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# RESPONSES OF LEAF ARCHITECTURE TRAITS AND YIELD IN MAIZE TO DIFFERENT ROW ORIENTATION AND PLANTING PATTERNS IN NORTHEAST CHINA

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## ABSTRACT

**Planting pattern and row orientation can be manipulated to optimize the canopy structure under high plant density to improve the light condition within the canopy and grain yield in maize (*Zea mays* L.). Therefore, field experiments were conducted from 2014 and 2015 in Northeast China to investigate the effects of planting pattern and row orientation on canopy distribution, light attenuation and grain yield under high plants density. Maize was planted in three planting patterns and two row orientations. Row oriented in an east-to-west orientation (E-W) and northeast-to-southwest orientation (NE20-SW), where the orientation was 20° of south bias west. Three planting patterns were set under each orientation: '65+65' with 65 cm of both rows (P0); '90+40' (P1) with 40 cm of narrow row and 90 cm of wide row and '160+40' (P2) with 40 cm of the narrow rowand 160 cm of wide row. It was found that plant height of maize was significantly affected by planting pattern and row orientation. Plant height under P1 and P2 was 28.2 cm and 29.0 cm higher than that under P0, respectively. Green leaf area of vertical distribution and light interception ratio was different in height upper 150 cm, its horizontal distribution was different under P1 and P2 compared to under P0, green leaf area of vertical and horizontal was not significant effect by row orientation. Compared with P0 in E-W, weight of grains per ear under P2 in NE20-SW was increased. It suggested that the planting pattern with 40 cm of the narrow row and 160 cm of wide row optimizes the canopy structure of maize in Northeast China.**

**Key words:** planting pattern, maize, wide-narrow row, row orientation.

## INTRODUCTION

Maize (*Zea mays* L.) is one of the major crops in Northeast China. In recent years the planting density was increased for higher maize yield (Li et al., 2011; Zhang et al., 2007). However, higher planting density results in poor illumination and ventilation in internal canopy of maize, which may cause plant pathology (Widdicombe and Thelen, 2002) and affects grain yield.

Varied planting pattern can modify plant spatial distribution, which plays important roles in yield formation (Han et al., 2014; Liang et al, 2009; Maddonni et al., 2006). In the field, 65-cm row spacing is the conventional uniform-row planting pattern for maize in Northeast China. Numerous studies about the planting pattern of so-called 'wide-narrow row' (WNR) were reported in maize (Liu et al, 2006; Liu et al., 2012), wheat and rice (Li et al., 2008; Wang et al., 2004; Yao et al., 2001). The canopy in WNR systems are characterized by strong horizontal heterogeneity of foliage distribution. In winter wheat, it was documented that optimized canopy architecture in WNR systems improves light condition within the canopy and increases higher yield compared with conventional uniform-row planting pattern (Li et al., 2008; Liang et al, 2009). However, the study on canopy architecture and yield under WNR systems in maize is rare.

Canopy of maize is sensitive to plant spatial arrangement. Lower leaf length, higher plant height and larger leaf vertical angle was found in high-density population, and plant height and leaf length were increased with reduced row spacing in maize (Maddonni et al., 2001a). Shoot components of maize can be influenced by plating patterns (Maddonni et al., 2001a; Widdicombe and Thelen, 2002; Hu and Lan, 2001; Ku et al., 2010). However, the canopy distribution of planting pattern in

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WNR systems of maize under higher plant density was not well studied.

Row orientation can influence growth and development (Kasperbauer, 1987), interception of photosynthetically-active, incident solar radiation (Karlen and Kasperbaues, 1989). Inconsistent results were reported on optimal row direction in maize planting (Widdicombe and Thelen, 2002; Timlin et al., 2014). Some literatures documented that planting in north-south orientation was better than that in east-west orientation; while some of studies suggested that planting in east-to-west orientation was better. Widdicombe and Thelen (2002) suggested optimal row orientation is related to the location of experiments at different latitude and crop planting.

Light interception varies with canopy architecture. Many studies documented that light interception is affected by the distribution of leaf area, length and width of leaf and LOV (Stewart et al., 2003; Boote and Loomis, 1991). Also, light interception can be influenced by plant density, row spacing and row orientation (Maddonni et al., 2001a; Zhou et al, 2011; Karlen and Kasperbauer, 1989). However, light attenuation in canopy under wide-narrow row planting pattern has received little attention.

Three planting patterns (two models of wide-narrow row planting pattern 80+40 cm and 160+40 cm and one equidistant plant spacing (65 cm)) in two row orientation were evaluated in the present study. The objectives were: 1) to quantify of canopy architecture under three planting patterns and two row orientations; 2) to determine the effect of planting patterns and row orientations on light attenuation; 3) to measure the grain yield component in response to these management practices.

## MATERIAL AND METHODS

### Field experimental design

Field experiments were conducted at the experimental station in Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun (44°12′ N, 125°33′ E) in 2014 and 2015. The precipitation in 2014 and 2015 are shown in Figure 1. Maize cv. LY 99 was sown on 3 May in experimental years. Before planting, 220 kg $ha^{-1}$ N, 60 kg $ha^{-1}$ P and 60 kg $ha^{-1}$ K were applied. The experiment was a split-plot design with row direction as main plots and planting pattern as subplots and each treatment had three replicates. The size of each plot was 300 $m^2$ (20 m width × 15 m long). Each plot was planted maize of same planting pattern and row orientation form 2013. The plant density is 6.5 plants $m^{-2}$. The plot comprised black soil clay. Plots were hand-planted at two healthy seeds per hill and one seedling was retained after emergence. The plants were not irrigated during the experimental periods. Weeds, insects and diseases were well-controlled.

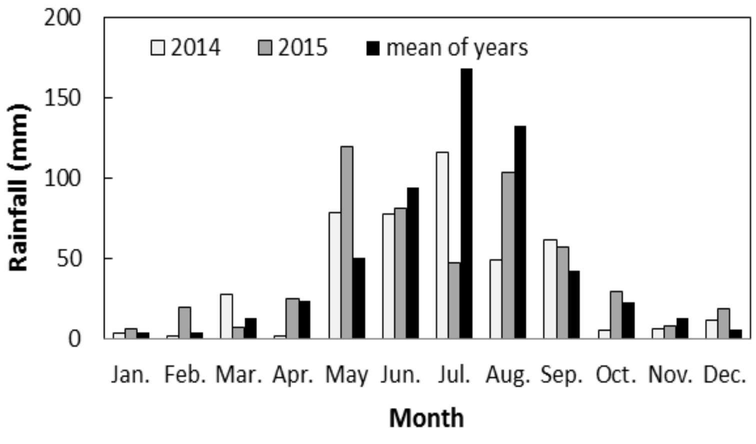


*Figure 1.* Rainfall during the experimental period in 2014 and 2015 and mean value of last decade

Two row orientations were set: east-to-west orientation (E-W) and northeast-to-southwest orientation (NE20-SW), where the orientation was 20° of south bias west. The previous study showed that this row orientation benefits growth of maize. Three planting patterns were set under each orientation: 90+40 (P1) with 40 cm of narrow row and 90 cm of wide row; 160+40 (P2) with 40 cm of the narrow row and 160 cm of wide row, and 65+65 with 65 cm of both rows (P0) (Figure 2). After harvesting the corn, the straw of P2 was returned to field, stubble height was 35 cm, the rest of straw was kept in twin-narrow-rows (Figure 2).

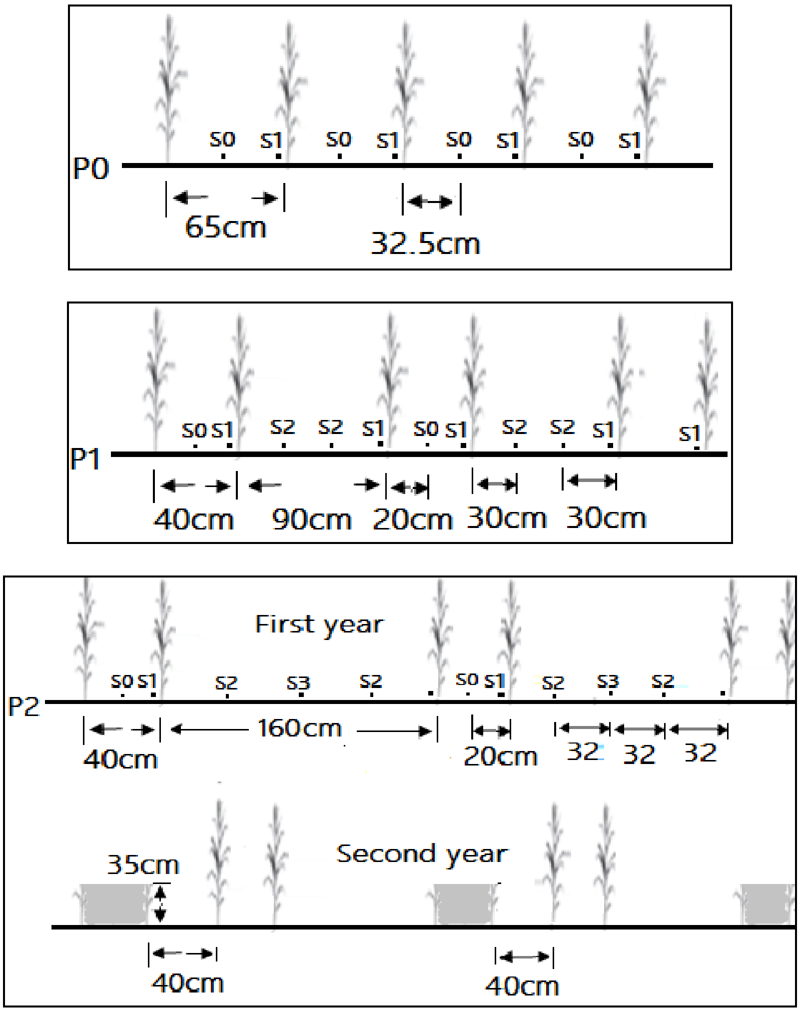


*Figure 2*. The schematic diagram showing planting pattern of P0 (65+65), P1 (90+40) and P2 (160+40) in this experiment

**Canopy architecture and LMA**

The crop plants in a land area of 1.3 $m^2$ (100 cm×130 cm) were sampled to determine the spatial distribution of leaves on 90 DAS (anthesis stage) in each plot. An area of 1.3 $m^2$ was selected in neighboring twin-narrow-row and divided into four equal parts: A0: area that range of 32.5 cm from the twin-narrow-row center line, A1: area that range of 32.5 cm to 65 cm from the twin-narrow-row center line. For each plant sample, the leaves, sheaths, stems and ears were separated. After the measurement of green leaves, the samples were dried in an oven for 72 h at 70°C and weighed. Green leaf area was estimated as the sum of green leaf areas per sample and LMA was calculated.

**Leaf orientation value (LOV)**

Leaf angle from the horizontal plane (θ) was measured on 90 DAS in 2015 (Girardin and Tollenaar, 1994). The leaf orientation value (LOV) was calculated as in Pepper et al. (1977):

$$LOV = 1/n \sum \theta \times (Lf/L) \quad (1)$$

where: θ is the leaf angle of measured leaf, L is leaf length, Lf is the length from beginning of ligula to flagging point of leaf, and n is the number of leaves measured.

**Light attenuation**

The radiant flux density was measured 30 cm above the top of maize canopy using Li-190 quantum sensor (LI-COR, Lincoln, NE). The transmitted photosynthetically active radiation (PAR) was measured 3 cm, 50 cm, 100 cm, 150 cm and 200 cm above the soil surface, respectively, using Li-191 quantum sensor (LI-COR, Lincoln, NE) on 90 DAS. When measuring the transmitted radiation, the line quantum sensor was placed parallel to the row direction and near the plant in different positions (P0: S0 and S1; P1: S0, S1 and S2; P2: S0, S1, S2 and S3) as shown in Figure 2 (Li et al., 2010; Shi et al., 2005). The average of these positions was calculated as the radiation transmitted by each height. Four independent measurements were made at each canopy layer within each plot between 10:30 and 13:00 on clear days. The intercepted radiation was calculated as the ratio of the difference between the incident and transmitted radiation to the incident radiation.

**Yield components**

Yield components were measured with the 50 plants in the central rows of an experimental unit. The grain weight per ear, number of kernels per ear, 1000-seed weight, length of ear, diameter of ear, kernel row number per ear, kernel number per row, grain number per ear and was measured.

**Analysis**

All data were subjected to the two-way ANOVA using the SPSS (SPSS Inc., released 2009; PASW Statistics for Windows, Version 18.0, SPSS Inc., Chicago, IL). Duncan's multiple range test was applied to assess the differences between treatments at a significance level of 0.05.

## RESULTS

**Plant height and ear height**

Plant height of maize was significantly affected by planting pattern and row orientation (Figure 3A). Plant height under P1 and P2 was 28.2 cm and 29.0 cm higher than that under P0, respectively. Plant height in NE20-SW was 5.89 cm higher than that of in E-W. In addition, there was no significant difference in ear height among all treatments (Figure 3B).

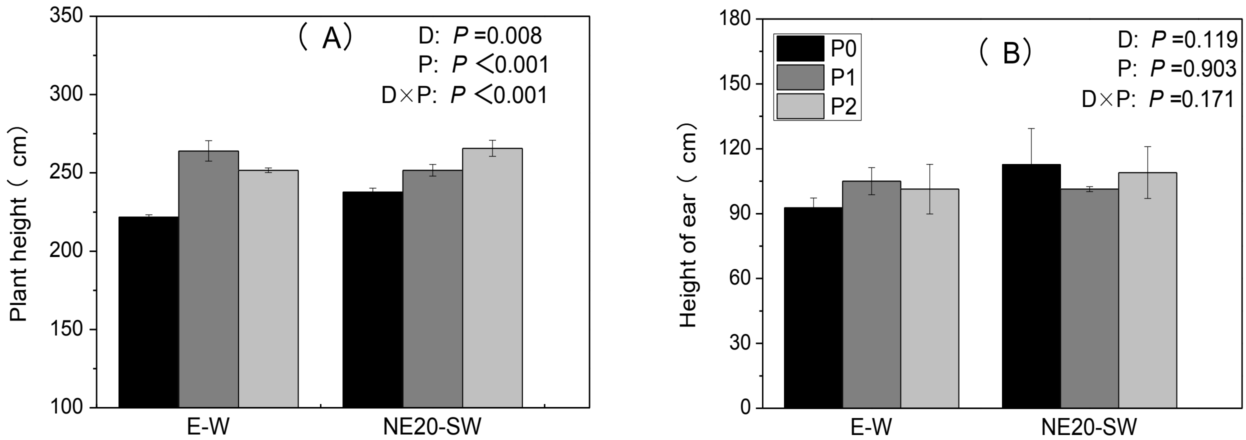


*Figure 3.* Plant height and ear height under three planting patterns and two row orientations
(E-W and NE20-SW were East-West row orientation and South bias West 20 degrees row orientation, respectively. P0, P1 and P2 were planting pattern model of 65+65, 90+40 and 160+40, respectively)

**GLAI, leaf mass per unit area (LMA) and green leaf area of spatial distribution**

No significant difference was found in GLAI and LMA among all treatments (Figure 4 A, B). On 90 DAS, green leaf area of vertical distribution was different in height range of 100-150 cm, 150-200 cm and above 200 cm in E-W (Table 1). The green leaf area of vertical distribution was not significantly affected by row orientation. Green leaf area of horizontal distribution under P0 was different under P1 and P2 however, it was not significantly different under P1 and P2 in E-W and NE20-SW (Figure 5).

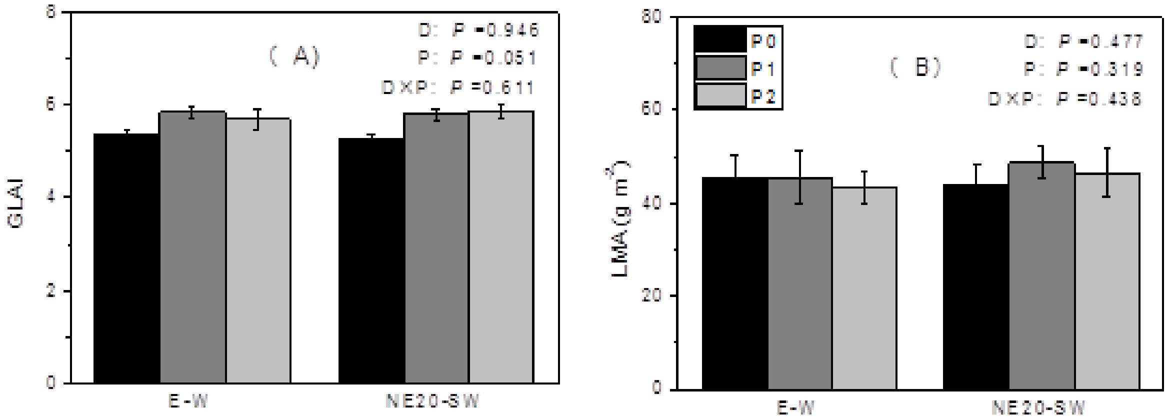


*Figure 4.* Green leaf area index and leaf mass per unit area (LMA) under two row orientations (D) and three planting patterns (P) on DAS 90. DAS, days after sowing

*Table 1.* Green leaf area of vertical distribution on DAS 90 under P0, P1 and P2 in E-W and NE 20-SW

Unit: %

| Row orientation | Planting pattern | Height | | | | |
|---|---|---|---|---|---|---|
| | | 0-50 cm | 50-100 cm | 100-150 cm | 150-200 cm | Above 200 cm |
| E-W | P0 | 3 | 19 | 28.7 a | 22.66 b | 26.62 ab |
| | P1 | 3.6 | 18.64 | 23.6 b | 24.63 b | 29.5 a |
| | P2 | 2.2 | 16.79 | 25.8 ab | 31.47 a | 23.8 b |
| NE20-SW | P0 | 3.6 | 17.64 | 25.4 b | 32.1 a | 21.26 b |
| | P1 | 4.3 | 14.1 | 27.4 a | 26.61 b | 27.65 a |
| | P2 | 4.3 | 14.71 | 26.8 a | 25.75 b | 28.38 a |

Different letters represent significant difference among same row orientations, significant at $p < 0.05$.

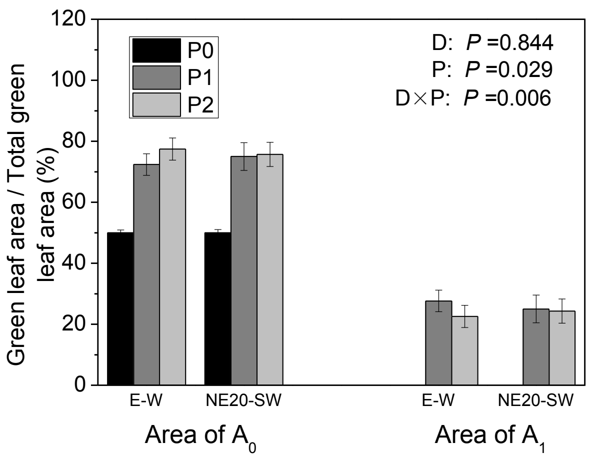


*Figure 5.* Green leaf area of horizontal distribution under two row orientations (D) and three planting patterns (P) on DAS 90. (DAS: days after sowing; $A_0$ : area that range of 32.5 cm from the twin-narrow-row center line; $A_1$ : area that range of 32.5 cm to 65 cm from the twin-narrow-row center line)

### Leaf length and LOV

There was no significant difference in leaf length under P0, P1 and P2 in E-W. However, leaf length of 13$^{th}$-17$^{th}$ leaf under P0, P1 and P2 in NE20-SW was higher compared with P0 in E-W. As compared with P0 in E-W, LOV of 7$^{th}$-12$^{th}$ under P1 and P2 in E-W and P0, P1 and P2 in NE20-SW was significantly decreased (Table 2), LOV of 13$^{th}$-17$^{th}$ under P1 and P2 in NE20-SW was significantly decreased, while LOV of 18$^{th}$-21$^{st}$ under P2 in NE20-SW was significantly increase.

*Table 2.* Leaf length and leaf orientation value (LOV) of P1 and P2 in E-W and P0, P1 and P2 in NE20-SW compared with P0 in E-W

Unit: %

| Leaf rank | VS P0 in E-W | | | | |
|---|---|---|---|---|---|
| | in E-W | | in NE20-SW | | |
| | P1 | P2 | P0 | P1 | P2 |
| Leaf length | | | | | |
| 7th to 12th leaf | ns | ns | ns | ns | ns |
| 13th to 17th leaf | ns | ns | ↑12.41 b | ↑ 17.06 a | ↑ 14.29 a |
| 18th to 21st leaf | ns | ns | ns | ns | ns |
| LOV | | | | | |
| 7th to 12th leaf | ↓5.60 b | ↓ 7.12 b | ↓ 9.86 a | ↓ 29.93 b | ↓ 21.78 b |
| 13th to 17th leaf | ns | ns | ns a | ↓ 27.21 c | ↓ 6.84 b |
| 18th to 21st leaf | ns | ns | ns b | ns b | ↑ 9.74 a |

Different letters represent significant difference among same row orientations, significant at p＜0.05;
ns = not significant; '↑' means that value was increased and '↓' value was decreased compared with P0 in E-W.

## Light interception ratio

Light interception ratio varies with height of canopy (Figure 6). Light interception ratio at the height of 150-200 cm was highest, followed by that at the height of 100-150 cm, and that of 3-50 cm of canopy height was lowest. Light interception ratio at 3-50 cm and 50-100 cm of canopy height was not significantly affected by these treatments (Figure 6 and Table 3). However, light interception ratio at the height of 100-150 cm, 150-200 cm and upper 200 cm of canopy was significantly affected by plant patterns.

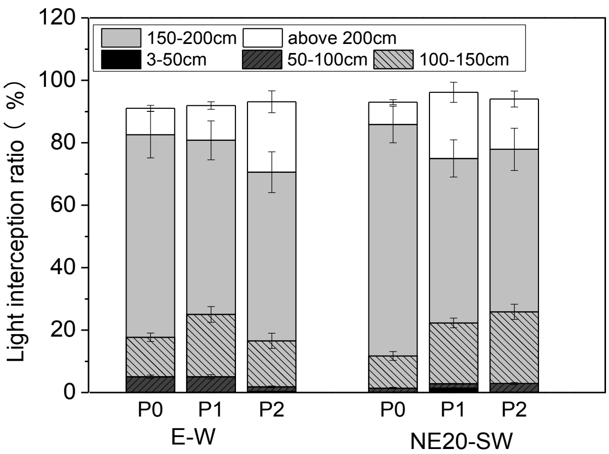


*Figure 6.* Light interception ratio under three row orientations (D) and three planting patterns (P) on DAS 90 (DAS, days after sowing)

*Table 3.* Output of statistical analysis on light interception ratio under three row orientations (D) and the three planting patterns (P)

| Factor | Height | | | | |
|---|---|---|---|---|---|
| | 3-50 cm | 50-100 cm | 100-150 cm | 150-200 cm | Above 200 cm |
| D | ns | ns | ns | ns | ns |
| P | ns | ns | * | * | * |
| D×P | ns | ns | * | * | * |

* significant at p＜0.05; ns - not significant.

**Yield components**

Grain weight per ear and 1000-seed weight was significantly affected by planting pattern and interaction of row orientation and planting pattern in 2014. Grain weight per ear and kernels per ear were significantly affected by planting pattern and interaction of row orientation and planting pattern in 2015 (Table 4). Compared with P0 in E-W, weight of grains per ear under P2 in NE20-SW was increased by 7.75% and 11.71% in 2014 and 2015, respectively.

*Table 4.* Grain yield components under two row orientations and three planting patterns and out-put of statistical analysis for the effect of row orientation (D), the planting pattern (P), and year (Y) and interactions (D×P) on yield components

| Row orientation | Planting pattern | Weight of grains per ear (g) | Kernels per ear (no.) | 1000-seed weight (g) | Length of ear (cm) | Kernel rows per ear (no.) | Kernels per row (no.) |
|---|---|---|---|---|---|---|---|
| 2014 | | | | | | | |
| E-W | P0 | 208.5±4.6 | 662.7±14.3 | 314.6±4.7 | 17.8±0.3 | 17.5±0.3 | 37.8±0.9 |
| | P1 | 211.0±5.7 | 671.3±6.8 | 314.3±4.4 | 18.2±0.7 | 17.5±0.5 | 38.3±1.3 |
| | P2 | 206.5±6.3 | 660.5±6.8 | 312.6±5.4 | 18.4±0.3 | 17.4±0.6 | 37.9±1.3 |
| NS20-SW | P0 | 207.3±4.1 | 660.6±6.9 | 313.7±4.6 | 19.5±0.3 | 17.8±0.4 | 37.1±0.9 |
| | P1 | 213.1±4.3 | 677.9±6.1 | 315.1±3.9 | 19.5±0.2 | 17.950.4 | 37.8±1.3 |
| | P2 | 220.1±4.8 | 679.1±7.4 | 325.2±6.8 | 19.7±0.5 | 17.9±0.3 | 37.9±1.4 |
| 2015 | | | | | | | |
| E-W | P0 | 98.8±7.6 | 333.8±25.8 | 296.0±6.4 | 12.9±0.3 | 15.2±0.4 | 20.6±1.0 |
| | P1 | 93.9±11.7 | 330.1±42.1 | 284.6±4.1 | 13.3±0.7 | 15.2±0.6 | 21.7±1.5 |
| | P2 | 107.0±10.5 | 357.5±32.1 | 299.3±3.7 | 13.9±0.6 | 16.2±0.4 | 22.0±1.3 |
| NS20-SW | P0 | 89.8±13.7 | 324.0±33.9 | 277.2±4.8 | 13.1±0.7 | 16.4±0.4 | 20.1±1.7 |
| | P1 | 105.7±8.5 | 351.2±24.8 | 301.1±5.2 | 12.8±0.5 | 15.1±0.5 | 24.5±1.9 |
| | P2 | 111.9±7.8 | 373.±19.5 | 312.0±5.9 | 16.0±0.4 | 16.2±0.2 | 29.4±1.2 |
| 2014 | | | | | | | |
| D | | ns | ns | ns | ns | ns | ns |
| P | | ns | ns | ns | ns | ns | ns |
| D×P | | * | ns | * | ns | ns | ns |
| 2015 | | | | | | | |
| D | | ns | ns | ns | ns | ns | ns |
| P | | * | * | ns | ns | ns | ns |
| D×P | | * | * | ns | * | * | ns |
| Y | | * | * | * | * | * | * |

*significant at $p < 0.05$; ns= not significant.

## DISCUSSION

For canopy distribution, plant height and ear height are key parameters in maize. It showed that ear height was not significantly affected (Figure 3 B), while plant height was significantly affected by three planting patterns and two row orientations (Figure 4A). This is similar with the study of Maddonni et al. (2001b), which documents that the difference in plant height is mainly due to the difference in internodes length above ear. The present study showed that planting pattern and row orientation affected the vertical distribution of leaves area of upper height of plant, especially at 150-200 cm and upper 200 cm. Here, amount of total internodes and leaves per plant and that under ear was similar among all treatments (data not shown). Therefore, difference in internodes length above ear was caused by the vertical distribution of green leaves area at the height 150-200 cm and upper 200 cm under three planting pattern and tow row orientation on 90 DAS (Table 1).

Normally, the leaf of maize was row oriented to space available in the canopy (Akmal et al., 2013). Verhagen (1963) documented that ideal leaf spatial structure can be achieved by regulating leaves angle. The horizontal distribution of green leaf area was relatively uniform under the planting pattern ‘65+65’, while it was not uniform in planting pattern ‘90+40’ and ‘160+40’

(Figure 5). Liu et al. (2012) reported an uniformly distribution leads to a better internal microenvironment of canopy, which increases the carbon dioxide concentration and decreases the humidity within canopy in wide-narrow row planting pattern. Leaf angle was affected by horizontal distribution of maize leaf (Duncan, 1971; Gustavo Angel, 2002; Ku et al., 2010). Here, the result showed that planting pattern affected significantly LOV, which was consistent with the results of Wu et al. (2005). The LOV of 7$^{th}$-12$^{th}$ of P1 and P2 was lower as compared with P0. It was caused by non-random distribution in canopy. The lower LOV was helpful to intercept more solar energy (Ku et al., 2010; Wu and Dong, 2010). Lower LOV increases leaf shade and decreases photosynthetic efficiency, whereas plants with relatively high LOV have a plant architecture that is more efficient in capturing light for photosynthesis (Ku et al., 2010). As compared with P1, LOV of 7$^{th}$-12$^{th}$ of P1 was lower than that of P2. This may be caused by the interactive effects of density and planting pattern on LOV, as LOV was increased with plant density (Tang et al., 2013). LOV of 18$^{th}$-21$^{th}$ under P2 was increased, which suggested the benefit of light transported downwards.

Row orientation and planting pattern had significant effects on length of 13$^{th}$-17$^{th}$ leaves. Length of 13$^{th}$-17$^{th}$ leaves in E-W was lowest, while that in NE20-SW was higher. In NE20-SW, the length of 13$^{th}$-17$^{th}$ leaves under P1 and P2 was greater than those under P0. This result is similar with the result of Wang et al. (2015). The increase of leaf length helps the leaf extend into block space in the canopy (Akmal et al., 2013). Maddonni et al. (2001a) reported that length of maize leaves is increased and width of maize leaves is decreased when row wide from 0.7 m decreases to 0.3 m. However, our result showed that the width of maize leaves was not significantly affected by planting patterns and row orientations (data not shown).

Light distribution and interception can be modified by row spacing and orientation. This study showed that light interception ratio at different height varies significantly, which was in lines with the results of Wei et al. (2014). Planting pattern and its interaction with row orientations significantly affected the light interception ratio (Figure 6 and Table 3). This is not caused by the difference in total light interception of canopy, but due to the difference of light interception ratio at different height of canopy. This was in agreement with the results of Dong et al. (2013), that documented that there was significant difference in light interception ratio at the height of 60-80 cm of canopy in wheat. Light interception ratio at the height of 150-200 cm under P1, P2 and P0 was 52.68-4.03%, 52.04-54.03% and 64.86-74.12% of the total, respectively. As compared with P1 and P2, light interception ratio at the height of 150-200 cm under P0 was the highest, this was detrimental for the maize population (Tang et al., 2012; Duncan, 1971), since light interception ratio at the height of150-200 cm was too high, which leads to lower light distribution for the canopy below 150 cm. If there is greater light in lower canopy, it will favor for photosynthesis in the lower leaves. Ao et al. (2008) showed that the wide-narrow row and wide row and narrow plant spacing planting can improve the light interception of the lower part of canopy of the rice, so as to improve the utilization of light energy to obtain high yield. Compared to P0, light interception ratio at the height of 100-150 cm under P1 and P2 was higher, which suggested that there is greater light at the height of 100-150 cm of the plant canopy. Therefore, as compared with P0, the maize canopy architecture of P1 and P2 is more reasonable for light distribution. Therefore, optimal canopy structure can be optimized by P1 and P2 for optimal leaf distribution and better light interception in maize. No significant effect of row orientation on light interception of maize canopy was found (Figure 6 and Table 3). The similar result was reported by Steiner (1986).

Green tissues lend to more absorb blue (400-500 nm) and red (600-700 nm) wavebands and more reflect more far-red (700-800 nm) waveband, therefore red:far-red (R/FR) reaching the plant base was reduced

(Borrás et al., 2003). Row orientation and row spacing can influence red:far-red (R/FR) (Kasperbauer,1971; Maddonni et al., 2006). Change in spectral light qualityacts as an environmental signal inside the maize canopy (Varlet Grancher and Gautier, 1995), that affects leaves distribution and light distribution and interception, then influences the crop photochromic system (Borrás et al., 2003; Kasperbauer, 1971). This is natural bioregulation process (Karlen and Kasperbauer, 1989). Optimized spatial distribution of canopy can provide a means to create light saturated conditions for the crop canopy for the purpose of efficient harvest of solar energy (Lunagaria and Shekh, 2006). Evaluation showed that there is a relatively more far-red light under narrow rows compared with that under wide rows at the lowermost leaf stratum of canopy (Borrás et al., 2003; Maddonni, et al., 2006). For the efficiently harvest solar energy, wide row spacing provide a means to create light saturated conditions.

In the previous studies, it was demonstrated that row spacing have no significant effect on GLAI in maize (Maddonni et al., 2001b; Westgate et al., 1997; Akmal et al., 2013). Our results were consistent with this (Figure 4A). However, GLAI was not significant different between E-W and NE20-SW, this was not consistent with Akmal et al. (2013.), where leaf area was greater in E-W than that in N-S. Previous studies show that LMA is correlated with net photosynthesis, growth rate and leaf structure (Gunn et al., 1999). Normally, LMA was increased with light intensity, and it was changed by the physiological parameters in plant leaves. It was documented that physiological adaptation of leaves to the external environment was due to changes in LMA (Rosati et al., 1999; Zhang and Feng, 2004). Our results indicated LMA was not different among all treatments on DAS 90 (Figure 4B).

Opposite effects of row spacing and row orientation on grain yield of maize have been documented (Andrade et al., 2002; El-Mekser, 2009; Farnham, 2001; Tsubo and Walker, 2004; Widdicombe and Thelen, 2002). Here, it showed that grain weight per ear and 1000-seed weight was significantly affected by planting pattern and interaction of row orientation and planting pattern in 2014.

Grain weight per ear and kernels per ear were significantly affected by planting pattern and interaction of row orientation and planting pattern in 2015 (Table 4). There is the highest yield under P2 in NE20-SW.

Rain-fed agriculture is popular in most maize planting area in Northeast China. Rainfall mainly occurs in from June to September. This experimental site was located in this area, therefore, the water needed for maize growth and development mainly comes from natural rainfall. Rainfall in August in 2014 decreased by 83.5 mm as compared with the same period of the previous years (Figure 2), which caused water shortage for maize growth. Rainfall in July in 2015 decreased by 117.9 mm as compared with the same period of the previous years (Figure 2), which also caused water shortage for grain filling in maize. It is the key stages of flowering and grain formation in maize, soil water deficit significantly affects fertilization, seed set (Song and Dai, 2000), and hence affecting the grain number. However, it was found that 1000-seed weight and weight of grains per ear under P2 in NE20-SW was higher than others in 2014. This result should be related to straw mulching and wide-narrow row. Under P2, straw mulching can adjust the soil water and temperature, and improve the water condition of maize root zone (Liu et al., 2006; Wang et al., 2014).This planting pattern effects on soil evaporative loss was weak, as compared with the maize grown under other planting patterns, which improves the soil heat condition. In addition, wide-narrow-row plating pattern can also keep more soil water for the growth and development of maize during reproductive stage (Lyon et al., 2009).

Drought occurs frequently in the Northeast China, especially in decades, the risk of drought is increasing in this region (Zhang et al., 2004). Therefore, suggested that the planting pattern with 40 cm of the narrow row and 160 cm of wide row in NE20-SW optimizes the grain yield in maize.

## CONCLUSION

Planting pattern and row orientation can be manipulated to optimize the canopy structure under high plant density to improve light conditions within the canopy and get more grain yield. In Northeast China, maize was traditionally cultivated in uniform spaced rows '65+65' (P0). It was found that plant height of maize was significantly affected by planting pattern and row orientation. Plant height under P1 and P2 was 28.2 cm and 29.0 cm higher than that under P0, respectively. Green leaf area of vertical distribution and light interception ratio was different in height upper 150 cm, its horizontal distribution was different under P1 and P2 compared to under P0, green leaf area of vertical and horizontal was not significant effect by row orientation. Compared with P0 in E-W, weight of grains per ear under P2 in NE20-SW was increased. It suggested that the planting pattern with 40 cm of the narrow row and 160 cm of wide row optimizes the canopy structure of maize in Northeast China.

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