Hindawi Publishing Corporation
International Journal of Agronomy
Volume 2010, Article ID 543261, 8 pages
doi:10.1155/2010/543261

Research Article

Wheat (*Triticum aestivum* L.) Cultivar Selection Affects Double-Crop and Relay-Intercrop Soybean (*Glycine max* L.) Response on Claypan Soils

Kelly A. Nelson,[1] Clinton G. Meinhardt,[1] and Randall L. Smoot[2]

[1] *Division of Plant Sciences, University of Missouri, Novelty, MO 63460, USA*
[2] *Greenley Research Center, University of Missouri, Novelty, MO 63460, USA*

Correspondence should be addressed to Kelly A. Nelson, nelsonke@missouri.edu

Received 29 March 2010; Accepted 26 May 2010

Academic Editor: Kent Burkey

Field research (2003–2005) evaluated the effect of wheat row spacing (19 and 38 cm) and cultivar on double-cropped (DC) soybean response, 38-cm wheat on relay-intercrop (RI) response, and wheat cultivar selection on gross margins of these cropping systems. Narrow-row wheat increased grain yield 460 kg ha^{-1}, light interception (LI) 7%, and leaf area index (LAI) 0.5 compared to wide rows, but did not affect DC soybean yield. High yielding wheat (P25R37) with greater LI and LAI produced lower (330 kg ha^{-1}) soybean yields in an RI system than a low yielding cultivar (Ernie). Gross margins were $267 ha^{-1} greater when P25R37 was RI with H431 Intellicoat (ITC) soybean compared to Ernie. Gross margins were similar for monocrop H431 non-coated (NC) or ITC soybean, P25R37 in 19- or 38-cm rows with DC H431 NC soybean, and P25R37 in 38-cm rows with RI H431 ITC soybean in the absence of an early fall frost.

1. Introduction

Claypan soils cover approximately 4 million hectares in the Midwestern U.S. These soils are poorly drained partially because of an argillic claypan layer 15 to 24 cm below the soil surface, and they are highly erodible due to slopes up to 20% and surface water runoff [1, 2]. Conservation tillage systems are recommended to reduce soil loss [3]. Due to economic considerations and relatively strong corn and soybean prices, cropping systems have shifted from a rotation of corn (*Zea mays* L.) soybeans [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.) to a rotation of corn and soybeans. Small grains such as wheat are important crops to increase water infiltration, organic matter, soil structure, and to reduce soil erosion from surface water runoff [4–6]. No-till soybeans, double-cropped after wheat, had 75% of the runoff of monoculture, conventional tilled soybeans in upland silty soils [5]. Some farmers have used double-cropped soybean production to increase wheat profitability [7–9]. In the absence of government programs, a risk and return analysis in southeast Kansas favored double-cropped wheat-soybeans over monocropped wheat or soybeans [10]. Relay-intercrop production has been proposed in the Midwest to reduce production risks of double-cropping. Double-cropping soybeans after wheat is risky above 38° latitude due not only to low rainfall and dry soils at planting, but also to a relatively short growing season that can be limited by early frost which reduces grain quality and yield [11, 12].

Relay-intercrop production involves overlapping growth cycles of two or more crops. This production system is common with legumes seeded into small grains; however, the companion crops may compete for water, nutrients, and sunlight, which may slow development of either crop [13–15]. Relay-intercropped soybean production involves seeding wheat in the fall and an intercrop seeding of soybeans into standing wheat. This cropping system has been proposed to reduce risk associated with double-crop soybean production, move double-crop production farther north, and increase farm profitability. Consistent relay-intercropped soybean production may qualify farmers for low-risk Federal Crop

Table 1: Fertilizer rates, application dates, and seeding dates for wheat and soybean cropping systems from 2003 to 2005.

Field information and management	2003	2004	2005
Wheat			
Seeding date	12 Oct. 2002	24 Oct. 2003	9 Nov. 2004
Fertilizer (N-P_2O_5-K_2O kg ha^{-1})	45-67-90	45-56-67	100-67-90
Application date	12 Oct. 2002	31 Oct. 2003	1 Mar.
Fertilizer (N-P_2O_5-K_2O kg ha^{-1})	55-0-0	55-0-0	
Application date	18 Mar.	14 Mar.	
Soybean[a]			
Seeding date (RI and MC)	23 Apr.	28 Apr.	25 Apr.
Seeding date (DC)	7 Jul.	26 Jun.	1 Jul.

[a]Abbreviations: DC, Double-crop; MC, Monocrop; RI, Relay-intercrop.

Insurance because soybeans are planted before the double-crop soybean cut-off date.

Previous research has evaluated relay-intercropped soybean planted in the southern United States [16], Missouri [17], Kansas [12], and Nebraska [14]. Several studies have evaluated the effect of soybean planting dates [17], aerial seeding [13], soybean cultivars [12, 18, 19], skip-row spacings [12, 13, 16, 17], spring N rates [17], and cost-effectiveness of relay-intercropped soybeans [12, 14] on relay-intercrop production systems. Late-planted, relay-intercropped soybeans caused mechanical planter injury to wheat plants and in some instances reduced grain yields 0% to 34% [12, 14, 17]. Soybean grain yield in a relay-intercrop production system ranged from 27% to 72% of monocropped soybean while grain yields were 0% to 35% greater than double-crop soybean [12, 14, 17]. Early seeding dates for soybeans lowered wheat grain yields due to soybean interference, while wheat harvest damaged soybeans in some instances [17, 20]. Relay-intercropped soybeans increased gross returns over double-cropped wheat-soybean or monocropped wheat, but gross returns were equal to monocropped soybeans [12].

One of the main opportunity costs farmers encounter with relay-intercropping is the risk of seeding wheat in 38-cm wide rows and not being able to plant soybeans due to inclement weather conditions. Wheat is typically seeded in narrow rows (15 to 25 cm). Most wheat row spacing research has evaluated 10- to 30-cm wide rows in order to reduce weed competition [21–24]. Beuerlein et al. [25] reported that high-yielding wheat planted in 38-cm wide rows had grain yields similar to a 19-cm row spacing. However, a single wheat cultivar in 41-cm rows yielded 91% of 21 cm rows in other research [13]. Differences in light interception and competitiveness among wheat cultivars have been reported in narrow-row wheat [21, 24]. In 20-cm rows, there was 2% to 5% greater light interception than 80-cm wide row wheat [17], but the impact on early planted relay-intercropped soybean cultivars has not been evaluated. High yielding monocropped soybean cultivars were high yielding in a relay-intercropping system since no cultivar × cropping system interaction was detected when soybeans were planted after wheat heading [19]. Researchers have evaluated growth of late-planted, relay-intercropped soybean [20], but few studies have looked at wheat canopy development differences for early-planted, relay-intercropped soybean. Reinbott et al. [17] evaluated light interception of 20 and 80-cm row spacings, but no research has evaluated 38-cm spacings, which are typical in today's crop production systems.

Since this previous relay-intercrop research was conducted, imidazolinone-tolerant wheat [26], glyphosate-resistant soybean [27, 28], polymer-coated soybean seed technology [29], and tractor guidance systems have been introduced while widespread use of planters on 38-cm wide-row spacings is common. Polymer-coated seed technology regulates germination based on soil temperature and moisture content [29] which may allow earlier relay-intercropped soybean planting dates and reduce mechanical damage to wheat compared to later planting dates. Delayed soybean germination may also reduce interference between wheat and soybeans. However, no research has evaluated the impact of wheat cultivars on light interception and subsequent wheat yields, relay-intercropped soybean response, or the cost-effectiveness of these systems using currently available technology. The objectives of this research were to (1) evaluate the effect of wheat row spacing and cultivar on wheat and double-cropped soybean response, (2) evaluate the effect of wheat cultivar in a relay-intercropping system on wheat and soybean response, and (3) determine the effect of wheat cultivar selection on gross margins of relay-intercropped and double-cropped soybeans compared to monocropped soybeans.

2. Materials and Methods

2.1. General Procedures. Field research was conducted at the University of Missouri Greenley Research Center near Novelty (40°01′ N, 92°11′ W) in 2003, 2004, and 2005. The soil was a Kilwinning (fine, montmorillonitic, mesic, Vertic Ochraqual) silt loam with pH 6.6 to 7.3 and 29 to 33 g kg^{-1} organic matter. This study included fifteen treatments and was arranged as a randomized complete block design with three to four replications in plots 3 by 12.2 m. Individual treatments are explained in the sections below.

Seeding dates and fertilizer application rates are listed in Table 1. Fertilizer was applied according to University of

Missouri soil test recommendations [30]. Wheat was no-till seeded into soybean stubble with a Great Plains Solid Stand 10 (Great Plains Manufacturing Inc., P.O. Box 218, Assaria, KS 67416) grain drill on 19-cm row spacings. Every other row was blocked to seed 38-cm wide rows at 124 kg ha^{-1}. Soybeans were no-till seeded in 38-cm wide rows at 494,000 seeds ha^{-1} with a John Deere 7200 (John Deere 7200, Deere and Co., 501 River Drive, Moline, IL 61265-1100) planter. Relay-intercropped soybeans were planted during favorable weather conditions prior to jointing (Zadoks 30) in wheat to avoid mechanical injury to wheat [31]. Soybean plots were maintained weed-free with three applications of glyphosate (*N*-(phosphonomethyl)glycine) (Roundup WeatherMAX, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167) at 0.84 kg ae ha^{-1} plus diammonium sulfate at 20 g L^{-1} and manual weed removal while no herbicides were required for wheat.

Soybean height and emergence was evaluated 30 d after planting relay-intercropped and monocropped soybeans. At this time, wheat shoots and soybean plants were counted in two, 30- by 76-cm quadrats in each plot, and the stage of soybean development [35] of each plant was determined. Prior to harvest, a 1.2-m section of soybean row was counted to determine plant population at harvest. Plots were harvested with a small-plot combine (Kincaid Equipment Manufacturing, P.O. Box 400, Haven, KS 47543) and moisture was adjusted to 130 g kg^{-1} prior to analysis. Wheat grain samples were collected and evaluated for test weight (GAC 2100, DICKEY-john Corporation, 5200 DICKEY-john Rd., Auburn, IL 62615). Data were subjected to ANOVA using the SAS general linear model procedure (PROC GLM) [36].

2.2. Wheat Row Spacing and Double-Crop Soybeans. The experiment included a factorial arrangement of wheat row spacing (19 cm and 38 cm) and cultivar ["Pioneer 25R37" (Pioneer Hi-Bred International, Inc., PO Box 1000, Johnston IA 50131-0184), "AgriPro 502CL" (AgriPro Seeds, Inc., P.O. Box 30, Berthoud, CO 80513) and "Ernie"] which was followed by double-crop H431 (Hubner Seed Co., Inc., West Lebanon, IN 47991) noncoated (NC) soybeans. Double-cropped soybeans were planted in 38-cm rows the same day wheat was harvested. Pioneer 25R37 was selected as a high yielding cultivar in the region, and Ernie was a common public soft red winter wheat cultivar [37]. Since AgriPro 502CL was a new imidazolinone-tolerant cultivar with limited seed supply at the initiation of this experiment, we evaluated light interception only in the P25R37 and Ernie cultivars. Incident and diffused photosynthetically active radiation (PAR) measurements were utilized as a nondestructive method to measure soybean leaf area index (LAI) and evaluate differences in crop canopy development [38, 39]. Five PAR measurements were recorded at ground level with a one-m SunScan Canopy Analysis System (Dynamax, Inc., 10808 Fallstone Road Suite #350, Houston, TX 77099) near solar noon positioned diagonal to three 38 cm rows and five 19 cm rows on 11 June each year. A simultaneous measurement of incident PAR, time, and zenith angle was recorded to calculate percent light interception (LI) and LAI. All data were combined over years since there was no 3-way interaction (year × wheat row spacing × wheat cultivar). In the absence of an interaction between these factors, we present main effects for wheat cultivar and row spacing. All means were separated using Fisher's Protected LSD ($P = .1$).

2.3. Wheat Cultivar and Relay-Intercropped Soybeans. We included a factorial arrangement of wheat cultivar ("Pioneer 25R37" and "Ernie") and relay-intercropped soybean cultivars ["Hubner H431" Intellicoat (ITC) Polymer System (Landec Ag Inc., 201 N. Michigan St., Oxford MI 47971), "Hubner H431" noncoated (NC), and "DK 38–52" (Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167)]. DK 38–52 was utilized as a standard noncoated cultivar grown in the region. The Intellicoat Polymer System [29] included captan, PCNB, thiabendazole, carboxin, and thiram at rates recommended by the manufacturers. All soybean cultivars were resistant to soybean cyst nematode (*Heterodera glycines* Ichinohe.) and glyphosate. Soybean height interaction between factors (year × wheat cultivar × soybean cultivar) and soybean population at harvest main effect data were subjected to an *F Max* test for homogeneity of variance, [40] and data were combined over years. Means were separated using Fisher's Protected LSD ($P = .05$).

2.4. Gross Margins of Monocropped, Relay-Intercropped, and Double-Cropped Soybeans. Monocropped soybean cultivars (H431 ITC, H431 NC, and DK 38–52) were included along with the previously described factorial treatments to evaluate the cost-effectiveness of wheat cultivar selection on relay-intercrop and double-crop systems compared with monocrop soybean [10]. In keeping with previous research [10, 12, 14], we calculated gross margins for the cropping systems using the product of yield and average receipts for wheat ($0.21/kg) and soybean ($0.32/kg) over the past three years [33, 34] minus input costs (Table 2) [32]. A single factor ANOVA revealed a significant treatment interaction with years. Wheat yield, soybean yield, receipts, expenses, and gross margin data were subjected to an *F Max* test for homogeneity at $P = .01$ [40] and combined over years because variances were homogenous. Means were separated using Fisher's Protected LSD at $P = .01$.

3. Results and Discussion

3.1. Wheat Row Spacing and Double-Cropped Soybeans. Ernie and AgriPro 502CL shoot density was 22% to 26% greater in narrow- (19 cm) than a wide-row (38 cm) spacing in late-May (Table 3). This did not cause an interaction in LI or LAI between row spacing and cultivar (Table 4). Narrow-row (19 cm) wheat LI and LAI was 7% and 20% greater, respectively, than wide (38 cm) rows. Subsequently, grain yields increased 470 kg ha^{-1} in narrow- compared to wide-row spacing. This was unlike more recent research in Ohio where wide- and narrow-row wheat yields were similar [25]. P25R37 intercepted 4% more light and had a greater LAI than Ernie when wheat was in the milk (Zadoks 75) to dough (Zadoks 85) stage of development [31]. This was 43 to 48 d after relay-intercropped soybeans were planted

Table 2: Custom crop-production expenses [32] and returns [33, 34] used to calculate gross margins.

Crop-production expenses and returns[a]	Wheat	Soybean
Planting ($/ha)	$36.56	$14.78
Average fertilizer application ($/ha)	$24.55	$12.28
Average fertilizer rate ($/ha)[b]	100-63-82 ($206.49)	10-63-82 ($102.75 MC soybean)
Seed ($/ha)[c]	$75.48	$115.60 (coated RI and MC)
		(personal communication, Claude Butt, Landec Ag.)
		$82.99 (noncoated DC and MC)
Weed control		
Custom application ($/ha)	$0	$27.81 (MC), $13.91 (DC and RI)
Herbicide ($/ha/application)	$0	$14.82
Harvest ($/ha)	$65.90	$66.69
Grain hauling ($/kg)	$0.008	$0.008
Grain receipts ($/kg)	$0.21	$0.32

[a]Abbreviations: DC, Double-crop; MC, Monocrop; RI, Relay-intercrop.
[b]Fertilizer cost was an average of local distributors in the fall, 2009.
[c]Soybean seed cost was the actual cost at the time of this research. Relative seed cost differences between coated and noncoated soybean were assumed to be similar.

Table 3: The effects of wheat row spacing and cultivar on wheat shoot density, wheat grain moisture, wheat grain test weight, double-crop (DC) soybean population, and yield.

Row spacing	Cultivar	Wheat			DC Soybean	
		Shoots	Moisture	Test weight	Population	Yield
38 cm		No. m^{-2}	%	kg m^{-3}	No. m^{-2}	kg ha^{-1}
	P25R37	577	16.4	745	28	1820
	Ernie	633	15.2	690	25	1880
	AgriPro 502CL	594	14.7	695	32	1770
19 cm						
	P25R37	624	17.2	732	28	1780
	Ernie	856	15.0	723	30	1820
	AgriPro 502CL	766	14.5	717	32	1790
LSD ($P = 0.10$)		138	0.6	15	4	NS

Table 4: Wheat light interception, leaf area index, and grain yield for row spacing and cultivar main effects. Data were averaged over years.

Treatment main effect	Light interception	Leaf area index	Yield
Row spacing	%		kg ha^{-1}
38 cm	73	2.0	3030
19 cm	80	2.5	3500
LSD ($P = .10$)	3	0.2	140
Cultivar			
P25R37	78	2.4	4240
Ernie	74	2.1	3030
AgriPro 502CL	—[a]	—	2690
LSD ($P = .10$)	3	0.2	200

[a]Treatment was not evaluated.

in this experiment. Differences in light interception among wheat cultivars may affect the ability of wheat to compete with weeds [21, 24]. Canopy closure in narrow-row wheat may help suppress weeds more than wide-row spacing. Narrow-row wheat spacing has reduced yield of early planted soybeans in other research [17]. This was especially true when wheat interfered with soybeans from mid-June until wheat harvest, a critical time in relay-intercropping when wheat and soybeans compete for water, nutrients, and light. As a result of an open canopy in 38-cm wide-row wheat, there may be greater weed densities or more weed species present than in 19-cm row widths. We observed no difference in weed species diversity or density between row spacings. However, in relay-intercropping, this eventuality could be important because, as wheat-row spacing increases, winter annual weeds may reduce wheat grain yields [22, 23] and subsequently reduce soybean yields due to additional interference with the soybean plant. Imidazolinone-tolerant wheat cultivars, such as AgriPro 502CL, may allow residual acetolactase synthase (ALS) herbicide applications in wheat [29] that would be beneficial to relay-intercropped soybeans.

Wheat cultivar grain yields were ranked P25R37 > Ernie > AgriPro 502CL when averaged over row spacing (Table 4). Wheat grain moisture at harvest was slightly wetter in narrow rows (0.8%) for P25R37 than in wide rows (Table 3), which

Table 5: Wheat cultivar shoot density, test weight, moisture, and soybean yield main effects for cultivar in a relay-intercropping system planted in 38-cm wide rows in 2003, 2004, and 2005. All data except shoot density were averaged over relay-intercropped soybean cultivars (H431 NC, H432 ITC, and DK 38–52).

Wheat cultivar	Wheat shoot density			Wheat test weight			Wheat moisture			Wheat yield			Soybean
	H431 NC	H431 ITC	DK 38–52	2003	2004	2005	2003	2004	2005	2003	2004	2005	Yield
		No. m^{-2}			kg m^{-3}			%			kg ha^{-1}		
Pioneer 25R37	547	486	560	762	726	709	15.4	18.4	15.6	3840	2220	4310	1820
Ernie	620	628	529	707	722	667	14.2	15.6	15.0	2290	1880	2220	2150
LSD ($P = .05$)		116		40	NS	30	0.6	1.2	0.2	340	NS	340	200

[a]Abbreviations: ITC, Intellicoat; NC, Noncoated; NS, Nonsignificant.

Table 6: Monthly and average rainfall during the soybean growing season from 2003 to 2005.

Month	2003	2004	2005	10-yr average
			cm	
Apr.	16.0	7.9	6.9	9.9
May	9.4	11.9	5.6	11.2
June	8.1	8.4	14.5	12.4
July	8.4	6.6	5.6	9.4
Aug.	15.7	20.6	8.1	12.2
Sept.	16.0	2.5	7.1	8.6
Oct.	5.3	16.5	8.6	8.4
Total	79.0	74.4	56.1	72.1

Table 7: Soybean plant population and height 30 d after planting (DAP), plant population at harvest, and yield main effects for soybean cultivars in a relay-intercropping system, planted in 38-cm wide-row wheat in 2003, 2004, and 2005. All data except height were averaged over relay-intercropped wheat cultivars (Pioneer 25R37 and Ernie).

Soybean cultivar	Population 30 DAP	Height P25R37	Height Ernie	Population at harvest	Yield
	No. m^{-2}	cm		No. m^{-2}	kg ha^{-1}
H431 NC	37	12	13	26	2010
H431 ITC	17	8	4	22	2290
DK 38–52	38	13	12	28	1700
LSD ($P = .05$)	4	3		3	270

[a]Abbreviations: ITC, Intellicoat; NC, Noncoated.

could result from increased air circulation through the wide-row canopy. Ernie and AgriPro 502CL test weight was 22 to 33 kg m^{-3} greater in narrow rows compared to wide rows, but test weights did not differ when P25R37 was seeded in a wide- or narrow-row arrangement. This was similar to research in Illinois where test weights were greater in narrow- (20 cm) than wide-row (40 to 80 cm) spacings [13]. Soybean plant population at harvest was lower when Ernie was seeded in 38-cm rows, possibly because the amount of residue in the field affected available soil moisture for soybean plants [41]; but there was no effect of wheat row spacing on double-crop soybean grain yield. Similarly, wheat residue management had no effect on double-crop soybean yield in eastern Arkansas [41].

3.2. Wheat Cultivar and Relay-Intercropped Soybean. The choice of soybean cultivar did not affect wheat shoot density; however, wheat variety selection affected shoot density since P25R37 had a greater shoot density than Ernie where H431 ITC was planted (Table 5). In the relay-intercrop system, environmental differences among years affected wheat test weight, moisture, and yield between cultivars. P25R37 had higher test weights, moisture, and yield in 2003 and 2005 when compared to Ernie, but test weights and yields were similar in 2004 when there was more rainfall in May (Table 6) and lower overall yields. However, relay-intercropped soybean yields were 330 kg ha^{-1} greater when seeded into Ernie than P25R37 (Table 5). This indicated that a high-yielding wheat cultivar such as P25R37 may interfere with soybean and reduce relay-intercropped soybean yield more than a low-yielding wheat cultivar (Ernie). This was probably related to a greater LI and LAI of P25R37 when compared to Ernie in the absence of soybean (Table 4).

Soybean cultivar response to wheat cultivars was similar, regardless of which high-yielding (P25R37) or low-yielding (Ernie) cultivar we evaluated; therefore, data were pooled over wheat cultivar (Table 7). Emergence of H431 ITC was delayed 10 to 14 d (visual observation) and was at least one vegetative stage of development [35] later when compared to noncoated H431 or DK 38–52 at this point in time (data not presented). Noncoated H431 were at stage V1 to V2 while coated (H431 ITC) soybeans were either still emerging or at the cotyledon stage of development (VC) 30 d after planting (DAP) soybean. Soybean plant population of DK 38–52 or H431 NC was 55% to 56% greater than H431 ITC 30 DAP (Table 7). Similarly, DK 38–52 and H431 NC plants were 4 to 9 cm taller than H431 ITC when relay-intercropped into P25R37 or Ernie 30 DAP. H431 ITC plant heights were taller where P25R37 was planted due to greater elongation between the internodes and narrower stems than Ernie (visual observation). Early in the season, soybeans commonly grow rapidly as indicated by taller plants, when weeds [42] or noncoated, relay-intercropped soybeans are present [20]. However, all relay-intercropped plants were shorter than monocropped soybeans at harvest (visual observation), in keeping with other studies [12, 18–20]. Soybean plant population at harvest remained 13% to 18% greater in noncoated (H431 NC and DK 38–52) cultivars than H431 ITC, but grain yield was ranked H431 ITC > H431 NC > DK 38–52. Relay-intercropped H431 ITC

Table 8: Monocropped (MC), double-cropped (DC), and relay-intercropped (RI) system wheat yields, soybean yields, receipts, expenses, and gross margins. Data were averaged over years.

Soybean cropping system	Wheat cultivar and row spacing	Soybean cultivar	Wheat yield	Soybean yield	Receipts	Expenses	Gross margins
			kg ha^{-1}			\$ ha^{-1}	
MC	None	H431 NC	0	3480	1104	387	717
	None	H431 ITC	0	3480	1104	419	684
	None	DK 38–52	0	3360	1065	386	679
DC	Pioneer 25R37, 19 cm	H431 NC	4460	1780	1521	674	847
	Pioneer 25R37, 38 cm	H431 NC	4070	1820	1449	671	778
	Ernie, 19 cm	H431 NC	3320	1820	1288	665	623
	Ernie, 38 cm	H431 NC	2730	1880	1180	661	519
	AgriPro 502 CL, 19 cm	H431 NC	3110	1790	1232	663	569
	AgriPro 502 CL, 38 cm	H431 NC	2230	1770	1039	656	383
RI	Pioneer 25R37, 38 cm	H431 NC	3580	1720	1313	667	647
	Pioneer 25R37, 38 cm	H431 ITC	3560	2240	1473	703	770
	Pioneer 25R37, 38 cm	DK 38–52	3480	1500	1220	664	556
	Ernie, 38 cm	H431 NC	1960	2290	1145	658	487
	Ernie, 38 cm	H431 ITC	2110	2340	1195	692	503
	Ernie, 38 cm	DK 38–52	2310	1890	1094	658	437
LSD ($P = .01$)			400	450	170	5	165

[a]Abbreviations: ITC, Intellicoat; NC, Noncoated.

grain yield was 280 to 590 kg ha^{-1} greater than noncoated soybean.

3.3. Gross Margins of Monocropped, Relay-Intercropped, and Double-Cropped Soybeans. P25R37 and Ernie grain yield was reduced 490 and 770 kg ha^{-1}, respectively, when H431 NC soybean were relay-intercropped into 38-cm wide-row wheat compared to DC 38-cm wide-row wheat (Table 8). P25R37 wheat grain yield was greater than Ernie in both double-cropped and relay-intercropped production systems. Soybean grain yield was similar among monocropped H431 ITC, H431 NC and DK 38–52 cultivars. Relay-intercropped H431 ITC soybean yield was 64% of monocropped coated or noncoated H431. Soybean yields were 19% to 32% greater when H431 ITC was relay-intercropped into 38-cm wheat than double-cropped H431 NC soybeans following 19- or 38-cm wheat row spacings. However, no significant increase in soybean yield resulted when relay-intercropped H431 NC was compared to double-crop H431 NC.

Although the greatest gross receipts and margins were from P25R37 with double-cropped H431 NC soybeans, gross margins were statistically similar for monocropped H431 NC or ITC soybeans, P25R37 in 19- or 38-cm rows with double-crop H431 NC soybean, and P25R37 in 38-cm rows with relay-intercropped H431 ITC. Early frost did not affect double-cropped soybean yields in this study. Double-cropping soybean with wheat was as profitable or more profitable than monocropping soybean in the Eastern Great Plains and other regions of the U.S. [7–9]. Gross receipts of P25R37 with relay-intercropped H431 ITC were similar to P25R37 with double-cropped H431 NC soybean, but expenses were \$29 ha^{-1} greater with the relay-intercropping system. The development of relay-intercropped soybeans was similar to monocropped soybeans (visual observation), which indicated there was no risk of early fall frost reducing grain yield or quality which is commonly associated with double-cropped soybeans.

4. Conclusions

Narrow-row (19 cm) wheat increased grain yield 460 kg ha^{-1}, light interception 7%, and leaf area index 0.5 when compared to wide rows, while wheat-row spacing did not affect double-cropped soybean yield. A high yielding wheat cultivar (P25R37) with greater LI and LAI had lower (330 kg ha^{-1}) soybean yields in a relay-intercropping system than a low-yielding cultivar (Ernie). However, gross margins were \$267 ha^{-1} greater when P25R37, compared to Ernie, was relay-intercropped with H431 ITC. Gross margins were similar for monocropped H431 NC or ITC soybeans, P25R37 in 19- or 38-cm rows with double-cropped H431 NC soybean, and P25R37 in 38-cm rows with relay-intercropped H431 ITC. In an attempt to reduce risk associated with double-cropped soybean production due to an early fall frost and dry conditions at planting, a relay-intercropping system using coated soybeans was as cost-effective as monocropped and double-cropped soybeans, even in the absence of a yield limiting early frost in the three years of this research. Farmers considering relay-intercropped soybean production in order to keep wheat in their crop rotation should utilize high-yielding wheat cultivars and coated-soybeans to maximize gross margins. Early-planted, relay-intercropped soybean into 38-cm wide-row wheat production must consider not only the soybean cultivar and seed coat technology, but also a high yielding wheat cultivar.

Nomenclature

Soybean:	*Glycine max* (L.) Merr. "Hubner 431," "DeKalb 38–52"
Wheat:	*Triticum aestivum* L. "AgriPro 502CL," "Ernie," and "Pioneer 25R37."

Abbreviations

DAP:	d after planting
LI:	light interception
LAI:	leaf area index.

Acknowledgment

The authors would like to thank S. Devlin, M. Jones, A. Barta, D. Harder, C. Bliefert, A. Jones, and H. Collier for their technical assistance with this research.

References

[1] S. H. Anderson, C. J. Gantzer, and J. R. Brown, "Soil physical properties after 100 years of continuous cultivation," *Journal of Soil and Water Conservation*, vol. 45, pp. 117–121, 1990.

[2] H. Blanco-Canqui, C. J. Gantzer, S. H. Anderson, E. E. Alberts, and F. Ghidey, "Saturated hydraulic conductivity and its impact on simulated runoff for claypan soils," *Soil Science Society of America Journal*, vol. 66, no. 5, pp. 1596–1602, 2002.

[3] F. Ghidey and E. E. Alberts, "Runoff and soil losses as affected by corn and soybean tillage systems," *Journal of Soil and Water Conservation*, vol. 53, no. 1, pp. 64–70, 1998.

[4] G. S. McMaster, R. M. Aiken, and D. C. Nielsen, "Optimizing wheat harvest cutting height for harvest efficiency and soil and water conservation," *Agronomy Journal*, vol. 92, no. 6, pp. 1104–1108, 2000.

[5] L. D. Meyer, S. M. Dabney, C. E. Murphree, W. C. Harmon, and E. H. Grissinger, "Crop production systems to control erosion and reduce runoff from upland silty soils," *Transactions of the American Society of Agricultural Engineers*, vol. 42, no. 6, pp. 1645–1652, 1999.

[6] M. R. Savabi and D. E. Stott, "Plant residue impact on rainfall interception," *Transactions of the American Society of Agricultural Engineers*, vol. 37, no. 4, pp. 1093–1098, 1994.

[7] L. A. Farno, L. H. Edwards, K. Keim, and F. M. Epplin, "Economic analysis of soybean-wheat cropping systems," *Crop Management*, 2002.

[8] K. W. Kelley, "Double-cropping winter wheat and soybean improves net returns in the Eastern Great Plains," *Crop Management*, 2003.

[9] S. Kyei-Boahen and L. Zhang, "Early-maturing soybean in a wheat-soybean double-crop system: yield and net returns," *Agronomy Journal*, vol. 98, no. 2, pp. 295–301, 2006.

[10] R. O. Burton Jr., M. F. Crisostomo, P. T. Berends, K. W. Kelley, and O. H. Buller, "Risk/return analysis of double-cropping and alternative crop rotations with and without government programs," *Review of Agricultural Economics*, vol. 18, pp. 681–692, 1996.

[11] R. A. Dewell, W. G. Johnson, K. A. Nelson, J. Li, and J. D. Wait, "Weed removal timings in no-till, double-crop, glyphosate-resistant soybean grown on claypan soils," *Crop Management*, 2003.

[12] S. R. Duncan, W. T. Schapaugh Jr., and J. P. Shroyer, "Relay intercropping soybeans into wheat in Kansas," *Journal of Production Agriculture*, vol. 3, pp. 576–581, 1990.

[13] L. M. Chan, R. R. Johnson, and C. M. Brown, "Relay intercropping soybeans into winter wheat and spring oats," *Agronomy Journal*, vol. 72, pp. 35–39, 1980.

[14] R. S. Moomaw and T. A. Powell, "Multiple cropping systems in small grains in Northeast Nebraska," *Journal of Production Agriculture*, vol. 3, pp. 569–576, 1990.

[15] J. Wiersma, C. Sheaffer, G. Nelson, D. Wyse, and K. Betts, "Intercropping legumes in hard red spring wheat under semi-arid conditions," *Crop Management*, 2005.

[16] P. M. Porter and A. Khalilian, "Wheat response to row spacing in relay intercropping systems," *Agronomy Journal*, vol. 87, no. 5, pp. 999–1003, 1995.

[17] T. M. Reinbott, Z. R. Helsel, D. G. Helsel, M. R. Gebhardt, and H. C. Minor, "Intercropping soybean into standing green wheat," *Agronomy Journal*, vol. 79, pp. 886–891, 1987.

[18] R. L. McBroom, H. H. Hadley, and C. M. Brown, "Performance of isogenic soybean lines in a monoculture and relay intercropping environments," *Agronomy Journal*, vol. 21, pp. 669–672, 1981.

[19] R. L. McBroom, H. H. Hadley, C. M. Brown, and R. R. Johnson, "Evaluation of soybean cultivars in monoculture and relay intercropping systems," *Crop Science*, vol. 21, pp. 673–676, 1981.

[20] S. U. Wallace, T. Whitwell, J. H. Palmer, C. E. Hood, and S. A. Hull, "Growth of relay intercropped soybean," *Agronomy Journal*, vol. 84, pp. 968–973, 1992.

[21] S. Drews, D. Neuhoff, and U. Köpke, "Weed suppression ability of three winter wheat varieties at different row spacing under organic farming conditions," *Weed Research*, vol. 49, no. 5, pp. 526–533, 2009.

[22] G. G. Justice, T. F. Peeper, J. B. Solie, and F. M. Epplin, "Net returns from cheat (*Bromus secalinus*) control in winter wheat (*Triticum aestivum*)," *Weed Technology*, vol. 7, pp. 459–464, 1993.

[23] J. A. Koscelny, T. F. Peeper, J. B. Solie, and S. G. Solomon Jr., "Effect of wheat (*Triticum aestivum*) row spacing, seeding rate, and cultivar on yield loss from cheat (*Bromus secalinus*)," *Weed Technology*, vol. 4, pp. 487–492, 1990.

[24] J. R. Roberts, T. F. Peeper, and J. B. Solie, "Wheat (*Triticum aestivum*) row spacing, seeding rate, and cultivar affect interference from rye (*Secale cereal*)," *Weed Technology*, vol. 15, no. 1, pp. 19–25, 2001.

[25] J. Beuerlein, P. Lipps, and R. Minyo Jr., *Ohio Wheat Performance Trials*, vol. 228 of *Horticulture and Crop Science Series*, Ohio State University, 2002.

[26] P. S. Baenziger, B. Beecher, R. A. Graybosch, et al., "Registration of 'Infinity CL' wheat," *Crop Science*, vol. 46, pp. 975–977, 2006.

[27] R. W. Elmore, F. W. Roeth, and R. N. Klein et al., "Glyphosate-resistant soybean cultivar response to glyphosate," *Agronomy Journal*, vol. 93, no. 2, pp. 404–407, 2001.

[28] R. W. Elmore, F. W. Roeth, and L. A. Nelson et al., "Glyphosate-resistant soybean cultivar yields compared with sister lines," *Agronomy Journal*, vol. 93, no. 2, pp. 408–412, 2001.

[29] N. Balachander, "Temperature responsive polymer seed coatings," in *Annual Meeting Abstracts, American Society of Agronomy*, Denver, Colo, USA, November 2003, non-paginated CD-ROM.

[30] D. D. Buchholz, *Soil Test Interpretations and Recommendations Handbook*, Department of Agronomy, University of Missouri, Columbia, Mo, USA, 1992.

[31] J. C. Zadoks, T. T. Chang, and C. F. Konzak, "A decimal code for the growth stages of cereals," *Weed Research*, vol. 14, pp. 415–421, 1974.

[32] R. Plain, J. White, and J. Travlos, *2009 Custom Rates for Farm Services in Missouri*, MU Extension, University of Missouri, Columbia, Mo, USA, 2009.

[33] USDA Economic Research Service. 2010, "Oil Crops Yearbook," January 2010, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290.

[34] USDA Economic Research Service, "Wheat Data: Yearbook Tables," January 2010, http://www.ers.usda.gov/Data/Wheat/WheatYearbook.aspx.

[35] W. R. Fehr and C. E. Caviness, "Stages of soybean development," *Crop Science*, vol. 11, pp. 929–930, 1971.

[36] SAS Institute, *SAS User's Guide*, SAS Institute, Cary, NC, USA, 2009.

[37] S. Liu, Z. A. Abate, and A. L. McKendry, "Inheritance of Fusarium head blight resistance in the soft red winter wheat Ernie," *Theoretical and Applied Genetics*, vol. 110, no. 3, pp. 454–461, 2005.

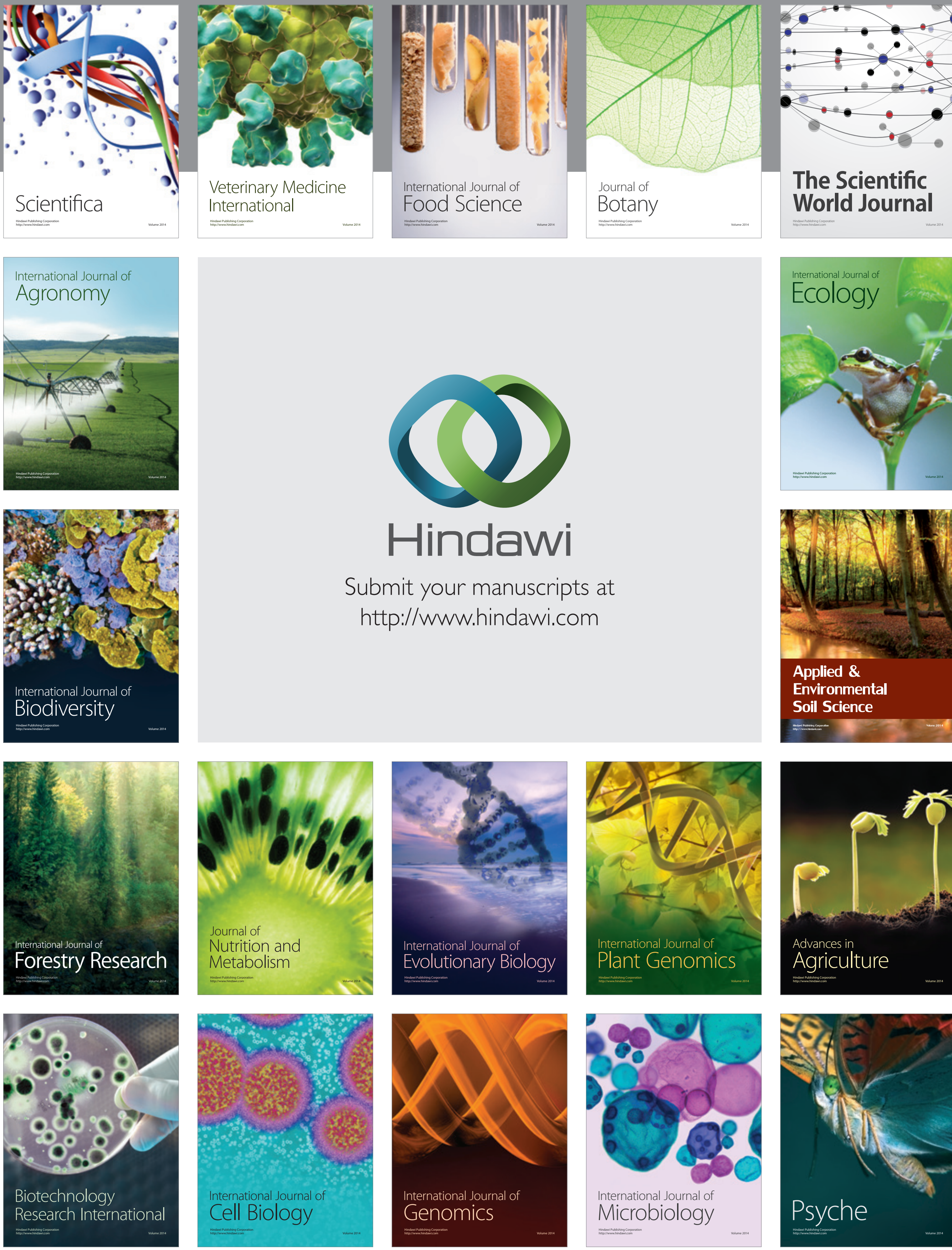
[38] C. D. Dalley, J. J. Kells, and K. A. Renner, "Effect of glyphosate application timing and row spacing on weed growth in corn (*Zea mays*) and soybean (*Glycine max*)," *Weed Technology*, vol. 18, no. 1, pp. 177–182, 2004.

[39] K. A. Nelson and K. A. Renner, "Soybean growth and development as affected by glyphosate and postemergence herbicide tank mixtures," *Agronomy Journal*, vol. 93, no. 2, pp. 428–434, 2001.

[40] R. O. Kuehl, *Statistical Principles of Research Design and Analysis*, Duxbury Press, Belmont, Calif, USA, 1994.

[41] T. L. Verkler, K. R. Brye, J. H. Popp, E. E. Gbur, P. Chen, and N. Amuri, "Soil properties, soybean response, and economic return as affected by residue and water management practices," *Journal of Sustainable Agriculture*, vol. 33, no. 7, pp. 716–744, 2009.

[42] J.-L. Jannink, J. H. Orf, N. R. Jordan, and R. G. Shaw, "Index selection for weed suppressive ability in soybean," *Crop Science*, vol. 40, no. 4, pp. 1087–1094, 2000.


Scientifica
Veterinary Medicine International
International Journal of Food Science
Journal of Botany
The Scientific World Journal
International Journal of Agronomy
Hindawi
Submit your manuscripts at
http://www.hindawi.com
International Journal of Ecology
International Journal of Biodiversity
Applied & Environmental Soil Science
International Journal of Forestry Research
Journal of Nutrition and Metabolism
International Journal of Evolutionary Biology
International Journal of Plant Genomics
Advances in Agriculture
Biotechnology Research International
International Journal of Cell Biology
International Journal of Genomics
International Journal of Microbiology
Psyche