

# Effect of Cultivation Pattern on the Light Radiation of Group Canopy and Yield of Spring Soybean (*Glycine Max L. Merrill*)

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## ABSTRACT

Heilongjiang Province is the main soybean-producing area in China. In this study, we analyzed the canopy structure, dynamic characteristics of light radiation and yield of Hefeng50 (the main variety of soybean in Heilongjiang Province) under six different cultivation patterns (ORP, TPCR, ORCP, BRHD, SRHD and FPHD). The results showed that SRHD and BRHD at different growth period (blossom period R1, podding R3 and grain filling period R5) produced an even distribution of the population leaf area, suitable mean foliage inclination angle (MFIA), low transparency coefficients for diffuse penetration (TCDP) and transparency coefficients for radiation penetration (TCRP), high leaf area index (LAI), extinction light coefficient (K value), fraction of radiation intercepted (FRI) and light energy utilization rate. Grain number, dry matter weight per plant, and yield of SRHD and BRHD were significantly higher than those of other cultivation patterns. The yield of SRHD, BRHD, ORCP, FPHD and TPCR was increased by 136%, 112%, 79%, 50.1% and 14.7%, respectively, compared to that of ORP. These results suggest that SRHD and BRHD are the optimal cultivation pattern for the improvement of soybean yield in phaeozem region of northeastern China.

**Keywords:** Cultivation Methods; Light Enrichment; Soybean Canopy; Yield Components; Population Canopy

## 1. Introduction

Intensity and quality of solar radiation intercepted by a soybean canopy during the reproductive period are important environmental factors for the soybean yield and yield components [1-4]. Elevation of soybean yield in narrow rows can be attributed to the increased light interception during reproductive period [5,6]. Light enrichment initiated at early flowering stages increases the productive pod number, resulting in 144% - 252% increases of the seed yield [7]. In contrast, reduction of light source through shading during the seed filling stage decreases the yield [8,9]. Adjusting the planting density is an important tool to optimize crop growth and canopy closure time and to achieve maximum biomass and grain yield [11-14]. High populations provide a way to optimize grain yields in short-season production systems [15].

Breeding of semi-dwarf cultivars and adoption of narrow row spacing cultivation could increase the densities and the soybean yield [16]. Decrease in the radiation utilization efficiency was responsible for the yield ceiling commonly observed in population density experiments. Theoretically, enriched light in field conditions could permit an increase of plant population. However, cultivation patterns differ in responses to light enrichment, and there probably exists interactions between light enrichment and plant population density [17,18]. Population structure is one of the important factors to achieve high yield. Soybean canopy is an important system for interception and conversion of light radiation. Cultivation pattern affects the yield of soybean by directly influencing soybean population structure and the light energy utilization efficiency. Therefore, establishment of a good canopy structure is essential for high yield of soybean and improvement of the variety.

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Heilongjiang Province is the main soybean producing area in Northern China and it has an average soybean planting area of 333 million hectares. In this study, we examined the canopy structure and light radiation characteristics and their relationship to the yields of soybean variety Hefeng50 under different cultivation patterns. Our results suggest that SRHD and BRHD are the optimal cultivation pattern to improve the soybean yields in phaeozem region of northeastern China. This study sheds lights on soybean cultivation and ecological breeding.

## 2. Results

### 2.1. The Impact of Cultivation Patterns on the Leaf Area Index (LAI) of Soybean Canopy

SRHD and BRHD produced an even distribution of the population leaf area at the podding stage (Figures 1(d) and (e)), while the other cultivation patterns produced an uneven distribution in 2010 (Figures 1(a)-(c) and (f)).

### 2.2. The Impact of Cultivation Pattern on LAI of Soybean

Soybean LAI affects light distribution, energy utilization and crop yields. LAI of soybean was gradually increased from the blossom (R1) to the seed filing (R5) periods under all cultivation patterns in 2010 and 2011 (Figure 2). During R1 period (2010), LAI of SRHD, BRHD and ORCP was increased by 153%, 126% and 76.1%, respectively, compared to that of ORP ( $P \leq 0.05$ ). During R3 period in 2010, LAI of ORCP, BRHD, SRHD and FRHD was increased by 83.2% - 99.3% compared to that of ORP. During R5 period, LAI of BRHD, SRHD and FRHD was increased by 23.3% - 26.1% compared to that

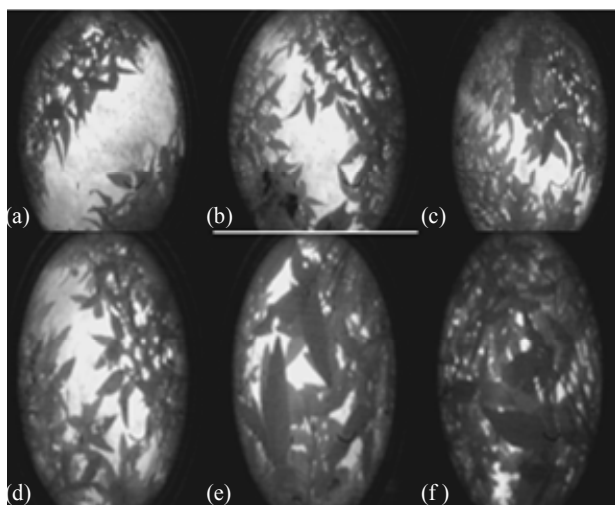


Figure 1. Distribution of soybean groups under ORP (a), TPCR (b), ORCP (c), BRHD (d), SRHD (e) and FPHD (f) in pod stage (2010).

of ORP ( $P \leq 0.05$ ) (Figure 2).

### 2.3. The Impact of Cultivation Pattern on MLA of Population Canopy

The mean foliage inclination angle (MFIA) was affected by the cultivation pattern (Figure 3). MFIA of ORP, TRCP and SRHD was increased from R1 to R3 and decreased from R3 to R5 (Figure 3). MFIA of FRHD and BRHD was gradually decreased from R1 to R5 (Figure 3). MFIA of ORCP was decreased from R1 to R3 and then increased from R3 to R5. In 2010, in R1 period, the highest MFIA was observed under ORCP (53.68°), followed by BRHD (49.59°) and the lowest MFIA was under ORP (9.55°). In R3 period, the highest MFIA was observed under SRHD, followed by TPCR, ORCP and FPHD. In R5 period, the highest and lowest MFIA was under ORCP and ORP, respectively. The average MFIA under different cultivation patterns was 9.55° - 53.68°, 30.41° - 54.46°, and 9.55° - 48.11° in R1, R3 and R5 periods, respectively. Statistical analysis showed that MFIA of ORP at R3 and R5 was significantly lower than that of other cultivation patterns. ORCP produced the highest MFIA in R1 and R5 periods.

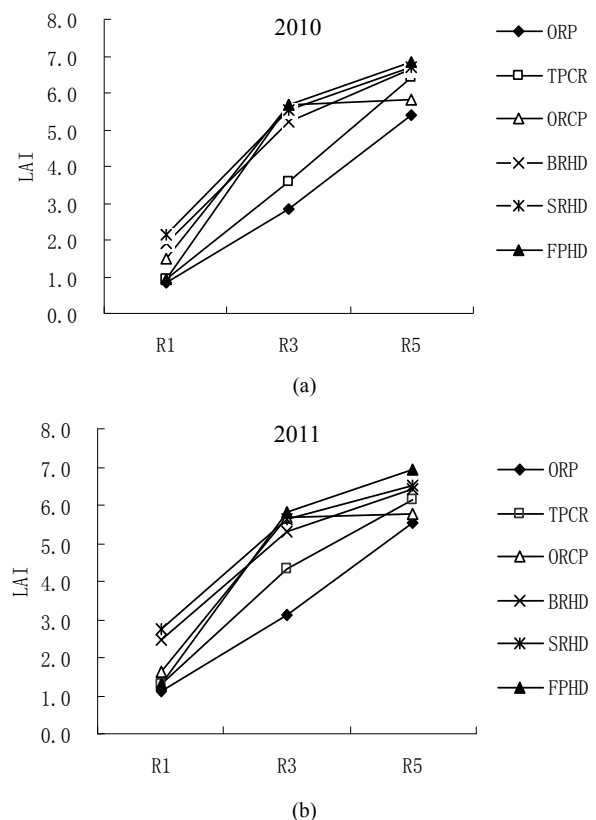


Figure 2. The change of leaf area index of soybean canopy (2010, 2011). X axis indicates the growth stage of soybean; Y axis indicates LAI.

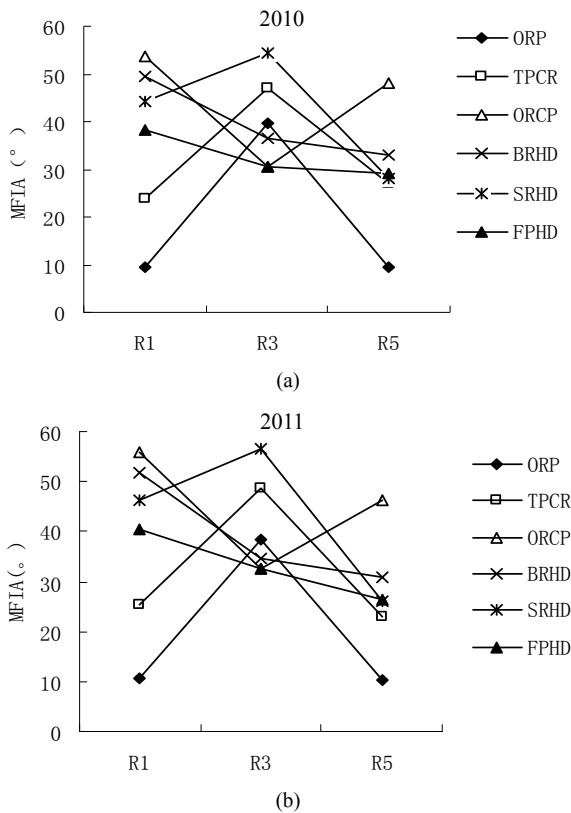


Figure 3. The change of MLA of population canopy of soybean under different cultivation patterns. X axis indicates the growth stage of soybean; Y axis indicates MFIA.

2.4. The Impact of Cultivation Pattern on TCDP

TCDP of soybean under different cultivation patterns was decreased from R1 to R5 (Figure 4). TPCR produced the highest TCDP in R1, R3 and R5 periods, while OPR produced the lowest TCDP at R1 and R5 periods. TCDP at R3 and R5 periods under BRHD and SRHD was relatively low, suggesting that BRHD and SRHD are beneficial to the light interception and utilization.

2.5. The Impact of Cultivation Pattern on TCRP

TCRP of soybean under different cultivation patterns was decreased with the increases of zenith angle (Figure 5). TCRP under the same cultivation pattern was decreased from R1 to R5 (Figure 5). The order of TCRP with a 7.5° - 67.5° of zenith angle was R1 > R3 > R5. In R1 period, TRCP, FRHD and ORCP had higher light leakage and lower light interception and utilization efficiency. In R5 period, the leaves of the plant became gradually withered and yellow and the remaining leaf area was not significantly different between different cultivation patterns. Therefore, the light interception and TCRP were not significantly different among different cultivation patterns.

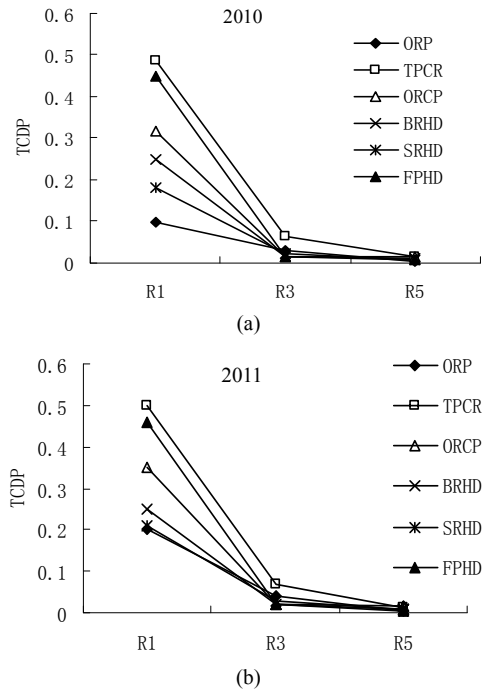


Figure 4. The change of TCDP of population canopy of soybean under different cultivation patterns. X axis indicates the growth stage of soybean; Y axis indicates TCDP.

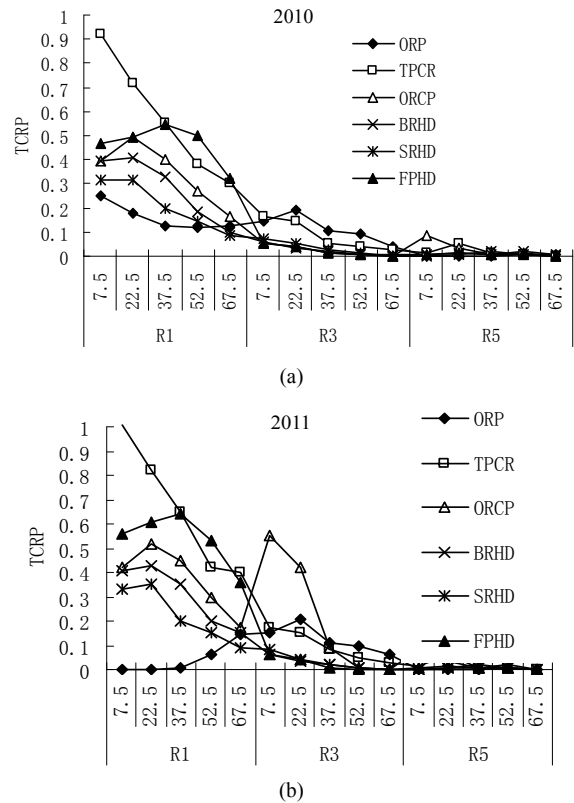


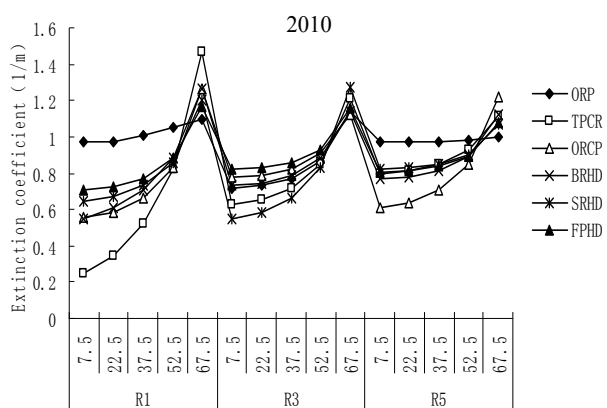
Figure 5. The change of TCRP of population canopy of soybean under different cultivation patterns. X axis indicates the growth stage of soybean; Y axis indicates TCRP.

## 2.6. The Impact of Cultivation Pattern on Extinction Light Coefficient

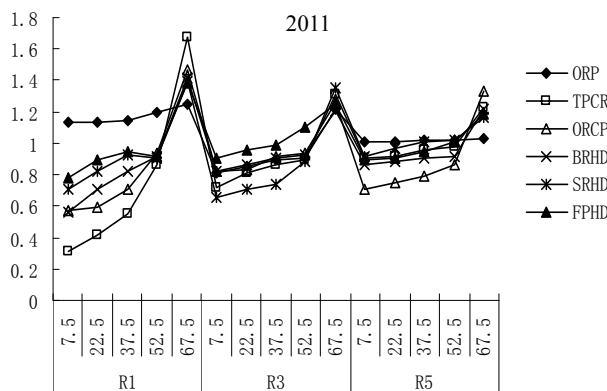
The extinction coefficient (K) was increased with the increases of zenith angle (Figure 6). K value was statistically different among different cultivation patterns. The order of K value at the upper part of the soybean (zenith angle: 67.5°) was ORCP > BRHD > TPCR > FPHD > SRHD > ORP (Figure 6).

## 2.7. The Impact of Cultivation Pattern on Dry Matter Accumulation, Height and Stem Diameter of Soybean

Dry matter accumulation and plant height were continuously increased in R1 and R5 periods. In R5 period, dry matter accumulation of different cultivation patterns was significantly higher than that of the control (ORP). Dry matter accumulation of ORCP, SRHD and FPHD was increased by 3.25, 2.12 and 1.71 times, respectively, compared to that of the control (ORP). In R5 period, the highest plant height was observed in SRHD, followed by



(a)



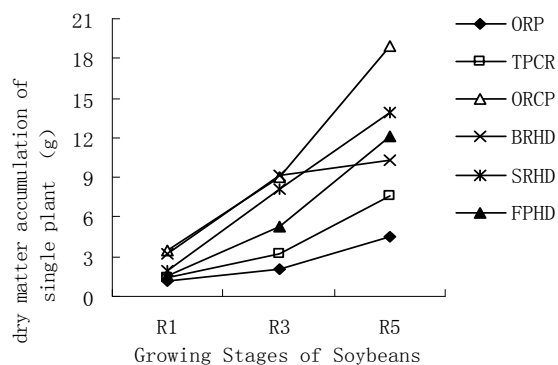
(b)

Figure 6. The change of extinction light coefficient of population canopy of soybean under different cultivation patterns (Left 2010, Right 2011). X axis indicates the growth stage of soybean; Y axis indicates K value.

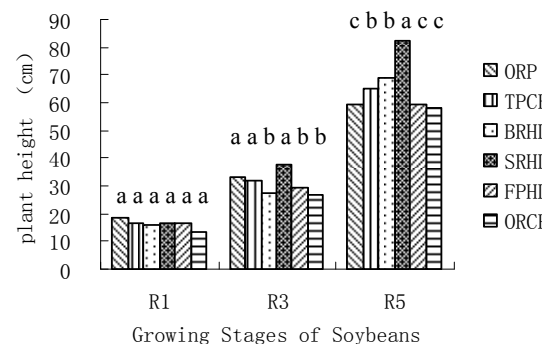
BRHD and TPCR. The plant height of SRHD, BRHD and TPCR was increased by 38.9%, 16.1% and 10.2%, respectively, compared to the control (ORP). In R5 period, the stem diameter of TPCR was the highest, which was increased by 34.4% compared to that of the control. There was no significant difference among other cultivation patterns (Figure 7).

## 2.8. The Impact of Cultivation Pattern on the Yield of Soybean

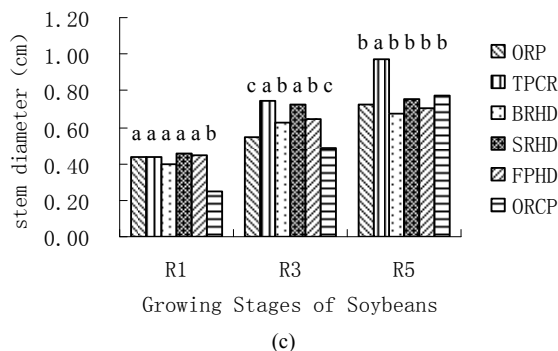
Soybean grain number, grain weight per plant and yield



(a)



(b)



(c)

Figure 7. The change of dry matter accumulation (a), plant height (b) and stem diameter (c) of soybean under different cultivation patterns (2010). X axis indicates the growth stage of soybean; Y axis indicates dry matter accumulation (a), plant height (b) and stem diameter (c).

were significantly different between different cultivation patterns (**Table 1** and **Table 2**). BPHD produced the highest grain number (39.7/plant), followed by SRHD (28.9/plant). The grain number of SRHD and BRHD was increased by 135% and 112% compared to that of ORP. The order of the yield for each cultivation pattern was SRHD > BRHD > ORCP > FPHD > TPCR > ORP. The yield of SRHD, BRHD, ORCP, FPHD and TPCR was increased by 136%, 112%, 79.4%, 50.1% and 14.7%, respectively, compared to that of ORP. These results suggest that SRHD and BRHD can be used as high-yield cultivation pattern in Heilongjiang Province.

### 3. Discussion

Light intercepted by the soybean canopy during the re-productive period is an important environmental factor for the soybean yield components and grain yield [7,19]. At low or moderate density, light enrichment increases seed yield per plant and yield per unit area by 26% - 94% regardless of cultivars. However, the yield increase effect was not observed in H339 and HN35 cultivars at the high density. Elucidation of the mechanisms that increase yields in high population as demonstrated under light-enriched conditions may provide insights for crop management and phenotypic improvement [15]. Coordinated

**Table 1. The analysis for yield index of soybean under different cultivation patterns (2010).**

Cultivation patterns	Grain number/plant	Grain weight /plant (g)	Yeilds (g/m <sup>2</sup> )
ORP	25.8c	6.8d	162.97f
TPCR	25.4c	12.2b	186.94e
ORCP	25.8c	12.2b	292.39c
BRHD	39.7a	14.4a	345.12b
SRHD	28.9b	16.0a	383.48a
FPHD	25.2c	10.2c	244.46d

Different leter indicate significant at  $P \leq 0.05$ .

**Table 2. The analysis for yield index of soybean under different cultivation patterns (2011).**

cultivation patterns	Grain number/plant	Grain weight/ plant (g)	Yeilds (g/m <sup>2</sup> )
ORP	25d	8.8d	170.96f
TPCR	27c	13.4b	190.88e
ORCP	27c	13.2b	298.35c
BRHD	39a	14.8b	348.11b
SRHD	29b	16.2a	388.45a
FPHD	26c	10.8c	250.43d

Different leter indicate significant at  $P \leq 0.05$ .

development of the population and individuals, reasonable distribution of canopy internal radiation source, and high light energy utilization rate could lead to high yield [5]. Asanomie and Ikeda reported that light distribution in soybean canopy is a major limiting factor of seed yield [3]. Liu *et al.* suggests that high density (54 plants/m<sup>2</sup>) of plants resulted in similar competition for light in both the ambient light and light enriched treatments [15,16].

The relationship between the light radiation, planting density and yield of soybean relationship has been widely studied, but studies for light energy utilization, canopy structure and yield of soybean under different cultivation modes have not been studied. In this study, we examined the canopy structure and light radiation characteristics and their relationship to the yields of soybean variety Hefeng50 under different cultivation patterns including SRHD, BRHD, ORCP, FPHD, TPCR and ORP. LAI, MFIA, Extinction coefficient (K), TCDP and TCRP and yield index were determined under 6 different cultivation patterns.

The results showed light penetration area is large and there was more light radiation loss under the cultivation pattern of ORPA and TPCR (**Figure 1**), which is not good for photosynthesis. In contrast, cultivation mode SRHD, BRHD and ORCP have good light transparence, which ensures the lower leaves to fully carry out photosynthesis (**Figure 1**). Many studies have shown that optimal LAI is required to obtain high yields of soybean [20,21]. In this study, the LAI of BRHD and SRHD was significantly higher than that of ORP and TPCR. We also showed that FPHD had highest LAI, but not the highest yield, which may be due to the low solar energy utilization of the lower leaves.

In this study, MFIA of SRHD and BRHD in R3 and R1 period was the highest, while in R5 it is relatively low, indicating lower leaves have high ventilation and light use utilization efficiency to promote the form of yield (**Figure 3, Tables 1 and 2**).

TCDP and TCRP can clearly reflect the inter-line and intra-line light distribution and utilization status. We studied TCDP and TCRP at different levels and different angles, which is conducive to understanding the radiation characteristics of soybean canopy in the three-dimensional space and the creation of high-yield population. Our results also showed that the difference for TCDP and TCRP of the six kinds of cultivation mode, mainly was in R1, TCDP and TCRP were low under SRHD and BRHD, which further explains the low light loss. This might be another reason that leads higher yield of these 2 cultivation modes.

The extinction coefficient K is an effective index of the canopy light interception. Great K value indicates a serious population intensity attenuation [22,23]. Studies

have shown that large K value can result in serious leaf shading, less light received by lower leaves, which is bad for pod of soybean [24]. In this study, ORP cultivation mode has a largest K value and SRHD and BRHD had medium K value and the TPCR had a minimum K value (**Figure 6**). Small K values of SRHD and BRHD is favorable to the light utilization and yield formation.

In summary, the light interception ability of soybean canopy is closely related to the yield. The radiation characteristics of the canopy are mostly affected by canopy structure. LAI, MFIA, TCDP, TCRP and extinction coefficient (K) are important parameters to evaluate soybean population [19]. Growth and development of the soybean at different stages will, in turn, change canopy parameters of soybean population and affect soybean yield [25]. Particularly, subsoiling and cultivation techniques are the most important factors to influence population parameters. In this study, grain number/plant, dry matter accumulation and yield were significantly different between different cultivation patterns. Our results suggest that SRHD and BRHD are the optimal cultivation pattern for the improvement of soybean yield in phaeozem region of northeastern China.

## 4. Experimental Section

### 4.1. Plant Materials

Soybean cultivar used in this study was Hefeng50. This cultivar had sub-limited pods, 85 - 90cm of plant height, sharp leaves, strong stalks, resistance to high density and short internodes.

### 4.2. Experimental Design

This study was conducted in Fuyu Agroecological Experimental Station of Heilongjiang Academy of Sciences in Northeast China in 2010 and 2011. The research site (47°18'N, 124°0'E, Altitude: 240 m) is in the north temperate 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 time is approximately 2600 - 2800 h, annual solar radiation is 113 MJ·cm<sup>-2</sup> 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.

Soybean was cultivated with 6 cultivation Patterns: Big ridge and high density, ridge width 140 cm (BRHD), Small ridge and high density, ridge width 45 cm (SRHD),

Flat planting and high density (FPHD), Three line planting in ridge, ridge width 70 cm (TPCR), Original ridge and cards planting, Maize stubble (ORCP) and ORP (Ordinary ridge planting, 70 cm) (**Table 3**). The planting area for each cultivation pattern was 1260 m<sup>2</sup> (21 m × 60 m) and each experiment was performed in split plot with three replicates. The seeds were sowed on 1 May, 2010. Mechanical precision sowing was used and the experimental field management was similar to the production field. Fertilizer standard for BRHD SRHD and FPHD was 40 kg·ha<sup>-1</sup> carbamide (46% N), 180 kg·ha<sup>-1</sup> diammonium phosphate (18% N, 46% P<sub>2</sub>O<sub>5</sub>) and 80 kg·ha<sup>-1</sup> of K<sub>2</sub>SO<sub>4</sub> (50% K<sub>2</sub>O). The fertilizer standard for TPCR, ORCP and ORP was 75 kg·ha<sup>-1</sup> carbamide, 150 kg·ha<sup>-1</sup> diammonium phosphate and 45 kg·ha<sup>-1</sup> of K<sub>2</sub>SO<sub>4</sub>.

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. Canopy parameters and pictures measurements were obtained at 15:00-17:00 each day at the beginning flower stage R1 (15th Jul 2010, 20th Jul 2011), podding stage R3 (1st Aug 2010, 5th Aug 2011) and the seed filing stage R5 (20th Aug 2010, 25th Aug 2011) using a plant canopy digital image analyzer (CI-110, CID, US) that was placed parallel to and beside the center row plants. Canopy structure indicators included LAI, FIA, VHFD, TCDP, TCRP, extinction light coefficient and picture of population structure at R1, R3 and R5 stage. In each plot, the yield parameters including mature pod number per plant, seeds per plant and seed size (mg/seed) were measured on 15 plants. The plant was cut at ground level, bulked and a total biomass was determined. Mass of a 100-seed subsample was used to determine the mass of an individual seed. 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).

**Table 3. Experimental design in 2010 and 2011.**

Cultivation Pattern	Density (plants/m <sup>2</sup> )	Line distance, Line number	Plant distance	Ridge width
ORP(control)	25	12 cm, 2 line	5 cm	70 cm
TPCR	25	12 cm, 2 line	5 cm	70 cm
ORCP	30	12 cm, 2 line	5 cm	70 cm
BRHD	45	12 cm, 6 line	5 cm	140 cm
SRHD	38	12 cm, 12 line	5 cm	45 cm
FPHD	38	12 cm, 12 line	5 cm	70 cm

## 5. Conclusion

In this study, we analyzed the canopy structure, dynamic characteristics of light radiation and yield of Hefeng50 (the main variety of soybean in Heilongjiang Province) under six different cultivation patterns (ORP, TPCR, ORCP, BRHD, SRHD and FPHD). The results showed that SRHD and BRHD at different growth period (blossom period R1, podding R3 and grain filling period R5) produced an even distribution of the population leaf area, suitable mean foliage inclination angle (MFIA), low transparency coefficients for diffuse penetration (TCDP) and transparency coefficients for radiation penetration (TCRP), high leaf area index (LAI), extinction light coefficient (K value), fraction of radiation intercepted (FRI) and light energy utilization rate. Grain number, dry matter weight per plant, and yield of SRHD and BRHD were significantly higher than those of other cultivation patterns. The yield of SRHD, BRHD, ORCP, FPHD and TPCR was increased by 136%, 112%, 79%, 50.1% and 14.7%, respectively, compared to that of ORP. These results suggest that SRHD and BRHD are the optimal cultivation pattern for the improvement of soybean yield in phaeozem region of northeastern China.

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