Soybean Growth and Development in Various Management Systems and Planting Dates

Palle Pedersen* and Joseph G. Lauer

ABSTRACT

Soybean [*Glycine max* (L.) Merr.] has the ability to produce similar yields across a broad range of management systems and planting dates. Our objective was to better understand growth factors affecting yield component compensation in the upper Midwest under different management systems. An older cultivar, Hardin, and two newer cultivars, DeKalb CX232 and Spansoy 250, were grown in five management systems during four growing seasons from 1997 to 2000. Four of the five management systems were located near Arlington, WI, on a silt loam soil consisting of conventional and no-tillage systems with and without irrigation. The fifth management system was located near Hancock, WI, on a conventionally tilled, irrigated sandy loam soil. Yield component compensations gave similar grain yield among cultivars, planting dates, and management systems. At R6, CX232 and Spansoy 250 averaged greater dry matter (DM) accumulation, leaf area index (LAI), and crop growth rate (CGR) than Hardin. Early planted soybean had more total DM than the late-planted soybean. No-tillage systems produced more total DM, LAI, and CGR after R3 than the two conventional tillage systems at Arlington. Irrigated systems had higher LAI than the nonirrigated systems. These results indicate that the compensatory growth and alterations in plant development among cultivars, management systems, and planting dates had no impact on soybean yield.

Soybean yield is determined by the genetic yield potential and the interactions with environmental conditions, and is correlated with the number of seeds and seed size (Salado-Navarro et al., 1986). Genetic and cultural strategies for increasing soybean yield might be improved by identifying growth periods where potential yield is limited by assimilatory capacity. Schou et al. (1978) concluded that yield is more influenced by changes in source strength during R1 to R7 (Fehr and Caviness, 1977) compared with emergence to R1 period. Several studies suggest that yield is more source-restricted during the early vs. late reproductive period. The early reproductive period (R1 to shortly past R5) is most sensitive to altered source strength and CGR (Board and Harville, 1994) since it is the time in which the final pod numbers are formed (Board and Tan, 1995).

Duncan (1986) proposed that greater total DM results in greater seed yield if the total DM is produced before seed initiation. In contrast, Weber et al. (1966) found that both total DM and LAI were poor predictors of seed yield. Wells (1991) examined four population-density and row-width combinations and showed that similar grain yield occurred despite significant differences in total DM yield over the growing season. Overproduction of vegetative DM does not always reduce seed yields, but improved partitioning of dry weight could result in higher seed yields (Shibles and Weber, 1966; Beuerlein et al., 1971).

Total DM is influenced by CGR, relative growth rate, relative leaf area growth rate, and net assimilation rate (Hunt, 1982). Crop growth rate is a prime dynamic growth factor to study since it reflects canopy assimilatory capacity, and affects total DM levels and equilibrates through adjustments of LAI and/or net assimilation rate (Imsande, 1989). Shibles and Weber (1966) demonstrated that optimal CGR and yield resulted when LAI was sufficient (3 to 3.5) to achieve an optimal light interception of 95% by R5. However, subsequent studies showed that the relationship between LAI and optimal CGR varied with environmental conditions (Jeffers and Shibles, 1969).

Several quantitative determinations have been made of soybean growth and development using growth analysis. However, most research has investigated soybean yield compensation using various plant populations (Wells, 1991; Carpenter and Board, 1997; Board, 2000).

There has been a rapid increase in use of soybean in cropping systems of the upper Midwest. The region is different from the rest of the Corn Belt since no-tillage systems can yield as well as conventional tillage systems (Pedersen and Lauer, 2002; Pedersen and Lauer, 2003), sandy soil can yield as well as silt loam soils (Pedersen and Lauer, 2003), and early planting is not always associated with higher yield (Pedersen and Lauer, 2003). Effects of management system, planting date, and cultivar on growth dynamics and yield formation are not well understood, especially for the upper Midwest. The objective of this study was to describe compensatory growth and alterations in plant development as influenced by management system and planting date for two new and one old cultivar grown in Wisconsin.

MATERIALS AND METHODS

Field experiments were conducted during 4 yr (1997–2000) in five different management systems. These management systems were 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 Argiudoll) at the Arlington, WI, Agricultural Research Station. They consisted of two conventional tillage and two no-tillage systems with and without irrigation. The fifth management system was a conventional tillage system with irrigation conducted on a Plainfield sandy loam soil

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Abbreviations: CGR, crop growth rate; DAE, days after emergence; DM, dry matter; LAI, leaf area index; LER, leaf expansion rate; MG, maturity group.

(mixed, mesic, Typic Udipsamment) at the Hancock, WI, Agricultural Research Station.

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; Maturity Group (MG) 2.0], DeKalb CX232 (1995; MG 2.3), and Spansoy 250 (1995; MG 2.5). All experiments were planted in 38-cm row spacing. Management practices and descriptions of the management systems have been previously described (Pedersen and Lauer, 2003).

Sections of 0.76 m^2 were hand harvested from each plot to determine DM accumulation on 21-d intervals starting 21 days after emergence (DAE). There were six sampling dates throughout the growing season (21, 42, 63, 84, 105, and 126 DAE). Each section was randomly selected and thinned to approximately 350 000 plants ha^{-1}. Growth and development stages 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 of Fehr and Caviness (1977). The same three plants were separated into leaves, stems, pods, and seeds. Dry weight samples were oven-dried at 60°C to a constant weight to determine growth on a dry-weight basis. Total aboveground DM was the sum of all plant parts. Leaf area index was measured with a leaf area meter (Model LAI-2000, LI-COR, Lincoln, NE) at 42, 63, 84, and 105 DAE. Calculations of the growth analysis parameters were made using the techniques given by Radford (1967). Crop growth rate during R1 to R5 was calculated by subtracting total DM at R1 from total DM at R5 and dividing by the number of days of the R1-to-R5 period Board (2000). Leaf expansion rate (LER) during R1 to R5 [cm^2 m^{-2} (land area) d^{-1}] was calculated by subtracting LAI at R1 from LAI at R5 and dividing by the number of days from R1 to R5 (Board, 2000).

All data were subjected to an ANOVA using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Institute, 1995) with the six sampling dates analyzed as sub-subplots (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 a fixed effect in determining the expected mean square and appropriate F tests in the analysis of variance. Homogeneity of error variances was found for data collected during 1998 and 1999, and a combined ANOVA was performed. For ease of illustration, most emphasis will be focused on the combined analysis; however, data were discussed for each individual year if they deviated 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 by Fisher's protected LSD test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Growing conditions were favorable at the experimental sites during 1998 and 1999. Rainfall during the growing season (May–September) was 591 mm in 1998 and 469 mm in 1999. The irrigated management systems at Arlington received 120 and 269 mm of irrigation water beginning at anthesis in 1998 and 1999, respectively, whereas the management system at Hancock received 439 and 221 mm throughout the whole season in 1998 and 1999, respectively. A detailed description of rainfall, temperature, and irrigation applications are presented elsewhere (Pedersen and Lauer, 2003). Seed yield showed no significant differences among cultivars, planting dates, or management systems. A more detailed yield analysis can be found in a companion paper (Pedersen and Lauer, 2003).

Planting date was used in this study as a means to change the rate of plant emergence and delay the time of flowering. Additionally, delays in emergence and flowering force the plant to experience different environmental conditions under which they flower and set pods and seed. This is particularly important depending on location, soil type, and establishment method.

Vegetative Growth Characteristics

Vegetative growth characteristics from emergence to harvest were evaluated by changes in node number on the main stem and plant height. The formation of a node and its associated leaf represents a new vegetative sink, which has the potential for competing with reproductive plant parts for assimilate.

Differences in the number of nodes on the main stem first appeared at 60 DAE (R3/R4) for the three cultivars (Fig. 1A). At R3, Hardin had 6% more nodes on the main stem than the other two cultivars. After R5, number of nodes on the main stem was 9% higher for Spansoy 250, with no difference between Hardin and CX232.

Formation of nodes on the main stem was more rapid after emergence for the delayed planting than the earlier planting (Fig. 1B). Delayed planting tended to reduce the number of nodes produced on the main stem between R1 and R5 compared with the early planting and caused a lower number of nodes on the main stem at harvest (15.5) than the early planting (16.3). This is consistent with work by Egli et al. (1985). Differences in number of nodes produced during R1 to R5 can result from differences in the rate of node production or variation in the length of the flower to pod setting period. The differences between the two planting dates were primarily because of differences in rate of node production and not in the length of the flower to pod setting period (data not shown).

Soybean in the different management systems tended to have similar node number on the main stem and small differences were observed during the vegetative stages (Fig. 1C). From R3 to harvest, the most nodes on the main stem was found at the four management systems at Arlington, averaging 5% more nodes on the main stem at harvest than the management system at Hancock. Tillage system did not affect node number on the main stem at Arlington. However, soybean in the two irrigated systems at Arlington averaged 2% more nodes on the main stem than those in the nonirrigated systems, which is consistent with Korte et al. (1983). In contrast, Momen et al. (1979) observed little effect on node number from irrigation.

Changes in plant height followed a similar pattern to number of nodes on the main stem (Fig. 2A,B,C), with CX232 being the shortest variety through out the whole growing season (Fig. 2A). Increases in plant height had

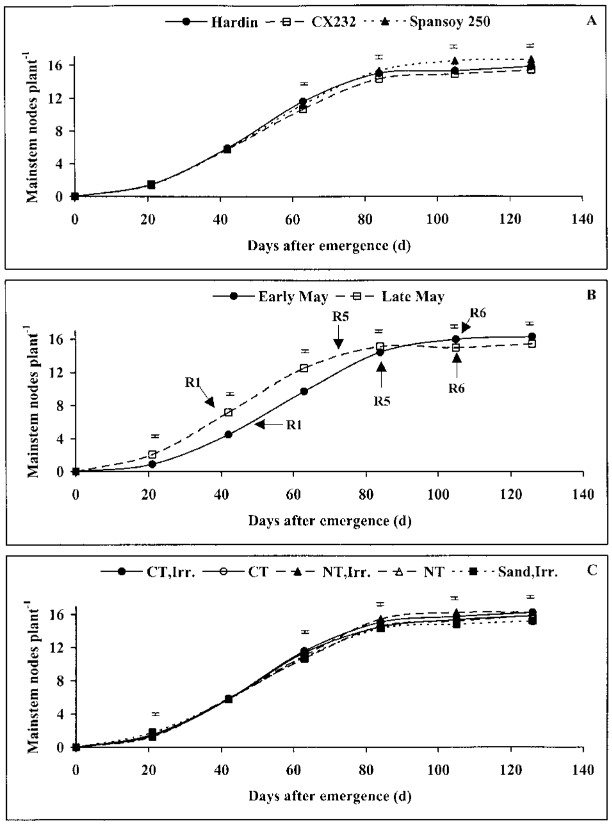

Fig. 1. Total number of nodes on the mainstem for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

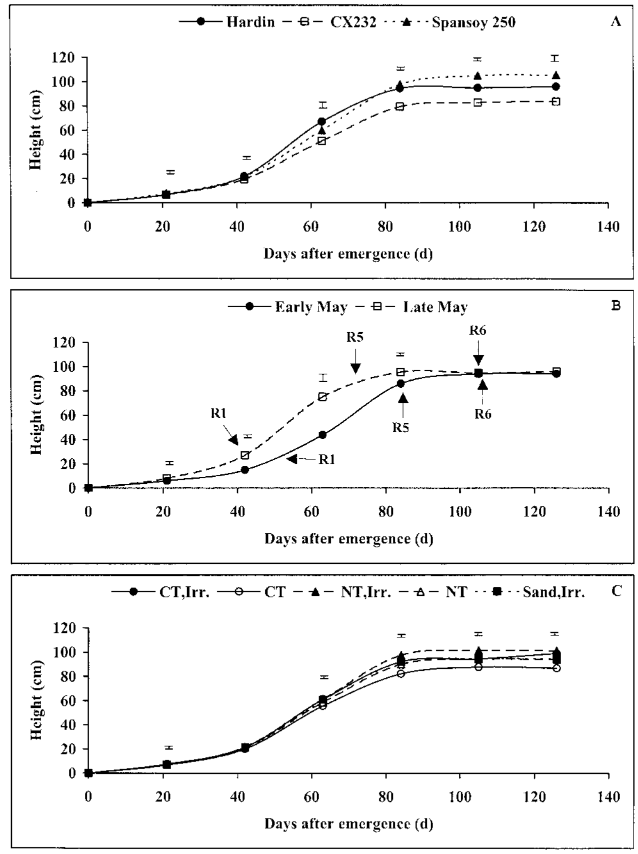

Fig. 2. Plant height for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

essentially ceased by R5 for all cultivars, management systems, and planting dates. Hardin was 19 and 7% taller than the CX232 and Spansoy 250 from emergence to R3, respectively (Fig. 2A). At harvest, Spansoy 250 was 9 and 20% taller than Hardin and CX232, respectively.

Similar to the number of nodes on the main stem, differences in plant height for the two planting dates from emergence to seed setting was influenced by the postponed development of the reproductive stages (Fig. 2B). Planting date did not have an effect on plant height at harvest. Considering the typical photoperiod response, this was a surprise and is contradictory to previous work by Parvez et al. (1989), where planting date across a six-week range influenced plant height. However, their work was conducted in Florida with other maturity groups of soybean that may have been a factor.

Tillage system and irrigation influenced plant height in the management systems at Arlington (Fig. 2C). Averaged across the season, plants in the irrigated systems were 10% taller than the nonirrigated systems, and plants in the no-tillage systems were 5% taller than the conventional tillage systems. Across all management systems, plants in the two no-tillage systems at Arlington were 4% taller than the remaining three management systems. Doss and Thurlow (1974) observed similar results and found plant height increased significantly under irrigation. In 1997 and 2000, the tallest plants were observed at Hancock (data not shown). An explanation for that could be the difficult establishment and growing conditions at Arlington in those 2 yr (Pedersen and Lauer, 2003).

Other comparisons of cultivars have shown that even though a cultivar produced the fewest nodes on the main stem, it may have produced the most nodes on the plant, and more extensive branching (Egli et al., 1985; Parvez et al., 1989). Unfortunately, nodes on branches were not counted in this experiment. All management systems and cultivars at both planting dates showed substantial production of new vegetative sinks between growth stages R1 and R5. Thus, there would be the potential for competition for assimilates between vegetative and reproductive sinks.

Table 1. Leaf area index (LAI) at R1 and R5, and average crop growth rate (CGR) and average leaf expansion rate (LER) during R1 to R5 for three soybean cultivars planted in five management systems and two planting dates during 1998-1999.

	LAI		CGR (R1–R5)	LER (R1–R5)
	R1	R5		
			$g\ m^{-2}\ d^{-1}$	$cm^2\ m^{-2}\ d^{-1}$
Management system (S)				
Silt loam, conventional tillage, irrigation	1.44	4.96	11.42	273
Silt loam, conventional tillage	1.36	4.68	11.66	269
Silt loam, no-tillage, irrigation	1.60	5.39	13.04	311
Silt loam, no-tillage	1.55	5.16	12.40	303
Sandy loam, conventional tillage, irrigation	2.15	4.86	12.62	127
LSD (0.05)	0.16	0.24	0.79	35
Planting date (D)				
Early	0.92	5.20	11.71	400
Late	2.32	4.82	12.74	106
LSD (0.05)	0.08	0.15	0.50	23
Cultivar (C)				
Hardin	1.59	4.75	12.01	242
CX232	1.69	5.19	12.22	256
Spansoy 250	1.58	5.10	12.46	261
LSD (0.05)	0.07	0.11	NS†	NS
ANOVA				
S × D	***	NS	***	***
S × C	NS	NS	NS	NS
D × C	NS	**	NS	NS
S × D × C	NS	NS	NS	NS

* Significant at the $P = 0.05$, 0.01, and 0.001 probability level.
** Significant at the $P = 0.05$, 0.01, and 0.001 probability level.
*** Significant at the $P = 0.05$, 0.01, and 0.001 probability level.
† NS = no significant differences at $P \leq 0.05$.

Dry Matter Accumulation

Dry matter accumulation was similar during 1998 and 1999 and much greater than in 1997 and 2000 (data not shown). This difference may be attributed to better establishment, growth, and higher temperatures, but also because of more regular, timely rainfall in 1998 and 1999 (Pedersen and Lauer, 2003). While no yield differences were observed between cultivars, planting dates, and management systems (Table 1), it was visually obvious that total DM accumulation was different (Fig. 3A,B,C).

Dry matter accumulation peaked around R6 for all cultivars (average 777 g m^{-2}) before declining. The decline in DM was consistent with the onset of leaf senescence and coincided with the decline in LAI (Fig. 4A). Dry matter accumulation for the three cultivars was similar before R5. However, after R5, the gap between the three cultivars widened such that DM accumulation and the percentage of DM partitioned into leaves (leaves + petioles; Fig. 5A) and stems (stems + branches; Fig. 6A) of CX232 and Spansoy 250 exceeded that of Hardin. By harvest maturity, CX232 and Spansoy 250 had 5 and 11% greater DM accumulation than Hardin, respectively. Hardin partitioned proportionally less DM into stems than CX232 and Spansoy 250, and thus DM accumulation of Hardin was significantly lower during the seed filling period (Fig. 3A). In 2000, Hardin had 3% lower and 3% higher DM accumulation than CX232 and Spansoy 250, respectively. These results are consistent with those of Kumudini et al. (2001) and support the assertion that genetic improvement of cultivars has resulted in continued carbon assimilation further into the seed filling period. The results also agree with Wells (1991), where despite cultivar differences in DM accumulation, cultivars yielded similarly. Several researchers have also maintained the importance of DM accumulation to soybean yield. However, most studies, like Hayati et al. (1995), have shown that yield is best correlated with an increase in DM accumulation and photosynthesis at R5.

Planting date influenced DM accumulation via a delay because of cooler temperature that also delayed reproductive growth stages (Fig. 3B). Maximum DM accumulation occurred for the early planting at R6, which was 5% higher than for the late planting date. At R6, fraction DM in leaves was 56% higher for the early planting date compared with the late planting date. The trends were different for percentage DM partitioned in stems. Before R3, the percentage of DM in stems averaged 18% higher for the late planting date. After R3/R4, fraction DM in stems was 26% higher for the early planting date than the soybean planted later (Fig. 5B). Late-planted soybean had 5% higher DM accumulation at harvest than the early planted in 1997, which may be attributed to the establishment difficulties at the early planting date.

Management system did not affect time of emergence (data not shown), but did affect subsequent DM accumulation (Fig. 3C). Dry matter of the four management systems at Arlington consistently lagged behind the management system at Hancock. Before R1, no differences were observed between the four management systems at Arlington, but these averaged 27% less total DM than the management system at Hancock. After R1, soybean plants in the two no-tillage systems at Arlington developed more rapidly and fractioned relatively more DM in stems (Fig. 6C), producing 6% more total DM at harvest maturity than the conventional tillage systems. No total DM differences were observed between the irrigated and nonirrigated systems at Arlington.

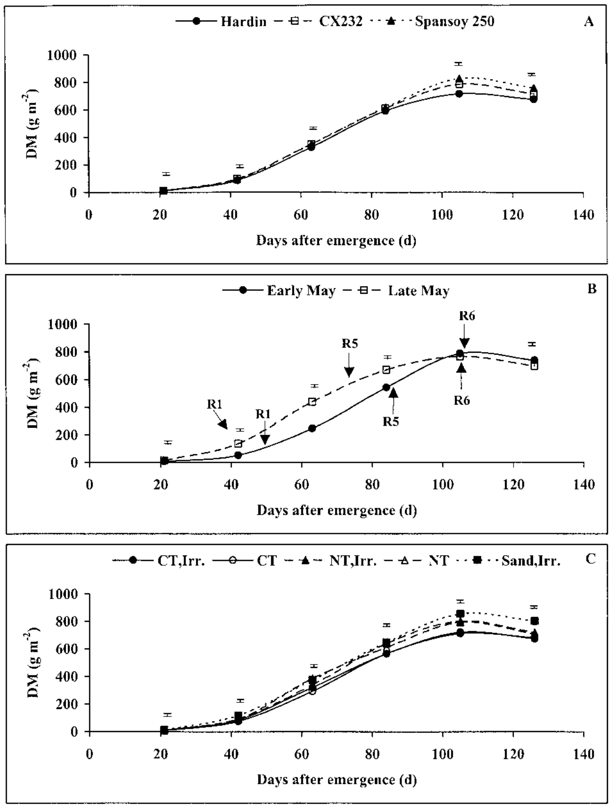

Fig. 3. Total aboveground dry matter (DM) for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT (Δ) = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

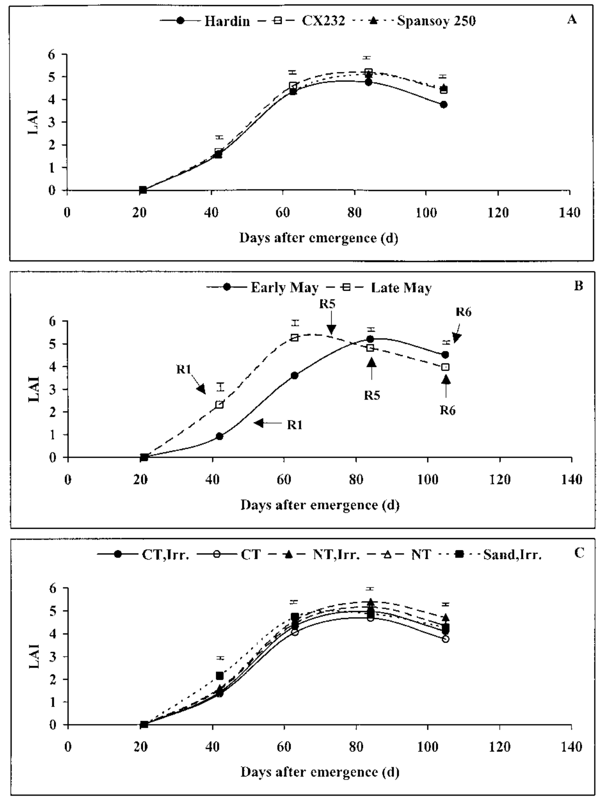

Fig. 4. Leaf area index (LAI) for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq$ 0.05) on dates when significant differences were found.

Egli et al. (1987) described a 500 g m^{-2} total vegetative DM threshold as desirable at R5. This threshold was attained by all cultivars, management systems, and planting dates, and indicated that reduced growing conditions before flowering for some treatments was compensated before R5 (Fig. 3A,B,C). In addition, biomass was about 800 g m^{-2} at physiological maturity, a level associated with optimum pod production (Board and Harville, 1994).

Leaf Area Index

A management system by planting date interaction was observed at R1 (Table 1). At Arlington, LAI at R1 was 76% greater for the late planting date compared with the early planting date, and no differences were observed between planting dates at Hancock (data not shown). A planting date × cultivar interaction was observed at R5 (Table 1). Leaf area index for Hardin was 19% lower compared with the newer cultivars in the management systems at Arlington, and no differences were observed among cultivars at Hancock.

Leaf area index at R1 was similar for the three cultivars with the highest LAI found for CX232 (1.69) and no differences were observed between the other cultivars that averaged 1.59 (Table 1). After R1, the gap between CX232 and Spansoy 250 and the older cultivar Hardin widened, and the LAI rose to a maximum around R5 for the three cultivars (Fig. 4A; Table 1). No difference was observed between CX232 and Spansoy 250 throughout the growing season. However, in 1997 and 2000, Spansoy 250 had significantly greater LAI than CX232 and Hardin. The trends observed suggest that the onset of senescence occurred about the same time for both Hardin and the two newer cultivars, but the decline in LAI of Hardin was more rapid, resulting in lower LAI throughout the seed filling period. Thus, CX232 and Spansoy 250 maintained greater LAI for a longer duration than Hardin. The pattern for DM accumulation correlated well with the pattern in LAI for the three cultivars. Kumudini et al. (2001) observed a similar pattern between old and new cultivars and concluded that new cultivars have the ability to accumulate more DM during the seed filling period because of greater light interception and photosynthesis.

Board and Harville (1994) reported that optimal light interception during vegetative and the early reproductive period was not required to maximize yield. Our data

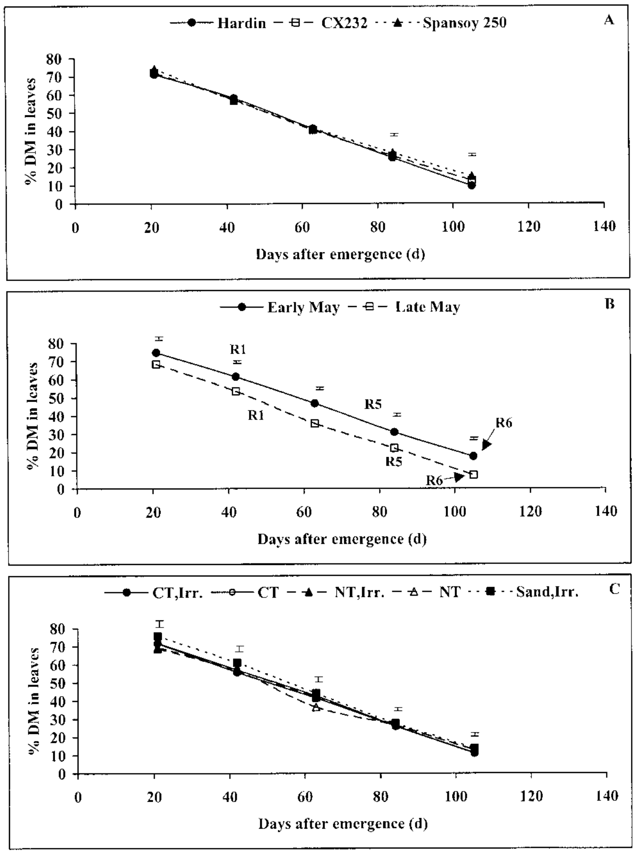

Fig. 5. Percentage of total dry matter (DM) present in leaves for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT (Δ) = no-tillage management system at Arlington; and Sand, Irr. = Irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

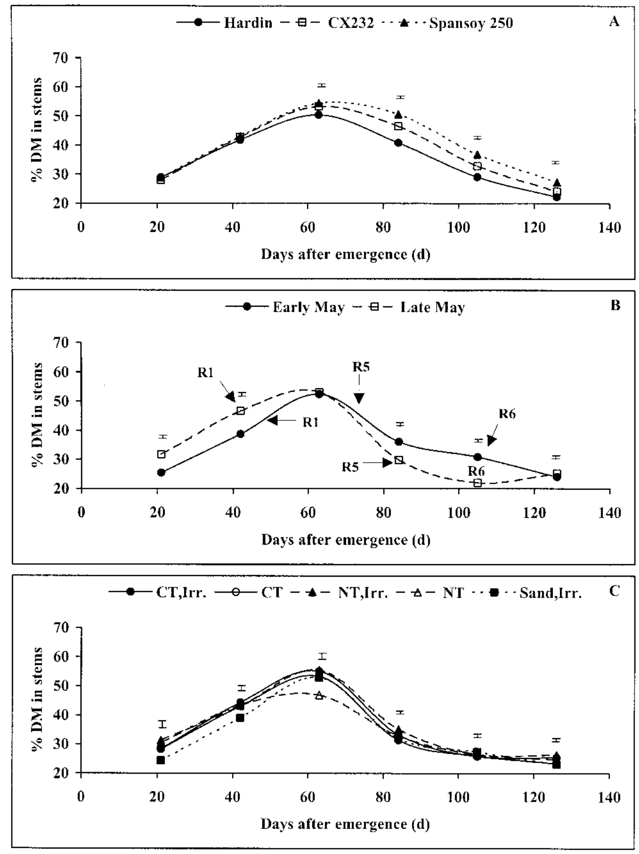

Fig. 6. Percentage of total dry matter (DM) present in stems for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

show that LAI was highest during the early reproductive period and peaked at approximately R5.5 to R6. The early planted soybean had a 6% higher LAI at R6 than delayed planting (Fig. 4B). This is, to our knowledge, the first observation of planting date response to pattern of LAI through the whole growing season in the upper Midwest.

Before R3, LAI was on average 31 and 9% greater for the first two sampling dates, respectively, for the management system at Hancock compared with the four management systems at Arlington (Fig. 4C). This resulted in a maximum LAI around R4 for the management system at Hancock compared with the management systems at Arlington that peaked at R5/R5.5. After R3/R4, LAI was 7% lower for the two conventional tillage system at Arlington compared with the other three management systems. Our results contradict results by Yusuf et al. (1999), who found LAI to be larger in a conventional tillage system compared with a no-tillage system before R5, but we did not see any difference in the LAI during the majority of the seed filling period. Irrigation influenced LAI at Arlington. After R3/R4, LAI was 6% higher in the irrigated systems than in the nonirrigated systems, which is in agreement with Scott and Batchelor (1979).

Shibles and Weber (1966) demonstrated that optimal CGR and yield resulted when LAI was sufficient (3.0–3.5) to achieve an optimal light interception of 95% by R5. However, subsequent studies showed that the relationship between LAI and optimal CGR varied with environmental conditions (Jeffers and Shibles, 1969). The three cultivars reached a LAI of 3.0 and optimum light interception approximately 10 d after flowering (Fig. 4). The early planted soybean achieved optimal light interception at 60 DAE compared with 45 DAE for the late-planted soybean. The four management systems at Arlington reached optimum light interception at the same time (55 DAE) or 5 d later than the management system at Hancock.

Thus, the potential photosynthetic capacity of the plants differed in favor of the no-tillage system at Arlington throughout the pod and seed filling period. The

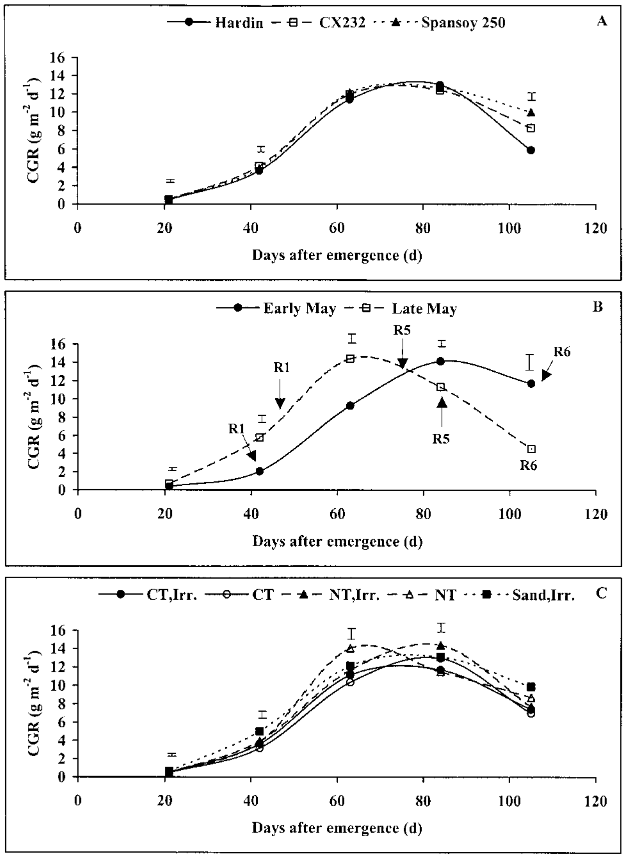

Fig. 7. Crop growth rate (CGR) for (A) cultivars (Hardin, CX232, and Spansoy 250), (B) planting dates (early May and late May), and (C) management systems (CT, Irr. = irrigated, conventional tillage management system at Arlington; CT = conventional tillage at Arlington; NT, Irr. = irrigated, no-tillage management system at Arlington; NT = no-tillage management system at Arlington; and Sand, Irr. = irrigated, conventional tillage management system at Hancock) during 1998-1999. Reproductive growth stages are shown for the two planting dates. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

management system at Hancock had higher LAI during the vegetative period and early flowering, but declined at a faster rate when the photosynthetic capacity mattered most (Fig. 4C; Table 1). Greater LAI of CX232 and Spansoy 250 will enable greater radiation absorption during seed filling, especially when LAI values are below the critical value for 95% radiation interception. This was, however, never the case in this study. The greater LAI during the seed filling period is consistent with the maintenance of DM accumulation later into the seed filling period of newer cultivars.

Crop Growth Rate and Leaf Expansion Rate

A management system × planting date interaction was observed from R1 to R5 for CGR (Table 1). Crop growth rate was 13% greater for the late-planted soybean than the early planted soybean across the management systems at Arlington, whereas the early planting date had 14% greater CGR at Hancock than the late planting date. A management system × planting date interaction was observed for LER from R1 to R5 (Table 1). Early planted soybean at Arlington had 4.8 times greater LER than late-planted soybean, and no differences were observed between planting dates at Hancock. The management system at Hancock maintained CGR from R1 to R5 similar to the two no-tillage systems at Arlington despite a 27% higher LAI at R1 since the LER from R1 to R5 was 59% lower at Hancock (Table 1).

Seasonal CGR patterns were highly associated with total DM (Fig. 3A,B,C) and LAI (Fig. 4A,B,C). These data correspond well with previous observations by Board (2000). Crop growth rate for Hardin was 29 and 41% lower than CX232 and Spansoy 250 at R6, respectively (Fig. 7A). No differences in CGR or LER were observed among the three cultivars from R1 to R5 (Table 1), and cultivars had similar DM accumulation (Fig. 3A) and LAI patterns (Fig. 4A).

Delayed planting resulted in a more rapid CGR after emergence than early planting likely because the temperature was warmer. During R1 to R5, CGR averaged 8% higher for delayed planting. At R6, CGR for the delayed planting was 61% lower than the early planting date despite LERs for the early planting were four times higher than the late planting (Table 1). No difference in CGR was observed for the two planting dates in 1997 and 2000.

Crop growth rate was highly influenced by management system throughout the season. During vegetative growth stages, the highest CGR was at Hancock, averaging 30% greater than the four management systems at Arlington. No CGR differences were observed among management systems at Arlington before R1. However, from R1 to R5, soybean in the two conventional tillage systems averaged 9% lower CGR than the remaining three systems (Table 1). This contradicts previous results by Yusuf et al. (1999), who found soybean grown in the central Corn Belt in conventional tillage systems to have an initial higher CGR than those in no-tillage systems before R2. However, after R2, soybean in no-tillage systems possessed a greater CGR than those in conventional tillage systems, which was similar to our results. Irrigation did not affect CGR in the conventional tillage system at Arlington. However, irrigation influenced the no-tillage system in a positive (20%) direction at R5. After R6, no significant difference was found among the five management systems.

SUMMARY

The two new cultivars accumulated more DM, and had a higher LAI and CGR during seed filling than the old cultivar. Planting date influenced growth and development at Arlington; however, no differences were observed at Hancock. Small differences were observed between irrigated and nonirrigated systems at Arlington. However, yield stability in the no-tillage system at Arlington compared with the conventional tillage systems were achieved through maintenance of a greater LAI , CGR, LER, and total DM accumulation during the seed filling period. Yield stability of the management system at Hancock and for the late planting date at Arlington was achieved through high LAI, CGR, and

DM accumulation before R1, but with a low LER from R1 to R5. It was concluded that numerous combinations of compensatory growth exist between cultivars, management systems, and planting dates, and these data demonstrate the magnitude of compensatory growth and alterations in plant development and the complexity involving yield determination.

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