Soybean Agronomic Response to Management Systems in the Upper Midwest

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ABSTRACT

There has been a rapid increase of soybean [*Glycine max* (L.) Merr.] production in cropping systems in Wisconsin. The objective of this research was to determine the influence of five management systems on agronomic traits for three soybean cultivars grown at two different planting dates. An older cultivar (Hardin) and two newer cultivars (DeKalb CX232 and Spansoy 250) were grown in five management systems between 1997 and 2000. Four management systems were located on a silt loam soil and consisted of conventional and no-tillage systems with and without irrigation. The fifth management system was located on a sandy loam soil that was irrigated. A planting date × cultivar interaction was observed on the silt loam soil where CX232 yielded 7% greater for the early planting date (4.37 Mg ha^{-1}) than for the late planting date, but no planting date effect was observed for Hardin and Spansoy 250. Over all cultivars, yield was 4% greater for early planting on the silt loam soil. Grain yield and other agronomic traits were not influenced by cultivar and planting date on the sandy loam soil. Tillage and irrigation did not affect grain yield or most of the other agronomic traits. Regression of cultivar means on management system indicated an equal stability for yield among the cultivars tested with Hardin tending to be the most stable. It was concluded that soybean cultivar decisions in the Upper Midwest should be based on selecting the highest yielding cultivars adapted to a particular geographic region and location regardless of management system.

Wisconsin is unique agriculturally compared with the intensive corn–soybean [*Zea mays* L.–*Glycine max* (L.) Merr.] areas of the Midwest and is characterized by smaller farm size, small or irregular-shaped fields dominated by highly erodible soils, and with more diverse cropping systems. In Wisconsin, row crop land area has increased rapidly due to inadequate economic returns from previous cropping systems and the declining dairy industry. Soybean area has increased from 130 000 ha in 1980 to 680 000 ha in 2002 (NASS, 2002). During this period, average yield increased from 2.2 to 3.0 Mg ha^{-1}. This rapid upward trend in soybean production and yield has been attributed to the integration of new agronomic technology into the production system. Such technology includes use of improved management practices and the development of new, high-yielding cultivars (Johnson, 1987). Both new technology and improved management practices, and their interactions, are critical to ultimate optimization of crop yields (Evans, 1980; Luedders, 1977). Although it is possible that favorable long-term changes in climate may have contributed to the rise in soybean yields, evidence for a long-term climatic trend is difficult to ascertain against a background of short-term annual weather variability (Thomson, 1975).

Cultivars have a maximum yield potential that is genetically determined. This genetic yield potential is obtained only when environmental conditions are perfect, but such conditions rarely exist. Several studies have measured the genetic improvement of soybean cultivars in the northern USA. Luedders (1977) found a 1% per year increase in cultivars of maturity groups (MG) I to IV released from 1933 to 1977. Specht and Williams (1984) found a yield increase of 0.5% per year when they tested 240 MG 00 to IV cultivars released from 1902 to 1977. Boyer et al. (1980) used old and new cultivars in MG II and III to show that breeding resulted in a yield improvement of 0.6% per year, with the new cultivars suffering less from water stress than older ones.

In a field situation, soil and climate provide the major portion of the environmental influence on soybean development and yield; however, soybean producers can manipulate this environment with proven managerial practices. Delayed planting reduces yields when compared with earlier plantings (Beatty et al., 1982). This has been shown to be true in most regions of the USA (Carter and Boerma, 1979; Parker et al., 1981). However, early planting may not be feasible in some seasons or under some soil conditions (e.g., excess water, cool temperatures, heavy residue). In addition, early planting may conflict with established cropping systems employed for other crops.

Research on the association between tillage system and soybean yield has shown inconsistent results. Elmore (1987, 1990) reported that soybean yields were not affected by tillage system. However, in Wisconsin, soybean yields in no-tillage systems are often lower than yields in conventional tillage systems (Pedersen and Lauer, 2002; Philbrook et al., 1991). No-tillage planting into corn residue usually results in cooler and wetter soils than when tilled, which can reduce emergence and final plant population and may account for part of the yield reduction (Philbrook et al., 1991).

Little information exists on the effects of management system on cultivar performance. Given the recent expansion of soybean in the upper Midwest and its diverse agriculture and production practices, knowledge of soybean cultivar performance in different management systems will be useful. The objectives of this research were: (i) to determine agronomic performance for three soybean cultivars grown in management systems commonly employed used by farmers in the upper Midwest over two planting dates, (ii) to evaluate the response of soybean to tillage and irrigation, and (iii) to evaluate cultivar yield stability across environments and planting dates.

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Published in Agron. J. 95:1146–1151 (2003).

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Table 1. Management systems and planting dates from 1997 to 2000 at Arlington and Hancock, WI.

Management system	Location	Soil type	Tillage system	Irrigation
1†	Arlington	Silt loam	Conventional tillage	Irrigation
2	Arlington	Silt loam	Conventional tillage	No irrigation
3†‡	Arlington	Silt loam	No tillage	Irrigation
4‡	Arlington	Silt loam	No tillage	No irrigation
5	Hancock	Sandy loam	Conventional tillage	Irrigation

		Planting dates			
		1997	1998	1999	2000
Arlington	Early	6 May	5 May	4 May	3 May
	Late	27 May	26 May	25 May	23 May
Hancock	Early	13 May	8 May	10 May	8 May
	Late	3 June	27 May	1 June	26 May

† Not conducted in 1997.
‡ Was not harvested in 2000 due to excessive runoff.

MATERIALS AND METHODS

Field research was conducted during 4 yr (1997–2000) using five different management systems (Table 1). These management systems were chosen to represent current farmer management practices and potentially higher yielding systems for the upper Midwest. Four of the five management systems were conducted on a Plano silt loam soil (fine-silty, mixed, mesic, Typic Argiudolls) at the Arlington, WI, Agricultural Research Station. They consisted of two tillage systems (conventional and no-tillage) with and without irrigation. The four management systems were conducted separately and adjacent to each other in a field with corn as the previous crop. Conventional tillage was accomplished by chisel plowing in the fall and field cultivations twice in the spring before planting. For no-tillage, crops were planted directly into the undisturbed residue of the previous crop. In 2000, all early planted plots in the no-tillage management systems were lost due to severe storms that occurred causing excessive runoff and soil erosion. Irrigation was not conducted in 1997 (Table 1). A sprinkler irrigation system was used in 1998 and a drip irrigation system in 1999 and 2000. Irrigation was initiated from anthesis with two applications a week (approx. 40 mm wk^{-1}) with rates adjusted for rainfall. This was done by deducting the amount of natural rainfall from 40 mm and then applying the remaining amount. The fifth management system (conventional tillage with irrigation) was conducted on a Plainfield sandy loam soil (loamy-sand, mixed, mesic, Typic Udipsamments) at the Hancock Agricultural Research Station. Tillage was accomplished by moldboard plowing in the fall and two times dyna-driving (HHC, Mendota, IL) in the spring at a 15-cm depth. Irrigation was conducted throughout the growing season with a center pivot irrigation system three times a week to assume a total water amount (rainfall plus irrigation) of about 80 mm wk^{-1}. Weather data were obtained from weather stations at each location (Table 2).

The experimental design for each management system was a randomized complete block in a split-plot arrangement with four replications. Main plots were early and late planting dates (Table 1). The subplots were three soybean cultivars; Hardin (released in 1980, MG 2.0), DeKalb CX232 (1995, MG 2.3), and Spansoy 250 (1995, MG 2.5). Plot size of the subplot experimental units was 3 by 15.2 m and was divided into two sub-subplots of 3 by 7.6 m where one sub-subplot was used for harvest. Seed was inoculated with *Bradyrhizobium japonicum* (Liphatech, Milwaukee, WI) and each plot was planted in seven rows at 38-cm row spacing at a 4-cm depth and at a rate of 432 000 seeds ha^{-1}. The four management systems at Arlington were planted with a Kinze Interplant planter (Kinze Manufacturing, Williamsburg, IA). The management system at Hancock was also planted in seven rows spaced at 38 cm with a Tye no-tillage drill (The Tye Co., Lockney, TX) at a 4-cm depth and at a rate of 432 000 seeds ha^{-1}. The previous crop was pea (*Pisum sativum* L.) in 1997 and 1998, sweet corn in 1999, and potato (*Solanum tuberosum* L.) in 2000. Weed control was accomplished preplanting at Arlington with 2.24 kg a.i. ha^{-1} of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphe-

Table 2. Precipitation and mean monthly temperature during the 1997 to 2000 growing seasons at Arlington and Hancock, WI. Departures from 20-yr mean are shown in parentheses.

Year	Location	May	June	July	August	September	Mean
		Precipitation					
		mm					
1997	Arlington	53 (−27)	127 (14)	154 (47)	82 (−15)	36 (−61)	90 (−8)
	Hancock	81 (−10)	76 (−21)	203 (88)	70 (−29)	86 (−8)	103 (4)
1998	Arlington	121 (41)	181 (68)	47 (−60)	152 (55)	88 (−9)	118 (19)
	Hancock	117 (26)	163 (66)	62 (−53)	149 (50)	62 (−32)	111 (11)
1999	Arlington	96 (16)	121 (8)	134 (27)	75 (−22)	43 (−54)	94 (−4)
	Hancock	85 (−6)	93 (−4)	201 (86)	114 (15)	32 (−62)	105 (29)
2000	Arlington	214 (134)	233 (120)	85 (−22)	99 (2)	78 (−19)	142 (43)
	Hancock	129 (39)	196 (99)	58 (−57)	116 (17)	89 (−5)	118 (19)
		Mean monthly temperature					
		°C					
1997	Arlington	11 (−4)	20 (0)	20 (−2)	17 (−3)	15 (0)	17 (−2)
	Hancock	10 (−4)	20 (0)	20 (−1)	18 (−2)	15 (0)	17 (−2)
1998	Arlington	17 (2)	19 (−1)	21 (−1)	21 (1)	17 (2)	19 (1)
	Hancock	17 (3)	18 (−2)	21 (0)	21 (1)	18 (3)	19 (1)
1999	Arlington	16 (1)	19 (−1)	23 (1)	19 (−1)	14 (−1)	18 (0)
	Hancock	15 (1)	19 (−1)	22 (1)	19 (−1)	14 (−1)	18 (0)
2000	Arlington	15 (0)	19 (−1)	20 (−2)	20 (0)	16 (1)	18 (0)
	Hancock	14 (0)	18 (−2)	20 (−1)	21 (1)	15 (0)	18 (0)

Table 3. Management system, planting date, and cultivar influence on grain yield at Arlington, WI.

Main effects	Grain yield 1997	1998	1999	2000
	Mg ha^{-1}			
Management system				
Conventional tillage and irrigation	–	4.30	4.15	3.33
Conventional tillage	3.42	4.27	4.06	3.91
No-tillage and irrigation	–	4.54	4.17	–
No-tillage	3.38	4.93	4.24	–
Mean	3.40	4.51	4.16	3.62
LSD (0.05)	NS†	0.17	NS	0.21
CV, %	7	3	6	9
Planting date				
Early May	3.33	4.59	4.30	3.75
Late May	3.47	4.43	4.01	3.49
LSD (0.05)	0.13	0.08	0.11	0.21
Cultivar				
Hardin	3.30	4.25	4.14	3.83
CX232	3.52	4.63	4.35	3.83
Spansoy 250	3.39	4.65	3.97	3.20
LSD (0.05)	0.17	0.09	0.14	0.26

† NS = no significant differences at $P \leq 0.05$.

Table 4. Planting date and cultivar influence on grain yield at Hancock, WI.

Main effects	Grain yield 1997	1998	1999	2000
	Mg ha^{-1}			
Planting date				
Early May	3.63	5.25	4.58	3.79
Late May	3.51	5.12	2.93	3.33
LSD (0.05)	NS†	NS	0.82	0.36
CV, %	11	3	9	4
Cultivar				
Hardin	4.08	5.26	3.65	4.45
CX232	3.26	5.12	4.06	3.41
Spansoy 250	3.37	5.16	3.56	2.82
LSD (0.05)	0.61	NS	NS	0.44

† NS = no significant differences at $P \leq 0.05$.

nyl)-*N*-(2-methoxy-1-methylethyl)acetamide] and 0.03 kg a.i. ha^{-1} imazethapyr [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid]. At Hancock, weed control was accomplished preplanting with 2.24 kg a.i. ha^{-1} alachlor [2-chloro-2′,6′-diethyl-N-(methoxy-methyl) acetanilide] and 0.56 kg a.i. ha^{-1} linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea]. Escaping weeds were removed by hand weeding throughout the growing season.

Data collected during all years included: grain yield, grain moisture, plant height and lodging, and oil and protein content. Lodging was based on a 1 (erect) to 5 (flat) scale. Oil and protein content were determined at the Iowa State University Grain Quality Laboratory using near-infrared analysis. An Almaco plot combine (Allen Machine Co., Nevada, IA) was used to harvest the center four rows from each plot. Grain yields were adjusted to moisture content of 130 g kg^{-1}.

All data were subjected to an analysis of variance using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Inst., 1995). Data was first analyzed by years and locations. All effects except replicates were considered fixed in determining the expected mean squares. Data was then analyzed by location with year and management system considered an environment (Milliken and Johnson, 1994) after determining error variances were homogenous using the maximum likelihood estimation procedure in PROC MIXED. Block and environment were treated as random effects and cultivar and planting date were treated as fixed effects in determining the expected mean square and appropriate *F*-tests in the analysis of variance. At Arlington, tillage systems were compared from 1997 to 1999 and irrigation treatment was compared from 1998 to 2000. When significant treatment effects ($P \leq 0.05$) were found, orthogonal contrasts were constructed to compare cultivars in the different management systems with all possible interactions of the experimental factors calculated. Mean comparisons were made using Fisher's protected LSD test ($P \leq 0.05$).

The method of Finlay and Wilkinson (1963) was used to determine cultivar stability. The yield of each cultivar was regressed for each environment on the mean of all cultivars at those environments to determine whether differences in stability existed among cultivars grown in the environments.

RESULTS AND DISCUSSION

Seasonal patterns of rainfall and temperature were variable over the 4 yr (Table 2) and influenced soybean yield and other agronomic traits at each location and within each management system. Average precipitation for Arlington during the growing season (May–September) was greater than the 20-yr average in 1998 and 2000 and was similar to the 20-yr average for 1997 and 1999. Average precipitation for Hancock was above the 20-yr average in all years. Except for 1998, temperature was lower or equal to the 20-yr average at both Arlington and Hancock during the growing season. Growing conditions in 1998 were excellent, resulting in record soybean yields in Wisconsin. In 1999, growing conditions and grain yields were close to the 20-yr average. However, 1997 and 2000 yields were lower across the state because of cold weather and wet and cold weather, respectively.

Final plant population was, except for 2000 where no differences were observed, influenced by environment during all years inconsistently. The highest plant populations in 1997 and 1998 were observed at Hancock with 430 000 and 387 000 plants ha^{-1}, respectively. However, the lowest plant population was observed at Hancock in 1999 (262 000 plants ha^{-1}). No differences in plant population were observed among management systems at Arlington in any year or at Hancock in 2000. Between years plant population ranged from 313 000 plants ha^{-1} in 2000 to 378 000 plant ha^{-1} in 1997. Cultivar and planting date did not influence plant population in any year.

Planting Date and Cultivar Response

Grain Yield. Grain yield differed between cultivars and planting date and ranged from 2.93 to 5.26 Mg ha^{-1} depending on environments (Table 3 and 4). Most variability for grain yield was associated with year. It was speculated that temperature may have been the key environmental factor interacting with cultivars to

Table 5. Planting date × cultivar interaction on grain yield at Arlington, WI.

Cultivar	Grain yield Early May	Late May
	Mg ha^{-1}	
Hardin	3.97	3.99
CX232	4.37	4.07
Spansoy 250	4.09	3.86
LSD (0.05)	0.25	

Table 6. Planting date and cultivar influence on grain yield, grain moisture, plant height, lodging, oil content, and protein content averaged across management systems from 1997 to 2000 at Arlington, WI.

Main effects	Grain yield	Grain moisture	Plant height	Lodging	Oil	Protein
	$Mg\ ha^{-1}$	$g\ kg^{-1}$	cm	1–5†	$g\ kg^{-1}$	
Planting date (D)						
Early May	4.14	131.69	91.28	2.02	179.82	355.81
Late May	3.97	147.48	94.58	1.93	178.28	357.07
LSD (0.05)	0.14	11.14	2.50	NS‡	1.25	NS
Cultivar (C)						
Hardin	3.98	144.83	93.15	2.72	177.80	355.40
CX232	4.22	143.37	81.19	1.31	179.33	359.83
Spansoy 250	3.97	130.55	104.45	1.90	180.00	354.08
LSD (0.05)	0.20	9.83	3.84	0.39	1.39	2.57
ANOVA						
D × C	*	NS	NS	NS	NS	NS

* Significant at the $P = 0.05$ probability level.
† Lodging score: the range extends from 1 = erect to 5 = flat.
‡ NS = no significant differences at $P \leq 0.05$.

influence yield given the number of seasons tested in this experiment and that averaged precipitation during the four growing seasons were equal to or higher than the 20-yr average. At both locations, highest yield was obtained in 1998 and the lowest in 1997 (Table 3 and 4). This corresponds well with the highest and lowest average temperature during the growing season, respectively (Table 2).

Few interactions were observed among treatment effects in this study. A planting date × cultivar interaction for grain yield was observed at Arlington, indicating that cultivars responded differently to early and late planting (Table 5). Cultivar CX232 achieved a maximum yield at the early planting date (4.37 $Mg\ ha^{-1}$) but declined 7% when planting date was delayed. No planting date effect was observed for Hardin and Spansoy 250, indicating that they do not respond to early planting and have greater stability in yields over the two planting dates than CX232. Carter and Boerma (1979) and Elmore (1990) have previously reported planting date × cultivar interactions.

Small differences in grain yield were observed among cultivars at Arlington with CX232 yielding 5% greater than Hardin and Spansoy 250 (Table 6). No significant difference was observed among cultivars at Hancock, even though Hardin averaged 9 and 16% greater yield than CX232 and Spansoy 250, respectively (Table 7).

Soybean yield increased 4% for early vs. late planting at Arlington (Table 6). No significant differences were found between early and late planting at Hancock. Johnson (1987) found similar results and concluded that an advantage of soybean is its proven ability to yield well over a wide range of planting dates. Lack of yield response to planting date at Hancock was unexpected and early planting may not be required to achieve highest yields at all locations in Wisconsin. Hancock is located in the central part of Wisconsin, which often has a longer and colder spring than Arlington, which is located in the southern part of the state. Lower soil water content and in relation to that higher soil temperature in the sandy soil may have equalized the planting date effect at Hancock. However, further research is needed to document this. Carter and Boerma (1979) reported that lack of yield difference due to planting date was due to a low yield (2.2 $Mg\ ha^{-1}$). However, our yields were higher at 4.02 $Mg\ ha^{-1}$ and still yield differences were not detected in this study.

Grain Moisture. Planting date and cultivar affected grain moisture content at Arlington (Table 6). Grain moisture content increased 10% with delayed planting. Hardin and CX232 averaged 9% higher grain moisture content than Spansoy 250. No difference was found for grain moisture content among cultivars or planting date at Hancock (Table 7).

Plant Height and Lodging. Early planting resulted in 4% taller plants at Arlington (Table 6), but no differences were observed between planting dates at Hancock (Table 7). There were significant plant height differ-

Table 7. Planting date and cultivar influence on grain moisture, plant height, lodging, oil content, and protein content from 1997 to 2000 at Hancock, WI.

Main effects	Grain yield	Grain moisture	Plant height	Lodging	Oil	Protein
	$Mg\ ha^{-1}$	$g\ kg^{-1}$	cm	1–5†	$g\ kg^{-1}$	
Planting date (D)						
Early May	4.31	121.89	97.15	2.00	179.88	361.92
Late May	3.72	125.08	90.97	2.21	177.42	359.54
LSD (0.05)	NS	NS	NS	NS	NS	NS
Cultivar (C)						
Hardin	4.36	117.63	97.91	2.03	177.91	361.41
CX232	3.96	118.28	82.84	1.88	177.94	362.78
Spansoy 250	3.73	134.55	101.44	2.41	180.09	358.00
LSD (0.05)	NS	NS	14.30	NS	NS	NS
ANOVA						
D × C	NS	NS	NS	NS	NS	NS

† Lodging score: the range extends from 1 = erect to 5 = flat.
‡ NS = no significant differences at $P \leq 0.05$.

Table 8. Tillage effect on grain yield, grain moisture, plant height, lodging, oil content, and protein content from 1997 to 1999 at Arlington, WI. Values are averaged across planting dates and cultivars.

Main effects	Grain yield	Grain moisture	Plant height	Lodging	Oil	Protein
	$Mg\ ha^{-1}$	$g\ kg^{-1}$	cm	1–5†	$g\ kg^{-1}$	
Tillage						
No-tillage	4.25	144.13	96.95	1.98	179.08	358.90
Conventional	4.04	142.86	92.14	2.15	178.98	358.21
LSD (0.05)	NS‡	NS	NS	NS	NS	NS

† Lodging score: the range extends from 1 = erect to 5 = flat.
‡ NS = no significant differences at $P \leq 0.05$.

ences among cultivars at both Arlington and Hancock, but no association with year of release. At Arlington, Spansoy 250 was 11 and 22% taller than Hardin and CX232, respectively. At Hancock, no difference was observed between Spansoy 250 and Hardin, which on average were 17% taller than CX232. Planting date did not affect lodging at either Arlington or Hancock. However, lodging differed among cultivars at Arlington, but not at Hancock. At Arlington, Hardin had the highest lodging score (2.72) and CX232 had the lowest lodging score (1.31). Beatty et al. (1982) found similar response with no plant height and lodging response to planting date.

Oil and Protein. Oil and protein content were influenced by cultivars at Arlington (Table 6). Protein content varied from 354.08 $g\ kg^{-1}$ for Spansoy 250 to 359.83 $g\ kg^{-1}$ for Hardin. In contrast, Hardin had the lowest (177.80 $g\ kg^{-1}$) and Spansoy 250 had the highest (180.00 $g\ kg^{-1}$) oil content. Early planting had 1.54 $g\ kg^{-1}$ higher oil content at Arlington than the late planting. However, planting date did not influence protein content. In contrast, Kane et al. (1997) found delayed planting increased protein content and reduced oil content. Planting date and cultivar did not influence oil or protein content at Hancock (Table 7).

Tillage and Irrigation Response

Tillage system did not affect grain yield or any of the other agronomic traits at Arlington (Table 8). This is in agreement with Elmore (1987, 1990), who reported that soybean yields were not affected by tillage system. However, these data contradict earlier studies from Wisconsin. Pedersen and Lauer (2002) and Philbrook et al. (1991) found soybean grain yield in no-tillage systems to be lower than in conventional systems. However, Pedersen and Lauer (2003) observed the opposite, that no-tillage systems yielded greater than conventional systems. It is speculated that the variable patterns of rainfall and temperature and various soil pathogens may account for these contradictory results.

Except for plant height and lodging, irrigation did not affect grain yield or any of the other agronomic traits at Arlington (Table 9), thereby indicating that soybean on this silt loam soil was not subjected to yield-limiting drought stress during the study period. Lodging score was lower in the nonirrigated system (1.73) than in the irrigated system (2.41). Plant height was 10% greater in the irrigated system (97.79 cm) than in the nonirrigated system (88.38 cm). No lodging score or height differences were observed between tillage system or cultivars.

The yield benefits of increased residue cover resulting from no-tillage practices could have been greater under drought conditions. The present study was conducted without drought or lack of precipitation in any month (Table 2). Therefore, in years with soil moisture deficits at planting, cultivar and tillage responses may not be the same as those reported here.

Cultivar Yield Stability

Cultivar yield stability across management systems can be observed in Fig. 1. Eberhart and Russell (1966) and Smith et al. (1967) used a similar technique to determine genotypic and phenotypic stability of different soybean cultivars. They considered a regression coefficient (slope) >1 indicative of below average stability and a regression coefficient <1 as indicative of above average stability. Regression coefficients for Hardin, CX232, and Spansoy 250 were 0.91, 0.93, and 1.02, respectively. None of the coefficients differed significantly from 1, indicating that all three cultivars produced a uniform and consistent yield with Hardin tending to be the most stable and consistent cultivar. Salado-Navarro et al. (1993) observed similar results and concluded that older cultivars tended to yield equal to or greater than newer cultivars when tested over a wide range of environments. Wilcox et al. (1979) concluded that older cultivars tested in a number of diverse environments had lower absolute yields compared with modern cultivars, but have equal stability for yield performance. The small variation in yield among the cultivars used in this study

Table 9. Irrigation effect on grain yield, grain moisture, plant height, lodging, oil content, and protein content from 1998 to 2000 at Arlington, WI. Values are averaged across planting dates and cultivars.

Main effects	Grain yield	Grain moisture	Plant height	Lodging	Oil	Protein
	$Mg\ ha^{-1}$	$g\ kg^{-1}$	cm	1–5†	$g\ kg^{-1}$	
Irrigation						
Irrigated	4.10	145.02	97.79	2.41	180.10	360.92
Nonirrigated	4.28	138.49	88.38	1.73	183.42	353.22
LSD (0.05)	NS‡	NS	5.94	0.27	NS	NS

† Lodging score: the range extends from 1 = erect to 5 = flat.
‡ NS = no significant differences at $P \leq 0.05$.

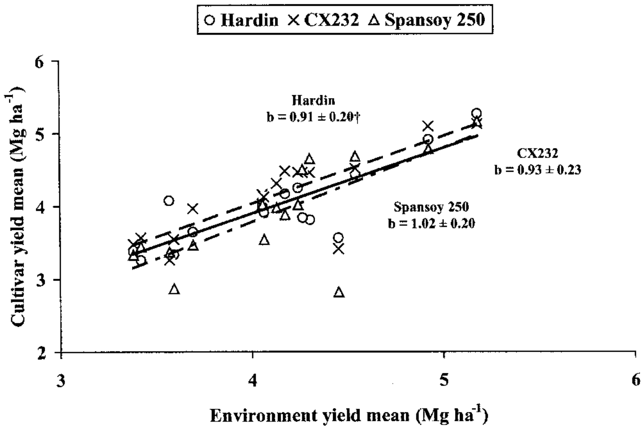

Fig. 1. Regression of three cultivar yield means on year–management system yield means. † Slope of regression line ± 95% confidence limits.

was likely the result of the relatively short time span between the releases of the three cultivars.

CONCLUSION

This 4-yr study found few differences existing in soybean yield and other agronomic traits for the three cultivars in five management systems and two planting dates. No improvement in grain yield was detected between the three cultivars released over a 15-yr period. Tillage system and irrigation did not affect grain yield or most of the other agronomic traits at the silt loam location with cultivar responding similarly to tillage and irrigation. Phenotypic stability for yield across a wide range of environments was maintained for both the older and the two newer cultivars. In fact, the older cultivar Hardin tended to be the more stable cultivar.

Most yield differences were small and inconsistent and associated with year variability during the growing season. Significant year effects were noticed for all management systems and showed that uncontrollable factors such as temperature still may play an important role in Wisconsin. Although planting date was shown to be significant at Arlington, this study has shown that planting date, and in particular early May planting, is not a critical factor at all locations in Wisconsin. Soybean cultivar decisions in the Upper Midwest should be based on selecting the highest yielding cultivars adapted to a particular geographic region and location, regardless of management system.

ACKNOWLEDGMENTS

The authors thank Dr. Edward S. Oplinger for assistance early in the development of this study and John M. Gaska, Mark Martinka, and Kathy Bures for their technical assistance. This research was partially funded by Iowa Soybean Promotion Board, Illinois Soybean Checkoff Board, and Wisconsin Soybean Marketing Board.

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