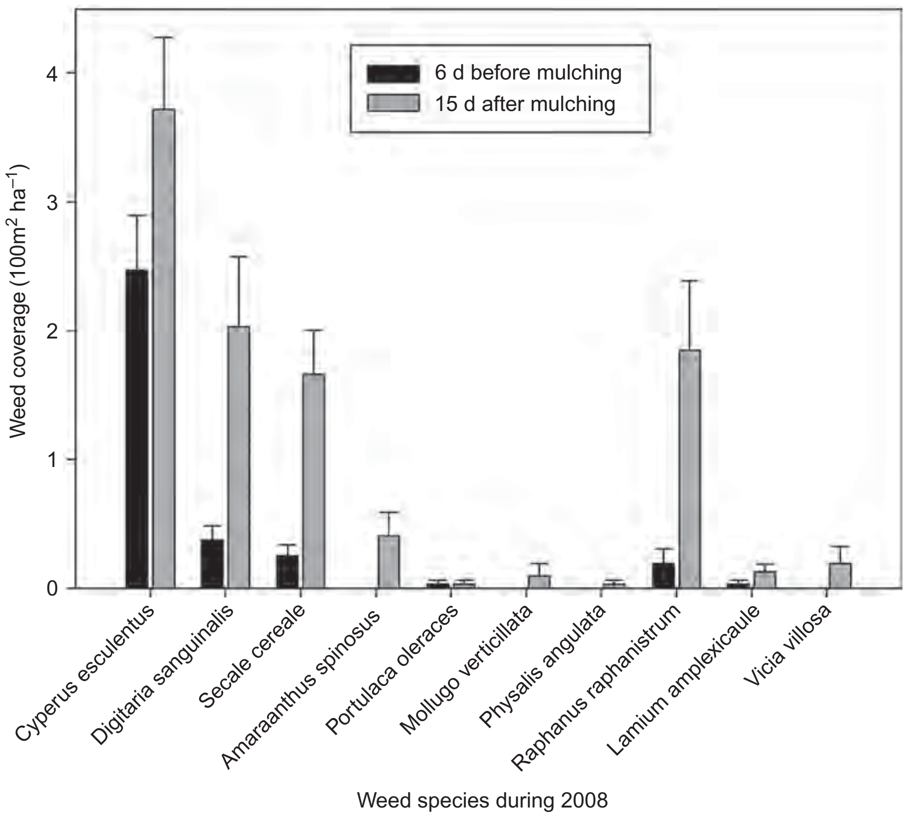

FIGURE 4 Weed species in no-till plots 6 days before and 15 days after mulching three years after conversion to no-till, averaged across experiment plots. Bars represent standard error of a mean.

after mulching, or five weeks after transplanting (Figure 4). This level of suppression may provide the main crop sufficient time to compete successfully with weeds later in the season. Yellow nutsedge was a major species present at that time, followed by large crabgrass (*Digitaria sanguinalis* (L.) Scop.). After three years of high-biomass no-till, the only grass weeds present were large crabgrass and winter rye, the latter due to viable seed germination from the previous winter cover crop, underscoring the importance of ensuring termination of cover crops and mulches before seeds become viable. Summer annual broadleaf weeds consisted of spiny pigweed (*Amaranthus spinosus* L.), common purslane (*Portulaca oleracea* L.), carpetweed (*Mollugo verticillata* L.) and cutleaf groundcherry (*Physalis angulata* L.), though all of these weeds were covered less than 0.5% of the soil surface three years after initiation of no-till. Summer weed populations were likely low because the measurements were made in early fall. Burgos and Talbert (1996) found that rye, wheat, and rye with hairy vetch suppressed 70% to 85% of redroot pigweed (*Amaranthus retroflexus* L.) and yellow nutsedge eight weeks after cover crop termination without herbicides, and that rye alone and rye with vetch suppressed 65% to 70% of large crabgrass. Among the winter annual broadleaf weeds, wild radish (*Raphanus raphanistrum* L.) coverage was much greater than henbit (*Lamium amplexicaule* L.), though the average coverage was still less than 2%. Even so, fall mulching was not effective for wild radish control 15 d after application ($p = 0.6738$) in 2008 (data not shown). The same can be said for all the major weed species present 15 days after mulching during 2008 with the exception of large crabgrass. This may be due to the fact that weed coverage was already under considerably good control after three consecutive years of no-till with high-biomass cover crops, given that even non-mulched control plots exhibited less than 4% coverage by any particular species. The mat of residue on the soil surface after three years of no-till appeared to be effective at weed suppression. All mulches effectively suppressed large crabgrass 15 days after mulch application compared to the no mulch control ($p < 0.05$). While not statistically significant at $p < 0.05$, straw mulch tended to be the best suppressor of the major weed species during 2008, likely due to the greater thickness of the straw residue compared to the other mulching treatments.

Collard yield averaged 23,109 ± 6411 kg ha^{-1} (standard deviation) in 2006, 14,005 ± 6204 kg ha^{-1} in 2007, and 16,477 ± 4442 kg ha^{-1} in 2008. Yield was not affected by any variable, including year. These yields are within the expected average for the area. Using a fertilization rate of 134 kg N ha^{-1} at Sand Mountain, AL, Guertal and Edwards (1996) reported fall collard yields of 10,400 to 14,700 kg ha^{-1} using various mulches.

In conclusion, weed populations were highly variable, with broadleaf and sedge populations decreasing over three years under the conditions of this study. The data showed that mulching suppressed monocot weed populations in no-till systems after a year compared with the control, and suggested that >2 years of no-till with high-biomass producing cover crops may be effective at reducing grass weeds. Mulching with mimosa, lespedeza and straw at 6.7 Mg ha^{-1} provided a reasonable level of grass weed control under continuous no-till. Although collard crop yields were not affected by application of various organic residues in the first three years of the no-till system, application of organic residues should improve soil quality over time while simultaneously limiting external inputs (Mulvaney et al., 2010). Further studies need to be conducted to determine nutrient cycling efficiency, nutrient relocation and release rates, organic matter accumulation, and C sequestration during continuous high residue no-till with organic mulches. As agricultural sustainability becomes increasingly vital for political and food security around the globe, it is important that solutions to obstacles affecting sustainable food production systems, such as weed management, be developed.

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