Emir. J. Food Agric. 2015. 27 (3): 258-265
doi: 10.9755/ejfa.v27i3.18889
http://www.ejfa.info/

REGULAR ARTICLE

The shoot dry matter accumulation and vertical distribution of soybean yield or yield components in response to light enrichment and shading

Liu Bing[1], Qu De-Ning[2*] and Zhou Xiao-Mei[1*]

[1]*The College of Life Science, Jilin Normal University, Siping 136000, China*
[2]*The College of Mathematics science, Jilin Normal University, Siping 136000, China*

Abstract

A two years field experiment was carried out to analyze the effects of light-enriched treatment and shading on shoot dry matter accumulation and vertical distribution of soybean seed yield or yield components. Light enrichment significantly increased shoot dry matter accumulation per plant to contrast with that of the natural light in 2-years. Under three different density condition, light enrichment averagely increased Hai339 (H339) shoot dry matter accumulation per plant by 43.2%; that of Heinong35 (HN35) by 40.1% and that of Kennong18 (KN18) by 28.7%. Compared with that of the ambient light, shade averagely decreased Hai339 (H339) shoot dry matter accumulation per plant by 33.6%; that of Heinong35 (HN35) by 29.2% and that of Kennong18 (KN18) by 41.7%. Most of yield and pod number was produced in the middle layer of the main stem. Seeds number per pod at middle layer also was more than lower and upper canopy layers. Light sensitivity of lower, middle and upper mainstem part from three soybean cultivars was very different. Compared with the other yield component, seed size was least affected by light treatment. In our experiment, seed size was mostly constant at lower, middle and upper stem layers, although the filling duration of seed produced lowermost node was longer approximate 18 days than that of seed produced uppermost node. Our data indicated that, through redistributing the assimilate at lower, middle and upper canopy layers, soybean plant could showed the mechanism to maintain seed size stable. Clarification of mechanisms responsible for dry matter accumulation and vertical distribution of yield components under different light treatments, may provide some reference for phenotypic improvement and cropping pattern.

Key words: light enrichment, Shading, Vertical distribution, Yield component, Dry matter accumulation

Introduction

Light is the energy source of plants photosynthesis and light intensity has important influence on plant morphology, physiology and reproduction (Li et al., 2010; Kosma et al., 2013; Mauro et al., 2014; Wang et al., 2014). Response of soybean seed yield and yield components to solar radiation's quality and intensity have been researched (Myers et al., 1987; Board and Harvill et al., 1996). Mathew et al. (2000) analyzed the effects of different light-enriched treatment time on soybean yield components and indicated that there are different responses of seed yield to light enrichment started at late vegetative and early pod formation. However, reducing of light intensity through shade will increase young pods or flowers abscission, lengthen internodes of soybean plant, decrease seed yield and increase plant lodging (Ephrath et al., 1993; Jiang and Egli, 1993; Li et al., 2006). Jiang and Egli (1995) stated that duration of shading also was an important factor influencing soybean yield. Increase of density to a certain extent in determinate area is an important way to achieve higher seed yield (Liu et al., 2008). However, excessive high density resulted in decrease of radiation use efficiency and hence the increase reached yield ceiling (Purcell et al., 2002). Under light-enriched treatment condition, the appropriate density for a certain soybean cultivar will increase and crop yield components also will change. Light enrichment may provide a new way to investigate characteristic of crop growth and reproduction.

The effect of light treatment such as shading on crop yield had been studied. However, response of dry matter accumulation and vertical distribution of yield components to light-enriched treatment and

Received 25 September 2014; Revised 08 December 2014; Accepted 02 January 2015; Published Online 01 March 2015

*Corresponding Authors

Qu De-Ning, Zhou Xiao Mei
The College of Life Science, Jilin Normal University, Siping 136000, China

Email: qudening@126.com, zhouxiaomei66@163.com

shading is less investigated. Our objective of this research was to survey the differential response of vertical distribution of yield components and assimilate accumulation of aerial part under light-enriched treatment and shading conditions.

Materials and Methods

Our study was carried out at Hailun Agroecological Experimental Station, China during 2007-2008. The research area belongs to the North Temperate Zone. Average annual precipitation and temperature respectively are 530mm and 1.5°C. Total annual solar radiation and sunshine is 113 M J cm^{-2} and 2700h. The area is the typical Mollisol (Black soil) region. Soil is silty clay and it is suitable for crop farming.

In two years, the field experiment is based on randomized complete block design with three replications. Three soybean cultivars were chosen as three experimental varieties in our research and they were Hai339 (H339), Heinong35 (HN35) and Kennong18 (KN18). Soybeans were planted at 14, 27 and 54 plants m^{-2}. A plot was composed of seven rows. The each row had 8.5m and inter-row spacing was 0.67m. The seeds were sown on May 7, 2007 and May 6, 2008. Before planting, soil area was applied with carbamide 50 kg ha^{-1}, and diammonium phosphate of 50 kg ha^{-1}, and composite fertilizer of 150 kg ha^{-1}. Weeds were wiped off by hand and normal field management was done.

The method of light enrichment was described by Mathew et al. (2010) and it had nondestructive and repeatable characteristic. A detailed description as follows, we installed wire mesh (tall 90cm and mesh hole size 4-5cm) on two side of one plant-rows, which were pushed down on neighbouring rows at a 45° angle from the two rows at the centre. Wire mesh were installed at soybean growth stage R1 (Fehr and Caviness, 1977) and was picked off after the harvest. The wire mesh prevented encroachment of plants from adjacent rows into the growing space, and thus increased the radiation interception of the sample plant, especially at the base of the soybean canopy. At every ten days interval, the wire mesh was inspected. Light intensity measurements indicated that soybean leaves at light-enriched condition were receiving more than 25% ambient light.

The method of shading was described by Liu et al. (2009). A detailed description as follows, Shade cloth is black polypropylene fabric and it was attached to metallic posts with 0.5m above the crop canopy. Compared with natural light, shade decreased about 25% light intensity. Canopy temperature, air circulation and humidity have not big changes under shading condition. Only center row in every plot received light enrichment and soybean plant of 3m light-enriched row was harvested. Therefore yield is expressed as yield m^{-1} rather than yield m^{-2}.

In each plot, 30 plants were selected to measure the vertical distribution of yield, pod number, seed number, seed number per pod and seed size. Three layers (upper layer, middle layer and lower layer) were defined and separated according to the plant height at harvest. To get a detailed analysis of yield components, data were recorded for all the selected plants. For each group of plants, data were recorded according to node position on the main axis and for each branch corresponding to the main axis node from which it arose. Node 1 was the unifoliate node, being the first node above the cotyledons. Due to workload problem, the vertical distribution of yield and yield component only were analyzed under moderate density (27 plants m^{-2}). Statistical analysis of experimental data was performed by using PROC ANOVA (analysis of variance), and calculated using SAS (SAS Institute, Inc. 1996). Figures were drawn by using sigma Plot 2000 software.

Results and Discussion

Shoot dry matter accumulation

In period of 20 to 60 days after flowering, shoot dry matter under light enrichment always were most, that under natural light was second, and that under shading was least regardless of the cultivars and densities (Figure 1-3). Enhanced the effectiveness of the soybean leaf photosynthesis under light enrichment is resulting in rapid shoot dry matter accumulation. However shading reduced source of leaf canopy photosynthesis, and decreased under-ground plant dry matter weight (Jiang and Egli, 1993).

Understanding the distribution of assimilates between the vegetative and reproductive organs have important effect on analyzing the source-sink activity interactions. The young pods or flowers produced in the bottom nodes often aborted and because in where solar irradiance is lowest (Wiebold et al., 1981). The nutrition area of soybean under low density (14 plants m^{-2}) was more than that under moderate and high densities condition (27 and 54 plants m^{-2}). This was resulting in the much larger amount of shoot dry matter in low density. From 40 days to 60 days, the shoot dry matter had a little decreased because of a few mature leaves was fallen.

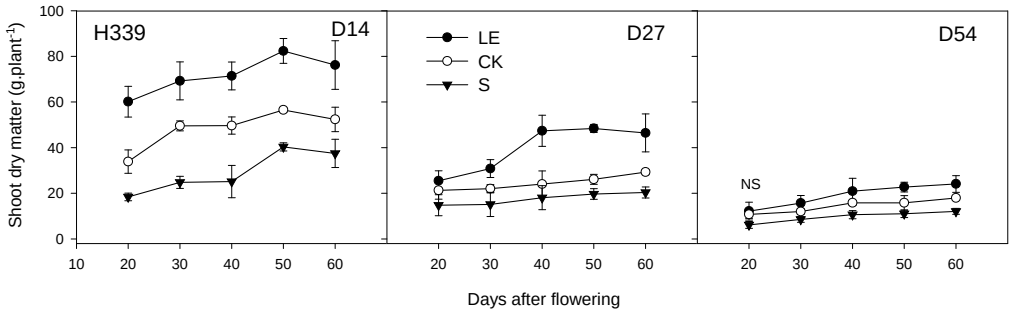

Figure 1. Shoot dry matter accumulation of soybean cultivar (H339) in light-enriched condition and shading treatment. Bar is standard error of the mean. NS represent no significantly different (P<0.05) between LE and CK.

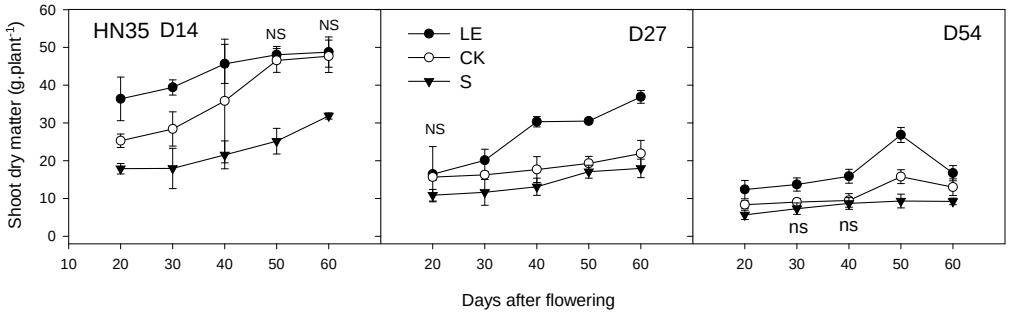

Figure 2. Shoot dry matter accumulation of soybean cultivar (HN35) in light-enriched condition and shading treatment. Bar is standard error of the mean. "NS" represent no significantly different (P<0.05) between LE and CK; however "NS" represent no significantly different (P<0.05) between S and CK.

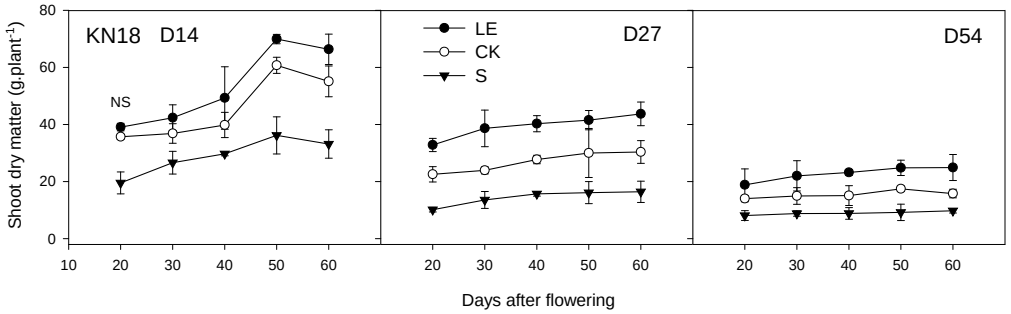

Figure 3. Shoot dry matter accumulation of soybean cultivar (KN18) in light-enriched condition and shading treatment. Bar is standard error of the mean. "NS" represent no significantly different (P<0.05) between LE and CK.

Yield per unit row length

Light-enriched treatment significantly increased seed yield m^{-1} compared with that of natural light control in 2-years. Under high, middle and low density conditions, light enrichment respectively increased 17%, 72% and 57% seed yield m^{-1} for H339; 11%, 52% and 48% seed yield m^{-1} for HN35; 61%, 28% and 27% seed yield m^{-1} for KN18. The extent of yield m-1 increase was highest under middle density for H339 and HN35, however the extent yield m^{-1} increase was highest under high density for KN18. Light enrichment increased seed yield m^{-1} for H339 and HN35 under high density, but the increase is no significant. This may means three soybean cultivars have different canopy structure and physiological character, and this result in difference in yield sensitivity to light enrichment. Therefore, it is indicated that, under high density, light isn't primary restrictive condition for the two soybean cultivars (H339 and HN35). While under high density condition, light possibly is a determinant of seed yield for KN18.

It is suggested that there are difference from nutrient area of three soybean plant. Consideration

of plant nutrient area is the premise of determining suitable density for certain soybean cultivar. Previous research reported that light-enriched treatment started at the beginning of flowering greatly increased 144-252% seed yield (Mathew et al., 2000). However, the highest value of yield increase merely was 72%. There are maybe two reasons for this difference. One reason is that, three soybean cultivars planted in our experiment were main axis ones without branches, however soybean cultivar in previous research was profusely branching one. This is obvious that profusely branching cultivars have ability to producing more branches in bottom nodes under light enrichment treatment. There is self-adjusting mechanism to distribute assimilates across main axis, make an attempt to gain maximum seed yield in good environmental condition. Based on the data of yield increase, we speculated that profusely branching cultivars had better ability in self-regulation mechanism than main stem style ones. Second reason is that, row width was 67cm in our field research, while inter-row spacing was 25cm in previous experiment. Therefore, this is clear that effect of light-enriched treatment in narrow row condition is more obvious than that in wide row condition.

Sharma et al. (1996) suggested that shading treatment decreased pod number and seed yield per plant because of increase in flower and pod abscission. Same as previous studies, compared with that of the natural light in our experiment, shading treatment significantly decreased soybean seed yield m^{-1}. Under three different density conditions, shading averagely reduced 45% yield m^{-1} for H339; 43% yield m^{-1} for HN35 and 46% yield m^{-1} for KN18 respectively (Table 1). Different soybean cultivars have different yield sensitivity to decrease of light intensity. The extent of seed yield m^{-1} decrease by shading was highest under high density for H339 and HN35, while maximum yield decrease for KN18 was observed under middle density.

The vertical distribution of soybean yield

The vertical distributions of soybean yield per plant were similar in three cultivars. Under natural light and shading conditions,

The least pod were produced at the lower nodes, with fewer produced at the upper nodes, and the majority pods produced at the middle node (Figure 4). Under light enrichment condition, the vertical distributions of soybean yield per plant still was same as that for HN35 and KN18, while this is a little different for H339. The yield of lower main stem part is much better than that of upper for H339 under light enrichment condition. In the individual level, yield sensitivity of three soybean cultivars to light-enriched treatment was great different. For HN35 and KN18, light enrichment mainly increase the yield of middle and upper main stem part, while light enrichment primary increase the yield of lower part for H339. This is obvious that, under light-enriched treatment, lower main stem part of H339 had much greater reproductive potential than other two cultivars.

Table1. Effects of light-enriched treatment and shading on seed yield of three soybeans under different densities (Yield g. m^{-1}).

cultivars	Light treatment	D14	D27	D54
	LE	337.7a	409.2a	356.4a
H339	CK	215.1b	238.3b	303.6a
	S	135.1c	131.3c	146.3b
	LE	217.8a	289.0a	337.7a
HN35	CK	147.4b	189.7b	303.6a
	S	88.2c	123.8c	138.8b
	LE	201.7a	362.0a	423.8a
KN18	CK	159.5b	283.5b	262.6b
	S	86.3c	142.6c	153.8c

Different letters within the row represent significantly different from light-enriched treatments, natural light and shading under same cultivar and density ($P<0.05$).

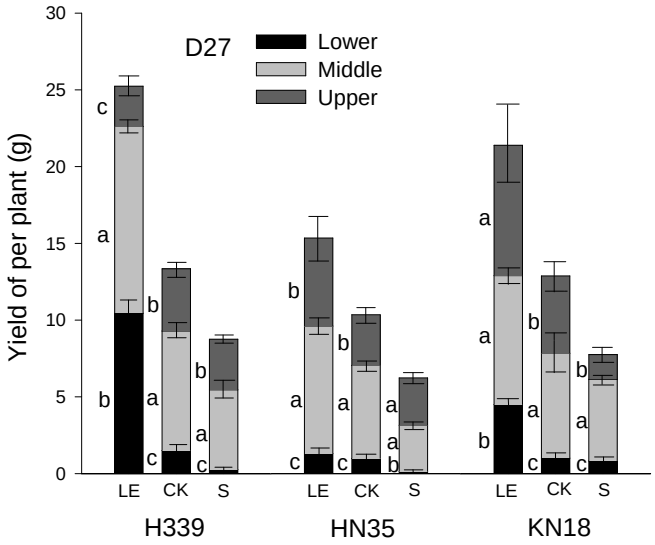

Figure 4. The vertical distribution of yield per plant (g) from three soybean cultivars.
Bar is standard error of the mean. Different letters on the left side of vertical row are significantly different (P<0.05) from lower, middle and upper canopy layer under same light condition and cultivar, same as the follow.

The vertical distribution of pod number per plant

Light-enriched treatment or shading significantly increased or decreased pod number per plant (Figure 5). This indicates that light-enriched treatment and shade alter availability of assimilates to influence young and flower abscission, resulting in final pod number variation. Board et al. (1992) reported that yield component, which was most easy to be influenced in changing environment, was pod number per plant. Our research also demonstrated previous conclusion. The pod number vertical distributions of three cultivars to light enrichment and shading condition were very different. Under light enrichment condition, the pod number in lower parts accounted for 42.3% of the total pod number for H339, while that is only 10.3% for HN35 and 22.3% for KN18. Compare with the above, under shading condition, the pod number in lower parts accounted for 14.2% of the total pod number for KN18, while that is only 2.8% and 3.4% for H339 and HN35. Our study suggested that lower, middle and upper main stem part form three soybean cultivars had different sensitivity to light treatment. The vertical distributions of pod number of three cultivars are very inconsistent. This is reflected that the light sensitivity of different stem main part from three cultivars to light treatment is not the same.

The vertical distribution of seed number per pod

Our experiment suggested that seed number per pod of middle part is more than that of lower and upper part under natural light (Figure 6). Compared with natural light condition, light-enriched treatment reduced seed number per pod in upper mainstem part in H339 and HN35. Reduction of seed number per pod may was a compromise to a great increase of pod number per plant under light-enriched treatment. Light-enriched treatment increased seed number per pod in upper mainstem of KN18. There is only a smaller effect on seed number per pod by light-enriched treatment. It is obvious that yield component such as seed number per pod had much stronger stability than pod number per plant.

For HN35 and KN18, shading significantly decreased seed number per pod in lower main stem part. This indicated that decrease of seed number per pod is one of yield mechanism to respond the source reduction. There is little effect on seed number per pod by shading treatment for H339 in lower main stem part. For some soybean cultivars, seed number per pod main was controlled by genetic element (Liu et al., 2007). Previous research also found that seed number per pod is a weaker yield component (Herbert and Litchfield, 1982). However, there were a few effects on seed number per pod by light-enriched treatment and this suggested that the proportion of one, two, three and four-seeded pods was changed in light-enriched condition.

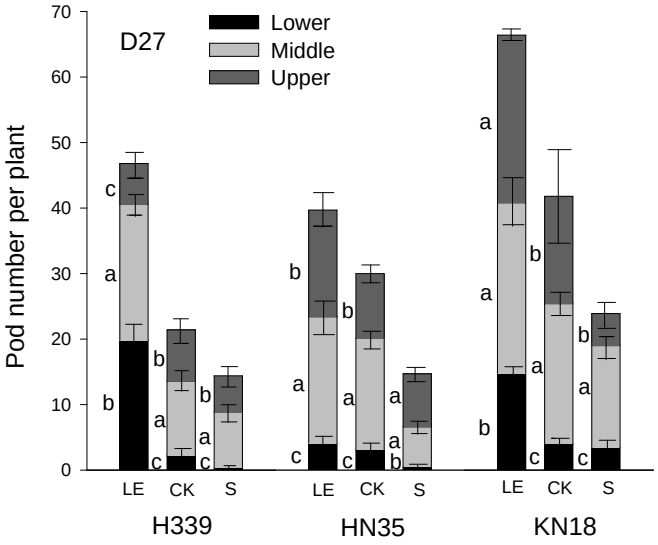

Figure 5. The vertical distribution of pod number per plant from three soybean cultivars.
Bar is standard error of the mean. Different letters on the left side of vertical row are significantly different (P<0.05) from lower, middle and upper canopy layer under same light condition and cultivar.

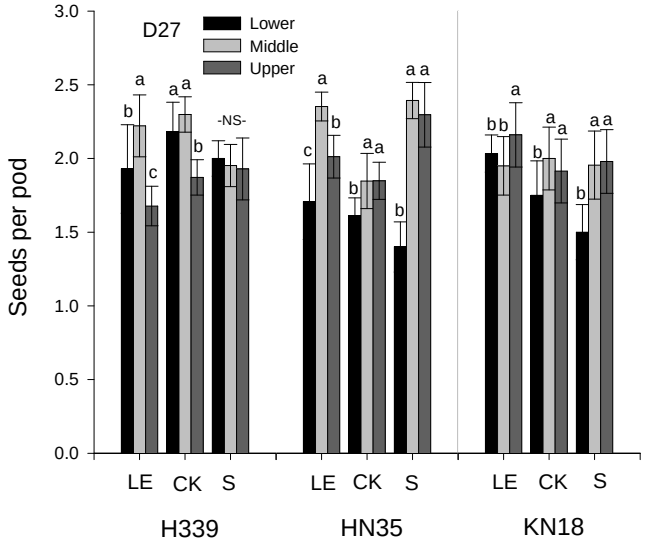

Figure 6. The vertical distribution of seeds per pod from three soybean cultivars.
Bar indicate standard error of the mean. Different letters on vertical row are significantly different (P<0.05) from lower, middle and upper canopy layer under same light treatment and cultivar. "NS" represent no significantly different (P<0.05) from lower, middle and upper canopy layer.

The vertical distribution of seed size

Seed size of three soybean cultivars maintained strong stability. Compared with natural light, light enrichment decreased seed size for H339, however shading slightly increased seed size. This may be the complementary mechanism for reduction of pod number under shading condition. Seed size is a minor yield component in determining soybean yield, and it had little or no variation in lower, middle and upper main stem parts of three soybeans (Figure 7). Three soybean plants in this experiment, when the flowers were produced in upper axis node, the seeds in full-size pods already were filling in lower axis node. Though the duration of seed filling in lower node was about 18 days more than that in upper node, seed size was same from lower and upper mainstem nodes.

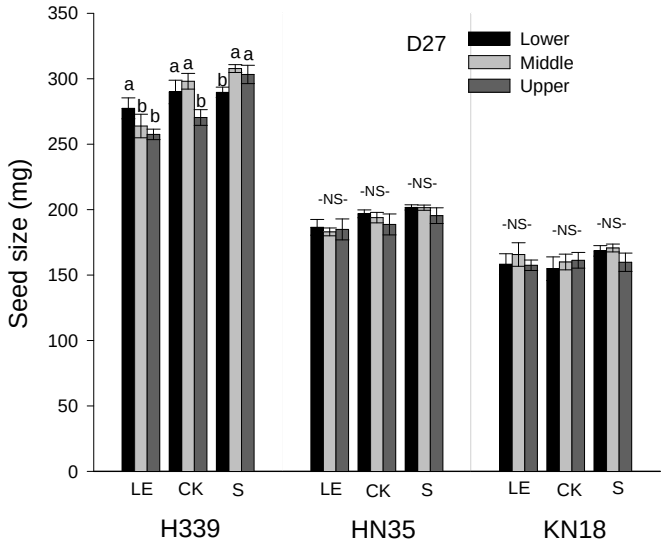

Figure 7. The vertical distribution of seed size from three soybean cultivars.
Bar indicate standard error of the mean. Different letters on vertical row are significantly different (P<0.05) from lower, middle and upper canopy layer under same light treatment and cultivar. "NS" represent no significantly different (P<0.05) from lower, middle and upper canopy layer.

It is well known that seeds from lower, middle and upper nodes were synchronously arriving in physiological maturity. Thus, It is no difficult to estimate that seed-filling rate in upper nodes was higher than that in lower nodes (Egli et al., 1985). Mathew et al. (2000) reported that seed size is determined by cotyledon cell volume and number. Seed-filling rate and cotyledon cell number are closely related. We speculate that seed produced in upper axis nodes had more cotyledon cell number and smaller cotyledon cell volume than that in lower axis nodes. That is why seed sizes from the upper and lower axis nodes are so similar.

Conclusion

Our results indicate that lower, middle and upper mainstem part form three soybean cultivars had different sensitivity to light treatment. Under light enrichment, the pod number in lower parts accounted for 42.3% of the total pod number for H339, while that is only 10.3% for HN35 and 22.3% for KN18. Yield component, which was most easy to be influenced by light treatment, was pod number per plant. Seed number per pod in lower mainstem part for HN35 and KN18 was significantly decreased by shading. This suggests that decrease of seed number per pod be a one mechanism for soybean plant to respond the available source reduction. Seed size was least affected by light treatment. Our data indicated that, through redistributing the assimilate at lower, middle and upper canopy layers, soybean plant could showed the mechanism to maintain seed size stable. Seeds produced in the upper and lower axis nodes might have different cotyledon cell characteristics.

Acknowledgment

This research was supported by a grant from the Science and Technology Development Program of Jilin Province (20140411011XH), the Starting Foundation for Doctor of Jilin Normal University (2010020) and Project funded by China Postdoctoral Science Foundation.

Author contributions

L. B. designed the study, did the analysis; L. B. and Q. D. N. wrote the article and Z. X. M. corrected the article.

References

Board, J. E. and B. G. Harville. 1996. Growth dynamics during the vegetative period affects yield of narrow-row, late-planted soybean. Agron. J. 88:567-572.

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.

Egli, D. B., R. D. Guffy and L. W. Meckel. 1985. The effect of source-sink alterations on soybean seed growth. Ann. Bot. 55:395-402.

Ephrath, J. E., R. F. Wang, K. Terashima, J. D. Hesketh, M. G. Huck and J. W. Hummel. 1993. Shading effects on soybean and corn. Biotronics 22:15-24.

Fehr, W. R. and C. E. Caviness. 1977. Stages of soybean development. Iowa State Univ. Coop. Ext. Ser. Spec. Rep. 80.

Herbert, S. J. and G. V. Litchfield. 1982. Partitioning soybean yield components. Crop Sci. 22:1074-1079.

Jiang, H. and D. B. Egli. 1993. Shade induced changes in flower and pod number and flower and fruit abscission in soybean. Agron. J. 85:221-225.

Jiang, H. and D. B. Egli. 1995. Soybean seed number and crop growth rate during flowering. Agron. J. 87:264-267.

Kosma, C., V. Triantafyllidis, A. Papasavvas, G. Salahas and A. Patakas. 2013. Yield and nutritional quality of greenhouse lettuce as affected by shading and cultivation season. Emir. J. Food Agric. 25:974-979.

Li, L., Y. T. Gan, R. Bueckert and T. D. Warkentin. 2010. Shading, defoliation and light enrichment effects on chickpea in northern latitudes. J. Agron. Crop Sci. 196:220-230.

Li, Y. C. and Z. D. Sun. 2006. Influence of shading stress during different growth stage on yield and main characters of soybean. Southwest China J. Agric. Sci. 19:265-269. (In Chinese)

Liu, B., C. Wang, J. Jin, J. D. Liu, Q. Y. Zhang, X. B. Liu and S. J. Herbert. 2009. Effects of shade during reproductive stage on accumulation of fatty acids in soybean seed. Soybean Sci. 28:53-58. (In Chinese)

Liu, X. B., J. Jin, G. H. Wang and S. J. Herbert. 2008. Soybean yield physiology and development of high-yielding practices in Northeast china. Field Crops Res. 105:157-171.

Liu, X. B., S. J. Herbert, Q. Y. Zhang and A. M. Hashemi. 2007. Yield-density relation of glyphosate-soya beans and their responses to light enrichment in north-eastern USA. J. Agron. Crop Sci. 193:55-62.

Mathew, J. P., S. J. Herbert, S. H. Zhang, A. A. F. Rautenkranz and G. V. Litchfield. 2000. Differential response of soybean yield components to the timing of light enrichment. Agron. J. 92:1156-1161.

Mauro, R. P., O. Sortino and M. Dipasquale. 2014. Phenological and growth response of legume cover crops to shading. J. Agric. Sci. 152:917-931.

Myers, R. L., W. A. Brun and M. L. Brenner. 1987. Effect of raceme-localized supplemental light on soybean reproductive abscission. Crop Sci. 27:273-277.

Purcell, L. C., R. A. Ball, J. D. Reaper and E. D. Vories. 2002. Radiation use efficiency and biomass production in soybean at different plant population densities. Crop Sci. 42:172-177.

SAS Institute, Inc., 1996. SAS/STAT User's Guide Release 6.09. SAS Institute, Inc., Cary, NC, USA.

Sharma, K., W. Neelu, K. Sharma and N. Walia. 1996. Growth and yield of soybean [*Glycine max* (L.) Merrill] as influenced by light intensity and cytokinin. Indian Agric. Res. 39:253-257.

Wang, N. N., Q. J. Huang and J. R. Sun. 2014. Shade tolerance plays an important role in biomass production of different poplar genotypes in a high density plantation. Forest Ecol. Manage. 331:40-49.

Wiebold, W. J., D. A. Ashley and H. R. Boerma. 1981. Reproductive abscission levels and patterns for eleven determinate soybean cultivars. Agron. J. 73:43-46.