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Effects of Cereal and Legume Cover Crop Residues on Weeds, Yield, and Net Return in Soybean (*Glycine max*)[1]

KRISHNA N. REDDY[2]

Abstract: A 2-yr field study was conducted during 1998 and 1999 at Stoneville, MS, on a Dundee silt loam to determine weed control, yield, and net return associated with winter cover crops in soybean. Cover crop systems included Italian ryegrass, oat, rye, wheat, hairy vetch, crimson clover, subterranean clover, no-cover crop conventional tillage (CT), and no-cover crop no-tillage (NT), all with standard preemergence (PRE), postemergence (POST), PRE + POST, and no-herbicide weed management. Oat (11.1 Mg/ha) had highest dry biomass compared to all other cover crops (6.0 to 7.6 Mg/ha) at soybean planting. Biomass decreased 9 wk after planting (WAP) compared to the respective biomass at soybean planting in all cover crops. Italian ryegrass and rye biomass decay was slow and about two-thirds of plant residue persisted at 9 WAP. Cover crops had no effect on densities of barnyardgrass, prickly sida, and yellow nutsedge, but altered the density of browntop millet. Total weed biomass was higher in rye, wheat, and subterranean clover than in Italian ryegrass cover crop systems, and higher with the PRE-only vs. POST-only or PRE + POST programs at 10 WAP soybean. Soybean yield decreased in the order of no-cover crop NT ≥ no-cover crop CT ≥ hairy vetch ≥ crimson clover ≥ rye ≥ oat ≥ wheat ≥ subterranean clover > Italian ryegrass. None of the cover crop systems gave soybean yield higher than the no-cover crop CT system in the absence of herbicides. Under a PRE-only program, all cover crop systems had lower yield compared to the no-cover crop CT system. When late-emerged weeds were controlled with POST applications (POST-only or PRE + POST programs), all cover crops, except Italian ryegrass, had no detrimental effect on soybean yields, which were not different from no-cover crop CT plots. In cover crops, input costs were high due to additional cost of seeds, planting, and desiccation. Net return was highest in no-cover crop NT ($105/ha) followed by no-cover crop CT ($76/ha) system. Net returns were negative for all cover crops and losses were highest in crimson clover (−$62/ha) and subterranean clover (−$161/ha).

Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. #[3] ECHCG; browntop millet, *Brachiaria ramosa* (L.) Stapf # PANRA; prickly sida, *Sida spinosa* L. # SIDSP; yellow nutsedge, *Cyperus esculentus* L. # CYPES; crimson clover, *Trifolium incarnatum* L. 'Dixie'; hairy vetch, *Vicia villosa* Roth; Italian ryegrass, *Lolium multiflorum* Lam. 'Gulf'; oat, *Avena sativa* L. 'Bob'; rye, *Secale cereale* L. 'Elbon'; soybean, *Glycine max* (L.) Merr. 'DP 3588'; subterranean clover, *Trifolium subterraneum* L. 'Mount Barker'; wheat, *Triticum aestivum* L. 'Cocker 9803'.

Additional index words: Allelopathy, conventional tillage, herbicide, integrated weed management, mulch, net return, no-tillage, weed emergence, weed biomass.

Abbreviations: ANOVA, analysis of variance; CT, conventional tillage; NT, no-tillage; POST, postemergence; PRE, preemergence; WAP, weeks after planting soybean.

INTRODUCTION

Public awareness of herbicide movement from farm lands and its impact on the environment has increased in recent years. Studies conducted by the U.S. Geological Survey have shown that the Mississippi River and its tributaries are contaminated with agrochemicals derived from farm lands (Pereira and Hostettler 1993). Undesirable herbicide mobility has resulted in label changes for some herbicides. One potential method to reduce herbicide input is to use cover crops and systems that are compatible with goals of sustainable agricultural systems.

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 (Mallory et al. 1998; Sainju and Singh 1997; Teasdale 1996; Varco et al. 1999; Yenish et al. 1996).

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Cover crops have been used to manage weeds in several crops, including corn (*Zea mays* L.) (Johnson et al. 1993; White and Worsham 1990; Yenish et al. 1996), cotton (*Gossypium hirsutum* L.) (Varco et al. 1999; White and Worsham 1990), soybean (Ateh and Doll 1996; Liebl et al. 1992; Moore et al. 1994), and southern pea [*Vigna unguiculata* (L.) Walp.] (Burgos and Talbert 1996). Weed suppression by cover crop residue is attributed to both physical and chemical interference. Rye is a commonly used cover crop that reduces density and biomass of several weed species in soybean (Liebl et al. 1992; Moore et al. 1994) and corn (Teasdale et al. 1991). Other annual grass species such as oat, Italian ryegrass, and wheat (Burgos and Talbert 1996; Moore et al. 1994; Weston 1990), and annual legume species such as crimson clover, hairy vetch, and subterranean clover (Teasdale et al. 1991; Teasdale and Daughtry 1993; White and Worsham 1990; Yenish et al. 1996) have been investigated for potential weed control benefits. In addition to benefits provided by cereal cover crops, legume cover crops biologically fix atmospheric nitrogen that subsequently becomes available during residue decomposition (Sainju and Singh 1997; Varco et al. 1999).

The purpose of using a winter annual cover crop for weed management is to produce plant residue to create an unfavorable environment for weed germination and establishment (Teasdale 1996). Cover crop residues generally provide species-specific, partial weed control during early-season crop growth (Teasdale 1996). Although numerous studies have examined the effect of cover crop residues on weed suppression and crop yield, information on cover crop residue effects on weed density and biomass, soybean response, and economic benefits in the Mississippi Delta region is lacking. In cover crop systems, there is an additional cost of seeds, planting, and chemical desiccation compared to a no-cover crop system. Thus, use of cover crops from a farmer's perspective must be justified economically by reduced herbicide input and/or by increased yield.

Although cover crops suppress and/or replace unmanageable winter annual weed species during early spring, cover crop residues do not provide total weed control in summer crops (Teasdale 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. Currently, a total herbicide weed control program for conventional (nontransgenic) soybean costs over \$110/ha (about \$55/ha for each PRE and POST herbicide application) (Anonymous 2000).

Table 1. Daily average air temperature, monthly rainfall, and the 30-yr average during March through August at Stoneville, MS.

	Daily average air temperature			Monthly rainfall		
Month	1998	1999	30-yr average	1998	1999	30-yr average
	C			cm		
March	12.2	10.8	12.2	11.6	10.1	13.7
April	17.2	20.3	17.6	11.0	16.1	13.6
May	24.7	23.0	22.2	11.7	14.5	12.6
June	28.1	26.7	26.3	4.0	7.1	9.5
July	29.2	28.3	27.6	14.5	2.6	9.3
August	28.3	28.3	26.7	1.8	0.6	5.8

Aside from improved soil fertility and crop productivity benefits, cover crops can complement chemical weed control and reduce herbicide input through eliminating either the PRE or POST herbicide application. Whether increased cost associated with a cover crop system can be offset by eliminating either the PRE or POST herbicide application compared to a total herbicide (PRE + POST) program merits investigation.

The objectives of this research were to (1) determine biomass of several winter annual grass (Italian ryegrass, oat, rye, and wheat) and legume (crimson clover, hairy vetch, and subterranean clover) cover crops over a growing season in soybean, and (2) study the effects of these cover crops on weed density and biomass, soybean yield, and net return to soybean using PRE-only, POST-only, and PRE + POST herbicide programs.

MATERIALS AND METHODS

Research was conducted in 1998 and 1999 at the USDA Southern Weed Science Research Farm, Stoneville, MS (33°N latitude). The soil was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualf) with pH 6.3, 1.1% organic matter, a cec of 15 cmol/kg, and soil textural fractions of 26% sand, 56% silt, and 18% clay. Rainfall during May through August was 32 and 25 cm in 1998 and 1999, respectively (Table 1). The 30-yr average rainfall for the corresponding period is 37 cm. The experimental area was naturally infested with barnyardgrass (10 plants/m^2), browntop millet (94 plants/m^2), carpetweed (*Mollugo verticillata* L. # MOLVE) (3 plants/m^2), hyssop spurge (*Euphorbia hyssopifolia* L. # EPHHS) (1 plant/m^2), pitted morningglory (*Ipomoea lacunosa* L. # IPOLA) (1 plant/m^2), prickly sida (7 plants/m^2), smooth pigweed (*Amaranthus hybridus* L. # AMACH) (1 plant/m^2), and yellow nutsedge (34 plants/m^2). Weed densities as means of both years were determined in nontreated control plots of the no-cover crop conventional tillage (CT) system from a 0.84-m^2 area 3 wk after planting (WAP) soybean in 1998 and 1999.

The experiment was conducted in a split-plot arrangement of treatments in a randomized complete block design with cover crop/tillage systems as main plots and herbicide programs (PRE-only, POST-only, PRE + POST, and no-herbicide) as subplots with four replications. Cover crop/tillage system treatments were no-cover crop with CT and no-tillage (NT), and NT with Italian ryegrass, oat, rye, wheat, crimson clover, hairy vetch, and subterranean clover cover crops. Subplot size was 4 m wide and 12.2 m long. The identity of each treatment was maintained by assigning the same treatment to the same plot in both years. The experimental area was planted to soybean in the summer of 1997. All treatments were maintained as NT except no-cover crop CT from the fall of 1997. All cover crops were drilled in 19-cm-wide rows using a no-till grain drill[4] in mid-October of 1997 and 1998. Seeding rates were 6 kg/ha for Italian ryegrass, 80 kg/ha for oat, rye, and wheat, and 30 kg/ha for crimson clover, hairy vetch, and subterranean clover.

Cover crops were desiccated with paraquat (Italian ryegrass, oat, rye, and wheat) at 1.1 kg ai/ha and glyphosate (crimson clover, hairy vetch, and subterranean clover) at 1.1 kg ai/ha 2 to 3 wk before planting soybean. At desiccation, all cover crops were in the flowering stage. Legume cover crops were about 40 to 50 cm tall and nonlegumes were about 100 to 130 cm tall. Because of the difficulty in soybean stand establishment, cover crops were desiccated about 2 wk prior to planting soybean. Soybean stand establishment was better with prior desiccation of cover crops due to physical disintegration of residue than with a fresh intact layer of residue at desiccation. No-cover crop NT plots were also treated with paraquat at 1.1 kg ai/ha to kill existing vegetation. The CT plots were tilled in the fall and spring with a disk harrow, and in the spring with a field cultivator before planting. Soybean cultivar 'DP 3588' was planted on June 3, 1998 and May 15, 1999, with a no-till grain drill[4] in 57-cm rows at 263,000 seeds/ha directly into desiccated cover crop residue, and no-cover crop CT or NT plots. Planting was delayed in 1998 due to rainfall.

Herbicide treatments included PRE-only, POST-only, PRE + POST, and a no-herbicide treatment. Preemergence herbicides were broadcast-applied immediately after planting, while POST herbicides were applied 4 WAP. Herbicide treatments were applied with a tractor-mounted sprayer with 8,004 standard flat spray tips[5] delivering 187 L/ha water at 179 kPa. A paraffinic petroleum oil[6] at 0.63% (v/v) was added to all POST treatments as suggested by the manufacturer. Flumetsulam at 0.07 kg ai/ha and metolachlor at 2.30 kg ai/ha were applied PRE. Acifluorfen at 0.28 kg ai/ha, bentazon at 0.56 kg ai/ha, and clethodim at 0.14 kg ai/ha were applied POST.

Total estimated costs of production were determined for each treatment in each year and included all direct and fixed costs, but excluded costs for land and management using enterprise budgets compiled by the Mississippi Agricultural and Forestry Experiment Station (Anonymous 1997, 1998). Costs included only those costs directly associated with each treatment such as seeds, planting, and desiccation of cover crop, tillage, herbicides, adjuvants, and applications. Prices for cover crop seeds, herbicides, and adjuvants were obtained from major suppliers in the region. In the no-cover crop CT system, the cost of tillage was $67.13/ha in 1998 and $66.62/ha in 1999. In the no-cover crop NT system, the cost of herbicides to control existing vegetation prior to planting was $45.60/ha in 1998 and $43.42/ha in 1999. The cost of cover crop seeds, planting, and desiccation in 1998 and 1999 were: $72.42 and 73.95/ha, respectively, for Italian ryegrass; $98.26 and 94.70/ha, respectively, for oat; $124.54 and 132.24/ha, respectively, for rye; $100.04 and 91.74/ha, respectively, for wheat; $171.71 and 177.62/ha, respectively, for crimson clover; $143.55 and 147.98/ha, respectively, for hairy vetch; and $238.03 and 244.68/ha, respectively, for subterranean clover. The cost of PRE herbicides was $57.03/ha in 1998 and $54.83/ha in 1999, whereas the cost of POST herbicides was $93.24/ha and 71.28/ha in 1998 and 1999, respectively. Herbicide application cost of $10.00/ha was assumed for each PRE and POST application. Soybean seeds, planting, harvest, and hauling charges of $123.77/ha in 1998 and $122.14/ha in 1999 were assumed identical for all treatments. Gross income was calculated for each treatment using an average soybean price of $0.20/kg in 1998 and $0.16/kg in 1999. Net return was determined by subtracting the estimated costs of production from gross income for each treatment (Reddy and Whiting 2000).

Cover crop biomass was determined at 0, 3, 6, and 9

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

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

[6] Agri-Dex is a proprietary blend of heavy range paraffin base petroleum oil, polyol fatty acid esters, polyethoxylated derivative nonionic adjuvant (99% active ingredient) marketed by Helena Chemical Company, Memphis, TN 38119.

WAP of soybean only in PRE + POST treated plots. The PRE + POST treated plots were selected for their weed-free environment to exclude weeds. Cover crop plant residue was clipped from two randomly selected 0.09-m^2 quadrats, oven-dried, and weighed. Weeds were counted by species in a fixed quadrat of 0.84 m^2 in the middle of each plot at 3, 6, and 9 WAP. Control of individual weed species was visually estimated based on density on a scale of 0 (no weed control) to 100% (complete weed control) 2 wk after POST application. Dry weights of grasses, broadleaf weeds, and yellow nutsedge were recorded separately from two randomly selected 0.09-m^2 areas at 10 WAP. Soybean stand was estimated from three rows of 0.91-m row length at 5 WAP both years. Soybean plant height was recorded at 12 WAP. Soybean was harvested from each entire plot using a combine, and grain yield was adjusted to 13% moisture. The data were subjected to analysis of variance (ANOVA) using Proc Mixed to determine significance of main effects and any interactions among main effects (SAS 1998). Treatment means were separated at the 5% level of significance using Fisher's protected least significant difference test. Data were averaged across years as interactions were not significant and are presented for cover crop/tillage system by herbicide programs when interactions occurred.

RESULTS AND DISCUSSION

Cover Crop Biomass. Oat (11.1 Mg/ha) residue biomass was 46 to 85% greater than all other cover crops ($\leq$ 7.6 Mg/ha) at soybean planting (Table 2). Overall, Italian ryegrass, rye, and wheat had dry biomass similar to that of legume cover crops (crimson clover, hairy vetch, and subterranean clover). In other research, biomass of several cereal and legume cover crops ranged from 0.7 to 9.3 Mg/ha (Sainju and Singh 1997). A trend similar to 0 WAP was observed for biomass at 3 and 6 WAP. At 9 WAP, Italian ryegrass, oat, and rye had higher dry biomass than wheat and legume cover crops. Biomass greatly decreased at 9 WAP compared to the respective biomass at planting in all cover crops due to plant residue decay over time. Among the cover crops, decay of plant residue was rather slow in Italian ryegrass and rye, and nearly two-thirds of the plant residue was still remaining at 9 WAP (Table 2). Italian ryegrass and rye residue remained somewhat constant during the first 6 wk, and this is similar to the 8 wk reported for rye by Masiunas et al. (1995). The rate of biomass decay depends on factors such as physical and chemical composition of residue, weather, soil microbial ecology, and

Table 2. Cover crop dry biomass remaining on the surface of soil during soybean growing season in 1998 and 1999 at Stoneville, MS.[a]

Cover crop system	Cover crop dry biomass[b] 0 WAP	3 WAP	6 WAP	9 WAP	Percent biomass remaining 9 WAP
	Mg/ha				% of 0 WAP
No-cover crop, CT	0	0	0	0	—
No-cover crop, NT	6.3	5.8	2.8	2.3	35
Italian ryegrass, NT	7.6	7.5	6.1	5.3	69
Oat, NT	11.1	10.1	6.8	5.5	50
Rye, NT	7.6	6.6	5.2	4.9	67
Wheat, NT	7.2	7.0	4.1	2.9	41
Hairy vetch, NT	6.8	6.3	4.4	3.0	46
Crimson clover, NT	6.0	5.4	3.6	2.7	46
Subterranean clover, NT	6.7	5.2	4.8	2.7	43
LSD 0.05	2.2	2.3	1.7	1.2	19

[a] Abbreviations: CT, conventional tillage; NT, no-tillage; WAP, wk after planting soybean.

[b] Data represent an average of 2 yr. Biomass in no-cover crop NT system was from winter annuals.

agronomic practices. Cover crop residues can interfere with heat and water transfer between soil and air, and light penetration to soil surface, thus influencing both weed and crop growth (Liebl et al. 1992; Teasdale and Daughtry 1993; Teasdale and Mohler 1993).

No-cover crop NT system plant biomass was from dense infestations of winter annuals. Predominant weed species included annual bluegrass (*Poa annua* L.), Carolina foxtail (*Alopecurus carolinianus* Walt.), hairy buttercup (*Ranunculus sardous* Crantz), henbit (*Lamium amplexicaule* L.), shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.], and sibara [*Sibara virginica* (L.) Rollins]. Warm temperatures and moist conditions during March and April of each year favored establishment and growth of winter annuals, resulting in weed biomass in the no-cover crop NT system similar to that in the legume cover crop systems.

Weed Density. Fourteen weed species were present in no-cover crop CT untreated control plot at 3 WAP. Barnyardgrass, browntop millet, prickly sida, and yellow nutsedge each ranged from 5 to 62% of the total weed density. Densities of other weed species were too low ($<$ 2%) to justify reporting. All cover crop residues suppressed browntop millet density (averaged across herbicide programs) compared to the no-cover crop CT at 3 WAP (Table 3). However, at 9 WAP, only Italian ryegrass and oat residues provided suppression of browntop millet compared to rye, subterranean clover, and wheat. Overall, browntop millet density increased from 3 to 9 WAP in all cover crop systems and the no-

Table 3. Effect of cover crop surface residue (averaged over herbicide programs) on browntop millet, barnyardgrass, prickly sida, and yellow nutsedge density at 3, 6, and 9 WAP in soybean grown at Stoneville, MS in 1998 and 1999.[a,b]

	Browntop millet			Barnyardgrass			Prickly sida			Yellow nutsedge		
Cover crop system	3 WAP	6 WAP	9 WAP	3 WAP	6 WAP	9 WAP	3 WAP	6 WAP	9 WAP	3 WAP	6 WAP	9 WAP
	plants/m^2											
No-cover crop, CT	40	29	19	3	1	1	2	2	1	24	19	6
No-cover crop, NT	7	27	15	0	1	0	1	3	2	10	11	7
Italian ryegrass, NT	2	8	16	2	1	1	1	1	1	13	14	15
Oat, NT	1	7	14	2	2	1	2	4	2	10	11	13
Rye, NT	9	11	28	1	1	0	2	2	2	3	2	3
Wheat, NT	9	25	30	2	2	1	1	1	1	19	10	15
Hairy vetch, NT	5	25	20	2	2	1	1	1	1	14	12	7
Crimson clover, NT	5	12	18	0	1	0	1	2	1	11	26	15
Subterranean clover, NT	4	23	31	3	4	0	2	2	3	13	18	13
LSD 0.05	13	ns	11	ns	ns	ns	ns	ns	ns	ns	ns	ns

[a] Abbreviations: CT, conventional tillage; NT, no-tillage; WAP, wk after planting soybean.
[b] Data represent an average of 2 yr.

cover crop NT system. This may be due partly to decay of cover crop residues, thus creating a more favorable environment for germination and establishment of weeds. Furthermore, presence of cover crop residues on the soil surface may result in higher soil moisture availability (Liebl et al. 1992; Teasdale and Mohler 1993) for weed establishment. Densities of barnyardgrass and prickly sida were not different among cover crop systems. Yellow nutsedge density was not affected by cover crop residues regardless of sampling time, but rye had consistently the lowest density at 3, 6, and 9 WAP.

Cover crop residues have been shown to suppress emergence of some weed species more than others (Teasdale 1996). Large crabgrass [*Digitaria sanguinalis* (L.) Scop.] density was not affected by rye and hairy vetch residue compared to no-cover crop, but carpetweed and common lambsquarters (*Chenopodium album* L.) density were suppressed by these cover crops (Teasdale et al. 1991). Redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters emergence patterns were not altered by rye and wheat residues compared to no-cover crop (Moore et al. 1994). Thus, as previously reported (Teasdale et al. 1991), cover crop specificity for specific weed species was also apparent in this study.

Weed Control and Weed Dry Biomass. 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, browntop millet, carpetweed, hyssop spurge, pitted morningglory, prickly sida, and smooth pigweed was 95% or better and control of yellow nutsedge was 88% or better among cover crops or herbicide programs at 2 wk after POST (data not shown).

Data for total weed biomass (total of grass weeds, broadleaf weeds, and yellow nutsedge) is presented as overall conclusions were similar to each weed type alone. Total weed dry biomass among cover crops was lowest in Italian ryegrass and highest in rye at 10 WAP (Table 4). Among nonlegumes, Italian ryegrass and oat had lower weed biomass compared to rye and wheat. However, weed biomass was similar among the three legume cover crops. Browntop millet dominated the composition of weed species in this study. Rye and wheat cover crops had a higher density of browntop millet at 9 WAP compared to Italian ryegrass and oat (Table 3); as a result weed biomass was higher in rye and wheat. Furthermore, total weed biomass was positively correlated with density of browntop millet (r = 0.77, P > 0.01). Visible control of eight weed species was good among cover crops or herbicide programs 2 wk after POST (data not shown). However, 4 wk later (10 WAP), total weed biomass was higher in all cover crops vs. Italian ryegrass or oat and higher with PRE-only vs. POST-only or PRE + POST program (Table 4). This may be due partly to growth of escaped weeds and regrowth of weeds that were partially controlled.

Soybean Stand, Height, and Yield. Among cover crop systems, soybean yield decreased in the order of no-cover crop NT ≥ no-cover crop CT ≥ hairy vetch ≥ crimson clover ≥ rye ≥ oat ≥ wheat ≥ subterranean clover > Italian ryegrass. Differences in yield were due partly to the effect of cover crop biomass on soybean stand establishment (Table 4) and plant height (Table 5). Soybean plant population is expressed as percentage stand reduction compared to the no-cover crop CT system (Table 4). In the no-cover crop CT and NT systems and hairy vetch system, stand reduction was negligible (≤ 2%) and soybean plant height was greater (≥ 105 cm)

Table 4. The main effects of cover crops and herbicide programs on soybean stand reduction and weed biomass in 1998 and 1999 at Stoneville, MS.

Main effect[a]	Soybean stand reduction[b]	Total weed dry biomass, 10 WAP[c]
	%	kg/ha
Cover crop		
No-cover crop, CT	0	1,620
No-cover crop, NT	0	650
Italian ryegrass, NT	17	650
Oat, NT	16	790
Rye, NT	10	1,720
Wheat, NT	14	1,520
Hairy vetch, NT	2	1,070
Crimson clover, NT	16	1,270
Subterranean clover, NT	20	1,480
LSD 0.05	10	800
Herbicide[d]		
Control	10	2,780
PRE	10	1,270
POST	8	610
PRE + POST	11	140
LSD 0.05	ns	530

[a] Abbreviations: CT, conventional tillage; NT, no-tillage; WAP, wk after planting soybean; PRE, preemergence; POST, postemergence; ns, not significant.

[b] Soybean plant population was expressed as percentage stand reduction compared to no-cover crop CT system. Data represent an average of 2 yr.

[c] Predominant weeds were barnyardgrass, browntop millet, carpetweed, hyssop spurge, pitted morningglory, prickly sida, smooth pigweed, and yellow nutsedge. Data represent an average of 2 yr.

[d] Flumetsulam (0.07 kg ai/ha) and metolachlor (2.30 kg ai/ha) were applied PRE. Acifluorfen (0.28 kg ai/ha), bentazon (0.56 kg ai/ha), and clethodim (0.14 kg ai/ha) were applied POST.

compared to a 17% stand reduction and shorter plants (79 cm) in the Italian ryegrass systems (Tables 4 and 5). Soybean stand reduction ranged from 10 to 20% and plant height from 83 to 93 cm in the oat, rye, wheat, crimson clover, and subterranean clover systems. The physical barrier of cover crop residue may have reduced emergence of soybean, and plant-derived chemicals released during decomposition of plant residue may have affected soybean growth. Reduction of up to 35% soybean emergence in rye and wheat residues compared to no-cover crop has been attributed to planting difficulty (poor seed–soil contact) and insect damage (Moore et al. 1994). Greater southern pea stand reduction in Italian ryegrass compared to oat residue has been attributed to greater phytotoxicity of Italian ryegrass to southern pea, or differences in nutrient and moisture availability (Burgos and Talbert 1996).

Application of herbicides resulted in 19 to 37% higher soybean yield than the no-herbicide control (1,360 kg/ha). Soybean yield with the PRE-only (1,620 kg/ha) program was less than yield with the POST-only (1,860 kg/ha) or PRE + POST (1,840 kg/ha) programs. There were no differences in stand reduction among herbicide programs. Plant height of 86 cm in the untreated control was slightly less than in PRE-only, POST-only, and PRE + POST programs (> 94 cm). Overall, soybean yields were inversely related to weed biomass among herbicide programs.

Analysis of variance of soybean yield indicated a significant interaction between cover crop and herbicide program. Soybean yields in the no-cover crop CT and NT systems were similar regardless of herbicide application. In Italian ryegrass, soybean yields were lower regardless of herbicide program compared to the untreated no-cover crop CT system and this may have been due partly to reduction in soybean stand and growth. In the PRE-only program, all cover crops had lower yield compared to the PRE-only program in no-cover crop CT system. This may have been due to growth of escaped and late-emerged weeds. Preemergence herbicides that are intercepted by surface residues may have been adsorbed and may not have reached the soil beneath the residue to prevent weed emergence. Thus, herbicide interception and retention by cover crop residues often results in partial or complete loss of herbicide efficacy (Reddy et al. 1995). In this study, when late-emerged weeds were controlled by the POST-only or PRE + POST programs, cover crops (except Italian ryegrass) had no detrimental effect on soybean yields, and their yields were not different from those of the no-cover crop CT system.

Because none of the cover crops resulted in soybean yield that was higher than that from the no-cover crop CT system in the absence of herbicides (untreated plots), use of cover crops cannot totally eliminate the need for herbicides under conditions of this study. Postemergence 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. Soybean yield from the POST-only program was similar to that from the PRE + POST program within each cover crop. This suggests a potential for eliminating PRE herbicides when using cover crops. Conversely, soybean yields from the cover crop systems with POST-only weed management were similar to that from the POST-only program in the no-cover crop CT system. This raises the question of economic benefits of cover crops because additional costs are incurred.

Net Returns. Treatment costs (seeds, planting, and desiccation of cover crops, tillage, herbicides, adjuvants, and applications) were higher for all cover crops compared to the no-cover crop CT ($136/ha) and NT ($114/ha) systems (Table 5). Treatment costs for cover crops ranged from $142/ha for Italian ryegrass to $311/ha for subterranean clover. The higher treatment cost in cover

Table 5. Soybean growth and yield, treatment cost, and net return as affected by cover crops and herbicide programs in 1998 and 1999 at Stoneville, MS.

Cover crop system[a]	Herbicide[b]	Soybean: Plant height	Soybean: Yield	Treatment cost[c]	Net return[d]
			kg/ha	$/ha	$/ha
No-cover crop, CT	Control	109	1,410	67	63
	PRE	102	2,020	123	117
	POST	105	1,960	149	80
	PRE + POST	113	2,050	205	43
	Mean	107	1,860	136	76
No-cover crop, NT	Control	95	1,690	45	135
	PRE	108	1,880	100	113
	POST	110	2,140	127	131
	PRE + POST	108	1,940	183	42
	Mean	105	1,910	114	105
Italian ryegrass, NT	Control	78	1,340	73	35
	PRE	76	1,350	129	−18
	POST	78	1,460	156	−29
	PRE + POST	85	1,240	211	−121
	Mean	79	1,350	142	−33
Oat, NT	Control	79	1,480	97	40
	PRE	94	1,550	152	−3
	POST	87	1,800	179	12
	PRE + POST	89	1,690	235	−62
	Mean	87	1,630	166	−3
Rye, NT	Control	79	1,450	128	8
	PRE	95	1,500	184	−42
	POST	86	1,690	211	−36
	PRE + POST	87	1,940	267	−43
	Mean	87	1,640	198	−28
Wheat, NT	Control	73	1,270	96	4
	PRE	90	1,440	152	−19
	POST	81	1,740	178	3
	PRE + POST	86	2,000	234	−3
	Mean	83	1,610	165	−4
Hairy vetch, NT	Control	91	1,340	146	−30
	PRE	118	1,700	201	−20
	POST	110	2,080	228	21
	PRE + POST	115	1,950	284	−57
	Mean	108	1,770	215	−22
Crimson clover, NT	Control	83	1,210	175	−84
	PRE	97	1,660	231	−58
	POST	95	1,980	257	−25
	PRE + POST	91	2,000	313	−80
	Mean	92	1,710	244	−62
Subterranean clover, NT	Control	89	1,060	241	−176
	PRE	94	1,460	297	−159
	POST	94	1,860	324	−116
	PRE + POST	94	1,750	380	−194
	Mean	93	1,530	311	−161
Mean	Control	86	1,360	119	−1
	PRE	97	1,620	175	−10
	POST	94	1,860	201	5
	PRE + POST	97	1,840	257	−53
LSD 0.05					
Cover crop		7	150	—	28
Herbicide		3	100	—	18
Interaction		11	300	—	55

[a] Abbreviations: CT, conventional tillage; NT, no-tillage; PRE, preemergence; POST, postemergence.

[b] Flumetsulam (0.07 kg ai/ha) and metolachlor (2.30 kg ai/ha) were applied PRE. Acifluorfen (0.28 kg ai/ha), bentazon (0.56 kg ai/ha), and clethodim (0.14 kg ai/ha) were applied POST.

[c] Treatment costs include only those costs associated with treatments such as seeds, planting, and desiccation of cover crop, tillage, herbicide, adjuvant, and application costs.

[d] Net return was calculated by subtracting total production cost from gross income. Total production costs include both treatment costs and other (soybean seeds, planting, harvesting, and hauling) costs that are common to all treatments.

crops was primarily due to the additional cost of seeds, planting, and desiccation of cover crops. Among cover crops, legumes ($215 to 311/ha) were more expensive to establish than non-legumes ($142 to 198/ha) because of the high cost of legume seeds. Treatment cost was highest in the PRE + POST ($257/ha) herbicide program. Herbicide costs decreased by $82/ha in the PRE-only and $56/ha in the POST-only programs compared to the PRE + POST program.

Net return was highest in the no-cover crop NT system ($105/ha) followed by the no-cover crop CT ($76/ha) system. Net returns were negative from all cover crop systems, and losses were highest in the crimson clover (−$62/ha) and subterranean clover (−$161/ha) systems. This was due partly to a comparable or smaller magnitude of difference in soybean yields and higher treatment costs associated with cover crops (except Italian ryegrass) compared to the no-cover crop systems. Although the Italian ryegrass system had a similar treatment cost (due to low seed cost) to the no-cover crop CT system, it resulted in negative net return due to a lower soybean yield. In general, soybean yields in this study were relatively low due to dry weather during the reproductive period (July and August) in both years (Table 1). During July and August, rainfall distribution was erratic in 1998 and was 78% less than a 30-yr normal in 1999. It should be stressed that improvement in soybean yield due to good rainfall or irrigation could have resulted in a positive net return from the cover crop systems. In a study with NT cotton, Varco et al. (1999) found that rye and hairy vetch systems were more profitable than winter fallow. Use of hairy vetch resulted in lower fertilizer N input.

Among herbicide programs (main effect), net returns were negative with PRE-only (−$10/ha) and PRE + POST (−$53/ha) programs compared to a positive net return of $5/ha in the POST-only program. This resulted from higher herbicide cost in the PRE + POST program compared to the PRE-only and POST-only programs. Soybean yield in the no-herbicide control was relatively large with the least treatment cost. As a result, the net return was comparable to that from the PRE-only and POST-only programs.

In this study, net return was influenced by yield to some extent and by treatment cost to a large extent. Cost of seed accounted for the largest expense in cover crop systems (except Italian ryegrass), whereas costs of planting and desiccation were similar for all cover crop systems. Cost of cover crop seed decrease is not expected unless cover crop–based crop production practices are more readily adopted by producers. Weed control and soybean yield were improved when cover crops were coupled with herbicides. Cover crops combined with an as-needed POST herbicide program could reduce herbicide cost compared to a total PRE + POST program.

The additional cost associated with use of cover crops resulted in negligible to negative net returns, even though all cover crops except Italian ryegrass under POST-only and PRE + POST programs provided soybean yield comparable to that of the no-cover crop CT system. Thus, the additional cost associated with cover crops must be compensated for by increased yield and/or reduced herbicide cost. Otherwise, cover crop-based soybean production will be uneconomical for producers. Nevertheless, a cover crop-based system of crop production may be attractive to those producers with highly erodible land mandated by government regulations to comply with soil conservation plan to remain eligible for certain program benefits. Furthermore, long-term agronomic, environmental, and sustainable monetary benefits of cover crops are difficult or impossible to calculate, but should be factored into crop management decisions. Cover crop–based systems can augment sequestering of atmospheric CO_2 into soil. If the cover crop is a legume, the atmospheric nitrogen fixed can be a renewable source of soil nitrogen.

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