CROPPING SYSTEMS

Soybean Growth and Development Response to Rotation Sequence and Tillage System

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] benefits in yield when rotated with corn (*Zea mays* L.), but the mechanism of the rotation effect is not fully understood. The objective of this study was to determine effects of cropping sequence and tillage on soybean growth and plant development. A 2-yr field study was conducted using conventional tillage and no-tillage systems in seven different corn and soybean rotation sequences. At physiological maturity, plots of first-year soybean after 5 yr of consecutive corn and the annually rotated soybean averaged 8% higher soil moisture content and 17% more dry matter per plant than the remaining five rotation sequences. Conventional tillage averaged 6% higher soil moisture content and 5% greater leaf area index than the no-tillage system. In 2000, leaf area index was 29% higher for the first-year soybean after 5-yr corn and the annually rotated soybean than the remaining five rotation sequences. No differences in leaf area index were observed among the different rotation sequences in 2001. Soybean plants were 6% taller in first-year soybean after 5-yr corn, second-year soybean, and annually rotated soybean than the remaining four rotation sequences. The no-tillage system averaged 6% more dry matter plant per plant and 7% taller plants than the conventional tillage system. These findings support the hypothesis that growth and alterations in plant development occur when soybean is grown in different rotation sequences and tillage systems. These alterations may reflect the plant response to the corn–soybean rotation effect on soybean growth and development, but the underlying mechanism of the effect remains unknown.

Benefits of crop rotations have been known for thousands of years though the types and sizes of such benefits have changed over time as technology develops. Rotating corn and soybean has been used as a management tool to increase crop yields (Peterson and Varvel, 1989). Barber (1972) reported that corn yields declined with increasing frequency of corn in the rotation. However, other results indicate that the type of crop in the rotation may not be important, as long as corn does not follow itself (Peterson and Varvel, 1989). Crookston et al. (1991) reported a 5% yield advantage for first-year corn after several years of soybean compared with corn rotated annually with soybean. Planting soybean in rotation has resulted in consistently higher yields than when grown in monoculture (Dabney et al., 1988; Edwards et al., 1988; Meese et al., 1991; Pedersen and Lauer, 2002). In Wisconsin, soybean yields in an alternating corn and soybean rotation were on average 7% lower compared with first-year soybean after 5 yr of corn (Pedersen and Lauer, 2002, 2003a).

Corn and soybean yield response to tillage system varies depending on previous crop and soil drainage characteristics (Dick and van Doren, 1985; Philbrook et al., 1991). No-tillage corn yields are least likely to equal or exceed those for conventional tillage with poorly drained soils (Dick and van Doren, 1985), but rotating corn and soybean usually minimizes yield reductions under no-tillage systems.

Duncan (1986) proposed that greater total dry matter corresponds to greater seed yield if the total dry matter is produced before seed initiation. In contrast, Weber et al. (1966) found that both total dry matter and leaf area index were poor predictors of seed yield. Wells (1991) showed that similar grain yield occurred despite significant differences in total dry matter yield over the growing season. Overproduction of vegetative dry matter 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 dry matter compensation is influenced by crop growth rate, relative growth rate, relative leaf area growth rate, and net assimilation rate (Hunt, 1982). Crop growth rate is a prime growth dynamic factor to study since it reflects canopy assimilatory capacity and affects total dry matter levels through adjustments of leaf area index and/or net assimilation rate (Imsande, 1989). Shibles and Weber (1966) demonstrated that optimal crop growth rate and yield resulted when leaf area index was sufficient (3 to 3.5) to achieve an optimal light interception of 95% by R5. However, subsequent studies showed that the relationship between leaf area index and optimal crop growth rate varied with environmental conditions (Jeffers and Shibles, 1969).

Research in the corn and soybean rotation has centered mostly on yield, the potential N contribution by legumes, and the effect of this contribution on the subsequent crop (Kurtz et al., 1984). Previous research focused on interactions of tillage (Dick and van Doren, 1985), plant population (Pedersen and Lauer, 2002), and row spacing (Pedersen and Lauer, 2003a). Limited information exists in the literature on the corn–soybean rotation effect on soybean growth and development; however, this effect might be useful for describing soybean response and health to environmental variations and management decisions.

The objective of this research was to determine effects of cropping sequence and tillage on soybean growth and plant development.

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Table 1. Soybean grain yield, grain moisture, and soil test characteristics for seven rotation sequences and two tillage system during 2000 and 2001.

	Grain yield†		Grain moisture		Soil test			
	2000	2001	2000	2001	pH	OM‡	P	K
	Mg ha^{-1}		g kg^{-1}			%	mg kg^{-1}	
Rotation sequence (R)								
First-year soybean	3.74	4.10	11.45	12.25	6.5	3.9	36	162
Soybean–corn	3.53	3.94	11.15	11.98	6.5	3.7	29	142
Second-year soybean	3.51	3.97	11.55	11.86	6.8	3.4	25	174
Third-year soybean	3.20	3.69	10.93	11.94	6.7	3.5	32	137
Fourth-year soybean	3.35	3.66	11.31	11.81	6.6	3.7	30	140
Fifth-year soybean	3.20	3.61	10.33	11.86	6.8	3.6	30	135
Cont. soybean	3.26	3.57	10.88	11.80	6.6	3.6	28	128
LSD (0.05)	0.25	0.25	0.77	NS§	0.2	0.4	7	NS
Tillage (T)								
No-tillage	3.57	3.97	11.31	11.85	6.6	3.6	26	137
Conventional tillage	3.23	3.61	10.86	12.01	6.7	3.6	29	151
LSD (0.05)	0.13	0.25	0.40	NS	0.1	NS	NS	10
ANOVA								
R × T	NS	NS	NS	NS	NS	NS	NS	NS

† A more detailed yield analysis can be found in Pedersen and Lauer (2003a).
‡ OM = organic matter.
§ NS = no significant differences at $P \leq 0.05$.

MATERIALS AND METHODS

Field research was conducted during 2 yr (2000 to 2001) on a Plano silt loam soil (fine-silty, mixed, mesic, Typic Argiudoll) at the University of Wisconsin Agricultural Research Station, located near Arlington, WI. The experiment was a randomized complete block in a split-split plot arrangement with four replications. Main plots were no-tillage and conventional tillage systems. The subplots consisted of 14 rotation sequences involving corn and soybean, which had been initiated in 1983 on land previously planted to corn (Pedersen and Lauer, 2003a). The sequences allowed comparisons during 2000 and 2001 of (i) first-year soybean (after a minimum of four consecutive years of corn), (ii) corn and soybean alternated annually with the other crop, and (iii) two, three, four, and five or more years of continuous soybean (18th and 19th year in 1998, 1999, 2000, and 2001, respectively). The sub-subplots were row spacing of 19, 38, and 76 cm, used for both crops. Soybean was planted at 555 600, 432 100, and 308 600 seeds ha^{-1}, respectively, for the 19-, 38-, and 76-cm row spacing. Data for this study were collected in the 38-cm row spacing plots. No differences in the final plant population were found in either year, with an average final plant population across the two years for 38-cm row spacing of 415 800 plants ha^{-1}. The soybean variety was 'Asgrow 2301RR'. Soybean plots were planted on 2 May 2000 and 2 May 2001. However, soybean was replanted in 2000 on 9 June because of poor emergence and soil crusting. Management practices and descriptions of the management systems have been previously described (Pedersen and Lauer, 2003a).

Ten consecutive plants in a row were hand-harvested from each plot and were used to determine dry matter yield four times throughout the growing season. Samples were not collected at the same growth stage because the experiment was replanted in 2000. In 2000, the four sampling dates were at 21, 41, 75, and 103 d after emergence or at growth stage V2, R1, R5, and R7 (Fehr and Caviness, 1977). In 2001, the sampling dates were at 35, 57, 72, and 119 d after emergence or growth stage R1, R3, R4, and R7. Growth and development stages and plant height information was taken based on a sample of three plants randomly collected from the hand-harvested section. Dry matter was determined from all plants that were oven-dried at 60°C to a constant weight to determine yield on a dry weight basis.

Leaf area index was measured using a leaf area meter (Model LAI-2000, LI-COR, Lincoln, NE) five times through the seed-filling period to evaluate rate of senescence and defoliation among rotation sequences and tillage systems.

From the time of emergence, gravimetric soil moisture content was measured every 2 wk in each plot by collecting two random soil samples with a 2.5-cm (inner diam.) soil probe from depths of 0 to 30 cm. Samples of field-moist soil were composited, and a subsample of approximately 0.4 kg was oven-dried at 105°C for 3 d to calculate gravimetric moisture content.

All data were subjected to an analysis of variance using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Inst., 1995), with 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. Data were analyzed by year, with block treated as a random effect. Rotation sequence and tillage system were treated as fixed in determining the expected mean square and appropriate F tests in the analysis of variance. Mean comparisons were made using Fisher's protected LSD test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Grain yield and grain moisture are presented in Table 1. No differences in plant populations were found among the different rotation sequences. A detailed yield analysis has already been presented in a companion paper (Pedersen and Lauer, 2003a). Precipitation and temperature during the growing seasons are shown in Table 2. The gravimetric soil moisture content in this

Table 2. Precipitation and mean monthly temperature during the 2000 and 2001 growing seasons near Arlington, WI. Departure from 20-yr mean is shown in parentheses.

Year	April	May	June	July	August	September
	Precipitation, mm					
2000	62 (23)	214 (134)	233 (120)	85 (−22)	99 (2)	78 (−19)
2001	80 (5)	143 (63)	122 (9)	72 (9)	128 (31)	102 (5)
	Mean monthly temperature, °C					
2000	7 (−1)	15 (0)	19 (−1)	20 (−2)	20 (0)	16 (1)
2001	10 (2)	15 (0)	19 (0)	22 (0)	21 (1)	14 (−2)

study was never below the permanent wilting point of 0.10 kg kg^{-1} for this soil type (Schulte and Walsh, 1994), and no interactions were observed between gravimetric soil moisture, tillage system, and rotation sequence (data not shown).

Differences in soil water content among rotation sequences remained relatively constant over the season and corresponded well to previous observations by Roder et al. (1989). The moderate temperatures combined with above-normal precipitation therefore minimized moisture stress both years. Gravimetric soil moisture content was greatest during the first 20 d after emergence and was influenced by rotation system each year (Fig. 1). First-year soybean after 5 yr of corn and the annually rotated soybean averaged 8% higher soil moisture content than the remaining five rotation sequences in both 2000 and 2001, respectively. In addition, continuous soybean tended to have the lowest soil moisture for all sampling dates during both years. Grain yield observed in this study (Pedersen and Lauer, 2003a) corresponds well with the early-season soil water content (Fig. 1). Increased residue cover with corn as a previous crop may be largely responsible for this effect in spring and early summer. Roder et al. (1989) observed similar results for a grain sorghum [*Sorghum bicolor* (L.) Moench] and soybean rotation. Rainfall for April, May, and June equals close to 50% of the total annual precipitation in Wisconsin (Pedersen and Lauer, 2003b) and is likely to affect stored soil water content for the entire growing season. An explanation for the higher soybean grain yield and early season soil water content for first-year soybean after 5 yr of consecutive corn could be the management-induced differences in soil water content related to residue cover and water infiltration that affected crop development, mainly during the initial period when the root system had not yet reached lower depths. Future research is needed to document this.

Before R1, no-tillage systems tended to have more soil moisture each year (Fig. 1). Johnson et al. (1984) and Chastain et al. (1995) observed similar results and concluded that the difference was due to increased infiltration and decreased evaporation. However after R1, conventional tillage averaged across years had 6% higher gravimetric soil moisture content than the no-tillage system.

Few studies have been published on the long-term corn and soybean rotation effects on soil moisture. The high soil moisture content associated with the conventional tillage system was unexpected and difficult to explain. Chastain et al. (1995) obtained 17% more seedzone soil moisture on high-residue plots compared with low-residue plots during early vegetative growth. How-

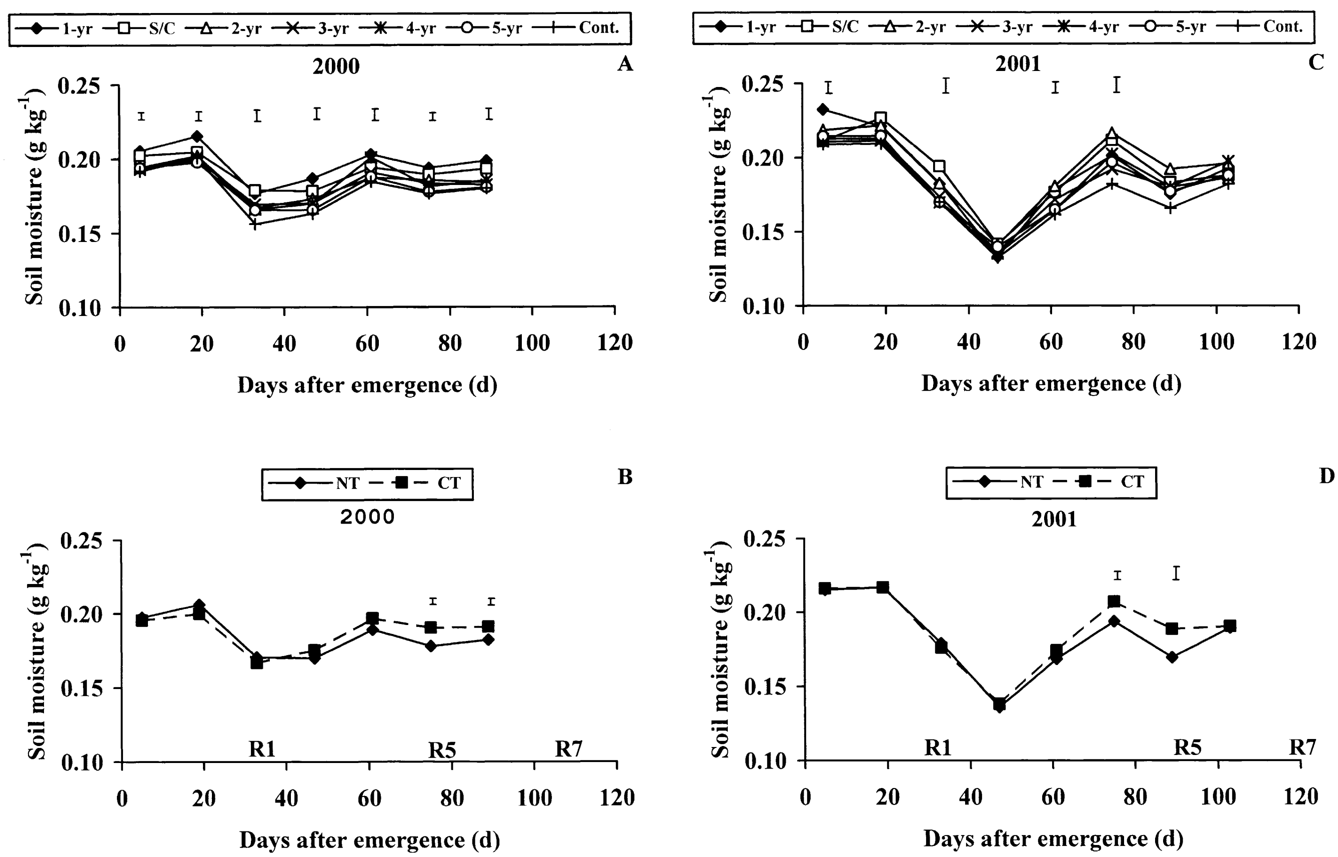

Fig. 1. Gravimetric soil moisture content from 0 to 30 cm in seven different rotation sequences (1-yr, 2-yr, 3-yr, 4-yr, and 5-yr = first-, second-, third-, fourth-, and fifth-year soybean, respectively; S/C = first-year soybean, alternated annually with corn; Cont. = continuous soybean since the experiment was started in 1983) during (A) 2000 and (C) 2001 and in two tillage systems [no-tillage (NT) and conventional tillage (CT)] during the (B) 2000 and (D) 2001 growing seasons. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

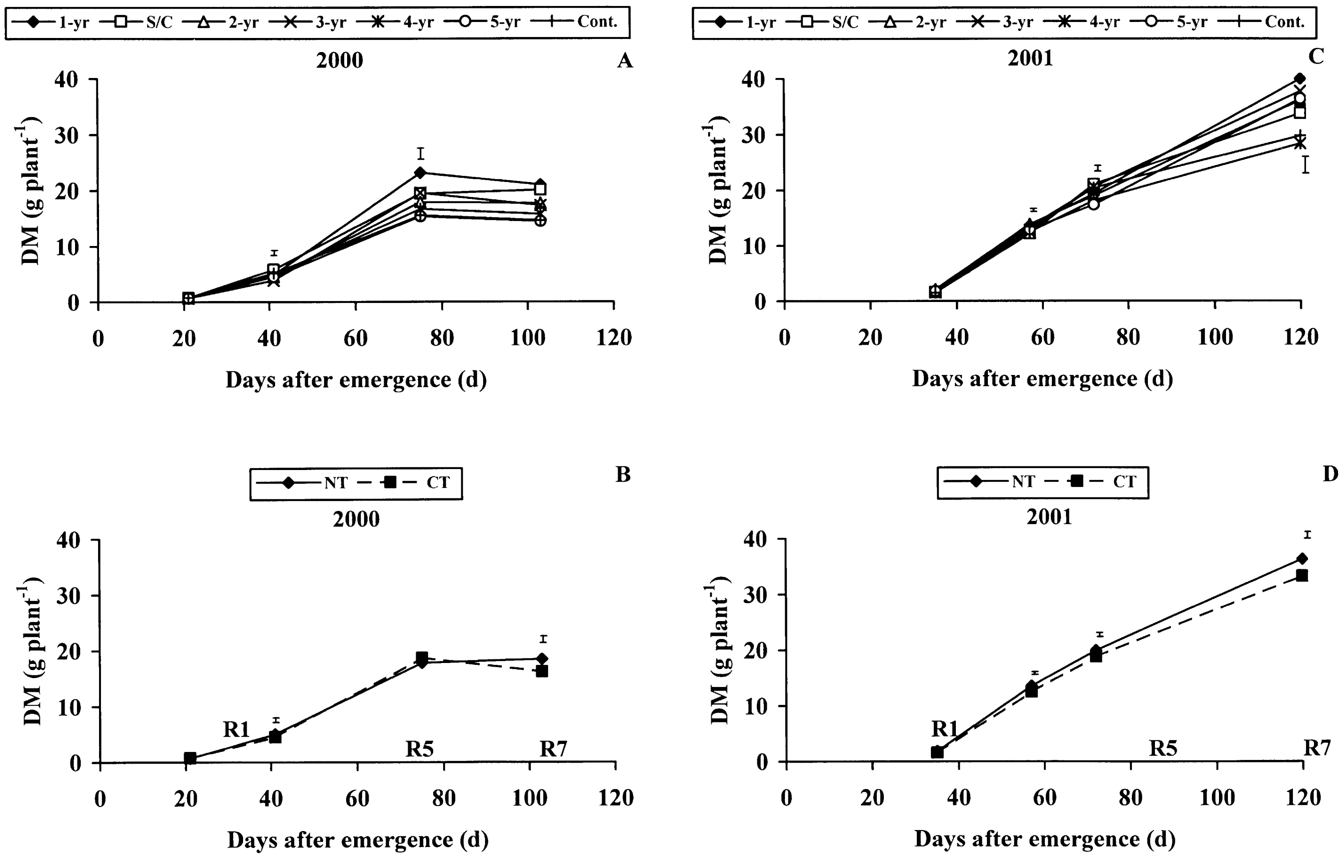

Fig. 2. Dry matter (DM) accumulation per plant in seven different rotation sequences (1-yr, 2-yr, 3-yr, 4-yr, and 5-yr = first-, second-, third-, fourth-, and fifth-year soybean, respectively; S/C = first-year soybean, alternated annually with corn; Cont. = continuous soybean since the experiment was started in 1983) during (A) 2000 and (C) 2001 and in two tillage systems [no-tillage (NT) and conventional tillage (CT)] during the (B) 2000 and (D) 2001 growing seasons. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

ever, the lack of significant differences in this study before R1 was expected because of the relatively high soil moisture level during both years that was close to field moisture capacity for this specific soil type (Schulte and Walsh, 1994).

Dry Matter Accumulation

Dry matter accumulation was different for the 2 yr, which may be attributed to delayed planting in 2000. No interaction of dry matter accumulation was found among rotation sequences and tillage systems.

No differences were observed among rotation sequences before R1/R2 (Fig. 2). However, after R2, the gap between the different rotation sequences started to widen. First-year soybean after 5 yr of consecutive corn and annually rotated soybean averaged 24.6 and 9.3% more dry matter per plant throughout the 2000 and 2001 growing seasons, respectively, than the remaining five rotation sequences. Cropping-induced differences in soil water content (Fig. 1) may have affected crop development and dry matter accumulation. This is to our knowledge the first observation on the influence of rotation sequence on soybean dry matter accumulation suggesting increased C assimilation later in the seed-filling period when soybean follows corn and not soybean.

Tillage system influenced dry matter accumulation during both years (Fig. 2). However, it was first after R1 that dry matter accumulation in the conventional tillage system started to lag behind the no-tillage system. The no-tillage system averaged 4.0 and 7.7% more dry matter per plant than the conventional tillage system for the 2000 and 2001 growing season, respectively (Fig. 2).

During both years, dry matter accumulation followed a consistent pattern to grain yield for the different rotation sequences and tillage systems. Several researchers have reported on the importance of dry matter accumulation to soybean yield (Duncan, 1986; Hayati et al., 1995; Wells, 1991). Our results agree with those of Duncan (1986) and Hayati et al. (1995) but not with those of Wells (1991).

Vegetative Growth Characteristics

Vegetative growth characteristics from emergence to harvest were evaluated by changes in number of nodes on the main stem (Fig. 3) and plant height (Fig. 4). 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.

No interactions were observed for number of nodes on the main stem during either year (data not shown). However, a rotation sequence × tillage system interaction was observed for plant height in both years (data not shown). In 2000, plants from three or more years of consecutively grown soybean were 13% taller in the

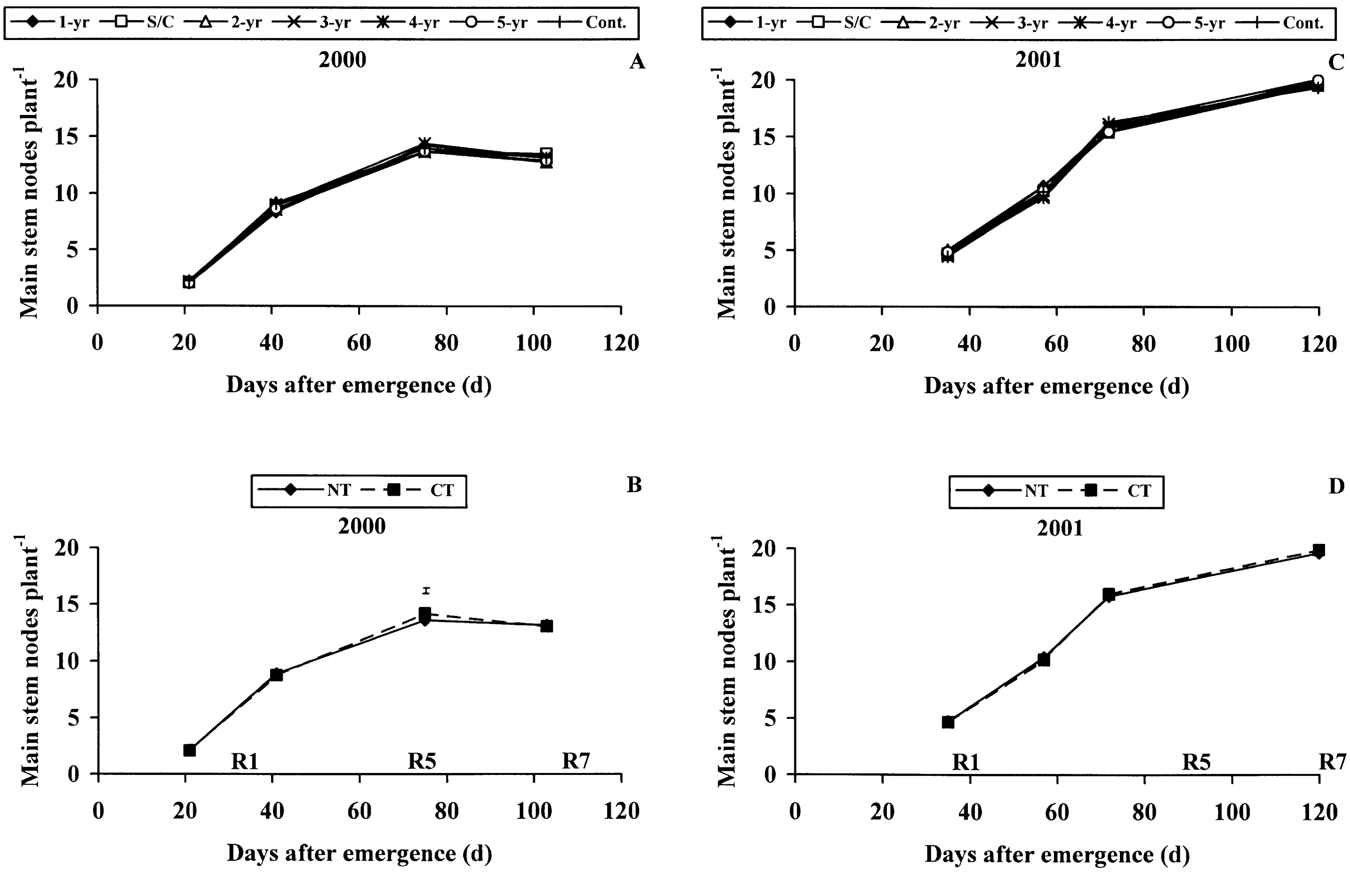

Fig. 3. Number of nodes on the main stem in seven different rotation sequences (1-yr, 2-yr, 3-yr, 4-yr, and 5-yr = first-, second-, third-, fourth-, and fifth-year soybean, respectively; S/C = first-year soybean, alternated annually with corn; Cont. = continuous soybean since the experiment was started in 1983) during (A) 2000 and (C) 2001 and in two tillage systems [no-tillage (NT) and conventional tillage (CT)] during the (B) 2000 and (D) 2001 growing seasons. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

no-tillage systems than the conventional tillage system. In 2001, plants from 3 and 4 yr of consecutive grown soybean were 20% taller in the no-tillage system than in the conventional tillage system.

Rotation sequence did not affect the number of nodes on the main stem, and only few differences were observed between tillage systems (Fig. 3). Plant height differences among rotation sequences were observed from the first sampling date in both years (Fig. 4). However, no differences were observed among the rotation sequences after R5 in 2000. The tallest plants at harvest were found in the first-year soybean after 5 yr of corn, second-year soybean, and annually rotated soybean, which were 2 and 9% taller than the remaining four rotation sequences in 2000 and 2001, respectively.

In 2000, the no-tillage system tended to have a lower number of nodes on the main stem between R1 and R5, with the no-tillage system having 4% fewer nodes (13.6) than the conventional tillage system (14.2) at R5. Differences in number of nodes produced during R1 and R5 can result from differences in the rate of node production or variation in the length of flowering. The differences in node numbers between tillage systems were primarily due to differences in rate of node production and not differences in the reproductive stages or the length of the flower to pod-setting period (data not shown). Plant height was greater for no-tillage than conventional tillage at later growth stages. On average, no-tillage plants were 6 and 7% taller in 2000 and 2001 than conventional tillage plants, respectively.

Egli et al. (1985) and Parvez et al. (1989) showed that number of nodes on the main stem is not correlated with total number of nodes on the plant. Nodes on the branches were not counted in this experiment. However, after observing the differences among rotation sequences and tillage systems, nodes on branches should be investigated.

Leaf Area Index

Leaf area index was used to evaluate rate of senescence and defoliation rate among the different rotation sequences and tillage systems during the seed-filling period.

Rotation sequence influenced leaf area index in both years (Fig. 5). In 2000, first-year soybean after 5 yr of consecutive corn and annually rotated soybean had greater leaf area index, averaging 9% more at R5 (6.93) and 29% more at R7 (2.18) than the remaining five rotation sequences. Except at R6, where inconsistent data were observed among the different rotation sequences (Fig. 5), no differences were observed among

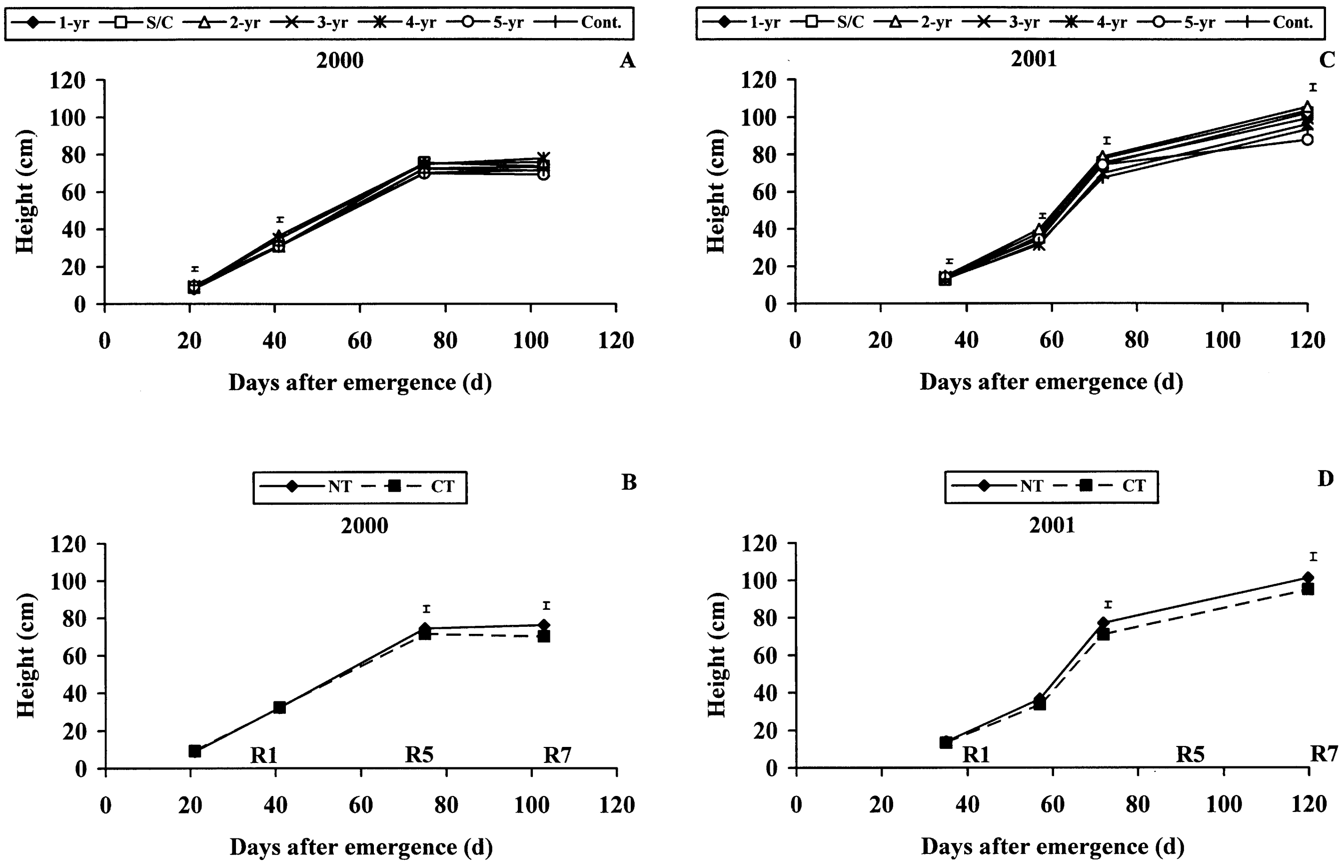

Fig. 4. Plant height in seven different rotation sequences (1-yr, 2-yr, 3-yr, 4-yr, and 5-yr = first-, second-, third-, fourth-, and fifth-year soybean, respectively; S/C = first-year soybean, alternated annually with corn; Cont. = continuous soybean since the experiment was started in 1983) during (A) 2000 and (C) 2001 and in two tillage systems [no-tillage (NT) and conventional tillage (CT)] during the (B) 2000 and (D) 2001 growing seasons. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

the rotation sequences in 2001. The data suggest that as leaf area index declines, dry matter accumulation increases in soybean after flowering (Fig. 2 and 5). The data indicate that the onset of soybean senescence is delayed when soybean is planted after corn compared with after soybean. Thus, first-year soybean after 5 yr of consecutive corn and annually rotated soybean maintained a greater leaf area index for a longer duration than the remaining five rotation sequences and will therefore enable greater radiation absorption and dry matter accumulation during seed filling. Kumudini et al. (2001) suggested that genetic improvement of yield of soybean cultivars might be associated with *stay green* characteristics. Our data indicate a potential for cultivars with these characteristics in cropping systems with more than 1 yr of consecutively grown soybean.

Leaf area index was influenced by tillage system, but results varied between years (Fig. 5). In 2000, the no-tillage system had 7% greater leaf area index than the conventional tillage system. However, in 2001, the conventional tillage system averaged 2% greater leaf area index than the no-tillage system. Yusuf et al. (1999) found leaf area index to be larger in the conventional tillage system compared with the no-tillage system before R5. However, they did not find any difference in leaf area index during the majority of the seed-filling period.

CONCLUSION

This study showed the impact of two different growing seasons on soybean growth and development. First-year soybean after 5 yr of consecutive corn yielded on average 10% more than the other six rotation sequences. Soybean yield response due to rotation sequence may result partly from higher early-season soil water content. The difference in soil moisture content among the different rotation sequences may have affected the changes in plant height, dry matter accumulation, and leaf area index, which were fundamental changes in plant growth and development. It is speculated that crop-specific evapotranspiration, the quantity of residue from the previous crop, and crop rotation effects on water infiltration were probably the main factors affecting soil water content in this study. This study indicates that soybean after corn accumulates more dry matter during the seed-filling period than soybean following soybean. Across years, no-tillage soybean yield was 9% higher than the conventional tillage system. However, the conventional tillage system had higher soil moisture content but less dry matter accumulation, leaf area index, and shorter plants. The growing season conditions resulted in crops that developed under minimal stress and that additional work is needed to assess rotation sequence and tillage system effects under more stressful growing conditions

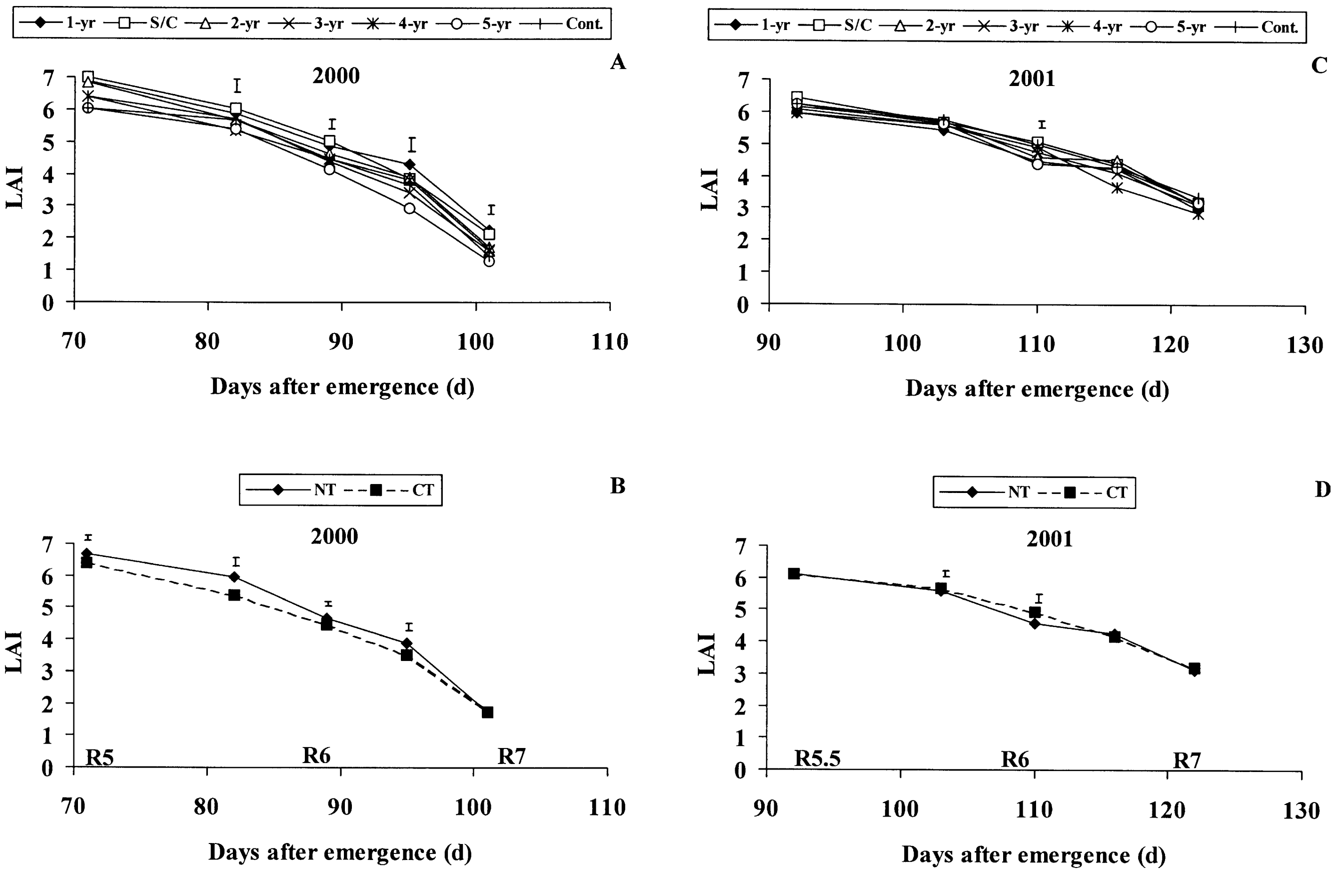

Fig. 5. Leaf area index (LAI) in seven different rotation sequences (1-yr, 2-yr, 3-yr, 4-yr, and 5-yr = first-, second-, third-, fourth-, and fifth-year soybean, respectively; S/C = first-year soybean, alternated annually with corn; Cont. = continuous soybean since the experiment was started in 1983) during (A) 2000 and (C) 2001 and in two tillage systems [no-tillage (NT) and conventional tillage (CT)] during the (B) 2000 and (D) 2001 growing seasons. Vertical bars represent the LSD ($P \leq 0.05$) on dates when significant differences were found.

or across a wider range of environmental conditions. This work supports the initial hypothesis that rotation sequence and tillage system influence growth and development of soybean.

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