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Responses of soybean yield and yield components to light enrichment and planting density

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Abstract

Light intensity intercepted by the soybean canopy during the reproductive period is an important environmental factor determining soybean yield components and grain yield. A 2-year field experiment was conducted to investigate the effects of light enrichment and its interaction with planting density on yield formation of soybean cultivars. Light enrichment increased seed yield per plant and yield per unit area dramatically ranging from 26-94% ($P<0.05$) regardless of density and cultivars at lower and moderate density however the yield increase effect was not observed in H339 and HN35 at the high density in 2007. Seed yield and pod number per plant declined with the increased density in 2007 for all cultivars but remained unchanged in 2008 for KN18. There was significant light enrichment-by-density ($P<0.05$) on yield per plant and pod number per plant, but not on seed number per pod and seed size across the two years. Yield sensitivity to light enrichment differed among soybean cultivars. Adjustments to light enrichment imposed at the early flowering R1 stage increased pod number. Pod number per plant increased 20-119% over the two-years. Seed size in this study was unchanged or reduced slightly by light enrichment. Our data suggest that clarification of mechanisms induced the greatest yields in high population as demonstrated under light enriched conditions may provide insights for crop management and phenotypic improvement.

Keywords: Light enrichment; Planting density; Soybean canopy; Yield components

Introduction

Intensity and quality of solar radiation intercepted by a soybean canopy during the reproductive period is an important environmental factor determining soybean yield and yield components (Board and Harvill, 1992; Evans, 1996; Jin and Liu, 2004; Biabani et al., 2008). Increased seed yield of soybean through narrow rows, can be attributed to increased light interception during reproductive period (Board et al., 1992; Board and Harville, 1996;

Liu et al., 2004). Light enrichment initiated at early flowering stages increased productive pod number, resulting in a 144 to 252% increase in seed yield (Mathew et al., 2000). In contrast, reducing light source through shading during the seed fill reduced seed yield (Zhang et al., 2000).

Adjusting planting density is an important tool to optimize crop growth and the time required for canopy closure, and to achieve maximum biomass and grain yield (Ball et al., 2000; Turgut et al., 2005; Svecnjak et al., 2006; Haddadchi and Gerivani, 2009). High populations provide a way to optimize grain yields in short-season production systems (Liu et al., 2007). The breeding and selection of semi-dwarf cultivars and adoption of narrow row spacing made high densities possible, and thus increased soybean yield (Cooper, 1989; Board and Harville, 1994). Purcell et al. (2002) proposed that a decrease in radiation use efficiency was responsible for the yield ceiling commonly observed in population density experiments.

Theoretically, enriched light in field conditions could permit an increase in plant population. However, cultivars differ in responses to light enrichment and planting density, and there is probably exists interactions between light enrichment and plant population density. Our objective was to examine the responses of soybean cultivars to light enrichment under different planting density, with emphasis on their interaction on yield components and grain yield.

Materials and Methods

This study was conducted in Hailun Agroecological Experimental Station of Chinese Academy of Sciences in Northeast China from 2007 to 2008. The research site (47°26′N, 126°38′E, altitude 240 m) is in the north temperate zone and continental monsoon area (cold and arid in winter, hot and rainy in summer). The average annual precipitation is 530 mm with 65% in June-August, and an average annual temperature of 1.5 °C. Annual sunshine is around 2600-2800h, total annual solar radiation is 113M J cm^{-2} and annual average available accumulated temperature (≥10 °C) is 2450 °C. The soil is the typical Mollisol (Black soil), and textural class is silty clay loam or silty clay with about 40% clay. In each year a cultivar-by-density factorial experiment, arranged in a randomized complete block design with three replications, was conducted. Three soybean cultivars, Hai 339 (H339), Heinong 35 (HN35) and Kennong 18 (KN18) were planted in three densities of 14, 27 and 54 plants m^{-2} in 2007 and two densities of 27 and 40 plants m^{-2} in 2008. The density change in 2008 was because of the insensitivity at 54 plants m^{-2} in 2007. Each plots consisted of seven rows of 8.5m long with an inter-row spacing of 0.67m. The seeds were sowed on May 7, 2007 and May 6, 2008. A total of 50 kg ha^{-1} carbamide (46% N), and 50 kg ha^{-1} diammonium phosphate (18% N, 46% P_2O_5), and 150 kg ha^{-1} of composite fertilizer (18% N, 16% P_2O_5, 16% K_2O) were applied before seeding. Weeds were controlled by hand.

Light enrichment consisted of making an increased solar radiation available to the center row of each plot by installing 90 cm tall wire mesh fencing (mesh hole size 4-5cm) adjacent to the center row and sloping away at a 45° angle. Fences were installed at early flowering R1 stage (Fehr and Caviness, 1977), and were left in place for the remainder of the growing season. Fences prevented encroachment of plants from neighboring rows into the growing space, and thus increased the radiation interception area of the sample rows. The fences were inspected periodically and all plants in rows bordering the center row were pushed behind the fences to prevent encroachment on the sample row. Light intensity measurements, using a Licor line quantum sensor (LI-188B) placed parallel to, and beside the center row plants, showed that leaves at the base of the canopy in light-enriched plots were receiving more than 25% ambient light.

In each plot, detailed yield component measurements at maturity for pod number per plant, seeds per plant and seed size (mg/seed) were taken on 15 plants, cut at ground level, bulked and determined for a total biomass. The seed yield components were separated and processed from plants by hand. Mass of a 100-seed subsample was used to determine the mass of an individual seed. Among the data recorded were pod number, seed number and seed dry weight for calculation of seed yield components. Statistical analysis of data was performed by using the PROC ANOVA of SAS, and mean comparison was made according to the Duncan's multiple range tests (SAS Institute, Inc. 1996).

Results and Discussion

Seed yield response

Light enrichment increased seed yield per plant compared with that of the ambient light regardless of density and cultivars (Figure 1), however a significant effect was not observed for H339 and HN35 at 54 plants m^{-2} density in 2007. In 2007, the two lower densities, 14 and 27 plants m^{-2} had an average increased seed yield per plant of 64% with light enrichment for H339 and 50% for HN35 but only 27% for KN18. In 2008, with densities of 27 and 40 plants m^{-2}, seed yield per plant increased with light enrichment, on average by 83% for H339, 42% for HN35, and 56% for KN18. Seed yield per plant declined with the increased density in all cultivars in 2007 but not in 2008 for KN18. The interaction between light enrichment and planting density was significant for seed yield per plant; however the three-way interaction among light enrichment, planting density and cultivars was not significant for seed yield per plant across the two years (Table 1). Except cultivars H339 and HN35 at higher density (54 plants m^{-2}) in 2007, highest yields per unit area were obtained higher densities (Table 2). Asanome and Ikeda (1998) reported that light distribution in soybean canopy is a major limiting factor of seed yield. The insensitivity of H339 and HN35 to light enrichment at higher density (54 plants m^{-2}) suggests the high density of plants resulted in similar competition for light in both the ambient light and light enriched treatments for these cultivars. The unchanged seed yield per plant with increased density in ambient light in 2008 for KN18 indicates this cultivar was adapted to the higher planting density. This difference in response to change in density and light enrichment may be helpful for making decisions on optimum planting densities for different soybean cultivars.

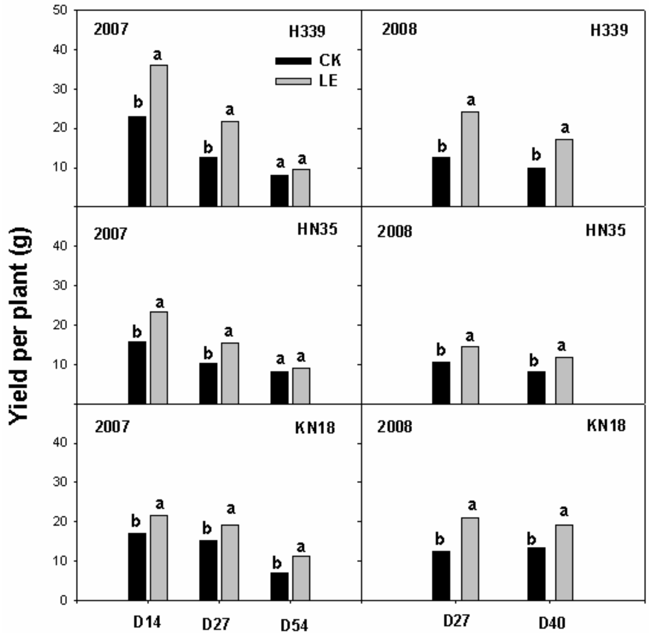

Figure 1. Seed yield per plant under light enriched condition with various densities. Within a cultivar, means of the same planting density followed by the same letter are not significantly different at the 5% level of probability. D14, D27, D40, D54 stands for planting density at 14 plants m^{-2}, 27 plants m^{-2}, 40 plants m^{-2}, 54 plants m^{-2} respectively. CK and LE are control and light enrichment treatment respectively.

Table 1. Analysis of variance of final harvest yield components for light enrichment and densities of three cultivars in each year.

Yield components	Source of variation	2007	2008
Yield/plant	densities (D)	**	**
	cultivars (Cul)	**	**
	light enrichment (LE)	**	**
	D × LE	*	*
	D × Cul × LE	NS	NS
Pods/plant	D	**	*
	Cul	**	**
	LE	**	**
	D × LE	*	*
	D × Cul × LE	NS	NS
Seeds/pod	D	*	*
	Cul	NS	NS
	LE	*	**
	D × LE	NS	NS
	D × Cul × LE	NS	NS
Seed size	D	NS	NS
	Cul	**	**
	LE	NS	*
	D × LE	NS	NS
	D × Cul × LE	NS	NS

*significant at P=0.05, **significant at P=0.01, NS-not significant.

Table 2. Effect of light enrichment treatment on seed yield per unit area under different densities.

Yield (g m^{-2})		2007			2008	
		D14	D27	D54	D27	D40
H339	LE	504a	589a	513a	656a	688a
	CK	321b	343b	437a	337b	400b
HN35	LE	325a	416a	486a	389a	468a
	CK	220b	273b	437a	281b	324b
KN18	LE	301a	521a	610a	567a	764a
	CK	238b	408b	378b	338b	532b

Within a cultivar, means of the same planting density followed by the different letter are significantly different at the 5% level of probability. D14, D27, D40, D54 stands for planting density at 14 plants m^{-2}, 27 plants m^{-2}, 40 plants m^{-2}, 54 plants m^{-2} respectively. CK and LE are control and light enrichment treatment respectively.

Yield components response

Pod number per plant had significant responses to the cultivars, planting density, and light enrichment (Table 1). Pod number per plant increased under light enriched conditions compared to under ambient light condition (Figure 2). The pod number per plant was reduced with the increased density in 2007 for all cultivars but remained unchanged for KN18 in 2008 in ambient light (Figure 2). In 2007, as density increased to 54 plants m^{-2}, the response to light enrichment decreased for pod number for H339 and HN35 but not for KN18. Thus, at high density, pod number of KN18 was more stable than the other cultivars. Other studies have confirmed pod number per plant is the yield component most influenced by changes in cultural and environmental conditions (Herbert and Litchfield, 1982; Mathew et al., 2000). Modification of the environmental conditions to reduce photosynthate supply during reproductive growth caused a reduction in pod number (Board and Harville, 1993; Egli, 1993; Jiang and Egli, 1993). Pod number was more responsive to altered source strength than other yield components, and plants that received more light were not forced to abort pods due to source limitations (Board et al., 1995; Liu et al., 2006). This suggests that light enrichment imposed during early flowering stage would increase availability of assimilates to the developing reproductive structures, and decrease flower and pod abscission with a resultant increase in final pod number at harvest.

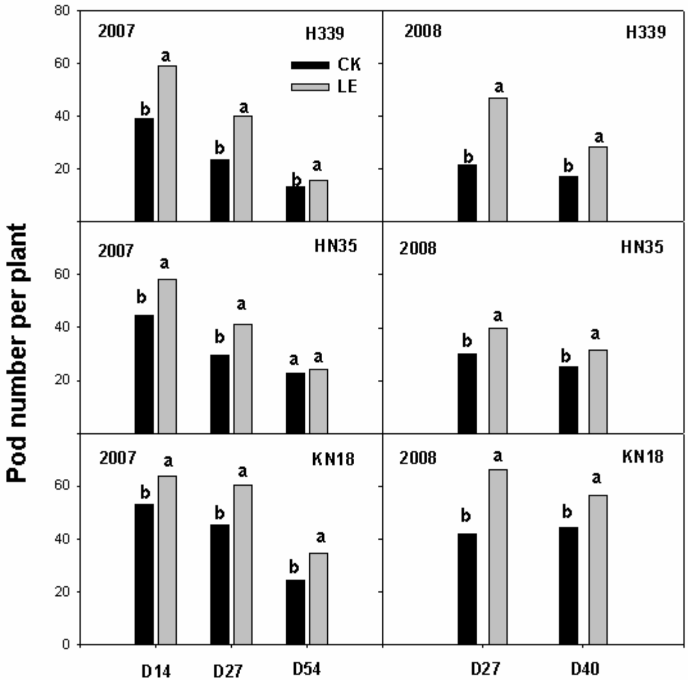

Figure 2. Pods number per plant under light enriched condition with various densities. Within a cultivar, means of the same planting density followed by the same letter are not significantly different at the 5% level of probability. D14, D27, D40, D54 stands for planting density at 14 plants m^{-2}, 27 plants m^{-2}, 40 plants m^{-2}, 54 plants m^{-2} respectively. CK and LE are control and light enrichment treatment respectively.

Seed number per pod was less affected by light enrichment compared to pod number per plant (Figure 3). Plant density had a significant but small effect on seed number per pod (Figure 3, Table 1). However, the interaction of light enrichment and density had no effect on seed number per pod (Table 1). Similar findings of small or no significant changes in seed number per pod have been reported in previous studies (Dominguez and Hume, 1978; Schou et al., 1978; Herbert and Litchfield, 1982; Liu, 2006). In our experiment, light enrichment had a tendency to increase seed number per pod compared with that of ambient light (Figure 3). This indicates that although seed number per pod is strongly determined by the internal genetic mechanism, it can be modified by environmental condition.Seed size was not affected by density and was similar or reduced by light enrichment in the two years (Figure 4). This result was opposite to Liu et al. (2007) who found that higher density and light enrichment increased seed size. The difference likely came from the timing of installation of the light enrichment. In this study light enrichment began at the beginning of flowering (R1) while in the study of Liu et al. (2007) light enrichment began at the end of flowering. Based on this study and others, we suggest that light intensity during flowering period determines the number of pods per plant formed. Pod number and seed number per plant increased 71% and 86% respectively with light enrichment, resulting in an increased sink capacity. However, the source would also be increased with light enrichment but with more seeds to fill there would be similar or lesser assimilates to fill each seed. The lack of response of seed size of KN18 to light enrichment suggests that the adjustment in yield was primarily via the change in pod number per plant. This has been shown in other studies where adjustments to light enrichment imposed at R1 or earlier stages are through increased pod number whereas light enrichment imposed at the beginning of pod fill resulted in an increase in seed size (Mathew et al., 2000). Defoliation studies during the reproductive stage of growth have shown that seed size is affected when source strength is decreased (Ingram et al., 1981). This is mainly because the photosynthetic activity by crop canopy declines gradually during the effective filling period and current photosynthesis (rather than remobilization of stored carbohydrate) is considered to be main source for seed growth in soybean (Jin and Liu, 2004; Liu et al., 2006). Cultivar response for seed size to source strength needs further investigation.

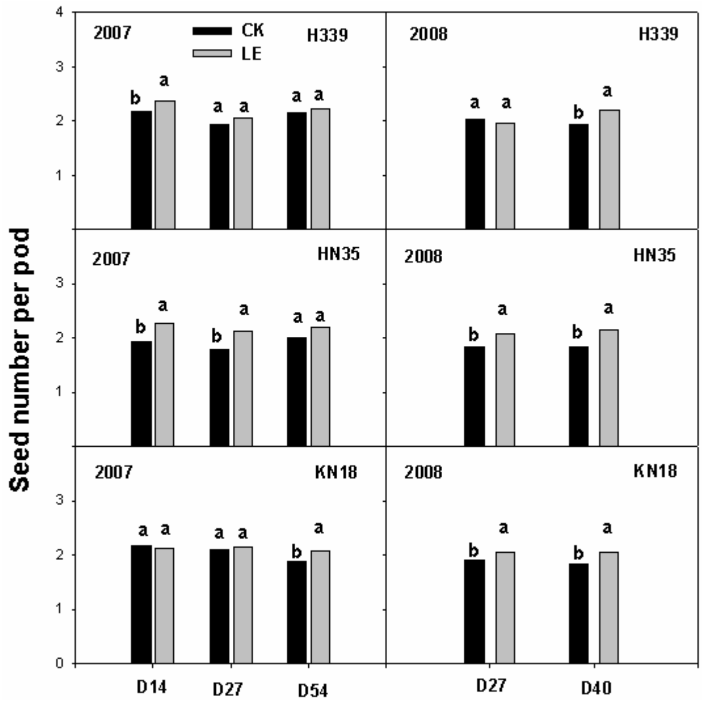

Figure 3. Seed number per pod under light enriched condition with various densities. Within a cultivar, means of the same planting density followed by the same letter are not significantly different at the 5% level of probability. D14, D27, D40, D54 stands for planting density at 14 plants m^{-2}, 27 plants m^{-2}, 40 plants m^{-2}, 54 plants m^{-2} respectively. CK and LE are control and light enrichment treatment respectively.

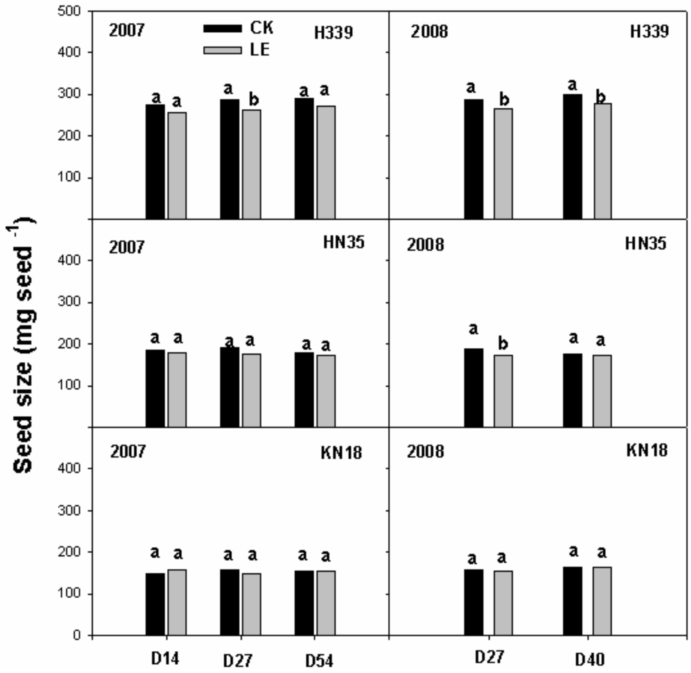

Figure 4. Seed size under light enriched condition with various densities. Within a cultivar, means of the same planting density followed by the same letter are not significantly different at the 5% level of probability. D14, D27, D40, D54 stands for planting density at 14 plants m^{-2}, 27 plants m^{-2}, 40 plants m^{-2}, 54 plants m^{-2} respectively. CK and LE are control and light enrichment treatment respectively.

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