SOYBEAN

Response of Soybean Yield Components to Management System and Planting Date

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] area has increased tremendously in the upper Midwest over the last decade, but little information exists regarding the impact of management systems on soybean yield components. Our objective was to assess the effect of management system and planting date on soybean seed yield components and their development for environments typical of the upper Midwest. A field study was conducted from 1997 to 2000 using five management systems. Two newer released cultivars (CX232 and Spansoy 250) and one older cultivar (Hardin) were planted at two planting dates. Few interactions were observed in this study. Management system influenced development of the different yield components and produced seed mass ranging from 10.5 to 16.5 g 100 seed^{-1}, seed number from 2878 to 3824 seeds m^{-2}, pod number from 1182 to 1571 pods m^{-2}, and seeds per pod from 2.36 to 2.49 seeds pod^{-1}. Harvest index ranged from 56.2 to 58.0% across management systems. Hardin produced the highest harvest index (60.1%) and Spansoy 250 the lowest harvest index (54.5%). Tillage system affected yield components, with no-tillage systems having 15, 9, and 9% greater seed mass, seed number per square meter, and pod number per square meter than the conventional tillage system, respectively. Early planting date produced higher seed number, pod number, and harvest index but lower seed number per pod than the late planting date. In conclusion, differences in yield components and their development emphasize the complexity of plant compensation in response to management system and tillage system.

EARLY SOYBEAN planting date and conservation tillage practices may not be feasible for some soil conditions in the upper Midwest. Management strategies might, however, be improved by identifying growth periods where potential yield is limited by assimilatory capacity. Such knowledge can be gained by determining yield component responses and knowing when optimum assimilatory capacity is necessary for highest yield.

Seed yield is determined by the number of seeds per unit area and seed mass. However, most, but not all, environmentally induced yield differences are due to difference in seed number. Seed mass is often inversely correlated with seeds per unit area (Hanson, 1986). Seed mass is determined by the rate of seed growth and the duration of seed fill, both of which are genetically controlled (Egli et al., 1981, 1984; Guldan and Brun, 1985) although there are environmental influences as well (Egli et al., 1985; Egli and Wardlaw, 1980; Meckel et al., 1984). Attempts to increase yield through increases in seed number or seed mass have been somewhat unsuccessful due to the compensation that occurs between these components (Swank et al., 1987). The compensation that occurs between seed mass and number led Hanson (1986) to conclude that soybean seeds are receptacles for assimilate and that yield-limiting factors occur somewhere outside the seed.

Yield decreases resulting from drought stress depend both on the phenological timing of the stress and on the degree of yield component compensation. Schou et al. (1978) reported that yield is more influenced by changes from flowering to physiological maturity compared with the emergence to flowering period. Numerous studies (Egli and Yu, 1991; Johnston et al., 1969; Schou et al., 1978) have indicated that seed number (per unit ground area) was responsive to altered environmental conditions during flowering and pod set. Cultivar differences in yield response to irrigation regimes (Kadhem et al., 1985a), however, depend not only on differences in individual yield component responses, but also on differences in yield component compensation (Kadhem et al., 1985b).

The negative effects of stress are particularly important during flowering, seed set, and seed filling where stress can reduce yield by reducing number of pods, number of seeds, and seed mass (Ashley and Ethridge, 1978; Doss and Thurlow, 1974; Sionit and Kramer, 1977). Specht and Williams (1984) noted that genotype × environment interactions often involve a "specific adaptation" component (i.e., a consistent superiority of some genotypes over others in specific environments but an inverse performance rank in other environments).

Cultivar adaptability to a region and its influence on soybean yield and yield components can be affected by growth habit and planting date. Since the hectares of soybean have increased in the northern USA, it is important to evaluate the magnitude of the genotype × management system interaction on soybean seed yield components. Information is lacking on the impact of management systems on soybean yield components under cooler temperature in the upper Midwest. The objectives of this research were to (i) determine the yield component response of soybean cultivar to management system and planting date and (ii) describe the soybean yield component development process throughout the growing season in the upper Midwest.

MATERIALS AND METHODS

Field research was conducted during 4 yr (1997 to 2000) in five management systems. These management systems were

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Abbreviations: DAE, days after emergence.

chosen to represent current management practices in 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. Irrigation was not conducted in 1997. 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 Udipsamment) at the Hancock Agricultural Research Station. 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}. Management practices and more detailed descriptions of the management systems have been described previously (Pedersen and Lauer, 2003).

The experimental design for each management system was a randomized complete block in a split-plot arrangement with four replications. Main plot was planting date (early May vs. late May). 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 was 3 by 15.2 m, and plots were further divided into two subplots of 3 by 7.6 m where one of the subplots was used for harvest that previously has been published (Pedersen and Lauer, 2003) and the other subplot was used for monitoring yield components. Seeding rate was 432 000 seed ha^{-1}. Sections of 0.76 m^2 were hand-harvested from each cultivar and planting date plot and were used to determine dry matter on 21-d intervals starting 21 d after emergence (DAE). There were six individual sampling dates (sections) throughout the growing season (21, 42, 63, 84, 105, and 126 DAE). Each section was randomly selected from the center rows of each cultivar and thinned to approximately 350 000 plants ha^{-1} before the first sampling date. Development, growth stage, and plant height information were taken based on a sample of three plants randomly collected from the hand-harvested section. Plant growth stages were determined according to the methods by Fehr and Caviness (1977). The three plants were separated into leaves, stems, pods, and seeds. The yield components measured were as follows: harvest index, which is the ratio of seed dry weight to total aboveground dry weight at time of measurement; seed number per square meter, a seed was counted when the diameter was larger than 3 mm; pod number per square meter, which was determined as a pod when larger than 1 cm; seeds per pod; and seed mass per 100 seeds, which was determined by a random sample of 100 seeds from the harvested seed from each plot. All dry weight samples were oven-dried at 60°C to a constant weight to determine yield on a dry weight basis. Seed mass per 100 seeds was adjusted to 130 g kg^{-1} moisture content.

Gravimetric soil moisture content was measured in samples taken every 3 wk from the time of the first hand-harvest sampling. Gravimetric soil moisture content was determined in each replication and in each management system by collecting two random soil samples with a 2.5-cm (inner diam.) soil probe from depths of 0 to 15, 15 to 30, 30 to 60, and 60 to 90 cm. Data from 30 to 60 and 60 to 90 cm were collected for another research project and will not be presented here. Samples of field-moist soil were composited for each sampling depth, and a subsample of approximately 0.4 kg was oven-dried at 105°C for 3 d to calculate gravimetric moisture content.

Data were subjected to an analysis of variance using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Inst., 1995) with the six sampling dates analyzed as sub-sub-plots (Gomez and Gomez, 1984). Individual analysis by year using the restricted maximum likelihood method for variance component estimation indicated that error variances were heterogeneous. Block was treated as a random effect in the individual analysis by year. Management system, cultivar, and planting date were treated as fixed effects in determining expected mean squares and appropriate *F*-tests in the analysis of variance. Management system was treated as fixed effect rather than random to determine interactions involving management system. Homogeneity of error variances was found for data collected during 1998 and 1999, and a combined analysis of variance was performed. For ease of illustration, most emphasis will be focused on the combined analysis; however, data will be discussed for each individual year if they deviate from the combined analysis. Analysis across years (1998 and 1999) treated year as a fixed effect to determine interactions involving year in PROC MIXED. Mean comparisons were made using Fisher's protected LSD test ($P \leq 0.05$). Phenotypic correlation coefficients between grain yield from the machine harvest plots and the grain yield components were computed using PROC CORR of SAS.

RESULTS AND DISCUSSION

Weather is a dominant factor controlling yield and soybean development in the upper Midwest. The four growing seasons for this study produced quite different effects on plant growth and development. Since rainfall was at or near above normal each year, none of the soils in any year or at any depth approached the permanent wilting point of 0.10 kg kg^{-1} soil for a silt loam soil and 0.05 kg kg^{-1} soil for a sandy loam soil (Schulte and Walsh, 1994). The data for 1998 and 1999 from Arlington illustrate the similarities in gravimetric soil moisture between the different management systems (Fig. 1). Gravimetric soil moisture content at Hancock did not vary significantly because of the three weekly irrigation applications and will therefore not be presented.

Most grain yield differences were small and inconsistent and associated with year variability during the growing seasons. A more detailed yield analysis from the machine harvest plots can be found in Pedersen and Lauer (2003). The combined yield analysis for 1998 and 1999 is presented in Table 1. Flowering (R1) occurred on average close to 6 wk after emergence for the late plating date and at around 7 wk after emergence for the early planting date. More detailed information on the growth and development can be found in Pedersen and Lauer (2004).

Development of Soybean Yield Components

Similar development of yield components was observed for the different management systems before 84 DAE or beginning of pod setting (Fig. 2). After this point, seed mass accumulation accelerated faster for the management system at Hancock and slowest for the two conventional tillage management systems at Arlington. Small gains in seed mass accumulation for the two con-

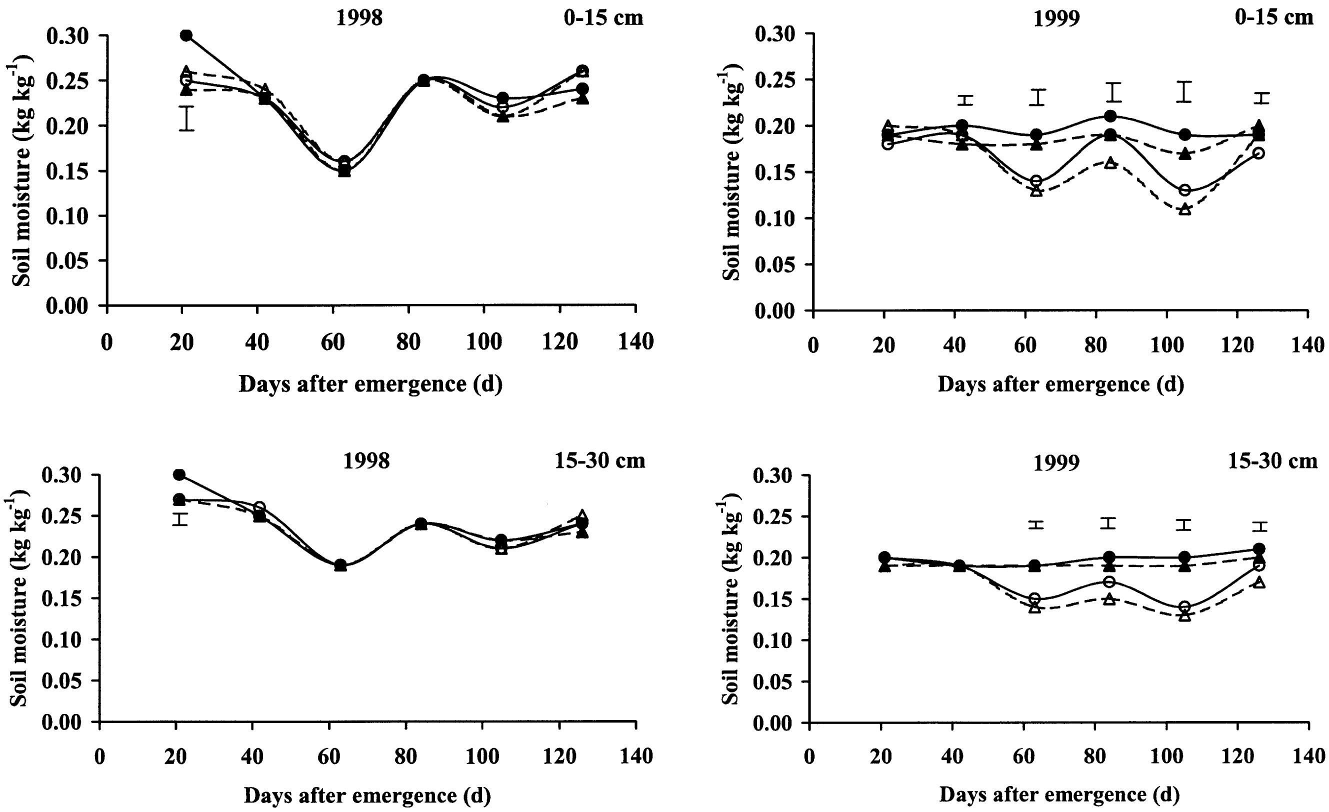

Fig. 1. Gravimetric soil moisture content from 0 to 15 cm and 15 to 30 cm during the 1998 and 1999 growing seasons at Arlington. Irrigation was initiated at 42 d after emergence. ● = irrigated, conventional tillage management system at Arlington; ○ = conventional tillage at Arlington; ▲ = irrigated, no-tillage management system at Arlington; and △ = no-tillage management system at Arlington. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

ventional tillage management systems occurred after 105 DAE. Development of seed number and pod number per square meter was in general similar across management systems. Lowest pod and seed number and the slowest development were observed with the management system at Hancock. The final seed and pod number were already determined at 84 DAE, which is in agreement with previous observations (Ashley and Ethridge, 1978; Doss and Thurlow, 1974; Sionit and Kramer, 1977). Small differences in seed and pod number were observed between the management systems at Arlington. Highest number was observed in the conventional

Table 1. Yield components as affected by management system, planting date, and cultivar, 1998–1999.

	Yield†	Seed mass	Seed number	Pod number	Seed number	Harvest index
	Mg ha^{-1}	g 100 seed^{-1}	no. m^{-2}		no. pod^{-1}	%
Management system (S)						
Arlington, conventional tillage, irrigation	4.2	10.5	3824	1569	2.45	56.2
Arlington, conventional tillage, no irrigation	4.2	11.2	3731	1571	2.39	57.9
Arlington, no tillage, irrigation	4.4	13.4	3295	1400	2.36	56.6
Arlington, no tillage, no irrigation	4.6	12.5	3384	1366	2.49	57.6
Hancock, conventional tillage, irrigation	4.5	16.5	2878	1182	2.45	58.0
LSD (0.05)	0.1	1.2	315	87	0.05	0.9
Planting date (D)						
Early	4.5	12.5	3607	1509	2.40	57.7
Late	4.2	13.0	3238	1326	2.46	56.8
LSD (0.05)	0.1	NS‡	199	55	0.04	0.6
Cultivar (C)						
Hardin	4.2	12.3	3565	1543	2.31	60.1
CX232	4.5	14.2	3005	1249	2.42	57.1
Spansoy 250	4.3	11.8	3697	1460	2.54	54.5
LSD (0.05)	0.2	0.9	244	68	0.04	5.5
ANOVA						
S × D	**	NS	NS	NS	NS	NS
S × C	NS	NS	NS	NS	*	*
D × C	NS	NS	NS	NS	NS	NS
S × D × C	NS	NS	NS	NS	NS	**

* Significant at the $P = 0.05$ probability level.
** Significant at the $P = 0.01$ probability level.
† Yield data adapted from Pedersen and Lauer (2003).
‡ NS = no significant differences at $P \leq 0.05$.

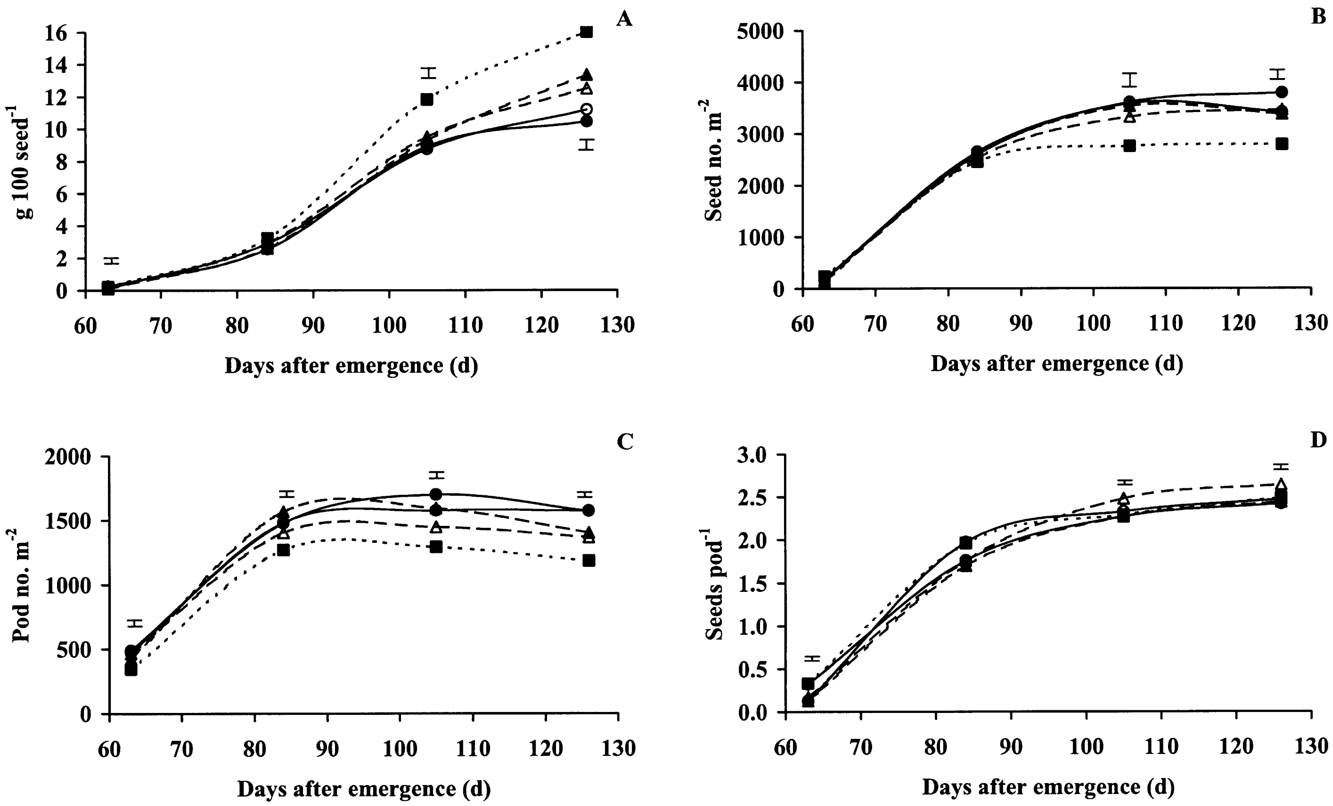

Fig. 2. Influence of management system on (A) seed mass, (B) seed number per square meter, (C) pod number per square meter, and (D) seeds per pod. Data are averaged over planting dates, cultivars, and years (1998 and 1999). ● = irrigated, conventional tillage management system at Arlington; ○ = conventional tillage at Arlington; ▲ = irrigated, no-tillage management system at Arlington; △ = no-tillage management system at Arlington; and ■ = irrigated, conventional tillage management system at Hancock. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

tillage systems, and the development of the seeds and pods continued until 105 DAE. Development of seeds per pod was similar for all management systems.

Development of seed mass was different for the two planting dates (Fig. 3). The late planting date acquired seed mass faster than the early planting date and achieved maximum seed mass at 105 DAE, whereas seed mass development of early planting date treatments continued throughout the entire season. The late planting date acquired a lower pod number than the early planting date but with a higher seed number per square meter and seeds per pod. Development of seed number per square meter and seeds per pod was all similar and higher for the late planting date and increased steadily throughout the season.

Before 84 DAE, seed mass development was in general similar among the different cultivars, but after 84 DAE, seed mass developed faster for Hardin and CX232 than for Spansoy 250 (Fig. 4). Development of seed number per square meter and pod number per square meter was similar with Hardin accumulating seed number per square meter and pod number per square meter faster than CX232 and Spansoy 250. Development of seeds per pod was different for the three cultivars with a faster development for CX232 and Spansoy 250 than for Hardin. However, the final number of seeds per pod was higher for Hardin, indicating a higher seed abortion rate for CX 232 and Spansoy 250.

Development of harvest index was very similar for all years, management systems, and planting dates. Development of harvest index was observed to be linear for all three cultivars, which is a potentially useful characterization of the rate of dry matter allocation into seed (Salado-Navarro et al., 1985; Spaeth and Sinclair, 1985). The R^2 values for the linear increase of harvest index during seed filling were on average 0.96, 0.96, and 0.93 for Hardin, CX232, and Spansoy 250, respectively. The corresponding slopes for the linear increase in harvest index were on average 0.93, 0.90, and 0.82 for Hardin, CX232, and Spansoy 250, respectively (data not shown).

Yield Components

Seed Mass

No interactions were observed for seed mass in the combined analysis. However, a management system × cultivar interaction was detected for seed mass in 2000. Hardin had a 37% higher seed mass in the management system at Hancock compared with the management systems at Arlington in 2000. Seed mass of CX232 and Spansoy was not influenced by any of the management systems during 2000. Additionally, a management system × planting date interaction was detected for seed mass in 2000. No differences in seed mass were observed

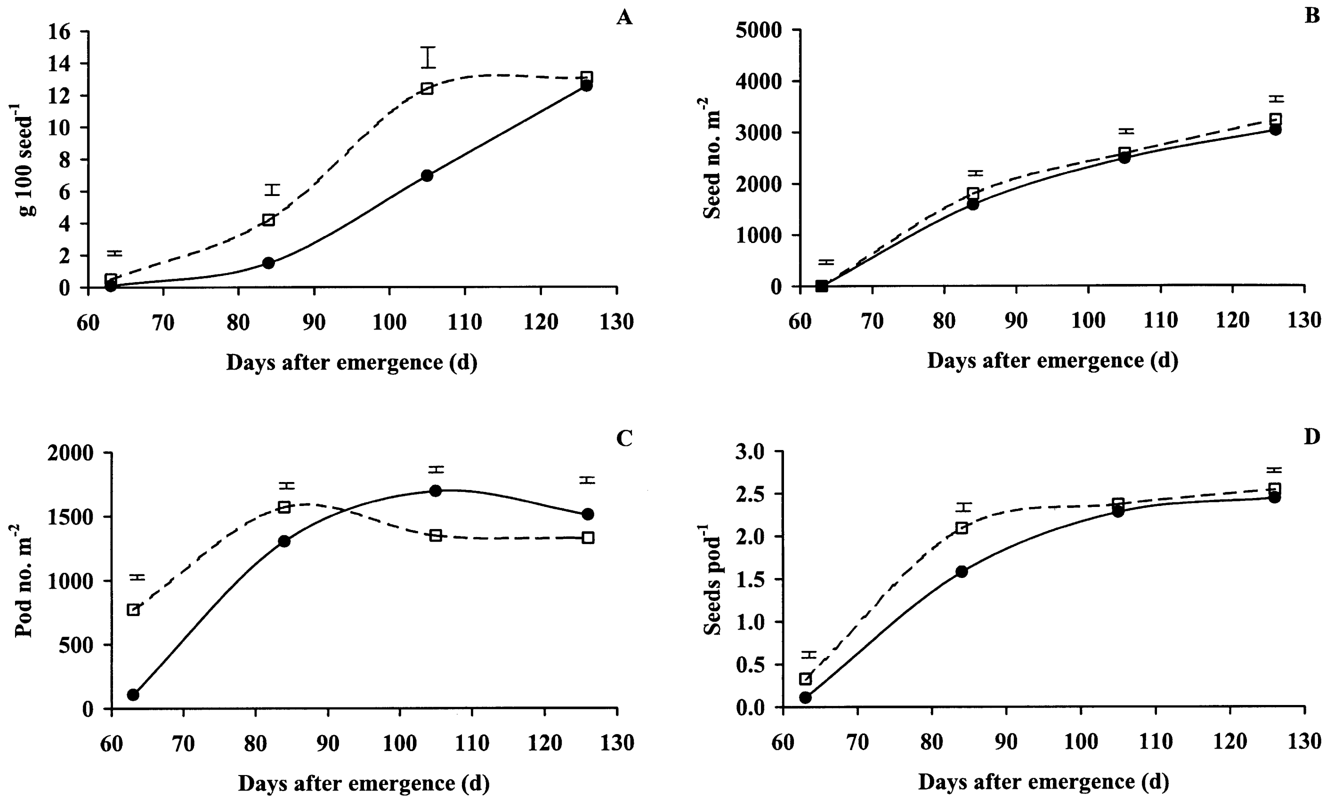

Fig. 3. Influence of planting date on (A) seed mass, (B) seed number per square meter, (C) pod number per square meter, and (D) seeds per pod. Data are averaged over management systems, cultivars, and years (1998 and 1999). ● = early May and □ = late May. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

among management systems for the early planting date. For the late planting date, however, seed mass was 31 and 19% lower in the no-tillage system at Arlington compared with the management system at Hancock and the conventional tillage management system at Arlington, respectively.

Soybean grown in the management system at Hancock produced on average 28% higher seed mass than all management systems at Arlington (Table 1). Seed mass at Hancock was highly correlated with yield ($r = 0.65$; $P < 0.001$) whereas no significant correlations were observed at Arlington (Table 2). It is well known that the soybean plant adjusts its sink size in response to environmental stress by aborting flowers, pods, or seeds (Shibles et al., 1975). It is speculated that the higher seed mass at Hancock may have resulted from a more uniform flowering pattern resulting in higher seed mass. At Arlington, the two no-tillage management systems produced 16% greater seed mass than the conventional tillage management systems. Irrigation did not affect seed mass in any tillage system at Arlington, perhaps because of the plentiful and evenly distributed precipitation throughout the growing seasons, which may have favored relatively long seed-filling periods, high seed mass, and equalized planting date and cultivar factors. Ashley and Ethridge (1978) showed that water deficit during seed filling reduces seed size and yield due to shorter seed-filling period and earlier maturity. This is in agreement with our observations since we never observed drought conditions during the study. However, Woodward and Begg (1976) showed a reduced seed mass for irrigated soybean.

Planting date did not affect seed mass, contradicting observations by Anderson and Vasilas (1985) and Raymer and Bernard (1988), who showed seed mass to decrease with delaying planting. Our observation was not a surprise given the small and inconsistent differences in yield between early and late planting (Pedersen and Lauer, 2003).

Hardin and Spansoy 250 produced 15% larger seed mass than CX232 (Table 1). No difference was found in seed mass among cultivars in 1997 and 2000 (data not shown). Gay et al. (1980) and Woodward and Begg (1976) showed that yield advantages between cultivars were correlated with seed mass, partially as a result of the number of seeds available for filling, the duration of the filling period, and total photosynthate production. Seed mass was overall significantly correlated with yield ($r = 0.33$; $P < 0.001$), but the r value was relatively small (Table 3). Board (1987) and Carter and Boerma (1979) also reported a weak relationship between seed mass and yield.

Seed Number

No interactions were observed for the combined analysis (Table 1). A management system × cultivar interaction was detected for seed number in 1997 and 2000 but with inconsistent results, and data will therefore not be presented. A management system × planting date

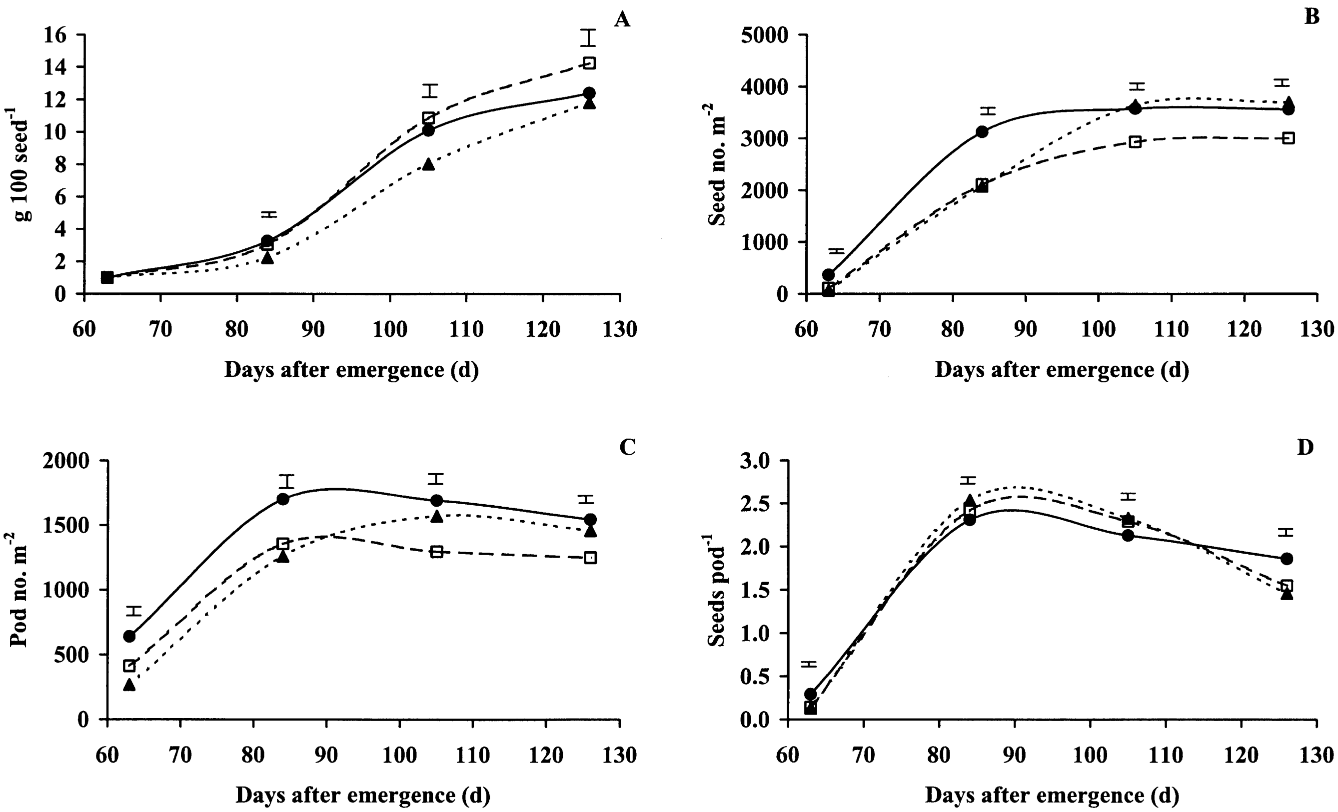

Fig. 4. Influence of cultivar on (A) seed mass, (B) seed number per square meter, (C) pod number per square meter, and (D) seeds per pod. Data are averaged over management systems, planting dates, and years (1998 and 1999). ● = Hardin, □ = CX232, and ▲ = Spansoy 250. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

interaction was observed for seed number in 2000. For the early planting date at Arlington, the conventional tillage management system with irrigation had 29% greater seed number than the early planted nonirrigated conventional tillage management system. No differences in seed number were observed between planting dates for the management system at Hancock.

Seed number was influenced by management system (Table 1). The four management systems at Arlington produced 19% more seeds per square meter than the management systems at Hancock. Irrigation did not influence seed number at Arlington since insufficient moisture during seed set and seed filling was not observed. However, tillage system influenced seed number, with the conventional tillage systems producing 12% more seeds per square meter than the no-tillage systems. These results support previous work that tillage practice has a positive effect on seed number per square meter (Frederick et al., 1998). Management system did not influence seed number in 1997.

Early planting date produced 3607 seeds m^{-2}, or 10% more seeds than the late planting date (3238 seeds m^{-2}; Table 1). This result is consistent with Beatty et al. (1982), who showed that early planted soybean would take advantage of favorable soil moisture conditions and seed number decreases consistently with later planting. Planting date did not influence seed number in 1997 and 2000.

Cultivars differed in seed number with Hardin and Spansoy 250 having 17% more seed m^{-2} than CX232. No difference was found among cultivars in 1997 and 2000.

Egli et al. (1978) suggested that the number of seeds produced by a soybean community is a function of the amount of photosynthate available for seed growth since soybean seed number is associated with crop growth rate during flowering and pod set (Egli, 1993; Egli and Yu, 1991; Herbert and Litchfield, 1984; Ramseur et al., 1985). Differences in seeds per square meter could therefore be derived from a more efficient utilization of assimilate in seed. Seed number was inversely correlated with seed mass at Arlington averaging –0.79 across the four management systems (Table 2). This is in agreement with observations by Hanson (1986). No correlation was observed between seed mass and seed number at Hancock (Table 2).

Pod Number

No interactions were observed for the combined analysis (Table 1). However, a management system × planting date interaction was found for pod number in 2000 where early planted soybean had 21% higher pod number per square meter than the late-planted soybean in the conventional tillage system with irrigation at Arlington. A management system × cultivar interaction was detected for pod number in 2000 with pod number per square meter being 39% higher for Hardin than for Spansoy 250 in the conventional tillage system with irri-

Table 2. Phenotypic correlation coefficients (*r*) between grain yield components for each of the two planting dates across cultivar and management systems during 1998 and 1999.

	Seed mass	Seed number	Pod number	Seeds pod^{-1}	Harvest index
			Management system		
CT, Irr.†					
Yield‡	−0.12	0.30	0.28	−0.04	0.27
Seed mass	–	−0.78***	−0.79***	0.22	0.02
Seed number	–	–	0.94***	−0.09	0.28
Pod number	–	–	–	−0.42	0.41
Seeds pod^{-1}	–	–	–	–	0.44
CT§					
Yield	0.20	0.03	0.04	−0.07	0.27
Seed mass	–	−0.79***	−0.72***	0.10	0.02
Seed number	–	–	0.95***	−0.20	0.23
Pod number	–	–	–	−0.49*	0.39
Seeds pod^{-1}	–	–	–	–	−0.55**
NT, Irr.¶					
Yield	0.41	−0.25	−0.33	0.18	0.45
Seed mass	–	−0.88***	−0.85***	−0.26	0.11
Seed number	–	–	0.94***	0.30	0.09
Pod number	–	–	–	−0.04	0.25
Seeds pod^{-1}	–	–	–	–	−0.38
NT#					
Yield	0.15	0.56*	0.46*	0.06	0.72***
Seed mass	–	−0.59**	−0.31	−0.43	0.39
Seed number	–	–	0.82***	0.16	0.23
Pod number	–	–	–	−0.43	0.35
Seeds pod^{-1}	–	–	–	–	−0.25
Hancock††					
Yield	0.65***	−0.01	0.05	−0.19	0.50*
Seed mass	–	−0.13	−0.04	−0.17	0.47*
Seed number	–	–	0.91***	0.10	0.17
Pod number	–	–	–	−0.32	0.30
Seeds pod^{-1}	–	–	–	–	−0.33
			Planting date		
Early					
Yield	0.31*	−0.04	0.09	−0.05	0.38**
Seed mass	–	−0.67***	−0.63***	−0.10	0.05
Seed number	–	–	0.95***	0.05	0.27
Pod number	–	–	–	−0.27	0.36*
Seeds pod^{-1}	–	–	–	–	−0.32*
Late					
Yield	0.34*	−0.01	−0.01	−0.04	0.50***
Seed mass	–	−0.72***	−0.61***	−0.13	0.31*
Seed number	–	–	0.92***	0.03	0.08
Pod number	–	–	–	−0.36*	0.24
Seeds pod^{-1}	–	–	–	–	−0.39**
			Cultivar		
Hardin					
Yield	0.63***	−0.10	−0.23	0.46***	0.29*
Seed mass	–	0.07	−0.03	0.39***	0.38**
Seed number	–	–	0.95***	0.20	0.54***
Pod number	–	–	–	0.54***	0.32*
Seeds pod^{-1}	–	–	–	–	0.08
CX232					
Yield	0.42***	0.07	0.22	−0.34**	0.43***
Seed mass	–	0.19	0.28*	−0.20	0.57***
Seed number	–	–	0.90***	0.23	0.24
Pod number	–	–	–	−0.21	0.26*
Seeds pod^{-1}	–	–	–	–	−0.05
Spansoy 250					
Yield	0.47***	0.33*	0.32*	−0.16	0.73***
Seed mass	–	0.39**	−0.53***	−0.18	0.56***
Seed number	–	–	0.98***	−0.27*	0.12
Pod number	–	–	–	−0.45***	0.13
Seeds pod^{-1}	–	–	–	–	−0.12

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† CT, Irr. = conventional tillage irrigated at Arlington.
‡ Correlated with yield data from Pedersen and Lauer (2003).
§ CT = conventional tillage at Arlington.
¶ NT, Irr. = no-tillage irrigated at Arlington
# NT = no-tillage at Arlington.
†† Hancock = conventional tillage irrigated at Hancock.

gation at Arlington, and no difference was observed between Hardin and CX232 or CX232 and Spansoy 250.

Pod number was influenced by management system in 1998 and 1999, with the management systems at Arlington producing 20% more pods per square meter than the management system at Hancock (Table 1).

Table 3. Phenotypic correlation coefficients (*r*) between grain yield and yield components across three cultivars, five management systems, and two planting dates during 1998 and 1999.

	Seed mass	Seed number	Pod number	Seeds pod^{-1}	Harvest index
Yield†	**0.33******	**0.09**	**0.10**	**−0.09**	**0.49******
Seed mass	–	**0.24****	**0.24******	**−0.06**	**0.45****
Seed number	–	–	**0.93******	**−0.02**	**0.18***
Pod number	–	–	–	**−0.37******	**0.32******
Seeds pod^{-1}	–	–	–	–	**−0.40******

*** Significant at the 0.05 probability level.**
**** Significant at the 0.01 probability level.**
***** Significant at the 0.001 probability level.**
† Correlated with yield data from Pedersen and Lauer (2003).

Irrigation did not influence pod number at Arlington since insufficient moisture during pod set was not observed. However, tillage system influenced pod number with the conventional tillage system producing 12% more pods per square meter than the no-tillage system. No difference was observed among pods per square meter and management systems in 1997.

Planting date affected pod number with the early planted soybean having 12% more pods per square meter than the late-planted soybean, which is in agreement with Beatty et al. (1982), who reported that delayed planting reduced pod number. No difference was observed among pods per square meter and planting dates for 1997 and 2000.

Cultivars differed in pod number with Hardin and Spansoy 250 both having 19% more pods per square meter than CX232. No difference was found among cultivars in 1997 and 2000. Our data correspond well with those of Woodward and Begg (1976), who showed that reduced seed mass of soybean resulted in greater pod and seed number (Table 3). However, no correlation between seed mass and pod number was observed in the nonirrigated, no-tillage system at Arlington (Table 2).

Seed Number per Pod

A cultivar × management system interaction was found in the combined analysis with the two newer cultivars, CX232 and Spansoy 250, having 8% more seeds per pod than Hardin at Arlington (Table 1). No difference was found among the three cultivars at Hancock. A management system × planting date interaction was found for seeds per pod in 1998. No difference was found between planting dates for the irrigated no-tillage management system at Arlington and the management system at Hancock. However, the remaining three management systems averaged 5% more seeds per pod for the late planting date.

Management systems influenced seeds per pod, but inconsistently (Table 1). The management system at Hancock and the no-tillage management system without irrigation and the irrigated conventional tillage management at Arlington had the highest number of seeds per pod, averaging 2.46 seeds pod^{-1} compared with the remaining two management systems that averaged 2.38 seeds pod^{-1}. Irrigation had a positive effect on seeds per pod in the conventional tillage system and a negative effect in the no-tillage system at Arlington (Table 2). No differences were found among seeds per pod and management systems in 1997 and 2000.

Delaying planting increased the number of seeds per pod from 2.40 to 2.46 seeds pod^{-1}. No differences were observed among planting dates and seeds per pod in 1997 and 2000.

Seeds per pod differed between cultivars with Hardin having 5 and 9% less seeds per pod than CX232 and Spansoy 250, respectively.

Differences between seasons for seeds per pod were small as expected (Dominguez and Hume, 1978) and did not correlate with seed yield (Table 3). However, pod number was inversely correlated with seeds per pod ($r = -0.37$; $P < 0.001$).

Harvest Index

A management system × cultivar interaction was detected for harvest index in the combined analysis (Table 1). Hardin had 8% higher harvest index in all management systems at Arlington compared with CX232 and Spansoy 250. No differences were observed among cultivars for harvest index at Hancock. A management system × cultivar interaction was detected for harvest index in 1997. Hardin and CX232 had on average 7% higher harvest index in all management systems at Arlington compared with Spansoy 250. No differences were observed among cultivars and harvest index at Hancock. A management system × planting date × cultivar interaction was detected for harvest index in the combined analysis. At Hancock, Hardin had 16% lower harvest index at the early planting and 5% higher harvest index at the late planting compared with CX232 and Spansoy 250. Few and inconsistent differences were observed between cultivars and planting date at the management systems at Arlington (data not shown). A planting date × cultivar interaction was detected in 1997. Hardin had on average a 9% higher harvest index for the late planting date, and no differences were observed between planting dates for CX232 and Spansoy 250.

Soybean grown in the management system at Hancock had 2% higher harvest index than the management systems at Arlington. Tillage system did not influence harvest index at Arlington, whereas irrigation lowered the harvest index by 2% on average. No difference was found among management systems and harvest index in 1997.

Early planting date had 2% higher harvest index than late planting date. No difference was found among management systems and harvest index in 1997 and 2000.

Highest and lowest harvest index was observed for Hardin and Spansoy 250, respectively. Hardin had 9% higher harvest index than Spansoy 250, and no difference was found between Hardin and CX232 or CX232 and Spansoy 250 (Table 1). No difference was found among cultivars and harvest index in 1997. Based on these results, it is assumed that the old cultivar Hardin had a more efficient utilization of assimilates during seed set than CX232 and Spansoy 250. Spaeth et al. (1984) showed harvest index to be a stable characteristic of cultivar with respect to variations in water availability and photoperiod, which corresponds well with our data. However, the association between harvest index and seed yield has been contradictory (Frederick et al., 1991; Schapaugh and Wilcox, 1980). Schapaugh and Wilcox (1980) found no correlation between harvest index and yield, whereas Frederick et al. (1991) found a relationship between increased harvest index and improved yield potential. Harvest index was in this study significantly correlated with yield and with all other yield components, with an inverse relationship between harvest index and seeds per pod (Table 3).

SUMMARY

Our data demonstrated that management system and planting date affected yield components and their development though we showed previously that yield differences were small, inconsistent, and associated with year variability during the growing season (Pedersen and Lauer, 2003).

Seed yield was highly correlated with seed mass and harvest index. In general, the two locations (Arlington and Hancock) were different for development of yield components. The management systems at Arlington had higher pod and seed number but lower seed mass compared with the management system at Hancock. Except for seeds per pod, small differences were found between irrigated and nonirrigated management systems at Arlington because of adequate precipitation during all growing seasons. Tillage system had an effect on soybean yield components at Arlington with the no-tillage systems having greater seed mass, seed number, and pod number than the conventional tillage systems. Planting date had an effect on soybean yield components with the early plating date having greater seed number, pod number, and harvest index than the late planting date. There was a difference in the development of yield components associated with planting date, but no treatment differences were detected by 105 DAE for most yield components. Hardin had a higher harvest index than the two new cultivars CX232 and Spansoy 250, indicating a greater efficiency of dry matter use in Hardin.

It was concluded that, despite cultivar differences in yield components and their development, the ability of cultivars to compensate among yield components was more affected by year variability than by management system and planting date.

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