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# Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield

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A field study was conducted during 1997 to 2001 on a Dundee silt loam soil at Stoneville, MS, to examine the effects of rye and crimson clover residues on weeds, soil properties, soil microbial populations, and soybean yield in conventional tillage (CT) and no-tillage (NT) systems with preemergence (PRE)-only, postemergence (POST)-only, and PRE plus POST herbicide programs. Rye and crimson clover were planted in October, desiccated in April, and tilled (CT plots only) before planting soybean. Both cover-crop residues reduced density of barnyardgrass, broadleaf signalgrass, browntop millet, entireleaf morningglory, and hyssop spurge but did not affect yellow nutsedge at 7 wk after soybean planting (WAP) in the absence of herbicides. Densities of these weed species were generally lower with PRE-only, POST-only, and PRE plus POST applications than with no-herbicide treatment. Total weed dry biomass was lower when comparing CT (1,570 kg ha$^{-1}$) with NT (1,970 kg ha$^{-1}$), rye (1,520 kg ha$^{-1}$) with crimson clover (2,050 kg ha$^{-1}$), and PRE plus POST (640 kg ha$^{-1}$) with PRE-only (1,870 kg ha$^{-1}$) or POST-only (1,130 kg ha$^{-1}$) treatments at 7 WAP. Soils with crimson clover had higher organic matter, $NO_3$–N, $SO_4$–S, and Mn, and lower pH compared with rye and no–cover crop soils. Total fungi and bacterial populations and fluorescein diacetate hydrolytic activity were higher in soil with crimson clover, followed by rye and no cover crop. Soybean yields were similar between CT (1,830 kg ha$^{-1}$) and NT (1,960 kg ha$^{-1}$), no cover crop (2,010 kg ha$^{-1}$) and rye (1,900 kg ha$^{-1}$), and rye and crimson clover (1,790 kg ha$^{-1}$), but they were higher in PRE plus POST (2,260 kg ha$^{-1}$) than in PRE-only (1,890 kg ha$^{-1}$) or POST-only (1,970 kg ha$^{-1}$) treatments.

**Nomenclature:** Acifluorfen; bentazon; clethodim; flumetsulam; metolachlor; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash BRAPP; browntop millet, *Brachiaria ramosa* (L.) Stapf. PANRA; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray IPOHG; hyssop spurge, *Euphorbia hyssopifolia* L. EPHHS; yellow nutsedge, *Cyperus esculentus* L. CYPES; crimson clover, *Trifolium incarnatum* L. 'Dixie'; rye, *Secale cereale* L. 'Elbon'; soybean, *Glycine max* (L.) Merr.

**Key words:** Conventional tillage, crimson clover, integrated weed management, organic matter, no tillage, rye, soil microbial populations, weed density, weed biomass.

Soybean is commonly grown under conventional tillage (CT), no-tillage (NT), and stale seedbed (SSB) systems in the lower Mississippi River alluvial flood plain (Delta). Wet soil in late winter and early spring often delays CT seedbed preparation tillage operations until late April or early May when planting should normally occur (Heatherly et al. 1992). These CT operations before planting can further deplete soil moisture and delay planting until significant rain occurs to replenish seedbed moisture (Elmore and Heatherly 1988; Heatherly and Elmore 1983). Furthermore, CT operations can also interfere with timely planting of corn (*Zea mays* L.) for those farmers who have limited labor and farm equipment.

Conservation tillage planting systems such as NT and SSB have become an alternative approach to CT systems in recent years. In the southern United States, the area planted with soybean using conservation tillage planting systems has increased from 14% in 1989 to 26% in 2002 (CTIC 2002). In conservation systems, tillage operations are either reduced or completely eliminated. The land may or may not be tilled after harvest of the crop in an SSB system. Any tillage conducted in fall, winter, or early spring will have occurred sufficiently ahead of the intended planting time to allow the seedbed to settle or become stale. The crop is planted in this unprepared seedbed, and weeds present before or at planting are killed with herbicides (Elmore and Heatherly 1988; Heatherly and Elmore 1983; Heatherly et al. 1992). In conservation production systems, equipment traffic is reduced, and plant residues on the soil surface can reduce soil and water runoff, reduce nutrient and pesticide movement, and conserve soil moisture. However, the energy reductions achieved with conservation tillage are sometimes offset by an increase in the cost of herbicides because greater demand is placed on them for weed control compared with CT.

Warm winter and spring temperatures, relatively high rainfall, and fertile soils of the lower Mississippi River Delta region provide a conducive environment for establishment of a wide array of annual and perennial weed species (Reddy 2001). However, weed species, density, and size vary greatly, depending on the time interval between tillage and planting. Control of emerged weeds at planting is critical to soybean stand establishment, which necessitates use of nonselective herbicides (Bruff and Shaw 1992a, 1992b).

Winter cover crops can be a useful tool to suppress or replace winter annual weed species (Locke et al. 2002; Teasdale 1996). The long growing season in the lower Mississippi River Delta region permits the use of winter cover crops in row-crop production. Cover crops are planted in the fall and desiccated with herbicides the following spring before NT planting of the summer crop (Koger et al. 2002; Reddy 2001, 2003). Cover crops have long been used to reduce soil erosion and water runoff and improve water infiltration, soil moisture retention, soil tilth, organic carbon, and nitrogen (Locke and Bryson 1997; Mallory et al. 1998; Sainju and Singh 1997; Teasdale 1996; Varco et al. 1999; Yenish et al. 1996). Both rye and hairy vetch (*Vicia villosa* Roth) enhance certain soil microbial populations in a soybean production system (Wagner et al. 1995; Zablotowicz et al. 1998).

Rye is often used as a cover crop because of its winter hardiness and production of abundant biomass that suppresses weeds by both physical and chemical interference during weed germination and plant growth (Barnes and Putnam 1986; Creamer et al. 1996). Annual legume species such as crimson clover, hairy vetch, and subterranean clover (*Trifolium subterraneum* L.) (Reddy 2001, 2003; Teasdale and Daughtry 1993; Teasdale et al. 1991; Yenish et al. 1996) have been investigated for potential weed control benefits. In addition to the benefits provided by cereal cover crops, the legume cover crops biologically fix atmospheric N, which subsequently becomes available to a crop during residue decomposition (Sainju and Singh 1997; Varco et al. 1999). Although natural winter vegetation provides soil cover in certain fields, it may not provide sufficient mulch for longer periods as is the case with cover-crop residues (Reddy 2001, 2003).

Cover crops suppress or replace winter annual weed species during early spring, but they do not provide full-season weed suppression (Ateh and Doll 1996; Burgos and Talbert 1996; Liebl et al. 1992; Reddy 2001, 2003; Teasdale 1996; Yenish et al. 1996). Thus, elimination of herbicides in summer crops is not a viable option. Both preemergence (PRE) and postemergence (POST) herbicides are commonly used to achieve optimal weed control in soybean production. The cover crops have the potential for eliminating the need for PRE herbicides that control early-season weeds, whereas late-season weeds can be managed with POST herbicides on an as-needed basis.

Although numerous studies have examined the effect of cover-crop residues on weed suppression and crop yield, information is lacking on the long-term impact of cover-crop residue with and without tillage on soil properties, soil microbial populations, weed density and biomass, and soybean response in the lower Mississippi River Delta region. This study examines the long-term impact of a cereal and a legume cover crop on various soil, crop, and weed parameters. Specific objectives of this research were (1) to determine multiyear effects of rye and crimson clover cover crops with and without tillage incorporation on soil properties and soil microbial populations and (2) to study the effects of these cover crops on weed density and control and soybean yield using PRE-only, POST-only, and PRE plus POST herbicide programs.

## Materials and Methods

Field studies were conducted from 1997 through 2001 at the USDA-ARS Southern Weed Science Research Farm, Stoneville, MS (33°26′N latitude). The soil was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualf) with 26% sand, 56% silt, and 18% clay. Before initiation of the study, the experimental area was under CT soybean. Rainfall during April through August was 43, 41, 63, and 60 cm in 1998, 1999, 2000, and 2001, respectively. The 30-yr average rainfall for this period is 51 cm. Although rainfall was highest in 2000, less than 2-cm rainfall was received during July and August.

Cover-crop treatments consisted of rye, crimson clover, or no cover crop. Rye and crimson clover were drilled in 19-cm-wide rows using a no-till grain drill[1] in mid-October each year. Seeding rates were 80 kg ha$^{-1}$ for rye and 30 kg ha$^{-1}$ for crimson clover. Plants in the entire experimental area were killed with paraquat at 1.1 kg ai ha$^{-1}$ in mid-April each year. All cover crops were in flowering stage at the time of paraquat application. Crimson clover was 25 to 40 cm tall, and rye was 100 to 125 cm tall. The two tillage treatments were NT and CT. The NT plots received no-tillage operations after the fall of 1997. The CT plots were not tilled before planting cover crops in fall. After cover-crop desiccation, the CT plots were tilled with a disk harrow and a field cultivator to thoroughly incorporate the plant residue before soybean planting. In NT plots, the desiccated cover crops were left undisturbed.

Because tillage operations were required to prepare a seedbed in CT plots, soybean in all treatments was not planted immediately after desiccation of cover crops. At soybean planting, newly emerged vegetation after cover-crop desiccation in all NT plots was killed with glyphosate at 1.1 kg ai ha$^{-1}$. Soybean cultivars and planting dates were 'DP 3478' on June 3, 1998, 'DP 3588' on May 15, 1999 and 2000, and 'DP 5989' on April 30, 2001. Planting was delayed in 1998 because of rainfall. Cultivars were selected based on regional use patterns by producers and seed availability. Soybean was planted with a no-till grain drill[1] in 57-cm-wide rows.

Herbicide treatments included PRE-only, POST-only, PRE plus POST, and a no-herbicide treatment. PRE herbicides were broadcast applied immediately after planting, whereas POST herbicides were applied 4 wk after soybean planting (WAP). Herbicide treatments were applied with a tractor-mounted sprayer with 8004 standard flat spray tips[2] delivering water at 187 L ha$^{-1}$ and 179 kPa. A paraffinic petroleum oil adjuvant[3] was added to all POST treatments at 0.63% (v/v) as suggested by the manufacturer. Flumetsulam at 0.07 kg ai ha$^{-1}$ and metolachlor at 2.30 kg ai ha$^{-1}$ were applied PRE. Acifluorfen at 0.28 kg ai ha$^{-1}$, bentazon at 0.56 kg ai ha$^{-1}$, and clethodim at 0.14 kg ai ha$^{-1}$ were applied POST.

Soil samples from the top 5-cm depth were collected by taking eight random cores (7.5-cm diameter) in each no-herbicide control plot 3 WAP. Soil samples were collected only from no-herbicide control plots to exclude the effects of herbicides on microbial populations. As the focus of this study was to assess long-term changes in soil properties as a consequence of continuous use of various tillage and cover-crop treatments, the soil samples were collected only for the third and final year. Bulk soil samples were homogenized by

Table 1. Effect of tillage and cover crops on soil (0–5 cm deep) properties in soybean studies conducted at Stoneville, MS, in 2000 and 2001.[a,b]

| Tillage/cover crop | pH | OM | CEC | $NO_3$-N | P | K | Ca | Mg | $SO_4$-S | Fe | Mn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil properties and mineral nutrient composition | | | | | | | | | | | | |
| | | % | mol $kg^{-1}$ | kg $ha^{-1}$ | | | | | | | | | |
| Tillage | | | | | | | | | | | | | |
| CT | 6.46 | 1.35 | 15 | 20 | 66 | 565 | 3,656 | 739 | 25 | 361 | 68 | 12 | 0.7 |
| NT | 6.17 | 2.12 | 15 | 20 | 98 | 670 | 3,613 | 752 | 29 | 367 | 69 | 10 | 0.7 |
| LSD (0.05) | 0.22 | 0.21 | NS | NS | 26 | 96 | NS | NS | 3 | NS | NS | NS | NS |
| Cover crop | | | | | | | | | | | | | |
| No cover crop | 6.41 | 1.51 | 15 | 17 | 80 | 589 | 3,692 | 759 | 26 | 335 | 69 | 12 | 0.7 |
| Crimson clover | 6.17 | 1.99 | 15 | 33 | 85 | 643 | 3,656 | 754 | 29 | 379 | 73 | 8 | 0.7 |
| Rye | 6.36 | 1.69 | 14 | 10 | 82 | 621 | 3,560 | 723 | 26 | 379 | 65 | 14 | 0.7 |
| LSD (0.05) | 0.14 | 0.26 | NS | 11 | NS | NS | NS | NS | 2 | 25 | 6 | 4 | NS |

[a] Abbreviations: OM, organic matter; CEC, cation exchange capacity; CT, conventional tillage; NT, no tillage; NS, not significant.
[b] Data are averaged across 2000 and 2001.

passing through a 2-mm sieve. Chemical soil analyses were conducted at the Soil Testing and Research Laboratory, University of Arkansas, Marianna, AR. Mehlich 3 extractant (Mehlich 1984) was used for P, K, Ca, Mg, Fe, $SO_4$-S, Mn, Cu, and B, and analysis was by inductively coupled plasma emission spectrometry. Soil pH was measured in water (1:2, soil–water). Cation exchange capacity (CEC) was estimated from the total number of exchangeable cations. $NO_3$-N was extracted with 0.025 M aluminum sulfate according to Donahue (1992), and organic matter was determined by the loss of mass after ignition (Nelson and Sommers 1996).

Microbial populations were determined by spiral plating serial dilutions of each soil on agar plates.[4] Total number of culturable bacteria was determined on dilute tryptic soy agar (10%) amended with cycloheximide (100 mg $L^{-1}$), and all culturable fungi were plated on rose bengal potato dextrose agar (Martin 1950). Microbial populations are expressed as $\log_{10}$ colony-forming units per gram of air-dried soil. Soil esterase was evaluated as an indicator of microbial activity, using fluorescein diacetate as substrate according to Schnürer and Rosswall (1982). In brief, 2 g of field-moist soil was incubated for 1 h in 45-ml centrifuge tubes containing 15 ml phosphate buffer (0.1 mM, pH 7.8) and 0.5 mg fluorescein diacetate on a rotary shaker at 125 rpm at 28 C. The reaction was terminated by addition of 15 ml acetone and extraction for 5 min at 125 rpm. The solution was clarified by centrifugation at 8,000 × $g$ for 10 min, and absorbance at 490 nm was recorded. Concentration of the product, fluorescein, was calculated based on an extinction coefficient of 80.34 $mM^{-1}$ $cm^{-1}$.

Control of individual weed species in all plots was visually estimated based on reduction in population on a scale of 0% (no weed control) to 100% (complete weed control) at 2 wk POST application. Soybean stand was estimated from two 0.91-m-long rows at 7 WAP. Weeds were counted by species in a 1-$m^2$ quadrat in the middle of each plot at 7 WAP in 1999 and 2000. Dry weight of all the weeds present was recorded from two randomly selected 0.09-$m^2$ areas at 7 WAP in 1999, 2000, and 2001. Soybean was combine harvested from each plot, and grain yield was adjusted to 13% moisture. The soybean crop failed in 2000 because of severe drought during July and August. Because of weather and inadequate resources, data were not collected for certain parameters in all the years; however, it should be stressed that the data presented in this study were collected for a minimum of 2 yr.

The experiment was conducted in a split–split plot arrangement of treatments in a randomized complete block design with tillage (CT and NT) as the main plot, cover-crop systems (rye, crimson clover, and no cover crop) as the subplot, and herbicide programs (PRE only, POST only, PRE plus POST, and no herbicide) as the sub-subplot with four replications. Each sub-subplot consisted of eight rows 12.2 m long and spaced 57 cm apart. The same treatment was assigned to the same plot every year. Because the experiment was conducted on the same site for 4 yr, years were treated as repeated measurements and included in the analysis as another split. The data were subjected to analysis of variance using Proc Mixed to determine significance of main effects and interactions (SAS 1998). Treatment means were separated at the 5% level of significance using Fisher's Protected LSD test. Data were averaged across years (as main effect means) if the year by treatment interactions were not significant.

## Results and Discussion

### Soil Chemical Properties

The soils from the third (2000) and fourth (2001) years of the study were analyzed to assess the multiyear effect of tillage and cover-crop systems on certain chemical parameters. The surface 5 cm of soil from CT and NT plots had similar levels of CEC, $NO_3$-N, Ca, Mg, Fe, Mn, Cu, and B (Table 1). Soil from NT plots had higher organic matter, P, K, and $SO_4$-S and lower pH than soil from CT plots. These differences can be attributed to incorporation of surface plant residues in CT compared with nonincorporation in NT plots. Among cover crops, there were no differences in CEC, P, K, Ca, Mg, and B in the surface 5 cm of soil. Soil from plots with crimson clover had higher organic matter, $NO_3$-N, $SO_4$-S, and Mn and lower pH than rye and no–cover crop plots. Soil from plots with both rye and crimson clover had higher Fe than soil from the no–cover crop

TABLE 2. Effect of tillage and cover crops on total fungi and bacterial populations, and FDA in soybean studies conducted at Stoneville, MS, in 2000 and 2001.[a,b]

| Tillage/cover crop | Total fungi | Total bacteria | FDA |
|---|---|---|---|
| | $log_{10}$ colony-forming units $g^{-1}$ soil | | nmol fluorescein formed $g^{-1}$ soil $h^{-1}$ |
| Tillage | | | |
| CT | 5.16 | 8.10 | 202 |
| NT | 5.36 | 8.19 | 317 |
| LSD (0.05) | 0.05 | 0.03 | 35 |
| Cover crop | | | |
| No cover crop | 5.12 | 7.97 | 179 |
| Crimson clover | 5.41 | 8.34 | 350 |
| Rye | 5.25 | 8.12 | 250 |
| LSD (0.05) | 0.06 | 0.04 | 43 |

[a] Abbreviations: FDA, fluorescein diacetate hydrolytic activity; CT, conventional tillage; NT, no tillage.
[b] Data are averaged across 2000 and 2001.

plot. Soil from rye–cover crop plots had higher Cu than soil from plots with crimson clover.

No–cover crop plots had plant residue from dense infestations of winter annual weed species. Warm temperatures and moist soil during March and April of each year were as favorable for growth of winter annual weed species as for cover crops, resulting in weed biomass in no–cover crop plots being similar to that in plots with legume cover crops (Reddy 2001). Sequestration of atmospheric $CO_2$ by winter cover crops and fixation of atmospheric N by legume cover crops are beneficial in maintaining or increasing organic C and N in the soil (Sainju and Singh 1997). Legume winter cover crops can provide part of the nitrogen requirement to the succeeding crop (Hargrove 1986; Varco et al. 1999).

## Soil Microbiological Properties

Soil from NT plots had greater total heterotrophic bacterial and total fungal propagules and fluorescein diacetate hydrolytic activity (FDA) than soil from CT plots (Table 2). Other researchers have observed a similar increase in microbial populations and soil enzyme activity in NT compared with CT soils (Reddy et al. 1995). Under a no-till system, the increased levels of bioavailable organic substrates are maintained in the surface soil because of accumulation of these organic residues on the soil surface. Soil from both cover-crop systems had a greater total bacterial and fungal propagule density and FDA activity than soils from the no–cover crop system. Between the cover crops, soil from crimson clover plots had a greater stimulatory effect on soil biological parameters than soil from rye plots

The FDA assay is a measure of soil enzyme esterase and is an indicator of both microbial activity and microbial biomass. The FDA assay may indicate that the soils under residue management were metabolically more active than CT soils with no cover crop, although the higher activity also may be indicative of greater organic substrate bioavailability. Previous studies on a Dundee silt loam soil under soybean production found a similar increase in total bacteria from hairy vetch and rye–cover crop treatments compared with soil from a no–cover crop treatment but no differences in fungal propagule densities among cover crop and no–cover crop treatments (Wagner et al. 1995; Zablotowicz et al. 1998). In this study, the changes in microbial populations were larger and occurred after 3 to 4 yr of cover-crop system. Similar enhancements in bacterial propagules and, to a lesser extent, fungal propagules associated with incorporation of a crimson clover cover crop were observed in North Carolina (Kirchner et al. 1993). Leguminous cover crops such as crimson clover typically have a lower C:N ratio than rye; thus, amino acids and carbohydrates would be more readily available to stimulate microbial populations and their activities.

## Weed Density, Control, and Biomass

Five summer annual species and one perennial weed species were counted in no-herbicide control plots to assess the level of weed suppression by rye and crimson clover in soybean at 7 WAP (Table 3). Barnyardgrass, broadleaf signalgrass, browntop millet, entireleaf morningglory, hyssop spurge, and yellow nutsedge densities were similar between CT and NT systems. Rye and crimson clover residues suppressed these weed species by 25 to 73%, with the exception of yellow nutsedge, compared with the no–cover crop system (Table 3). When weed densities were averaged across herbicide programs for the herbicide-treated plots, tillage and cover-crop effects were similar to those in the no-herbicide control plots (Table 4). However, weed suppression was similar for rye and crimson clover cover crops. Cover-crop residues have been shown to suppress emergence of some weed species more than others. Large crabgrass [*Digitaria sanguinalis* (L.) Scop] density was not affected by rye residue compared with no cover crop, but carpetweed (*Mollugo verticillata* L.) (Teasdale et al. 1991), barnyardgrass, and browntop millet (Reddy 2001, 2003) densities were suppressed by a rye cover crop. All herbicide programs reduced weed densities compared with the no-herbicide control (Table 4).

The PRE and POST herbicide programs were designed for effective control of weeds in soybean. Flumetsulam and metolachlor PRE and acifluorfen, bentazon, and clethodim POST control a broad spectrum of weed species. As a result, control of barnyardgrass, broadleaf signalgrass, entireleaf morningglory, and hyssop spurge was 92% or better, and control of browntop millet and yellow nutsedge was 85% or better regardless of tillage, cover crop, and herbicide programs at 2 wk POST (data not shown).

Table 3. Effect of tillage and cover crop residue on grasses, entireleaf morningglory, hyssop spurge, and yellow nutsedge density at 7 WAP in no-herbicide (untreated) plots of soybean grown at Stoneville, MS, in 1999 and 2000.[a,b]

| Tillage/cover crop | Grasses[c] | Entireleaf morningglory | Hyssop spurge | Yellow nutsedge |
|---|---|---|---|---|
| | plants $m^{-2}$ | | | |
| Tillage | | | | |
| CT | 17 | 6 | 6 | 3 |
| NT | 20 | 7 | 6 | 4 |
| LSD (0.05) | NS | NS | NS | NS |
| Cover crop | | | | |
| No cover crop | 28 | 11 | 8 | 3 |
| Crimson clover | 14 | 5 | 6 | 3 |
| Rye | 14 | 3 | 5 | 3 |
| LSD (0.05) | 3 | 3 | 2 | NS |

[a] Abbreviations: WAP, weeks after soybean planting; CT, conventional tillage; NT, no tillage; NS, not significant.
[b] Data are averaged across 1999 and 2000.
[c] Predominant grass weeds were barnyardgrass, broadleaf signalgrass, and browntop millet.

Total weed (grass weeds, broadleaf weeds, and yellow nutsedge) dry biomass was 20% lower in CT plots compared with NT plots at 7 WAP (Table 5). Among cover crops, weed dry biomass was lower in rye than in crimson clover, and both cover crops had similar weed dry biomass compared with the no–cover crop system (Table 6). Rye residue was detrimental to weed growth in soybean in other research (Reddy 2003). Weed dry biomass was highest in the no-herbicide plots (Table 6). Herbicide applications decreased weed dry biomass, and the PRE plus POST treatment resulted in lower weed dry biomass than the no-herbicide treatment. Overall, PRE-only, POST-only, and PRE plus POST applications resulted in 46 to 81% less weed dry biomass compared with the no-herbicide treatment. Among interactions, in the no-herbicide treatment, weed dry biomass was higher in crimson clover than in rye or no cover crop (Table 6). This may have been due to increased nitrogen availability to weeds resulting from decomposition of crimson clover root and shoot biomass, as evident from the higher $NO_3$-N level in crimson clover treatment. However, when weeds were controlled with herbicides, weed dry biomass was similar between POST-only and PRE plus POST applications in rye and crimson clover–cover crop systems.

## Soybean Stand and Yield

There were no differences in soybean yield between CT and NT systems (Table 5). Among cover crop systems, soybean yield decreased in the order of no-cover crop ≥ rye ≥

Table 4. Effect of tillage, cover crop residue, and herbicide programs on grasses, entireleaf morningglory, hyssop spurge, and yellow nutsedge density at 7 WAP in studies conducted at Stoneville, MS, in 1999 and 2000.[a,b]

| Tillage/cover crop | Grasses[c] | Entireleaf morningglory | Hyssop spurge | Yellow nutsedge |
|---|---|---|---|---|
| | plants $m^{-2}$ | | | |
| Tillage | | | | |
| CT | 7 | 4 | 2 | 2 |
| NT | 8 | 3 | 2 | 3 |
| LSD (0.05) | NS | NS | NS | NS |
| Cover crop | | | | |
| No cover crop | 10 | 5 | 3 | 2 |
| Crimson clover | 6 | 3 | 2 | 2 |
| Rye | 6 | 2 | 2 | 2 |
| LSD (0.05) | 1 | 2 | 1 | NS |
| Herbicide[d] | | | | |
| No herbicide | 19 | 7 | 6 | 3 |
| PRE | 2 | 3 | 1 | 2 |
| POST | 7 | 3 | 1 | 2 |
| PRE + POST | 1 | 1 | 0 | 1 |
| LSD (0.05) | 2 | 1 | 2 | 1 |

[a] Abbreviations: WAP, weeks after soybean planting; CT, conventional tillage; NT, no tillage; PRE, preemergence; POST, postemergence; NS, not significant.
[b] Data are averaged across 1999 and 2000.
[c] Predominant grass weeds were barnyardgrass, broadleaf signalgrass, and browntop millet.
[d] Flumetsulam (0.07 kg ai $ha^{-1}$) and metolachlor (2.30 kg ai $ha^{-1}$) were applied PRE. Acifluorfen (0.28 kg ai $ha^{-1}$), bentazon (0.56 kg ai $ha^{-1}$), and clethodim (0.14 kg ai $ha^{-1}$), were applied POST.

TABLE 5. Tillage effect (averaged across cover crops and herbicides) on total weed dry biomass and soybean population at 7 WAP and soybean yield in studies conducted at Stoneville, MS.[a]

| Tillage | Total weed dry biomass[b] | Soybean[c] Plant population | Yield |
|---|---|---|---|
| | kg ha$^{-1}$ | plants ha$^{-1}$ | kg ha$^{-1}$ |
| Conventional tillage | 1,570 | 252,000 | 1,830 |
| No tillage | 1,970 | 246,000 | 1,960 |
| LSD (0.05) | 320 | NS | NS |

[a] Abbreviations: WAP, weeks after soybean planting; NS, not significant.
[b] Total weed dry biomass data are averaged across 1999, 2000, and 2001. Predominant weeds were barnyardgrass, broadleaf signalgrass, and browntop millet, entireleaf morningglory, hyssop spurge, and yellow nutsedge.
[c] Soybean population data are averaged across 4 yr. Soybean yield data are averaged across 1998, 1999, and 2001.

crimson clover (Table 6). Differences in yield were partly due to the effect of cover-crop biomass on soybean stand establishment. Soybean plant population was 7% lower in rye compared with the no–cover crop system. Although soybean plant populations were similar between crimson clover–cover crop and no–cover crop systems, soybean yield was lower in the crimson clover treatment. This was related to an overall higher biomass of weeds in the crimson clover cover crop than in the no–cover crop treatment. Weed species may have benefited from the higher nitrogen content in the crimson clover–cover crop system. Overall, improvements in soil fertility and soil microbial activity with rye and crimson clover cover crops were not reflected in increased soybean yield compared with the no–cover crop system. Previous research indicated that a rye cover crop increased (Ateh and Doll 1996), decreased (Reddy 2001), or had no effect (Liebl et al 1992; Reddy 2003) on soybean yield compared with a no–cover crop system. Application of herbicides resulted in 28 to 53% higher soybean yield compared with the no-herbicide control (1,480 kg ha$^{-1}$). Soybean yields with the PRE-only (1,890 kg ha$^{-1}$) and POST-only (1,970 kg ha$^{-1}$) programs were similar but lower than yields from the PRE plus POST (2,260 kg ha$^{-1}$) program. The lower soybean yield in PRE- or POST-only compared with PRE plus POST program was related more to weed density and biomass than to soybean plant population. Overall, soybean yields were inversely related to weed biomass among herbicide programs.

In the absence of herbicides, rye and crimson clover cover crops resulted in equal or reduced soybean yield compared with the no–cover crop system (Table 6). Cover crops did not eliminate the need for herbicides under the conditions of this study. POST-herbicide applications should be considered to complement early-season weed suppression by cover crops to exploit their potential for improving soil fertility and crop productivity. However, soybean yield from

TABLE 6. Effect of cover crops and herbicide programs on total weed dry biomass and soybean population at 7 WAP and soybean yield in studies conducted at Stoneville, MS.[a]

| Cover crop | Herbicide[b] | Total weed dry biomass[c] | Soybean[d] Plant population | Yield |
|---|---|---|---|---|
| | | kg ha$^{-1}$ | plants ha$^{-1}$ | kg ha$^{-1}$ |
| No cover crop | No herbicide | 3,230 | 252,000 | 1,570 |
| | PRE | 1,670 | 260,000 | 2,140 |
| | POST | 1,440 | 247,000 | 2,010 |
| | PRE + POST | 630 | 260,000 | 2,310 |
| | Mean | 1,740 | 255,000 | 2,010 |
| Crimson clover | No herbicide | 4,300 | 242,000 | 1,240 |
| | PRE | 2,340 | 262,000 | 1,660 |
| | POST | 980 | 255,000 | 1,920 |
| | PRE + POST | 600 | 266,000 | 2,340 |
| | Mean | 2,050 | 256,000 | 1,790 |
| Rye | No herbicide | 2,810 | 216,000 | 1,630 |
| | PRE | 1,610 | 227,000 | 1,850 |
| | POST | 970 | 244,000 | 1,990 |
| | PRE + POST | 700 | 258,000 | 2,130 |
| | Mean | 1,520 | 236,000 | 1,900 |
| Mean | No herbicide | 3,450 | 237,000 | 1,480 |
| | PRE | 1,870 | 249,000 | 1,890 |
| | POST | 1,130 | 249,000 | 1,970 |
| | PRE + POST | 640 | 261,000 | 2,260 |
| LSD (0.05) | | | | |
| Cover crop | | 390 | 12,000 | 140 |
| Herbicide | | 450 | 14,000 | 140 |
| Cover crop × herbicide | | 790 | NS | 240 |

[a] Abbreviations: WAP, weeks after soybean planting; PRE, preemergence; POST, postemergence; NS, not significant.
[b] Flumetsulam (0.07 kg ai ha$^{-1}$) and metolachlor (2.30 kg ai ha$^{-1}$) were applied PRE. Acifluorfen (0.28 kg ai ha$^{-1}$), bentazon (0.56 kg ai ha$^{-1}$), and clethodim (0.14 kg ai ha$^{-1}$), were applied POST.
[c] Total weed dry biomass data are averaged across 1999, 2000, and 2001. Predominant weeds were barnyardgrass, broadleaf signalgrass, browntop millet, entireleaf morningglory, hyssop spurge, and yellow nutsedge.
[d] Soybean population data are averaged across 4 yr. Soybean yield data are averaged across 1998, 1999, and 2001.

the POST-only treatment was similar to that from the PRE plus POST treatment within the rye cover-crop treatment only, despite improved soil nutrient status in the crimson clover–cover crop system.

These findings indicate that rye and crimson clover have potential for improving soil quality and reducing weed density in soybean production systems; however, optimum weed control was obtained when either PRE or POST herbicides were used. Rye suppressed weeds better than crimson clover, whereas crimson clover treatments increased $NO_3$-N and soil organic matter to a greater extent. Although soil properties were improved in the rye treatment, soybean yield was equivalent to that in plots with no cover crop, whereas soybean yield in crimson clover treatment was reduced compared with no cover crop.

Additional costs (cover crop seed, planting, and desiccation) associated with cover crops can result in negligible or negative net returns for soybean production (Reddy 2001, 2003). The present study demonstrated that using cover crops such as rye in soybean is agronomically feasible and sustainable in terms of renewable inputs and may become economically viable if incentives and credits are made available under certain conservation management programs for implementing environmentally sound practices. Soybean yield and weed density were similar for both tillage systems; however, no-tillage enhanced microbial activity, organic matter, and availability of some nutrients (P, K, S) in soil. These findings demonstrate that no-tillage may be a practical and potentially sustainable option for soybean farmers who are looking for practices that provide environmental benefits.

## Sources of Materials

[1] John Deere 750 series grain drill, Deere and Co., 501 River Drive, Moline, IL 61265.

[2] TeeJet standard flat spray tips, Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60189.

[3] Agri-Dex is a proprietary blend of heavy-range paraffin base petroleum oil, polyol fatty acid esters, and polyethoxylated derivative nonionic adjuvant (99% active ingredient), Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

[4] Spiral Plater, Spiral System Instruments, 7830 Old Georgetown Road, Bethesda, MD 20814.

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