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Soybean-Wheat Doublecropping: Implications from Straw Management and Supplemental Nitrogen[1]

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ABSTRACT

Doublecropped soybean [*Glycine max* (L.) Merr.] following winter wheat (*Triticum aestivum* L.) is usually planted past the optimum date for monocropped beans. To make good yield, early growth of doublecropped soybean is very important. The purpose of this experiment was to determine wheat straw leachate, wheat straw management, and supplemental N effects on soybean germination, growth, and yield. Leachate concentrations of 0, 20, and 100 g L^{-1} (straw to deionized water) were used for germination and radicle growth studies. Leachate concentrations of 0, 2, and 20 g L^{-1} were used in sand culture and the Ap horizon of Okolona silty clay (fine, montorillonitic, thermic Typic Chromudert) to study germination and early growth of soybean. A 3-yr experiment on Okolona silty clay, consisting of six management practices and two N levels (0 and 28 kg ha^{-1}), was used to study soybean growth and yield in the field. Management practices consisted of monocropped soybean planted near the optimum date and at the doublecropped date and doublecropped soybean planted where wheat straw was either burned, physically removed, soil-incorporated, or left standing. Germination was not significantly affected by leachate but was reduced by late planting in the field. The 100 g L^{-1} leachate inhibited radicle growth, while 20 g initially inhibited but then stimulated radicle growth. The 20 g L^{-1} leachate inhibited early growth in the laboratory but only in the silty clay, while the 2 g L^{-1} leachate stimulated growth, especially in the sand. Wheat straw inhibited growth and yield in the field. Supplemental N was most effective in overcoming depressed growth and yield where straw was left on the soil surface. Early monocropped soybean produced the largest average yield, but doublecropped soybean where straw was burned produced the greatest economic returns.

***Additional index words:* Glycine max (L.) Merr., *Triticum aestivum* L., Wheat straw leachate, Allelopathy, Conservation tillage, Soybean germination, Radicle growth.**

DOUBLECROPPING wheat (*Triticum aestivum* L.) and soybean [*Glycine max* (L.) Merr.] has increased significantly in the southern United States. This cropping system gives farmers the opportunity to increase profits through increased productivity from their land. A primary factor affecting returns from these systems is the yield of soybean. Doublecropped soybean is planted about 3 to 5 weeks later than monocropped soybean. Good early growth is important for good doublecropped soybean yields. Factors affecting early growth include planting conditions, N immobilization, and phytotoxins released from decomposing wheat straw. Residue management practices influence all of these factors.

Traditionally, wheat straw was burned or left standing, then incorporated during primary tillage. With increased emphasis on soil and water conservation and declining soil organic matter, wheat straw is more commonly incorporated by shallow disk-tillage or left on the soil surface, with the soybean crop planted without tillage into the straw. Although burning is not environmentally acceptable in some areas, yields on fine-textured soils have been greater where wheat straw was burned in comparison to incorporated or left on the soil surface (Sanford, 1982; Boquet and Walker, 1984). This response may be related to weed control, immediate release of certain nutrients, destruction of phytotoxic chemicals, reduced immobilization of N or other elements, or some combination of these factors. The moisture conserving aspects of wheat straw mulch do not appear to be as important on fine-textured soils as on coarse-textured soils (Bond and Willis, 1971). Toxins that leach out of wheat straw may be more prevalent in the root zone of soils that are high in clay. If this is the case, plant growth could be stunted.

Phenolic acids from wheat residue have been shown to exhibit phytotoxicity (Guenzi and McCalla, 1966). Some of the same chemicals inhibit N_2 fixation by *Rhizobium* sp. (Rice, 1984). Supplemental N applied to doublecropped soybean would offset N immobilization. Supplemental N would also influence any allelopathic relationship by increasing the amount of N available for uptake where N uptake is inhibited by toxins.

The purpose of this experiment was to measure the effects of wheat straw and wheat straw management on soybean germination, growth, and yield. The objectives were (i) to determine how wheat straw leachate affects germination, radicle growth, and early plant growth in the laboratory, and (ii) to determine how wheat straw management and supplemental N affect soybean growth and yield in the field.

MATERIALS AND METHODS

Wheat Straw Leachate Studies

Wheat straw was harvested at physiological maturity and chopped into 15-mm lengths. Leachate samples were collected by soaking straw at rates of 100, 20, and 2 g L^{-1} in deionized water over a 24-h period with continuous agitation from, an end-over-end shaker followed by filtering. These are typical concentrations that could exist under field conditions; e.g., a 10-mm rainfall over 24 h with a straw yield of 4000 kg ha^{-1} would produce a ratio of approximately 40 g L^{-1}; a 20-mm rainfall, a ratio of 20 g L^{-1}; and a 4-mm rainfall, a ratio of 100 g L^{-1}. Leachate from the 100 and 20 g L^{-1} ratios was used for germination and radicle growth studies. Leachate from the 20 and 2 g L^{-1} ratios was used for early growth studies.

Germination and Radicle Growth

Three hundred soybean seeds (cv. Centennial) were visually selected for similar size and quality. Ten soybean seeds were evenly spaced on saturated filter paper within each of 30 Petri dishes (15 by 90 mm). The 30 Petri dishes represented 10 replications of three treatments. Treatments consisted of germination media of deionized water, and leachate concentrations of 20 and 100 g L^{-1} of straw to deionized water, respectively. Petri dishes were covered and arranged in a completely randomized design in an incubator where

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temperature was maintained at 25°C. Germination was monitored after 2 days, and radicle lengths were measured after 2, 3, 4, 6, and 7 days. After 7 days, radicles were cut from seed and weighed. Data were analyzed by analysis of variance procedures, and means were compared at the 0.05 probability level using LSD.

Growth on Sand and Silty Clay Under Artificial Light

This study was a 3 × 2 factorial, with three levels of leachate and two soils arranged in a completely randomized design with four replications. The study was conducted on a light table in the laboratory. The watering treatments (factor A), which consisted of 465 mL (equivalent to 25 mm of surface water) each of deionized water (check), 20 g L^{-1} leachate, and 2 g L^{-1} leachate, were applied to each pot 5 days prior to and 1 day after planting. All pots were allowed to drain freely and were watered with 465 mL of additional deionized water at 5, 9, 13, and 17 days after planting. The two potting soils (factor B) consisted of medium to fine sand (1.0–0.25mm) and silty clay material from the Ap horizon of Okolona silty clay (fine, montmorillonitic, thermic Typic Chromudert). Pots had a total volume of 3.8 L and were filled with 2.8 L (4.0 kg) of soil material. Prior to planting, 80, 320, 40, 60, 1.0, 1.0, 6.0, 2.6, 0.07, and 2.4 mg kg^{-1} of P, K, Mg, S, B, Cu, Fe, Mn, Mo, and Zn, respectively, were thoroughly mixed into the soil material by using a twin-shell blender. The sand culture also received 420 mg kg^{-1} of Ca.

Ten inoculated soybean seeds (cv. Centennial) were planted at a depth of 10 mm in each pot. Plants were thinned to three per pot at the first trifoliate stage. Average plant height was determined at 3, 6, 9, 15, 18, and 21 days after emergence. Data were analyzed by analysis of variance procedures, and means were compared at the 0.05 probability level using LSD.

Field Studies

A field experiment was conducted for three consecutive years on the same site at Brooksville, MS, beginning in November of 1981. The soil was Okolona silty clay with a pH of 7.2 in the surface 0.30 m and a slope of 1.5 to 2.0%. Plots were fertilized in the fall according to Mississippi soil test recommendations. Treatments (12) consisted of the factorial combination of management practices and N rates in a split plot with three replications. Management practices (6 levels) constituted the whole plots and consisted of two monocropped soybean treatments and four doublecropped soybean treatments, with the following wheat straw management alternatives: (i) burning, (ii) mowing to 50 mm and removal, (iii) incorporation to 0.1 m by disking twice, and (iv) standing straw at 0.20 m. Monocropped whole plots consisted of a May and June planting date. The June date corresponded to the doublecropped planting date, while mid-May was considered the optimum planting date for monocropped soybean. Whole plots contained four 0.91-m rows 12.2 m long. Nitrogen rates of 0 and 28 kg ha^{-1} constituted the subplot treatments. Nitrogen was applied as NH_4NO_3 in a 30-mm band on the soil surface 60 to 80 mm to the side of the row, immediately after planting. Nitrogen was not soil incorporated at any time during the growing season. Each subplot contained four 0.91-m rows 6.1 m long. All plots remained in the same field position throughout the duration of the study. Crop varieties were 'Southern Belle' wheat and 'Centennial' soybean.

Prior to planting wheat each fall, the entire experiment was disked twice to a depth of 0.1 m and fertilized with 47 and 89 kg ha^{-1} of P and K, respectively. Ridges that would be used as 0.91-m rows were prepared with a staggered gang disk bedder (hipper). Wheat seed was broadcast onto the surface of doublecropped plots in early November at a rate of 100 kg ha^{-1}, using a hydraulic powered seeder and covered by using the bedder once again. Monocrop plots were fallowed until seedbed preparation in the spring. Wheat was topdressed with 100 kg ha^{-1} of N as NH_4NO_3 in late February of each year.

Soybean was planted at 33 seed m^{-1} of row with a JD-7100[3] planter (John Deere & Co., Moline, IL) equipped with ACRA-Plant[3] trash-whipper attachments (ACRA Plant, Garden City, KS). The trash whippers were used to remove 0.1 to 0.15 m of the ridges and clear a 0.15 to 0.2-m-wide path for the double-disk openers in doublecropped plots. The planter was not equipped with coulters of any kind. Trifluralin (*a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) was incorporated at 1.12 kg ha^{-1} while disking twice to prepare a seedbed for moncropped plots. Doublecropped soybean received 3.36 kg ha^{-1} of alachlor [2-chloro-2′-6′-diethyl-N-(methoxymethyl)-acetanilide] broadcast in 0.37 m^3 ha^{-1} of water immediately after planting in 1982. Plots in which the straw was removed or left on the surface also received 0.56 kg ha^{-1} of paraquat (1,1′-dimethyl-4,4′-bipyridium ion) with the alachlor in 1982. In 1983 and 1984, a mixture of oryzalin (3,5-dinitro-N_4,N_4-dipropylsulfanilamide) and linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] at 1.40 and 1.12 kg ha^{-1}, respectively, in 0.37 m^3 ha^{-1} of water was used in place of the alachlor and paraquat as in 1982. Weed control was good and the soybean was not cultivated.

Soybean canopy heights were determined by averaging 10 random measurements from the two center rows of each subplot at 21, 55, and 88 days from emergence. These dates corresponded to the V_3, V_{12} to R_2, and R_4 to R_5 growth stages, respectively, for the May planted soybean and the V_4, V_{13} to R_3, and R_7 growth stages, respectively, for the June planted soybean. Yields were determined by harvesting 3.7 m from each of the two center rows of each subplot. Harvested beans were cleaned with a portable plot thresher, and yields were adjusted to 13.5% moisture. Plant heights and grain yield were analyzed by analysis of variance procedures. Orthogonal comparisons were made between main plot (management practice) effects and N interaction with main plot effects, utilizing the single degree of freedom comparisons. Means were compared at the 0.05 probability level using LSD.

Costs and net returns were calculated using a computerized budget generator developed by the Agricultural Economics Department at Mississippi State University (Spurlock et al., 1985). All equipment, labor, material, and service costs for each treatment were taken into account as well as interest on capital with one exception, that being no cost was assigned to removing wheat straw. The assumption here was that this practice would not be used unless the straw had a value to offset the cost of removal.

RESULTS AND DISCUSSION

Effects of Wheat Straw Leachate

Germination and Radicle Growth

Germination of soybean seed was unaffected by straw leachate. Over 95% of the seed in each solution germinated within 24 h. However, radicle length and weight were significantly affected by leachate as indicated by the mean squares in the first part of Table 1. Treatment means for radicle length at 2, 3, 4, 6, and 7 days after initial germination as well as means for radicle weight at 7 days from germination are given

[3] Mention of a product name does not constitute a guarantee or warranty of the product by the USDA or Mississippi Agricultural and Forestry Experiment Station and does not imply its approval to the exclusion of other products that may also be suitable.

Table 1. Mean squares from analysis of variance for effects of wheat straw leachate on early radicle and plant growth of soybean in the laboratory.

Source of variation	df	Radicle length, Days after germination: 2	3	4	6	7	Radicle weight at 7 days
		Mean squares					
Leachate	2	1.224**	2.755**	9.191**	10.454*	16.242*	0.0145**
Error	27	0.025	0.082	0.203	1.937	3.302	0.0012
		Plant height, Days from emergence: 3	6	9	15	18	21
		Mean squares					
Leachate	2	4.86**	6.17**	12.75**	36.54**	59.15*	2022.90**
Soil	1	5.22**	49.68**	171.09**	1036.75**	1217.38**	56.78**
Leachate × soil	2	1.105**	0.62	0.53	14.94	25.86	34.06*
Error	18	0.125	0.34	0.83	4.81	12.04	6.70

*,** Significance at the 0.05 and 0.01 probability levels, respectively.

in the first part of Table 2. Radicle growth and weight were both significantly affected by straw to leachate volume. At 2 days from germination, the 20 g L^{-1} leachate had significantly reduced radicle elongation below the control, and the 100 g L^{-1} leachate had reduced radicle growth below that of the control as well as the 20 g L^{-1} leachate. However, by 4 days after germination, the 20 g L^{-1} leachate had stimulated radicle growth above that of the control, but negative effects of the 100 g L^{-1} leachate were still apparent.

While differences in radicle length between the control and more concentrated leachate (100 g L^{-1}) had essentially disappeared by 7 days, the trend of reduced growth from the 100 g L^{-1} leachate was still reflected in overall radicle weight after 7 days.

This type of response is not surprising since researchers have found a number of phenolic acids (Guenzi and McCalla, 1966) and short-chain fatty acids (Tang and Waiss, 1978) in wheat straw that may have inhibitory or stimulating effects. These acids in mixtures have been reported to be antagonistic to each other in inhibiting radicle growth from a wide variety of seed (Blum et al., 1984). Researchers have also reported that the activity of one phenolic acid that reduces growth by stimulating decarboxylation of indole acetic acid (IAA) may disappear within 48 h, and another that is synergistic to IAA may stimulate growth by counteracting the destruction or decarboxylation of IAA (Thomaszewski and Thimann, 1966).

Early Plant Growth

Both leachate and soil affected early plant growth in the laboratory as reflected in plant height (Table 1). The low level of light (approximately 20 W m^{-2}) caused soybeans to elongate much faster than normal, thus producing a viny appearance. However, this should not have affected the relative comparisons in the study. There was a significant interaction between leachate and soil at 3 and 21 days from emergence (Table 1).

Table 2. The effects of wheat straw leachate on early radicle and plant growth of soybean in the laboratory.

Treatment	Radicle length, Days after germination: 2	3	4	6	7	Radicle weight at 7 days
	mm					mg
Deionized water	12.6	31.1	56.0	101.6	110.1	483
20 g L^{-1} leachate	10.3	28.8	63.4	115.8	133.5	474
100 g L^{-1} leachate	5.7	21.1	44.4	95.9	112.9	387
$LSD_{0.05}$	1.5	2.6	4.1	12.8	16.7	31.6

	Plant height, Days from emergence: 3		6			9			15			18			21	
	sic†	s†	sic	s	mean	sic	s	mean	sic	s	mean	sic	s	mean	sic	s
	m															
Deionized water	0.103	0.103	0.150	0.174	0.162	0.207	0.255	0.231	0.344	0.446	0.395	0.451	0.555	0.503	0.503	0.649
2 g L^{-1} leachate	0.107	0.120	0.163	0.191	0.177	0.228	0.283	0.256	0.359	0.515	0.437	0.460	0.635	0.548	0.507	0.735
20 g L^{-1} leachate	0.091	0.105	0.145	0.179	0.162	0.207	0.265	0.236	0.341	0.476	0.408	0.424	0.573	0.498	0.484	0.661
Mean			0.153	0.181		0.214	0.268		0.348	0.479		0.445	0.588			
$LSD_{0.05}$, soil (S)			0.005			0.008			0.019			0.030				
$LSD_{0.05}$, leachate (L)					0.007			0.011			0.027			0.042		
$LSD_{0.05}$, S × L	0.006		NS			NS			NS			NS			0.044	

† sic = silty clay and s = sand.

Table 3. Mean squares from analysis of variance for effect of management practice and N on soybean growth and yield, showing orthogonal single degree of freedom comparisons for management practices.

Source of variation	df	Plant height, Days from emergence: 21	55	88	Grain yield
		Mean squares			
Replications	2	1.97	44.28	39.97	6.68
Years	2	325.57**	11 403.04**	224.62*	1 745.46**
Management treatment	5	19.32**	217.42**	78.08	592.05**
Early monocropped vs. all others	(1)	(19.88*)	(24.02)	(13.98)	(2 790.74**)
Late monocropped vs. all doublecropped	(1)	(16.09*)	(226.26**)	(120.87)	(99.86**)
Straw burned + removed vs. incorporated + left standing	(1)	(47.21**)	(414.72**)	(126.14)	(48.68*)
Straw burned vs. removed	(1)	(6.33)	(167.70*)	(94.74)	(9.20)
Straw incorporated vs. left standing	(1)	(7.11)	(254.40**)	(34.61)	(11.79)
Management treatment × years	10	5.92	61.07	306.31**	67.64**
Error (a)	34	3.47	29.46	49.42	10.23
Nitrogen (N)	1	23.52**	122.67**	311.10**	114.91**
Years × N	2	0.54	2.10	0.50	8.63
Management treatment × N	5	6.98**	33.43**	67.98**	24.50**
Early monocropped vs. all others × N	(1)	(4.27)	(11.24)	(71.07**)	(0.30)
Late monocropped vs. all doublecropped × N	(1)	(20.78**)	(114.92**)	(234.26**)	(56.96**)
Straw burned + removed vs. incorporated + left standing × N	(1)	(1.15)	(12.50)	(6.72)	(13.18)
Straw burned vs. removed × N	(1)	(0.30)	(6.85)	(8.22)	(14.44)
Straw incorporated vs. left standing × N	(1)	(8.14*)	(21.62)	(19.65)	(37.62**)
Years × management treatment × N	10	1.06	12.44	8.35	8.72*
Error (b)	36	1.34	7.68	8.57	4.10

*,** Significance at the 0.05 and 0.01 probability levels, respectively.

Growth was inhibited on the silty clay at the 20 g L^{-1} concentration of leachate 3 days from emergence (second part of Table 2). This negative effect was still evident on the silty clay after 21 days. The 2 g L^{-1} leachate did not inhibit growth but actually stimulated growth over that of the control and the 20 g L^{-1} leachate on both soils, although differences were not significant at the 0.05 level in some cases (Table 2). The most notable plant height differences were due to soil, with soybean performing better in sand regardless of treatment after the first height measurements at 3 days from emergence. It should also be pointed out that the highest concentration of leachate (20 g L^{-1}), which reduced growth in silty clay, enhanced growth in sand.

This type of response is not surprising because most phenolic acids do not exist in the free state in wheat residue and must be hydrolyzed to be released into the soil system. Guenzi and McCalla (1966) found that autoclaving wheat residue with 2 mol L^{-1} of NaOH for 45 min was much more effective in hydrolyzing these phenolic acids than other methods involving the same concentration of HCL. Assuming that leachate from wheat straw contains chemicals that have potential to inhibit soybean growth, these chemicals must be hydrolyzed and retained in the soil in order to carry out this activity. These conditions are more likely to occur in a clay soil than sand. Soil pH as well as drainage and aeration conditions of the soil may have dramatic impacts on the hydrolysis of these chemicals. Researchers have concluded that many plant species and soil conditions are interrelated in determining the concentrating effects of allelopathic chemicals (Rice, 1984).

Effects of Wheat Straw Management and Supplemental N on Growth and Yield of Soybean in the Field

The 3-yr average wheat grain and straw yields were 3320 and 4165 kg ha^{-1}, respectively. Good soybean stands were obtained with the exception of 1984 when dry weather during germination reduced stands of both doublecropped and the June-planted monocropped soybean. No special weed or disease problems occurred. Trash attachments were effective in moving residue aside on the surface of ridges so that doublecropped soybean could be planted with no interference from straw.

Plant Growth

Mean squares for treatment effects on plant height are given in Table 3. Years, management practices, and N had significant effects on plant growth. The interaction between management practices and N was also significant. The difference between years is of little concern in this study and was related to environmental conditions beyond our control. By using number of days from emergence in comparing monocropped soybean planted in May with both monocropped and doublecropped soybean planted 3 to 5 weeks later, we eliminated much of the variation that would have occurred within management practices due to planting date. This also allowed for a better comparison of management practices and the interaction effect between management practices and N.

Leaving wheat straw on the surface or incorporating the straw stunted early growth of soybean in comparison to treatments where there was no straw or where straw was physically removed or burned (Tables 3 and 4). Within 2 weeks from emergence, soybean had a noticeable chlorosis where straw remained, but color differences were not rated. The most severe chlorosis occurred in plots where straw was left on the surface. Both burning and removal of straw reduced the chlorosis. Responses of this type have been attributed to immobilization of N by soil microflora, which almost certainly plays a role. However, very few studies where these responses have been attributed to N immobilization are designed to exclude potential allelopathic effects.

Table 4. The effects of management practice and N on soybean growth and yield.

	Plant height, Days from emergence						Grain yield	
	21		55		88			
	kg N ha^{-1}							
Management practice	0	28	0	28	0	28	0	28
	m						kg ha^{-1}	
Monocropped								
Planted early†	0.179	0.179	0.528	0.535	0.733	0.731	2674	2828
Planted at doublecropped date‡	0.180	0.172	0.561	0.540	0.777	0.753	2015	1937
Doublecropped‡								
Wheat straw burned	0.172	0.183	0.548	0.566	0.745	0.786	1780	1997
Straw removed	0.162	0.177	0.496	0.532	0.703	0.764	1797	1843
Straw incorporated	0.148	0.157	0.446	0.475	0.689	0.737	1728	1837
Straw left standing	0.148	0.176	0.484	0.543	0.694	0.772	1512	1897
$LSD_{0.05}$§	0.015		0.041		0.052		256	

† Planted 18, 27, and 14 May for 1982, 1983, and 1984, respectively.
‡ Planted 22 June, 1 July, and 4 June for 1982, 1983, and 1984, respectively.
§ For comparing means at the same or different level of N within days from emergence and grain yield.

Kimber (1973) studied the interaction of wheat straw residue and N fertilization on wheat yield and concluded that both toxic compounds and N immobilization were involved. Nitrogen immobilization was most apparent when straw was incorporated. Phenolic acids found in wheat straw have been shown to inhibit ion uptake, growth of *Rhizobia*, nodule formation, and acetylene reduction (Rice, 1984). Einhellig and Rasmussen (1979) found that *p*-coumaric acid (found in wheat straw) reduced chlorophyll in soybean leaves. Ammonium ions may detoxify phytotoxins (Chou and Chiou, 1979), and applied N also enables the soil microflora to break down potential toxins more readily.

Obviously, separating the effects of toxins, N immobilization, and N fertilization would be very difficult in a field situation, and the authors can only hypothesize that perhaps both N immobilization and phytotoxins played a part in the stunting and chlorosis of soybean noted in these experiments. Chemical analysis of the 20 g L^{-1} leachate showed that the leachate contained 7 mg kg^{-1} of phenolic acids and 10 mg kg^{-1} of acetic acid, so substantial quantities of phytotoxins were present in the leachate and could have been involved in the effects noted in these experiments.

Because of the significant interaction between management practice and N, the interaction means were compared in Table 4. Nitrogen had little affect on monocropped soybean but enhanced the growth of all doublecropped soybean. In general, the growth of doublecropped soybean was comparable to monocropped soybean at a similar number of days from emergence when supplemental N was applied. In reality however, all doublecropped and the late monocropped soybean had reached physiological maturity by 88 days from emergence, whereas the early monocropped beans reached maturity at approximately 110 days from emergence.

Grain Yield

Mean squares for treatment effects on grain yield are given in Table 3. All main effects (years, management practice, and N) were significant, and all interactions were significant with the exception of years × N. Othogonal single degree of freedom comparisons (Table 3) show that yields were significantly affected by planting date (early monocropped vs. all others), by doublecropping (late monocropped vs. doublecropped), and by presence of wheat straw (straw burned+removed vs. incorporated+left standing). Yield differences between years is not of major concern; however, it is of interest to point out that 1982 was the most favorable year; with early monocropped soybean yielding 3739 kg ha^{-1} in comparison to 2137 and 2318 kg ha^{-1} for 1983 and 1984, respectively. This large yield difference in 1982 was responsible for the significant interaction between years and management practices. Abnormally low rainfall (120 compared to 190 mm) during June and July reduced plant height at 88 days from emergence in 1984 for early monocropped soybean compared to 1982 and 1983, causing a similar interaction between management practice and years for this particular sample period (Table 3). The significant three-way interaction was caused by a negative response to N, which occurred only in 1984 and only on two management treatments (late monocropped soybean and doublecropped soybean where the straw was incorporated). The reason for this was not clear, but the NH_4NO_3 that supplied N actually stunted soybean with the drier soil conditions that existed in prepared plots during this time.

Because of the significant interaction between management practices and N, means for yields were compared across management practices at the same and different levels of N. The highest yield came from early monocropped soybean. Without supplemental N, both doublecropped treatments where straw was not re-

Table 5. Net returns for monocropped and doublecropped soybean with and without supplemental N.

Management practice	No N	28 kg N ha^{-1}
	\$ ha^{-1}†	
Early monocropped soybean	369	379
Late monocropped soybean	209	164
Doublecropped wheat-soybean		
Wheat straw burned	419	444
Wheat straw removed	394	379
Wheat straw incorporated	363	363
Wheat straw left on surface	325	392

† Economic values are based on average yields over 3 yr at \$0.249 kg^{-1} soybean, \$0.133 kg^{-1} wheat, six-row equipment using 0.91-m rows, and 1985 costs.

moved yielded significantly below that of the late monocropped soybean (Table 4). With supplemental N, all doublecropped yields were comparable to late monocropped soybean. Leaving wheat straw on the surface depressed yield more than any other treatment, and this was the only treatment that had a significant increase in yield due to addition of N. Nitrogen increased yield where straw was burned at the 0.10 probability level.

Allelopathic relationships have implications for management practices in agriculture, but most studies are still limited by the capability to determine the biological activity of suspected allelochemicals.

Economic Analysis

Net returns per hectare are given in Table 5 and are based on the 3-yr average yield for soybean with and without a 28 kg ha^{-1} rate of supplemental N. In addition, the 3-yr average wheat yield of 3320 kg ha^{-1} was used in calculating net returns for all doublecropped treatments. Yields of soybean at the 0 and 28 kg ha^{-1} rates of N that were used in calculating net returns are given in Table 4.

The doublecropped treatment where straw was burned had the highest returns with and without supplemental N. The largest increase in net returns from the supplemental N was in doublecropped soybean where straw was left standing, followed by the burning treatment. The economics would be different if the N lost by burning were taken into account. This would be 12.5 kg ha^{-1} for the average wheat yield in this study, using a concentration of 0.2 mol N kg^{-1} of straw. Yields and net returns might have been higher with late monocropped and doublecropped soybean planted in rows 0.75 m wide or less, but this was not feasible with the type of cultural practices used in this study.

CONCLUSIONS

There is much indirect evidence, but only a small body of direct evidence, concerning the movement of allelopathic compounds from plants that produce them and the uptake and translocation of these compounds in other plants. This is the weakest link in allelopathy, and until the paths of suspected compounds have been traced from donor plants to affected acceptor plants, there will be no absolute knowledge to prove that such effects do indeed occur. However, there is little doubt that plants and microorganisms produce compounds, which, if present in appropriate concentrations, can inhibit or stimulate the growth of other plants and microorganisms. Researchers have found that soil texture can impact on accumulation of allelochemicals (Rice, 1984), and in such cases, finer-textured soils, especially clays, had a greater retention capacity for water-soluble phenolic compounds and showed greater inhibitory effects than sand. There is little research in this area, but the evidence suggests that soil texture may be very important in determining the impact of species with allelopathic potential. Our leachate and laboratory studies support this theory, although N immobilization probably played a major role in reducing doublecropped soybean yield in the field. Further research would be needed, with several N rates applied to soybean doublecropped after wheat on a number of soils under different straw management conditions, before a N recommendation could be made.

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