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Effects of Stem Lengths on Seed Yield and Yield Components of Late Planted Soybeans

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Abstract: Soybeans (*Glycine max* L.) have late planted as a double crop, causing a short growing period. Because of short season, growers employ high plant density of cultivars developed primarily for a full-season practice to compensate a potential loss of seed yield. The objective of this study was to examine the effects of two plant densities and variable stem lengths on growth characteristics and to determine the casual relationships of growth characteristics with seed yield for the development of breeding strategies. All genotypes in high plant density significantly ($p<0.05$) reduced in leaf area (48.0-70.7%), dry weights of leaves (1.8-44.2%) and stems (14.0-54.0%). Short stem genotypes (Camp and HS 287) significantly ($p<0.05$) increased in number of pods at the upper nodes (3.1-15.6%) and in number of pods carried on the main stem (70.0-86.4%) as plant density increased. Larger decline in sink capacity (seed g plant^{-1}) was observed with high plant density in long stem (38.9-75.8%) than in short stem (30.0-38.2%) genotypes. Plant dry biomass apparently increased in all genotypes, ranging from 8.2 to 53.1% and among these a short stem genotype Camp significantly increased from 7,240 to11,082 kg ha^{-1} (53.1% increased) in high plant density. Harvest Index (HI) increased in most short stem genotypes in high plant density. Seed yield (kg ha^{-1}) of all genotypes increased (3.9-14.8%) in high plant density, particularly short stem genotypes, Camp and HS 287, which efficiently improved more seed yield than long stem ones (14.8 and 7.7%, respectively). The major components for increased seed yield in high plant density were an increase in number of pods per unit area and number of pods carried on the main stem.

Key words: Double crop · late planting · stem internode · plant density · soybean

INTRODUCTION

Planting soybeans (*Glycine max* L. Merr.) as a double crop following small grain crops such as winter wheat and barley has been of concern in many countries. Double cropped soybeans are often planted later than the best planting season, resulting in a short growing period. This short growing season prompts farmers to employ higher plant density of cultivars developed primarily for a full-season cropping practice rather than a standard plant density to minimize a loss of seed yield. High population density of the conventional soybean cultivars has caused a significant productivity decline [1]. Reductions in seed yields may be result from lower number of seeds per plant, small size of seed, lodging, or a compounding of these with other yield components. The previous results suggest that a high plant population affected to growth characteristics and ultimately limited seed yield due to insufficient development of the canopy of leaves for a full use of photosynthetically active radiation [1, 2]. Soybean yield and biomass had an asymptotic relationship with cumulative intercepted photosynthetically active radiation from emergence to seed development stage [3]. The complete establishment of the canopy prior to early reproductive stage might be very crucial to ensure high seed yields.

Soybean seed yields increased as row spacing reduced from 100 to 75 and to 50 cm [4]. High population

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density significantly increased plant dry biomass per unit area, but decreased both number of branches and accumulation of dry matter per plant [1, 2, 5]. Although the effects of diverse plant densities on seed yield and other agronomic traits varied and depended upon environmental conditions, a high seed rate was the most suitable choice under growth-restricting conditions such as late planting [6]. In other words, the increase in seeding rate of appropriate genotypes per unit area increased grainyield [7, 8].

Harvest index (HI), the ratio of grain dry weight to total above ground dry matter, was closely related to sink capacity [9] and the stability of HI reflected the important effect of the shoot drymatter on pod development during reproductive stages in soybeans [10]. Sink capacity, capacity of the plant to form yield, affected to plant growth and development that in turn generated greater plant dry biomass and increased the size of the sink and thus may be important for determining the final yield [11].

A constant demand for the development of superior cultivars and cultural practice under high plant density has been a major concern in many investigations [12]. One of the continuing goals of soybean breeders is to develop stable, high yielding cultivars that are agronomically superior [13]. But, little work has been accomplished in our understanding the effects of plant density with variable mainstem lengths on crop performance, particularly agronomic growth characteristics. Understanding of growth responses and patterns to various plant densities helps develop superior cultivars to perform well over varying growth conditions. The objective of this study was to examine the effects plant densities and diverse stem growths on plant growth and development and to determine the causal relationships of the growth characteristics with grain yield to develop strategies that can be used for breeding programs.

MATERIALS AND METHODS

Plant materials: Three groups of primary main stem growths with a total of five soybean genotypes (Camp, Eunhakong, HS 287, Iksannamulkong and Pureunkong) were used in this study: one group of a long main stem included Iksannamulkong and Pureunkong and ranged from 76±4 to101±8 cm in plant height (Table 1). Other group of short main stem involved Camp and HS 287 and ranged from 50±5 to 45±6 cm in plant height. Eunhakong was used as an intermediate stem, 63±5 cm in plant height. The long and short stem genotypes divided into two subclasses: highly and few branched types. Iksannamulkong possessed lateral (2°axis) branches with 4.2±0.4 more than those of Pureunkong which had branches with 1.2±0.3. Camp and HS 287 were 4.1±0.4 and 2.3±0.3 in number of branches, respectively. Eunhakong had 3.2±0.04 in number of branches. Other growth characteristics, including maturity and 100-seed weight, of genotypes are shown in Table 1.

Field experiments: Field experiments were conducted over a period of three years in Iksan (126.97' E, 36.00' N), Korea. Seeds were planted in fields during the first week of June in a randomized complete block design with three replicates at the Honam Agricultural Research Institute farms. Each plot consisted of four rows spaced at 0.60 m apart and 4 m in length, in which seeds were sown following a harvest of winter crop (wheat or barley). The seedlings were thinned to achieve designated plant population density (i.e., 33 and 66 plants m^{-2} as low and high plant densities, respectively). Fertilizer was applied to test plots at 1.0-1.7-1.5 kg ha^{-1} of N-P$_2$O$_5$-K$_2$O as a basal dose. No irrigation was provided during the crop growth period. Border rows were planted to eliminate edge effects.

At least three samples were randomly taken from each of the two central rows in each plot for growth characteristics, including number of mature pods per plant, seeds per pod, number of nodes, 100-seed weight and plant dry biomass. All plants from two rows were harvested for mean seed yield (kg ha^{-1}) and other important traits, including dry biomass. Leaf area was measured on a LI-3100 electronic area meter (Li-Co, Lincoln, NE). Total dry biomass was determined after

Table 1: Major vegetative and reproductive characteristics of genotypes with different stem growth habits and lateral branch types used in this study

Variety	Main stem	Branch[a] (no.)	Inflorescence	Plant height (cm)	R1[b] (d)	Maturity (d)	100-seed weight (g)
Eunhakong	Intermediate, with highly branched type	3.2±0.4	DT	63±5	31 Jul. (56)	9 Oct. (126)	11.6±0.4
Iksannamulkong	Long, with highly branched type	4.2±0.4	DT	76±4	4 Aug. (60)	9 Oct. (126)	12.6±0.2
Pureunkong	Long,with few branched type	1.2±0.3	IT	101±8	13 Jul. (38)	27 Sep. (114)	13.5±0.9
Camp	Short,with highly branched type	4.1±0.4	DT	50±5	2 Aug. (58)	10 Oct. (127)	8.0±0.2
HS 287	Short,with few branched type	2.3±0.3	DT	45±6	26 Jul. (51)	29 Sep. (116)	15.4±0.3

[a] Includes primary branches except for subbranches; [b] At least one flower is located at any node on the main stem; DT, determinate (monotelic) inflorescence; IT, indeterminate (polytelic) inflorescence

mature plants in a dry oven for 3 d at 65±5°C and pods were separately collected from each plant.

A visual rating between 1 to 9: 1, almost all plants erect; and 9, all plants prostrate was used to determine resistance to lodging [14]. Sink capacity indicating a capacity of the plant to form yield was estimated by total seed weight (g) per plant. Harvest index, the ratio of seed mass to total plant biomass, was calculated as total dry seed weight divided by total above ground dry biomass per plant [15].

Statistical analysis: The data were subjected to analysis of variance (ANOVA) using a factorial experiment in randomized complete block design over three years. Mean values from three replicates and pooled standard error of the mean were calculated by PROC GLM [16] and used for calculating Least Significant Differences (LSD) at the 0.05 level of probability comparison of means among treatments.

RESULTS

Responses of vegetative characteristics to plant density: Plant height increased in plots of high plant density (66 plants m^{-2}) from 4 to 18% as compared to low plant density (33 plants m^{-2}) (Table 2). Increase in plant height was more seen in short stem genotypes (Camp and HS 287) (up to 18%) than long stem ones, but the diameter of main stem in all genotypes declined from 11 to 21% in high plant density.

Lateral branches in high plant density decreased by 31-75% in all genotypes. Decreased number of lateral branches was more observed in few branched genotypes (Purenukong and HS 287) than the highly branched (Iksannamulkong and Camp). All genotypes showed delayed maturity of 1-3 days as numbers of plants increased per unit area. Internode length significantly ($p<0.05$) increased at mid-vegetative stages (V7-12) in long stem genotypes with highly branched cyme in high plant density (60×10 cm) (Fig. 1). Short stem genotype

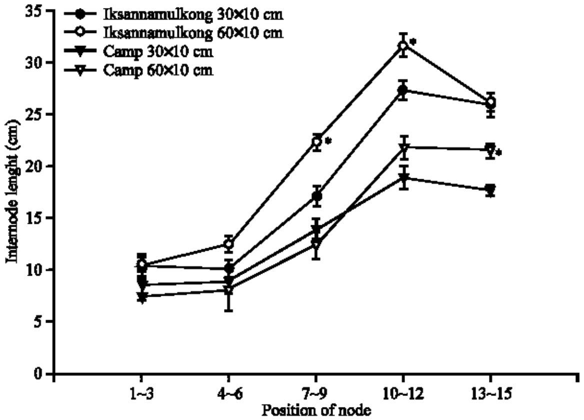

Fig. 1: Three-year mean of the position of nodes and internode length in two genotypes with long stem Iksannamulkong and with short stem Camp grown under different plant densities. n = 18, * Significantly different at the 0.05 probability level as compared to low plant density (30×10 cm)

Table 2: Vegetative growth characteristics in five soybean genotypes with different stem growth habits in two plant densities for three-year trials

Variety	Plant density (no. m^{-2})	Plant height (cm)	Lodging 1-9	Stem diameter (cm)	Branch (no.)	Maturity (d)
Eunhakong	33	81	6.3	7.4	3.2	3 Oct. (116)
	66	85	7.7	6.6	2.0	6 Oct. (119)
	5% up	22% up	11% down	38% down	3 days late	
Iksannamulkong	33	92	6.3	7.2	4.2	8 Oct. (121)
	66	101	8.3	5.9	2.9	9 Oct. (122)
		10% up	32% up	18% down	31% down	1 day late
Pureunkong	33	114	3.0	8.3	1.2	3 Oct. (116)
	66	119	4.3	7.2	0.3	4 Oct. (117)
		4% up	43% up	13% down	75% down	1 day late
Camp	33	71	2.3	7.8	4.1	10 Oct. (123)
	66	78	3.7	6.2	2.2	12 Oct. (125)
		10% up	61% up	21% down	46% down	2 days late
HS 287	33	45	2.3	6.2	2.3	1 Oct. (114)
	66	53	3.7	5.2	1.1	2 Oct. (115)
		18% up	61% up	16% down	52% down	1 day late
	Genotype (G)	9.2**	1.3**	1.1*	0.7**	0.6**
	Density (D)	4.9*	1.0**	0.7*	0.5**	0.4**
	G×D	NS	NS	NS	NS	0.8**

*, **Significant at the 0.05 and 0.01 probability levels, respectively; NS, Not significant at the 0.05 probability level. n = 18

Table 3: Mean numbers of pod and distribution of pods carried on main (1°axis, main inflorescence) stems and on different nodes in each soybean plant grown in different plant population density for three years

				Distribution of pods at node		
Variety	Plant density (no. m^{-2})	Pod no. (plant^{-1})	Pod on main stem no. (%)[a]	Lower (1-6)	Middle (7-10)	Upper (11-)
Eunhakong	33	48.0	22.4 (46.7)	18.9	23.9	5.2
	66	27.4	19.6 (71.9)	8.2	11.6	7.6
Iksannamulkong	33	51.1	19.7 (38.6)	15.8	27.5	7.8
	66	38.0	16.3 (42.9)	7.5	24.1	6.4
Pureunkong	33	39.2	28.2 (71.9)	16.4	15.0	7.8
	66	23.0	21.6 (93.9)	5.4	10.0	7.6
Camp	33	63.0	24.0 (38.0)	32.1	19.3	11.6
	66	48.3	33.8 (70.0)	8.2	24.5	15.6
HS 287	33	33.7	21.8 (64.5)	15.3	16.7	1.8
	66	27.2	23.5 (86.4)	8.3	15.8	3.1
	Genotype (G)	5.0**	13.3*	4.4**	NS	NS
	Density (D)	2.5**	4.5*	3.8**	NS	NS
	G×D	5.6**	10.0*	NS	NS	NS

[a]Indicates the percentage of number of pods on a peduncle against a total number of pods in a plant; *, ** Significantly different at the 0.05 and 0.01 levels of probability, respectively; NS, Not significant at the 0.05 probability level. n = 18

(i.e. Camp) with highly branched cyme in high plant density significantly increased in internode length at the upper nodes (V13-15).

Lodging scare for short stem genotypes was 2.3 in low and 3.7 in high plant density, respectively (Table 2). Lodging resistance apparently decreased from 22 to 61% as plant density increased, particularly genotypes with long stem rather than those with short stem.

Alteration of reproductive traits to the different stem growth habits: ANOVA (Table 3) indicates that significant ($p<0.05$) effects of genotype and plant density were found for number of pods per plant and pods on the main stem and at lower nodes (Table 3). Interaction of genotypes with plant density significantly affected number of pods per plant and pods on the main stem. The mean number of pods per plant in all genotypes ranged from 33.7 to 63.0 in low plant density, whereas it ranged from 23.0 to 48.3 in high plant density (Table 3). Long stem genotypes showed more reduction (25.6% in Iksannamulkong and 41.3% in Purenkong) in number of pods per plant than short stem genotypes (23.3% in Camp and 19.3% in HS 287).

Proportional percentages of number of pods carried on the main stem to the total pods per plant ranged from 42.9 to 93.9% in all genotypes in high plant density (Table 3). Short stem genotypes significantly increased in the percentages of number of pods on the main stem to the total pods per plant from 70.0% in Camp (highly branched type) to 86.4% in HS 287 (few branched type) as plant density increased. Number of pods at both lower and middle nodes of almost all genotypes declined in high plant density. However, short stem genotypes significantly increased in number of pods at the upper nodes in high plant density (Table 3).

Yield components and seed yield with sink capacity and harvest index: Genotypic effects were significant ($p<0.05$) on number of seeds, seed yield, leaf area, dry biomass, sink capacity and seed yield (Table 4 and 5). Interaction of genotype with plant density significantly ($p<0.05$) influenced number of seeds per plant and source-sink related leaf area and plant dry biomass. Seeds per plant in all genotypes decreased (17.1-69.2%, no numerical percentages shown in Table 4) in high plant density, however decreased relatively less (16.5-17.1%) in short stem genotypes (Camp and HS 287) than in long stem genotype.

Number of seeds in all genotypes remained the same in respective of plant densities. One hundred-seed weight declined (1 to 9%) in high plant density as compared to low plant density (Table 4). Seed yield (kg ha^{-1}) of all genotypes increased (3.9-14.8%) in high plant density. Particularly, short stem genotypes, Camp and HS 287, grown in high plant density produced more seed yield than long stem type of plants and efficiently improved seed yield from 14.8% and 7.7%, respectively.

Table 4: Effects of plant density on yield components and seed yield in soybean genotypes with long and short stem lengths and lateral branch types

Variety	Plant density (no. m^{-2})	Seed per plant (no. plant^{-1})	Seed per pod (no. pod^{-1})	100-seed weight g	Yield (kg ha^{-1})
Eunhakong	33	94.1	2.0	14.4	2,210
	66	55.6	2.0	14.3	2,300
Iksannamulkong	33	92.6	1.9	14.6	2,420
	66	68.8	1.8	14.1	2,620
Pureunkong	33	75.7	1.9	14.9	1,700
	66	45.7	2.0	14.5	1,790
Camp	33	108.1	1.7	12.0	2,470
	66	92.3	1.9	11.4	2,900
HS 287	33	64.8	1.9	15.4	2,530
	66	55.6	2.1	14.7	2,740
	Genotype (G)	16.4**	0.4*	0.7**	169.5**
	Density (D)	6.2**	NS	0.3**	101.9**
	GxD	14.0**	NS	NS	NS

*, ** Significantly different at the 0.05 and 0.01 levels of probability, respectively; NS, Not significant at the 0.05 probability level. n = 18

Table 5: Yield components and seed yield in relation to sink capacity and harvest index in various soybean genotypes grown in different plant population densities for three years

			Dry weight (g plant^{-1})				
Variety	Plant density (no. m^{-2})	Leaf area (cm^{2} plant^{-1})	Leaves	Stems	Sink Capacity^{a} (seed g plant^{-1})	Plant biomass (kg ha^{-1})	dry Harvest index^{b}
Eunhakong	33	1,705	6.9	16.9	6.9	7,220	0.31
	66	999	5.6	12.5	3.9 (76.9% ?)	8,210	0.28
Iksannamulkong	33	1,979	7.5	17.4	7.5	7,610	0.32
	66	1,267	5.2	11.3	5.4 (38.9% ?)	9,400	0.28
Pureunkong	33	1,912	6.3	18.8	5.8	6,700	0.25
	66	1,292	5.7	15.2	3.3 (75.8% ?)	7,250	0.25
Camp	33	2,109	9.0	21.0	7.6	7,240	0.32
	66	1,308	6.7	14.1	5.5 (38.2% ?)	11,082	0.35
HS 287	33	1,700	5.6	10.6	5.2	6,620	0.38
	66	1,094	5.5	9.3	4.0 (30.0% ?)	6,540	0.42
LSD$_{0.05}$	Genotype (G)	69.2*	0.5**	1.2**	0.4**	35.0**	0.01*
	Density (D)	51.7**	0.3*	0.7**	0.2**	31.8**	NS
	G×D	NS	0.7*	1.5*	0.5*	71.1**	NS

[a] Sink capacity (capacity of the plant to form seed yield) was estimated by seed grain weight (g) per plant; [b] Harvest index, the ratio of seed mass to total plant biomass, was calculated as total dry seed weight divided by total aboveground dry biomass per plant, that is estimated by a formula of (economic yield/production yield)×100; *, ** Significantly different at the 0.05 and 0.01 levels of probability, respectively

Leaf area (48.0-70.7%), dry weights of leaves (1.8-44.2%) and stems (14.0-54.0%) reduced in all genotypes in high plant density (Table 5). Similarly, sink capacity (seed g plant^{-1}) declined more in long stem genotypes (38.9-75.8%) than in short stem (30.0-38.2%) genotypes, but plant dry biomass (kg ha^{-1}) increased 8.2 to 53.1% in high plant density. Particularly, the dry biomass of Camp significantly increased from 7,240 to 11,082 kg ha^{-1} (53.1% increased) in high plant density (Table 5). For HI, the values ranged from 0.25 to 0.28, that slightly declined or remained constantly in all genotypes with long main stem (Iksannamulkong and Pureunkong), increased in all short stem genotypes from 0.35 in Camp and 0.42 in HS 287.

DISCUSSION

Growth characteristics to plant density: All genotypes grown in high plant density apparently decreased in stem diameter, number of branches, number of pods, number of seeds per plant, seed weight, but increased in plant height, lodging and number of pods on the main stem (Table 2-4). The previous studies reported decrease in lateral braches and pods per plant as the number of plants per unit area increased [6, 17].

Number of pods per plant in genotypes with short main stem decreased less than those with long stem (Table 3). Particularly, number of pods per plant at the lower nodes significantly decreased in all genotypes in high plant density, but number of pods on the main stem of each plant significantly increased, ranging from 42.9 to 93.9%. This indicates that the increase number of pods on the primary main stem rather than on the lateral branches in high plant density is likely to be an important component for high seed yield. Increasing number of pods on the main stem would contribute for the reproductive plasticity of the genotypes and would assure higher seed yield in high plant density [18, 19]. Number of pods per plant and number of seeds per pod are known as important components for an increase in seed yield [20, 21]. In relation to the effect of plant density on seed yield, Norsworthy and Ferderick [7] reported that total seed yield of highly branched genotypes was significantly correlated with total seed yield at the low plant density (r = 0.67).

In terms of internode, short stem genotype Camp with highly branched cyme mostly did not change length of internode at early vegetative stages (V1-12) in high plant density, but long stem genotype Iksannamulkong significantly ($p<0.05$) increased length of internode during mid-vegetative stage (V7-12) in high plant density (Fig. 1). Length of internode and stem diameter in short stem genotypes were likely to be less sensitive to high plant density than those with long stem. Growth traits such as length of internode and primary main stem diameter had a very close relation to the increased extent of lodging up to from 10 to 66% and decreased seed yield in various high plant density trials [22-25].

All genotypes improved mean seed yield up to 14.8% in high plant density even though some growth characteristics (e.g. seed numbers, seed pods, 100-seed weight, etc.) were not favorable for an increase of seed yield. Higher yield of all genotypes was clearly due to a large number of plants per unit area.

Growth characteristics and yield components to sink capacity: Leaf area and dry biomass per plant decreased in all genotypes with high plant density as sink capacity decreased. Sink capacity has been known to be affected by sink size (e.g., weight of the sink tissue, including seeds) and sink activity (e.g., rate of uptake photosynthates per unit weight of sink tissue) [26]. Seed weight as a key component of sink was not positively associated with yield increase in high plant density.

Under the conditions of increase plant density, much of the source leaves could be shaded for an extended period of vegetative and early reproductive growth stages. Shading by neighbor plants with accompanying resources competition due to a large number of plants decreased leaf area and negatively influenced a cascade of sink capacity, which determines yield components and seed yield [1]. Because of high plant density, photosynthesis could be inhibited, resulting in a change of photosynthate translocation and partitioning along with sink capacity. This study reveals that metabolic activities of source tissues (e.g., photosynthesis, assimilate loading in source tissues) could decline with resources competition (interception of light, nutrients, moi?sture, etc.) and influence to sink capacity under the field conditions of high plant density.

Although sink capacity per plant decreased in high plant density, plant dry biomass (kg ha^{-1}) per unit area was significantly improved (Table 4 and 5), resulting in high seed yield of almost all genotypes, particularly genotypes with short stem (Camp and HS 287). Genotypes with short stem were likely to be well adapted to high plant density cropping practice. The absence of an effect of plant density on number of pods to a total seed yield per unit area was apparently observed in high plant density, primarily because of compensation by the increasing number of pods per plant in low plant density. A similar study, Lopez-Bellido[6] showed that number of pods per plant and per unit area had most important direct and indirect effects on grain yield.

Values of traits and harvest index (HI) to breeding programs: The possible causal factor of declined HI in genotypes with long stem in high plant density was probably due to low light interception, negatively affecting number of seeds per plant, pods on the lower nodes, 100-seed weight and plant dry weight [3, 15]. Nevertheless, short stem genotypes showed a better performance as presented by higher HI (Table 5) in high plant density. Comparatively higher HI in Camp and HS 287 suggests that genotypes with short stem were genetically stable in their crop performance in an agricultural practice with heavy competition among plants. The stability of higher HI shown in genotypes with short stem reflects the important effect of the plant dry biomass increase on pod setting during reproductive growth period [10]. Plant types of short stems are likely to be a potential germplasm with favorable genetic compounds, which could be used for breeding programs to improve seed yield under the condition of high plant density (Table 5).

The major factors responsible for increasing yield in high plant density practice were an increase in number of pods per unit area and number of pods on the main stem (fertile node production) (Table 3). In a breeding strategy, genotypes of a short stem type may have some limited capacity to possess more numbers of pods on the main stem rather than lateral branches particularly in high plant density and late planting practice. But, we estimate from our study that a growth characteristic of long stem could not be ignored for breeding programs because plant type with long stem could have a potential capacity for more numbers of pods on the main stem, improving seed yield plasticity in a heavy competition growth environment with late planting practice following other crops.

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REFERENCES

1. Jones, B.P., D.L. Holshouser, M.M. Alley, J.K.F. Roygard and C.M. Anderson-Cook, 2003. Double-crop soybean leaf area and yield responses to mid-atlantic soils and cropping systems. Agron. J., 95: 436-445.
2. Ball, R.A., L.C. Purcell and E.D. Vories, 2000. Short-season soybean yield compensation in response to population and water regime. Crop Sci., 40: 1070-1078.
3. Edwards, J.T., L.C. Purcell and D.E. Karcher, 2005. Soybean yield and biomass responses to increasing plant population among diverse maturity groups. II. Light interception and utilization. Crop Sci., 45: 1778-1785.
4. Board, J.E., M. Kamal and B.G. Harville, 1992. Temporal importance of greater light interception to increased yield in narrow-row soybean. Agron. J., 84: 575-579.
5. López-Bellido, L. and M. Fuentes, 1990. Growth, yield and yield components of lupin cultivars. Agron. J., 82: 1050-1056.
6. López-Bellido, L., M. Fuentes and J.E. Castillo, 2000. Growth and yield of white lupin under mediterranean conditions: Effect of plant density. Agron. J., 92: 200-205.
7. Norsworthy, J.K. and J.R. Frederick, 2002. Reduced seeding rate for glyphosate-resistant, drilled soybean on the southeastern coastal plain. Agron. J., 94: 1282-1288.
8. Shield, I., H.J. Stevenson, J.E. Leach, T. Scott, J.M. Day and G.F.J. Milford, 1996. Effect of sowing date and planting density on the structure and yield of autumn-sown, florally-determinate white lupin (*L. albus*) in the United Kingdom. J. Agric. Sci., 127: 183-191.
9. Spaeth, S.C., H.C. Randall, T.R. Sinclair and J.S. Vendeland, 1984. Stability of soybean harvest index. Agron. J., 76: 482-486.
10. Kakiuchi, J. and T. Kobata, 2004. Shading and thinning effects on seed and shoot dry matter increase in determinate soybean during the seed-filling period. Agron. J., 96: 398-405.
11. Kim, H., M.Y. Hirai, H. Hayashi, M. Chino, S. Naito and T. Fujiwara, 1999. Role of O-acetyl-L-serine in the coordinated regulation of the expression of a soybean seed storage-protein gene by sulfur and nitrogen nutrition. Planta, 209: 282-289.
12. Scheiner, J.D., F.H. Gutierrez-Boem and R.S. Lavado, 2000. Root growth and phosphorous uptake in wide-and narrow-row soybeans. J. Plant Nutr., 23: 1241-1249.
13. Scott, R.A. and K.D. Kephart, 1997. Selection for yield, protein and oil in soybean crosses between adapted and introduced parents. Field Crops Res., 49: 177-185.
14. Bertram, M.G. and P. Pedersen, 2004. adjusting management practices using glyphosate-resistant soybean cultivars. Agron. J., 96: 462-468.
15. Denier van der Gon, H.A.C., M.J. Kropff, N. van Breemen, R. Wassmann, R.S. Lantin, E. Aduna, T.M. Corton and H.H. van Laar, 2002. Optimizing grain yields reduces CH_4 emissions from rice paddy fields. Proc. Natl. Acad. Sci., 99: 12021-12024.
16. SAS Institute, 1999. SAS/STAT user's guide, Version 8.0. 1st Edn., SAS Institute Inc., Cary, North Carolina.
17. Herbert, S.J., 1977. Growth and grain yield of *Lupinus albus* at different plant populations. N.Z. J. Agric. Res., 20: 459-465.
18. Board, J.E., M.S. Kang and M.L. Bodrero, 2003. Yield components as indirect selection criteria for late-planted soybean cultivars. Agron. J., 95: 420-429.
19. Egli, D.B. and W.P. Bruening, 2002. Synchronous flowering and fruit set at phloem-isolated nodes in soybean. Crop Sci., 42: 1535-1540.

20. Cho, Y., S.K. Suh, H.K. Park and A.J. Wood, 2002. Impact of 2, 4-DP and BAP upon pod set and seed yield in soybean treated with exogenous regulators at early reproductive stages. Plant Growth Reg., 36: 215-221.
21. Suh, S.K., Y. Cho, R.A. Scott, 2000. Gene action and heritability of leaf and reproductive traits in soybean. Breeding Sci., 50: 45-51.
22. Cober, E.R., M.J. Morrison, B. Ma and G. Butler, 2005. Genetic improvement rates of short-season soybean increase with plant population. Crop Sci., 45: 1029-1034.
23. Lee, H.J., H.S. Kim and H.S. Lee, 1991. Yield response and light utilization to planting density in soybean cultivars for bean sprouting and for cooking with rice. Kor. J. Crop Sci., 36: 177-184.
24. Park, K.Y., Y.H. Han, S.H. Song, B.H. Kim and D.W. Ree, 1990. Relationships between lodging and agronomic characters of soybean plant. Kor. J. Crop Sci., 35: 289-294.
25. Cooper, R.L., 1981. Influence of soybean production practices on lodging and seed yield in highly productive environments. Agron. J., 63: 490-493.
26. Borrás, L., M.E. Westgate and M.E. Otegui, 2003. Control of kernel weight and kernel water relations by post-flowering source-sink ratio in maize. Ann. Bot., 91: 857-867.