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How Growth Dynamics Affect Soybean Development across Cultural Practices

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1. Introduction

Determination of the most suitable planting date, plant population and cultivar for optimal yield is an important agronomic goal in soybean production. However, soybean yield is determined by interactions with environmental conditions as well as genetic yield potential. Compared to earlier planting, delayed planting reduces yields (Beatty *et al.*, 1982; Carter and Boerma, 1979; Parker *et al.*, 1981; Egli and Bruening, 2000). Yield reduction in late-planted, double-crop soybeans has been attributed to a lack of sufficient vegetative growth (Ball *et al.*, 2000 b; Herbert and Litchfield, 1984). Increasing the leaf area to maximize LI is the primary reason that increased biomass is associated with higher yields in late-planted soybean (Wells, 1991; Board *et al.*, 1992). Previous studies have indicated that optimal plant populations vary from 30,000 to 500,000 plants ha^{-1} (Costa *et al.*, 1980; Parks *et al.*, 1982; Egli, 1988; Ennin and Clegg, 2001). In general, optimal plant population is greater under poor growing conditions than good growing conditions (Wells, 1993). Also, row spacing, which determines plant population in a unit area, is a major agronomic factor affecting soybean yield. In previous studies on planting date and row spacing, yield increases associated with narrow rows appear to be greater from late planting dates than from optimum dates (Board *et al.*, 1990; Boerma and Ashley, 1982; Boquet *et al.*, 1982). There is interest in planting soybeans in narrow rows to increase the LI for higher yields (Board and Harville, 1993). However, Purcell *et al.* (2002) stated that yield does increase at high population densities because of decreased radiation use efficiency. A previous study reported that recommended populations for optimum planting dates were insufficient for late-planted soybean because of the failure of these populations to achieve maximum LI, especially in years of low rainfall (Ball *et al.*, 2000 a). Early-maturity groups have not been used late in the season because inadequate canopy development generally occurs in the recommended populations (Kane and Grabau, 1992). Early-maturing cultivars have a shorter period of vegetative development than full-season cultivars, but the length of the seed-fill phase is about the same as for conventional cultivars (Egli *et al.*, 1978; Egli, 1993).

Growth dynamics such as LAI, LI, LIE, TDM, and CGR are major predictors of soybean yield. The relationships between seed yield and growth dynamics vary with environmental conditions and cultural practices (planting date, plant population, and cultivar, etc.). Duncan (1986) detected that greater TDM results in greater seed yield if the TDM is produced before seed initiation. In contrast, Weber *et al.* (1966) reported that both TDM and

LAI were poor predictors of seed yield. Total dry matter (TDM) is influenced by CGR, relative growth rate, relative leaf area growth rate, and net assimilation rate (Hunt, 1982). On the other hand, CGR is controlled by LAI (which influences LI) and NAR (Hunt, 1978). In addition, LI is controlled by both LAI and LIE. Greater LI in narrow rows results from either greater LAI and/or increased LI per unit leaf area (LIE) due to a more uniform arrangement (Board and Harville, 1992). Earlier authors have reported that a LAI of 4.0 was needed to reach 95% LI, and that it is essential that the canopy reach this critical LAI by flowering (Egli, 1988; Westgate, 1999). Other previous studies have demonstrated that a LAI of approximately 3.2 is required to achieve optimal CGR, 95% LI and 95% of maximum dry matter production (Shibles and Weber, 1966). It is currently accepted that a LAI of 3.5 to 4.0 is correlated with a level of 95% LI and is also a dependable measure of yield potential (Board and Harville, 1992; Westgate, 1999). Soybean cultivars and cultural practices may affect LAI, LI, LIE, CGR and TDM development. Later-maturing cultivars are more likely to meet minimum leaf area requirements than early-maturing cultivars (Holshouser and Whittaker, 2002). A suboptimal plant population reduces CGR and TDM to levels that result in yield loss (Loomis and Connor, 1992). Bullock *et al.* (1998) stated that CGR increased with decreasing rows until about R_5, after which, rows had no significant effect on CGR. On the other hand, Egli and Bruening (2000) reported that CGRs were generally lower in the late plantings than in the early plantings, accounting for some of the reductions in seed number. Board and Harville (1992) reported that LIE was found to be important for LI increased by narrow rows early in crop growth, when LAI was low and there was little mutual shading of leaves.

In this study, we purpose to increase understanding of how certain developmental dynamics respond to planting date, plant population, and cultivar and their interactions and relations between soybean yield and developmental dynamics. Thus, the specific objectives of this research are to: (i) determinate the interactions and effects of cultural practice (planting date, plant population, and cultivar) on LAI, LI, LIE, TDM, and CGR at different development stages; and (ii) to determine the associations between seed yield and growth dynamics, such as LI, LAI, LIE, TDM, and CGR.

2. Materials and methods

2.1 Cultural practices

Field studies were conducted in 2005 and 2006 at the Research and Training Center of The Agricultural Faculty, Uludag University, Bursa, Turkey (Latitude 40° 15′ 29″ N, Longitude 28° 53′ 39″ E and altitude 72 m above sea level) on a clay soil (average 45.6% clay content). This soil had 0.11% total nitrogen content (Kjeldahl Method); 0.40 kg ha^{-1} phosphorus (Olsen Method, P_2O_5); 5.70 kg ha^{-1} exchangeable potassium (Ammonium Acetate Method, K_2O); 0.08% total salt; and 1.90% organic matter (Walkley-Black Method). It had a balk density of 1.45, 1.53, and 1.50 g cm^{-3} in 0-0.30, 0.30-0.60, and 0.60-0.90 m profiles, respectively. The soil pH was 7.2. The water-holding capacity of the experimental site was 130 mm in a 0.90 m soil profile. Water-holding capacity was determined by the difference between the water content at field capacity and at permanent wilting point.

The local climate at the test site is temperate; summers are hot and dry, and winters are mild and rainy. According to long-term meteorological data (1929-2001), the annual mean rainfall, temperature, and relative humidity are 699 mm, 14.6 °C, and 69%, respectively. A sub-humid climate prevails in the region according to mean rainfall amount (from 600 to 700 mm of annual precipitation) (Jensen, 1980). Total monthly precipitation, relative humidity and mean air temperature in 2005, 2006 and long-term at Bursa are presented in Table 1. The climate of the region is sub-humid, but rainfall amounts are extremely low in the summer period. The seasonal rainfall amount is 73 mm, which coincides with 10% of total annual rainfall, for the summer period (June, July, and August) (Table 1).

Months	Temperature (°C)			Relative humidity (%)			Precipitation (mm)		
	2005	2006	Long-term*	2005	2006	Long-term	2005	2006	Long-term
January	6.2	5.5	5.3	75.2	71.1	74.1	150.4	78.3	88.8
February	6.6	7.4	6.2	65.2	69.4	73.4	77.7	71.3	77.5
March	8.5	9.2	8.3	67.4	68.2	70.2	77.9	38.8	69.8
April	13.7	12.1	13.0	60.1	74.0	70.3	56.1	20.4	62.9
May	17.6	16.6	17.6	68.3	61.4	69.5	23.5	9.2	50.0
June	21.2	21.5	22.1	58.7	64.2	62.9	21.1	43.5	30.4
July	24.7	23.8	24.5	62.2	52.3	58.1	55.2	3.6	24.0
August	25.1	26.4	24.1	63.5	50.6	60.5	4.5	3.7	18.9
September	20.1	19.9	20.1	68.8	65.9	66.4	16.8	91.2	40.1
October	13.2	16.7	15.6	72.7	77.1	72.8	37.5	45.6	60.4
November	9.3	13.8	11.2	74.6	75.2	75.6	109.3	43.1	76.3
December	6.1	8.7	7.6	70.2	71.4	74.2	58.0	68.2	99.9
Average/total	14.3	15.1	14.6	67.2	66.7	69.0	688.0	516.9	699.0

*29-year average of evaporation values

Table 1. Mean air temperature, relative humidity, evaporation and total monthly precipitation in 2005-2006 and long-term (1929-2001) at Bursa.

The experimental design was a randomized complete block in a split-split-split plot arrangement with four replicates and two years as blocking factors. The planting dates of the main plots were mid-April and mid-May. The split plots had the following plant populations: high plant population (660.000 plants ha^{-1}), or narrow-row spacing, and low plant population (330.000 plants ha^{-1}), or wide-row spacing. The split-split plots were cultivars A-3127 (Maturity group III) and 1530 (Maturity Group IV). The split-split-split plots were the following developmental stages as defined by Fehr and Caviness (1977): V_5, R_2, R_4, and R_6. The individual plot size was 5.0 x 12.0 m = 60 m^2. Plantings were done by hand at a 4-cm depth on 15 April and 18 May in 2005 and on 19 April and 20 May in 2006. Fertilizer was applied before planting at a rate of 30-60-0 kg ha^{-1} (N-P-K) according to soil test recommendations. Weed control was maintained by the pre-emergence application of metolachlor [2-chloro-N-(2-ethyl-6-methyphenyl)-N-(2-methoxy-1-methylethyl) acetamide] and imazaquin [2-(4.5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1-H-imidazol-2-yl)-3-quino linecarboxylic acit]. The previous crop was sunflower (*Helianthus annuus* L.) in the 2005 and 2006 experiment years. Water was applied when soil moisture reached 65% of the soil field capacity in each experimental year. Irrigation was applied four times (at V_5, R_1, R_2, and R_4 stages) with a sprinkler irrigation system in both experimental years.

2.2 Data collected

Ten plants from each plot were systematically selected to measure LAI at V_5, R_2, R_4, and R_6, respectively. In addition, the average CGR (g $m^{-2}d^{-1}$) during the V_5 to R_2, R_2 to R_4, and R_4 to

R_6 periods was determined for each plot. The crop growth rate (CGR) (e.g., during V_5 to R_2) was calculated by the following equation (Board, 2000):

$$CGR = \frac{TDM_{R2} - TDM_{V5}}{T_{R2} - T_{V5}}$$

where TDM_{V5} and TDM_{R2} are the total dry matter at the V_5 and R_2 developmental stages, respectively, and T is the number of days of the V_5 to R_2 period. The leaf area index (LAI) was determined by placing the leaf blades through a LI-COR 3000A portable leaf area meter. Light interception was measured between 11.00 and 14.00 h on the same day as the TDM sampling at the V_5, R_2, R_4, and R_6 developmental stages. A line quantum sensor (LI-COR LI-191 SA, Lincoln, NE) was connected to a LI-1400 data logger (1 m in length). This instrument, used to measure photosynthetically active radiation (PAR, $\mu molm^{-2}$ s^{-1}), was first held above the canopy, and two measurements were then made from each plot at the soil surface (Board et al., 1992). Photosynthetically active radiation (PAR) measurements were recorded as an average of three readings made at different places of the row in each plot. Light interception (LI %) was calculated as follows (Ball *et al.*, 2000a):

LI = [1 – (average PAR beneath canopy / PAR above)] x 100

Light interception efficiency (LIE) was determined as LI / LAI (Board and Harville, 1992). Plant samples used to determine LAI were dried in a forced air dryer at 60 °C to a constant weight. Dried plant samples were weighed to determine total dry matter.

Analysis of variance of LAI, LI, LIE, TDM, and CGR was made by using main plot, split plot, split-split plot, and split-split-split plot. Data were analyzed by year in accordance with a general linear model (SAS Inst., 1989) with mean separation according to LSD (p = 0.05 and 0.01). Seed yield, LI, LIE, LAI, TDM, and CGR were correlated by using year x plant population x cultivar x replication; year x planting date x cultivar x replication; and year x planting date x plant population x replication data points; within planting date x developmental stage; plant population x developmental stage; and cultivar x developmental stage treatment combinations, respectively.

3. Results

3.1 Planting date, plant population, cultivar, and developmental stage effects on LAI, LI, and LIE

Analysis of variance for LAI, LI and LIE revealed that planting date, plant population, cultivar, growth stage, and plant population x growth stage, except the planting date for LI, had highly significant effects ($P \leq 0.01$). In addition, year x plant population, year x growth stage and planting date x growth stage interactions for both LAI and LI were significant, but non-significant for LIE. Planting in mid-April resulted in significantly higher LAI and LIE than mid-May, whereas LI was not affected by planting dates. Leaf area index (LAI) and LI increases were significantly greater in the narrow rows (high plant populations) compared with the wide rows (low plant populations). In contrast, LIE was significantly higher in wide rows or low plant populations than narrow rows or high plant populations. LIE was significantly reduced in narrow rows (high plant populations), where LAI was high, probably due to the mutual shading of leaves. On average, the mid-April planting date and narrow rows (high plant populations) had near-optimum LAI for maximum LI whereas LAI was suboptimum in the mid-May planting date and wide rows (low plant populations) (Table 2). Greater LIE levels in the mid-April planting date and narrow rows (high plant populations), compared with the mid-May planting date and wide rows (low plant populations), and failed to compensate for the near-optimum or lower than optimum LAI levels. Nevertheless, LI showed a low level in the mid-April planting date and wide rows (low plant populations).

Treatment	LAI	LI (%)	LIE (%)
Planting date			
Mid-April	3.16	74.8	27.4
Mid-May	3.09	74.5	26.8
LSD (0.05)	*0.003*	*ns*	*0.257*
Plant population			
High	3.63	78.8	24.0
Low	2.63	70.4	30.2
LSD (0.05)	*0.253*	*0.085*	*0.253*
Cultivar			
A-3127 (Early)	3.04	73.9	27.5
1530 (Late)	3.22	75.3	26.7
LSD (0.05)	*0.014*	*0.590*	*0.200*
Developmental stage			
V_5	1.24	46.7	38.2
R_2	2.99	84.8	29.8
R_4	4.44	85.8	19.4
R_6	3.85	81.4	21.1
LSD (0.05)	*0.024*	*0.540*	*0.280*

ns: not significant

Table 2. Means for leaf area index (LAI), light interception (LI) and light interception efficiency (LIE) for planting dates (mid-April and mid-May), plant populations (high and low), cultivars (A-3127 and 1530), and developmental stages (V_5, R_2, R_4, and R_6), over data combined of two years (2005 and 2006).

Late-maturity cultivar 1530 had higher LAI and LI but lower LIE than early-maturity cultivar A-3127 (Table 2). LAI was always suboptimum in both cultivars. LAI significantly increased from the V_5 to the R_4 stage and decreased at the R_6 stage. Light interception (LI) increased greatly from the V_5 to the R_4 stage but decreased at the R_6 stage. In contrast, LIE significantly decreased from the vegetative development stage to reproductive development stage. LAI had suboptimum levels at the vegetative and early reproductive development stages, but reached optimum levels at the reproductive development stages (Table 2).

The planting date x plant population interaction for LAI was statistically significant, but this interaction was not clear, as shown in Figure 1. However, a significant cultivar x developmental stage interaction effect on both LAI and LIE did occur ($P \leq 0.01$). These interactions indicate that late-maturity cultivar 1530 had higher LAI, but lower LIE, compared with early-maturity cultivar A-3127 at the R_2 and R_4 stages, whereas at the V_5 and R_6 developmental stages, LAI and LIE values were similar across cultivars (Figure 2).

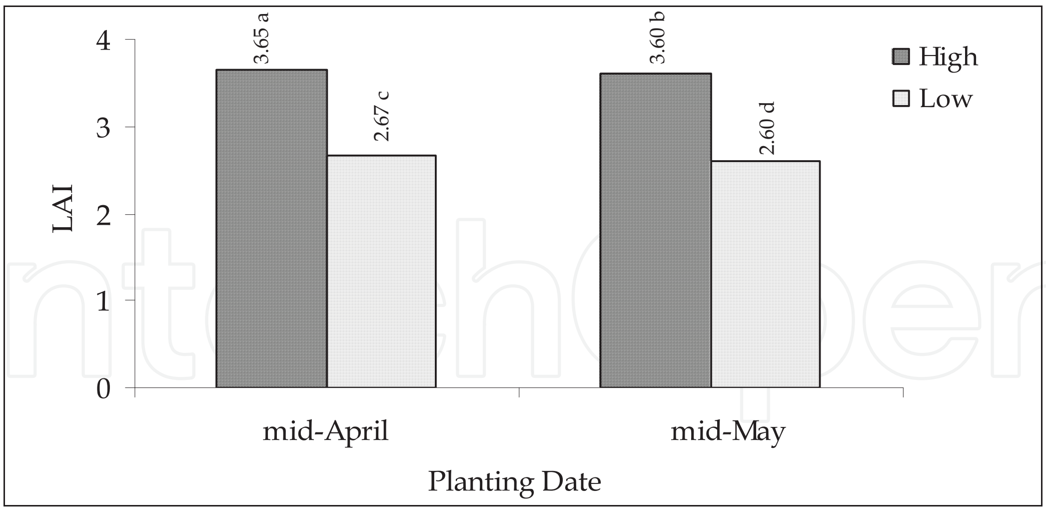

Fig. 1. Leaf area index (LAI) for soybean planted at high and low plant populations in mid-April and mid-May planting dates (2005-2006 combined data).

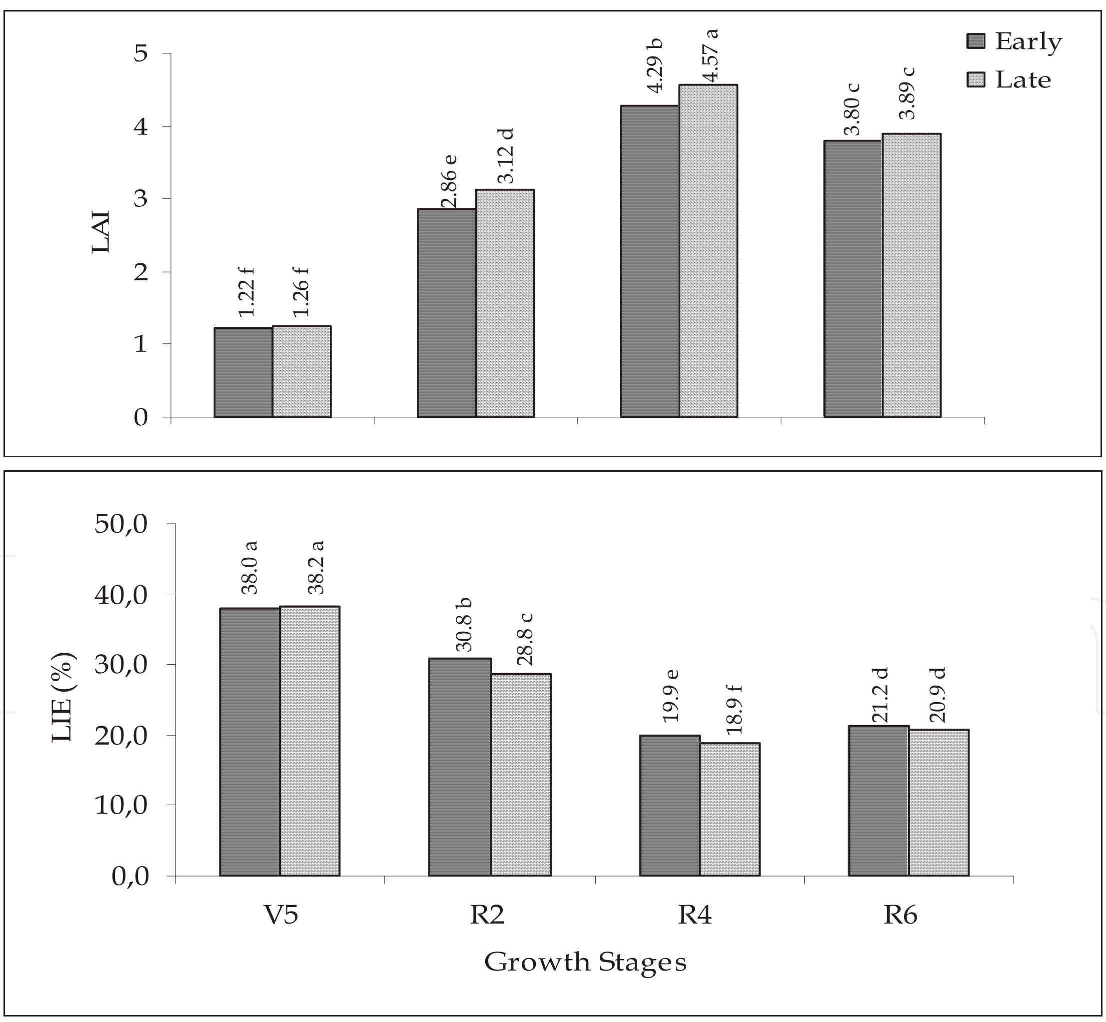

Fig. 2. Leaf area index (LAI) and light interception efficiency (LIE) during developmental stages for early and late maturity soybean cultivars (2005-2006 combined data).

Analysis of variance for LI and LIE revealed a statistically significant planting date x plant population x developmental stage interaction ($P \leq 0.01$), as shown Table 3. Light interception was significantly higher at the reproductive developmental stages than the vegetative developmental stage for each planting date and plant population combination. However, light interception at R_6 decreased in both plant populations at the mid-May planting compared with the mid-April planting. At the same time, high plant populations in both planting dates only had greater LIE at the vegetative stage, not the reproductive stages, while the highest LIE values were obtained from the V_5 and R_2 stages for low plant populations in both planting dates (Table 3).

Planting date	Plant population	Developmental stage	LAI	LI (%)	LIE (%)
Mid-April	High	V_5	1.33	48.9	36.4
		R_2	3.56	87.6	24.5
		R_4	5.08	90.4	17.7
		R_6	4.62	89.1	18.9
	Low	V_5	0.81	33.9	41.5
		R_2	2.16	77.9	36.1
		R_4	4.01	84.4	21.1
		R_6	3.69	86.2	23.3
Mid-May	High	V_5	1.74	61.7	35.3
		R_2	3.88	89.8	23.0
		R_4	4.84	87.4	17.8
		R_6	3.94	75.8	18.7
	Low	V_5	1.07	42.2	39.4
		R_2	2.35	83.8	35.5
		R_4	3.82	80.7	21.1
		R_6	3.15	74.4	23.6
LSD (0.05)			*ns*	*12.9*	*6.8*

ns: not significant

Table 3. Means for leaf area index (LAI), light interception (LI), and light interception efficiency (LIE) at different developmental stages of soybean planted at high and low plant populations in mid-April and mid-May planting dates over, data combined of two years (2005 and 2006).

The plant population x cultivar x developmental stage interaction was statistically significant for LI and LIE (Table 4). Light interception was much greater at the reproductive developmental stages than the vegetative stage (V_5) for each plant population x cultivar combination. LI increases at the reproductive developmental stages were greater for the low plant populations than the high plant populations. Light interception efficiency was statistically higher at the vegetative stage (V_5) than at the reproductive developmental stages for both cultivars in the high plant population, whereas the V_5 and R_2 stages had higher LIE than the other developmental stages for each cultivar in the low plant populations (Table 4).

Plant population	Cultivar	Developmental stage	LAI	LI (%)	LIE (%)
High	A-3127	V_5	1.51	54.7	35.9
		R_2	3.56	87.8	24.5
		R_4	4.85	88.6	18.1
		R_6	4.23	81.9	18.8
	1530	V_5	1.56	55.9	35.8
		R_2	3.89	89.6	23.0
		R_4	5.06	89.3	17.4
		R_6	4.33	83.0	18.9
Low	A-3127	V_5	0.93	37.1	40.2
		R_2	2.15	80.0	37.1
		R_4	3.73	81.3	21.7
		R_6	3.38	80.3	23.8
	1530	V_5	0.96	38.9	40.8
		R_2	2.35	81.7	34.5
		R_4	4.09	83.9	20.4
		R_6	3.47	80.3	23.1
LSD (0.05)			*ns*	*12.9*	*6.8*

ns: not significant

Table 4. Means for leaf area index (LAI), light interception (LI), and light interception efficiency (LIE) at different developmental stages of A-3127 and 1530 soybean cultivars planted at high and low plant populations, over data combined of two years (2005 and 2006).

3.2 Planting date, plant population, cultivar, and developmental stage effects on TDM and CGR

Analysis of variance indicated that planting date, plant population and cultivar significantly affected seed yield, total dry matter (TDM), and crop growth rate (CGR) ($P \leq 0.01$). The mid-April planting had a significantly higher seed yield and TDM, but lower CGR, than the mid-

Treatment	Seed yield (kg ha^{-1})	TDM (g m^{-2})	CGR (g m^{-2}d^{-1})
Planting date			
Mid-April	3082.4	647.8	6.26
Mid-May	2752.0	600.6	7.35
LSD (0.05)	*30.7*	*1.4*	*0.07*
Plant population			
High	3154.6	648.5	6.69
Low	2679.8	599.9	6.91
LSD (0.05)	*31.3*	*2.4*	*0.03*
Cultivar			
A-3127 (early)	2793.8	603.1	7.10
1530 (late)	3040.7	645.3	6.50
LSD (0.05)	*28.9*	*7.9*	*0.28*

Table 5. Means for seed yield, total dry matter (TDM) and crop growth rate (CGR) for A-3127 and 1530 soybean cultivars planted at high and low plant populations in mid-April and mid-May planting dates, over data combined of two years (2005 and 2006).

May planting (Table 5). The high plant populations gave a higher seed yield and TDM than the low plant populations. In contrast, CGR was significantly lower in the high plant populations than the low plant populations. In our study, late-maturity cultivar 1530 had a significantly higher seed yield and TDM than early-maturity cultivar A-3127, whereas cv. 1530 produced a lower CGR than cv. A-3127 (Table 5).
A year x developmental stage interaction was observed for TDM and CGR. In both years, TDM was significantly increased during the V_5 to R_6 period, and a higher TDM was obtained in 2005 compared with the 2006 experimental year for each developmental stage. However, differences among the years in TDM were greater at the R_4 stages than the V_5 and R_2 developmental stages (Figure 3). The crop growth rate decreased significantly from 9.7-11.7 g m^{-2} d^{-1} at the V_5-R_2 period to 1.7-2.0 g m^{-2} d^{-1} at the R_4-R_6 period in both years. CGR was higher at the V_5-R_2 and R_2-R_4 periods in 2005 than the 2006 experimental year, whereas no differences were observed between 2005 and 2006 in the R_4-R_6 period (Figure 3).

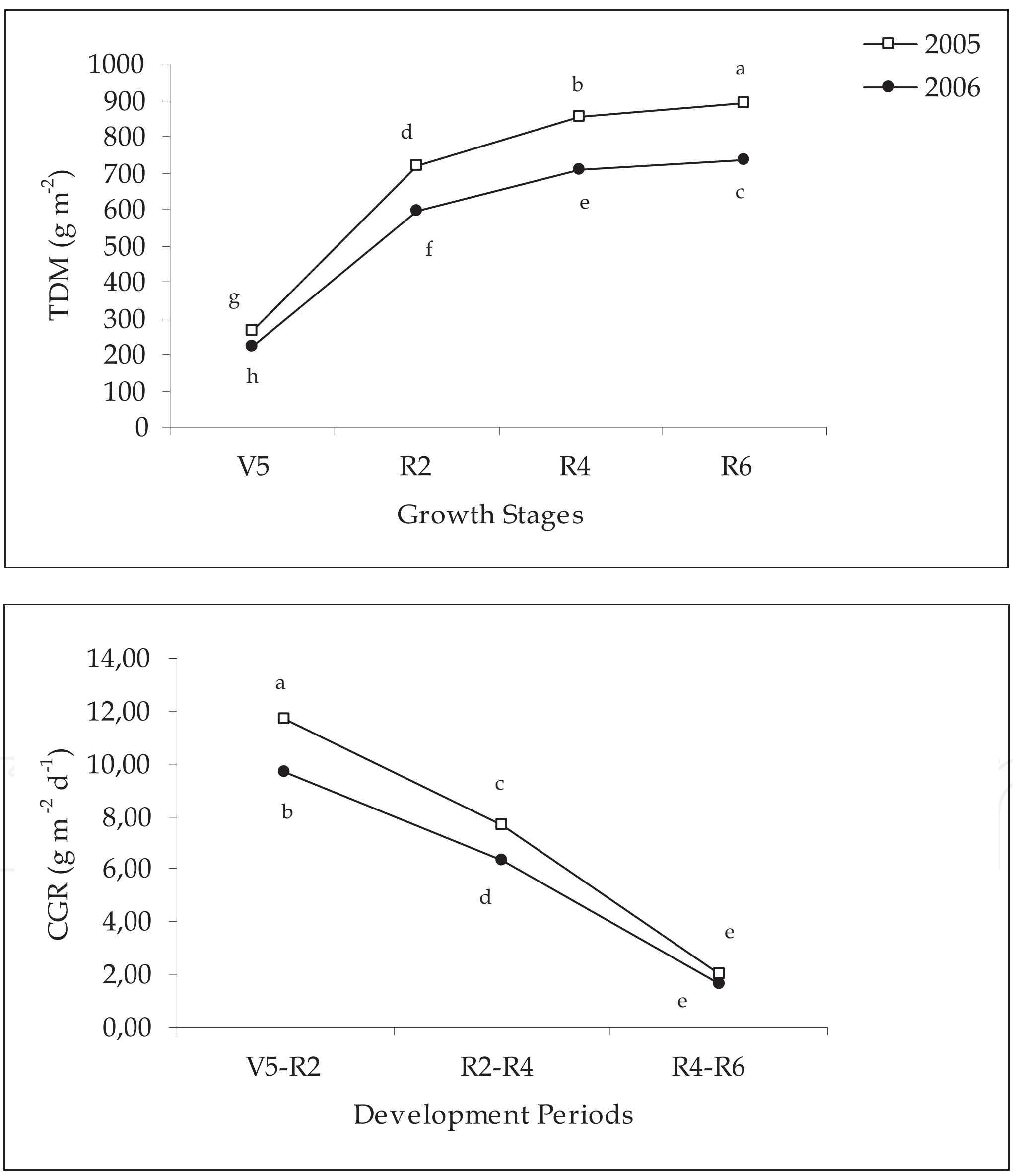

Fig. 3. Total dry matter (TDM) and crop growth rate (CGR) during growth stages and development periods for soybean planted in 2005 and 2006.

The total dry matter greatly increased during the V_5 to R_6 period in the mid-May planting, whereas these increases occurred during the V_5 to R_4 period in mid-April planting. TDM did not significantly increase at the R_6 stage (Figure 4). However, CGR decreased from 10.5-11.0 g m^{-2} d^{-1} in the V_5-R_2 period to 0.73 – 2.96 g m^{-2} d^{-1} in the R_4-R_6 period in each planting date. These decreases were statistically significant. Although differences in CGR between planting dates were not significant in the V_5-R_2 period, the mid-May planting date had greater CGR in the R_2-R_4 and R_4-R_6 periods than the mid-April planting (Figure 4). The highest CGR in both planting dates was obtained from the V_5-R_2 period. In both planting dates, however, a LAI of 3.0 was reached by R_2, and light interception was at an optimal level of 95% in R_2.

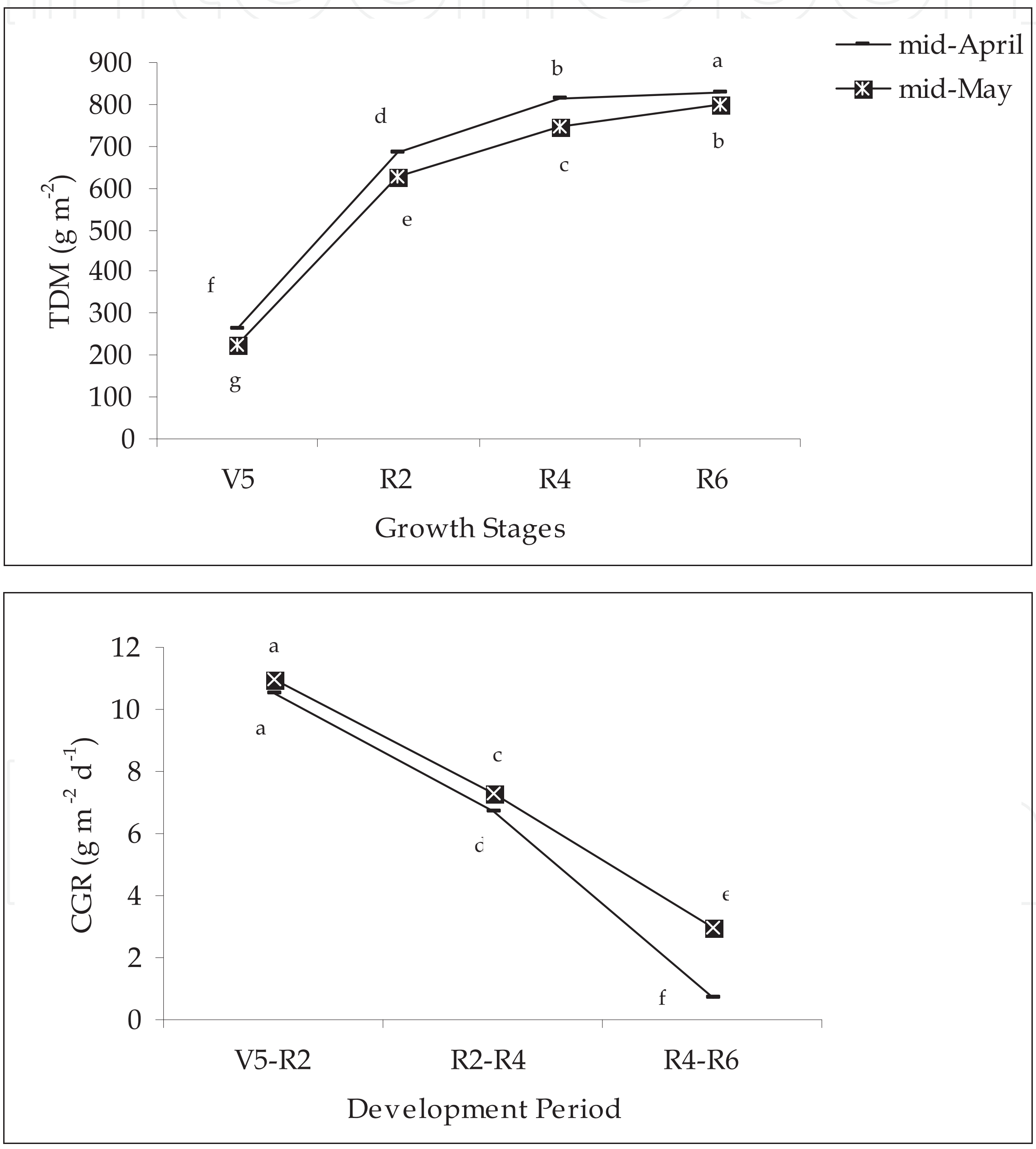

Fig. 4. Total dry matter (TDM) and crop growth rate (CGR) during growth stages and development periods for soybean planted in the mid-April and mid-May (2005-2006 combined data).

Total dry matter significantly increased during the V_5 to R_6 stages in each plant population, and these increases were always greater in the higher vs. lower plant populations during the same period. Crop growth rates significantly reduced from the V_5-R_2 period to R_4-R_6 period in each plant population (Figure 5).

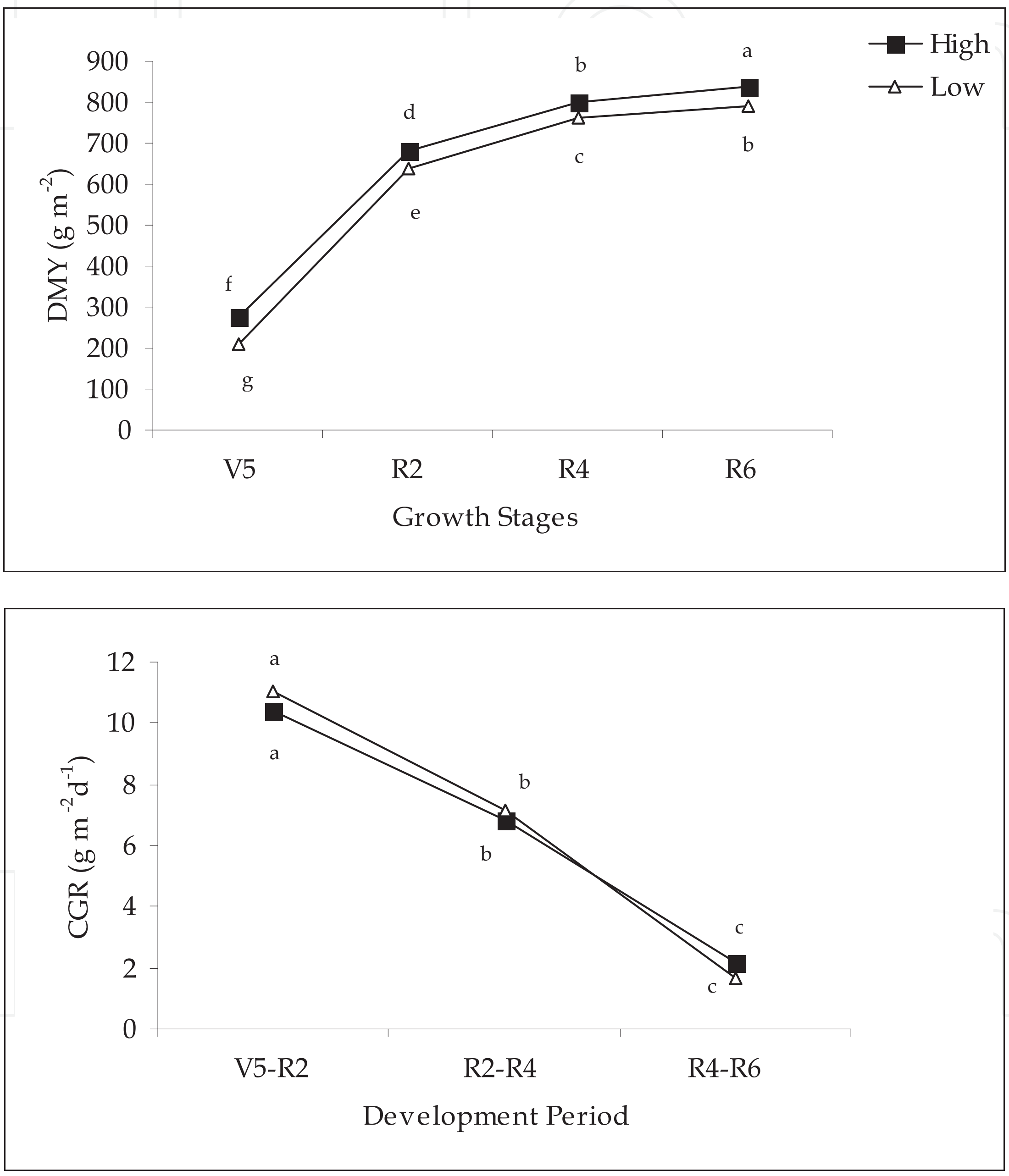

Fig. 5. Total dry matter (TDM) and crop growth rate (CGR) during growth stages and development periods for soybean grown at low and high plant populations (2005-2006 combined data).

Correlations between seed yield and LI, LAI, and TDM were positive and highly significant for all developmental stages in both planting dates. In addition, seed yield was positively and significantly associated with LI, LAI, and TDM for all plant population x developmental stage treatment combinations except for the V_5 developmental stages at high and low plant populations. Positive and significant correlations were also found between seed yield and LI, LAI, and TDM for all cultivar x developmental stage treatment combinations. In contrast, relationships between seed yield and LIE were mostly negative and significant, while the correlation between LI and LIE was not significant for most of the two-way treatment combinations (Table 6). Correlations between seed yield and CGR were nonsignificant for most two-way treatment combinations (Table 6).
Correlative relationships between LI with LAI and TDM were positive and significant ($P \leq 0.01$) for all developmental stages in each planting date. Correlations between LI and LAI were positively and highly significant for all plant population x developmental stage treatment combinations, while relationships between LI and TDM were nonsignificant for only the V_5 stage in both plant populations. Also, LI was positively and significantly associated with LAI and TDM for all cultivar x developmental stage treatments. On the other hand, correlations between LI and CGR were either nonsignificant or low for most treatment combinations (Table 6). Associations between LI and LIE were either negatively significant or nonsignificant for all treatment combinations (Table 6).

4. Discussion

Our data demonstrate that cultural practices affect developmental dynamics such as LAI, LI, LIE, CGR, and TDM in soybeans. Planting in mid-April resulted in significantly higher LAI and LIE than planting in mid-May, whereas LI was not affected by planting dates. LAI and LI increases were significantly greater in narrow rows (high plant populations) than wide rows (low plant populations). In contrast, LIE was significantly higher in wide rows (low plant populations) than narrow rows (high plant populations). Significant increases in LIE in the mid-April plantings were due to the insufficient shading effects of leaves because LAI was not high enough in the mid-April planting date. Late-maturity cultivar 1530 had higher LAI and LI but lower LIE than early-maturity cultivar A-3127. However, LAI was always suboptimum in both cultivars. The leaf area index significantly increased from the V_5 to the R_4 stages and reduced at the R_6 stage. Light interception greatly increased from the V_5 to the R_4 stage but decreased at the R_6 stage. In contrast, LIE significantly decreased from the vegetative development stage to the reproductive developmental stage. The leaf area index had suboptimum levels at the vegetative and early reproductive developmental stages, but they reached optimum levels at the reproductive development stages. Our findings do not correspond to those of Board and Harville (1992), who reported that significant increases in LIE in narrow compared with wide rows occurred only in the July planting date, when LAI was lower. Those authors noted that the mutual shading of leaves probably prevented any increase in LIE at the higher LAI of the May planting date.
In our study, the significant increase in LIE in the mid-April planting date was due to the insufficient shading effects of the leaves; this was because LAI was not high enough in the mid-April planting date. Our results were, however, partially in agreement with those of

Treatment combination		Correlation coefficient of seed yield with;					Cor
		LAI	LI (%)	LIE (%)	TDM (g m^{-2})	CGR($gm^{-2}d^{-1}$)	LAI
Mid-April	V_5	0.812**	0.849**	-0.466**	0.953**	0.254 ns	0.980**
	R_2	0.851**	0.951**	-0.692**	0.844**	0.122 ns	0.835**
	R_4	0.939**	0.892**	-0.723**	0.814**	-0.005 ns	0.834**
	R_6	0.935**	0.780**	-0.688**	0.823**	0.275 ns	0.704**
Mid-May	V_5	0.794**	0.815**	-0.563**	0.885**	0.281 ns	0.992**
	R_2	0.827**	0.880**	-0.652**	0.879**	0.226 ns	0.670**
	R_4	0.920**	0.896**	-0.654**	0.835**	0.173 ns	0.855**
	R_6	0.907**	0.758**	-0.608**	0.861**	0.404*	0.642**
High population	V_5	-0.131 ns	-0.099 ns	0.236 ns	0.932**	0.275 ns	0.982**
	R_2	0.425*	0.622**	0.169 ns	0.920**	0.160 ns	0.867**
	R_4	0.888**	0.819**	-0.337 ns	0.903**	-0.314 ns	0.949**
	R_6	0.916**	0.894**	0.197 ns	0.817**	0.089 ns	0.995**
Low population	V_5	-0.044 ns	0.096 ns	0.505**	0.855**	0.520**	0.973**
	R_2	0.534**	0.511**	-0.177 ns	0.934**	0.183 ns	0.931**
	R_4	0.945**	0.925**	-0.283 ns	0.931**	-0.220 ns	0.930**
	R_6	0.891**	0.849**	-0.386*	0.905**	0.305 ns	0.977**
A-3127	V_5	0.412*	0.418*	-0.346*	0.929**	0.271 ns	0.992**
	R_2	0.626**	0.663**	-0.512**	0.881**	0.171 ns	0.752**
	R_4	0.859**	0.930**	-0.518**	0.838**	-0.123 ns	0.862**
	R_6	0.943**	0.812**	-0.524**	0.802**	0.171 ns	0.756**
1530	V_5	0.477**	0.473**	-0.350*	0.935**	0.196 ns	0.988**
	R_2	0.709**	0.734**	-0.599**	0.847**	0.196 ns	0.754**
	R_4	0.946**	0.860**	-0.696**	0.825**	-0.168 ns	0.834**
	R_6	0.967**	0.799**	-0.687**	0.805**	0.110 ns	0.793**

*, **Significant at P= 0.05 and 0.01, respectively; ns: not significant.

Table 6. Coefficients of correlations of seed yield with all the other characteristics and coefficients of correlations of light interception (LI) with the other characteristics except seed yield at certain developmental stages for A-3127 and 1530 soybean cultivars planted at high and low plant populations in mid-April and mid-May.

Board (2000), who found that LAI and LI were higher in medium or high plant populations compared with low plant populations, and lower in high plant populations than low plant populations at R_1. Board and Harville (1992) reported that the planting date x row spacing interaction had highly significant effects on LIE, while the planting date x cultivar x row spacing interaction was highly significant for LI. In our study, although the year x developmental stage and year x plant population interactions were significant ($P \leq 0.01$) for LAI and LI, these interactions are not clear or explicable. However, the significant year x developmental stage interaction for LAI and LI reveal that increases in LAI and LI from the V_5 to R_4 were greater in 2005 than in 2006. Board and Harville (1992) reported the occurrence of a significant row spacing x developmental stage effect on LI ($P = 0.01$). The authors stated that narrow row width resulted in significantly higher LI at all developmental stages.

Soybeans planted in mid-April had significantly higher TDM, but lower CGR in those planted in mid-May. The high plant populations gave higher TDM than the low plant populations. In contrast, CGR was significantly lower in the high plant populations than the low plant populations. In addition, late-maturity cultivar 1530 had significantly higher TDM than early-maturity cultivar A-3127, whereas cv. 1530 produced lower CGR than cv. A-3127. Crop growth rates decreased greatly from 9.7-11.7 g $m^{-2}d^{-1}$ in the V_5-R_2 period and to 1.7-2.0 g $m^{-2}d^{-1}$ in the R_4-R_6 period in both years. The leaf area index for both planting dates was optimum (4.0) for a maximum LI of 95% by R_4, whereas LI and CGR at stage R_4 were less than optimal (95%). An earlier study has indicated that optimal CGR and yield result when LAI is optimal (3.0 to 3.5) for achieving an optimal light interception of 95% by R_5 (Shibles and Weber, 1966). Several studies have concluded that the relationship between LAI and optimal CGR vary with environmental conditions (Jeffers and Shibles, 1969). However, optimal LI during the vegetative and early reproductive periods were not required to maximize yield (Board and Harville, 1994). In our study, CGR for the R_2-R_4 period was not at an optimal level, although LAI and LI were at or near optimum for the R_2 and R_4 developmental stages in the high plant populations. These results were similar for low plant populations, except for LAI at the R_2 stage.

Seed yield was positively and significantly correlated with LI, LAI, and TDM for both planting date x developmental stage and plant population x developmental stage treatment combinations. Correlations between seed yield and CGR were nonsignificant, while seed yield was negatively associated with LIE for most of the two-way treatment combinations. LI was positively and significantly associated with LAI and TDM for all of the two-way treatment combinations, whereas correlations between LI with CGR and LIE were nonsignificant for most treatment combinations. Earlier studies reported that soybean yield is positively related to LAI and dry matter at the R_5 stage (Wells *et al.*, 1982; Board and Tan, 1995; Kumudi, 2002; Liu *et al.*, 2005). In addition, the results of Shibles and Weber (1966) demonstrated that seed yield is highly associated with LAI, LI, and CGR. On the other hand, our findings are in agreement with those of Carpenter and Board (1997) who reported that as LAI increased, LIE decreased due to the mutual shading of leaves.

5. Conclusions

Plant population per unit area and growth dynamics such as LAI, LI, LIE, TDM and CGR are major predictors of soybean yield. In our study, planting in mid-April resulted in significantly higher LAI, LIE, and TDM but lower CGR compared with the mid-May planting. Light interception (LI) was not affected by planting dates. Leaf area index (LAI), TDM, and LI increases were significantly greater in the narrow rows (high plant populations) than the wide rows (low plant populations). In contrast, LIE and CGR were significantly higher in the wide rows (low plant populations) than in the high plant populations (narrow rows). Late-maturity cultivar 1530 had higher LAI, LI, and TDM but lower LIE and CGR than early-maturity cultivar A-3127. Seed yield was positively and significantly correlated with LI, LAI, and TDM for most of the treatment combinations.

Our research group has also in work to determinate the associations between soybean yield and growth dynamics, intending in future to make different studies.

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7. References

Ball, R.A.; Purcell, L.C. & Vories, E.D. (2000a). Optimizing soybean plant population for a short-season production system in the southern USA. *Crop Science,* 40(3): 757–764. ISSN: 0011-183X.

Ball, R.A.; Purcell, L.C. &Vories, E.D. (2000b). Short-season soybean yield compensation in response to population and water regime. *Crop Science,* 40(4): 1070–1078. ISSN: 0011-183X.

Beatty, K.D.; Eldridge, I.L. & Simpson, A.M. (1982). Soybean response to different planting patterns and dates. *Agronomy Journal*, 74(5): 859– 862. ISSN: 0002-1962.

Board, J.E.; Harville, B.G. & Saxton, A.M. (1990). Narrow-row seed-yield enhancement in determinate soybean. *Agronomy Journal*, 82(1): 64-68. ISSN: 0002-1962.

Board, J.E. & Harville, B.G. (1992). Explanations for greater light interception in narrow- vs. wide-row soybean. *Crop Science*, 32(1): 198–202. ISSN: 0011-183X.

Board, J.E.; Kamal, M. & Harville, B.G. (1992). Temporal importance of greater light interception to increased yield in narrow-row soybean. *Agronomy Journal*, 84(4): 575–579. ISSN: 0002-1962.

Board, J.E. & Harville, B.G. (1993). Soybean yield component responses to a light interception gradient during the reproductive period. *Crop Science*, 33(4): 772–777. ISSN: 0011-183X.

Board, J.E. & Harville, B.G. (1994). A criterion for acceptance of narrow-row culture in soybean. *Agronomy Journal*, 86(6): 1103–1106. ISSN: 0002-1962.

Board, J.E. & Tan, Q. (1995). Assimilatory capacity effects on soybean yield components and pod number. *Crop Science*, 35(3): 846-851. ISSN: 0011-183X.

Board, J. (2000). Light interception efficiency and light quality affect yield compensation of soybean at low plant population. *Crop Science*, 40(5): 1285-1294. ISSN: 0011-183X.

Boerma H.R. & Ashley D.A. (1982). Irrigation, row spacing, and genotype effects on late and ultra-late planted soybeans. *Agronomy Journal*, 74(6): 995-998. ISSN: 0002-1962.

Boquet, D.J.; Koonce, K.L. & Walker, D.M. (1982). Selected determinate soybean cultivar yield response to row spacings and planting dates. *Agronomy Journal*, 74(1): 136-138. ISSN: 0002-1962.

Bullock, D.; Khan, S. & Rayburn, A. (1998). Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop Science*, 38(4): 1011–1016. ISSN: 0011-183X.

Carpenter, A.C. & Board, J.E. (1997). Branch yield components controlling soybean yield stability across plant populations. *Crop Science*, 37(3): 885–891. ISSN: 0011-183X.

Carter, T.E. & Boerma, H.R. (1979). Implications of genotype x planting date and row spacing interactions in double-cropped soybean cultivar development. *Crop Science*, 19(5): 607–610. ISSN: 0011-183X.

Costa, J.A.; Oplinger, E.S. & Pendleton, J.W. (1980). Response of soybean cultivars to planting patterns. *Agronomy Journal*, 72(1): 153–156. ISSN: 0002-1962.

Duncan, W.G. (1986). Planting patterns and soybean yields. *Crop Science*, 26(3): 584-588. ISSN: 0011-183X.

Egli, D.B.; Leggett, J.E. & Wood, J.M. (1978). Influence of soybean seed size and position on the rate and duration of filling. *Agronomy Journal*, 70(1): 127-130. ISSN: 0002-1962.

Egli, D.B. (1988). Plant density and soybean yield. *Crop Science*, 28(6): 977–981. ISSN: 0011-183X.

Egli, D.B. (1993). Cultivar maturity and potential yield of soybean. *Field Crops Research*, 32(1-2): 147-158. ISSN: 0378-4290.

Egli, D.B. & Bruening, W.P. (2000). Potential of early-maturing soybean cultivars in late plantings. *Agronomy Journal*, 92(3): 532–537. ISSN: 0002-1962.

Ennin, S.A. & Clegg, M.D. (2001). Effect of soybean plant populations in a soybean and maize rotation. *Agronomy Journal*, 93(2): 396–403. ISSN: 0002-1962.

Fehr, W.R. & Caviness, C.E. (1977). Stages of soybean development. Iowa Agric. Home Econ. Exp. Sta., Iowa Coop. Ext. Serv. Spec. Re. 80.

Herbert S.J. & Litchfield G.U. (1984). Growth response of short season soybean to variations in row spacing and density. *Field Crops Research*, 9(1): 163-171. ISSN: 0378-4290.

Holshouser, D.L. & Whittaker, J.P. (2002). Plant population and row spacing effects on early soybean production systems in the mid Atlantic USA. *Agronomy Journal*, 94(3): 603–611. ISSN: 0002-1962.

Hunt R. (1978). Plant growth analysis. Southampton, UK: Camelot Press, Inst. Biol. Stud. Biol. 96.

Hunt, R. (1982). Plant growth curves: The functional approach to plant growth analysis. Arnold, London, and Univ. Park Press, Baltimore, MD.

Jeffers D.L. & Shibles R.M. (1969). Some effects of leaf area, solar radiation, air temperature, and variety on net photosynthesis in field-grown soybeans. *Crop Science*, 9(6): 762-764. ISSN: 0011-183X.

Jensen, M.E. (Ed.). (1980). Design and Operation of Farm Irrigation Systems. Amer. Soc. Agric. Engr. St. Joseph, MI. 829 pgs.

Kane, M.V. & Grabau, L.J. (1992). Early planted, early maturing soybean cropping system: Growth, development, and yield. *Agronomy Journal*, 84(5): 769–773.

Kumudi, S. (2002). Trials and tribulations: a review of the role of assimilate supply in soybean genetic yield improvement. *Field Crops Research*, 75(2-3): 211–222. ISSN: 0378-4290.

Liu, X.B.; Jin, J.; Herbert, S.J.; Zhang Q.Y. & Wang G.H. (2005). Yield components, dry matter, LAI, and LAD of soybeans in Northeast China. *Field Crops Research*, 93(1): 85–93. ISSN: 0378-4290.

Loomis, R.S. & Connor, D.J. (1992). Community concepts. In: *Crop Ecology: Productivity and Management in Agricultural Systems.* pp. 32–59. Cambridge Univ. Press, Cambridge, UK. ISBN:0-521.38379-X.

Parker, M.B.; Marchant, W.H. & Mullinix, B.J., Jr. (1981). Date of planting and row spacing effects on four soybean cultivars. *Agronomy Journal*, 73(5): 759–762. ISSN: 0002-1962.

Parks, W.L.; Davis, J.; Evans, R.; Smith, M.; Mccutchen, T.; Sofley, L. & Sanders, W. (1982). Soybean yields as affected by row spacing and within row plant density. Univ. of Tenn. Agric. Exp. Stn. Bull. 615. Knoxville, TN.

Pedersen, P. & Lauer, J.G. (2004). Response of soybean yield components to management system and planting date. *Agronomy Journal*, 96(5): 1372-1381. ISSN: 0002-1962.

Purcell, L.C.; Ball, R.A.; Reaper, J.D. & Vories, E.D. (2002). Radiation use efficiency and biomass production in soybean at different plant population densities. *Crop Science*, 42(1): 172–177. ISSN: 0011-183X.

Sas Institute, (1989). SAS/STAT user's guide. Version 6 edition. Cary, NC: SAS Institute, Cary, NC.

Shibles, R.M. & Weber, C.R. (1966). Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Science*, 6(1): 55-59. ISSN: 0011-183X.

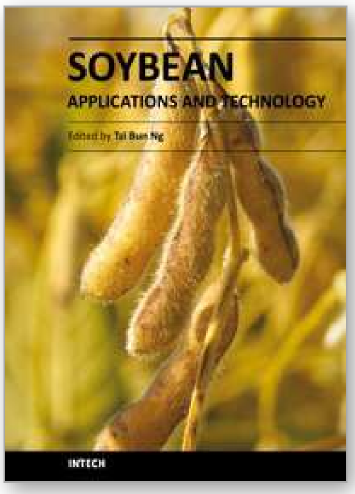
Weber, C.R.; Shibles, R.M. & Byth, D.E. (1966). Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58(1): 99-102. ISSN: 0002-1962.

Wells, R.; Schulze, L.L.; Ashley, D.A.; Boerma, H.R. & Brown, R.H. (1982). Cultivar differences in canopy apparent photosynthesis and their relationship to seed yield in soybeans. *Crop Science*, 22(4): 886–890. ISSN: 0011-183X.

Wells, R. (1991). Soybean growth response to plant density: relationship among canopy photosynthesis, leaf area, and light interception. *Crop Science*, 31(3): 755–761. ISSN: 0011-183X.

Wells, R. (1993). Dynamics of soybean growth in variable planting patterns. *Agronomy Journal*, 85(1): 44–48. ISSN: 0002-1962.

Westgate, M.E. (1999). Managing soybeans for photosynthetic efficiency. In: H.E. Kauffman (Ed.) World Soybean Research. Proc. World Soybean Res. Conf., 6th, Chicago, IL. 4–7 Aug. 1999. Supehybrid rior Printing, Champaign, IL.



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Soybean is an agricultural crop of tremendous economic importance. Soybean and food items derived from it form dietary components of numerous people, especially those living in the Orient. The health benefits of soybean have attracted the attention of nutritionists as well as common people.