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Planting Density of Spring Maize under Optimal Growth Conditions in North-eastern China

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Abstract: Light plays a key role in net primary productivity. To take full advantage of light interception and Radiation Use Efficiency (RUE) in maize, Reasonable planting densities should be suggested for different varieties to achieve optimal growth conditions in North-Eastern China. This study was performed in 2009, 2010 and 2011 at one of the CAAS North-East Research Stations. The experiment was conducted using a split-plot design based on a randomised complete block design with three replicates; treatments included planting densities of 37, 500, 52, 500, 67, 500 and 82, 500 plants per hectare (pl ha^{-1}) and 10 varieties were used as sub-treatments. We examined RUE values in different types (spreading leaf, intermediate type, upright leaf) and varieties and identified reasonable densities for different types in relation to the light distribution in North-Eastern China to achieve the highest RUE. All treatments showed significant effects of interception, RUE and density. Ideal planting density differed among types in combination with local light resources. In conclusion, the best densities for spreading-leaf, intermediate and upright-leaf types were 33, 381-41, 736 pl ha^{-1}, 44, 629-56, 584 pl ha^{-1} and 62, 573-82, 969 pl ha^{-1}, respectively, in North-Eastern China. Maximum grain yield should be realised when maize is grown at the optimum plant density for dry matter yield.

Key words: Planting density, maize, optimal growth conditions, north-eastern

INTRODUCTION

Successful modern methods for improved farming and breeding to achieve good yields partly depend on the management, use and distribution of light in plant populations (Tohidi *et al.*, 2012). Light is one of the main growth and biomass production factors in plant populations and dry matter accumulation under conditions without stress (Tsubo *et al.*, 2001).

Planting density is one of the most important agricultural practices determining grain yield, as well as other important agronomic attributes of the crop. Higher population densities allow maize to intercept virtually all of the available solar radiation earlier in the season, transforming this energy into storage carbohydrates and other foods and producing more grains per unit area (Sangoi, 2001).

A considerable amount of research has focused on determining the relationships between light radiation and physiology, canopy, row space, hybrids and morphological traits during the last decades (Mock and Pearce, 1975). However, little research has examined the relationship between light radiation and plant density in the large agricultural area that spans 14°50' of latitude in China. Scientific methods need to be found to maximise plant density under optimal growth conditions of light availability that will increase dry matter production and efficient grain production.

MATERIALS AND METHODS

Study area: The study area encompassed the provinces of Heilongjiang, Jilin and Liaoning, China which are located between 118°50'E and 135°05'E longitude and 38°43'N to 53°33'N latitude (Fig. 1), spanning 14°50' of latitude and including considerable variation in solar radiation. The area provided large samples for examining the effect of light distribution on maize. It includes the major maize-producing areas in China. This study was conducted at one of the CAAS (Chinese Academy of Agricultural Sciences)North-East Research Stations (Gongzhuling, China; 43.3°N, 124.5°E) which was located in the middle of North-Eastern China, where the soil and climate were reasonably representative.

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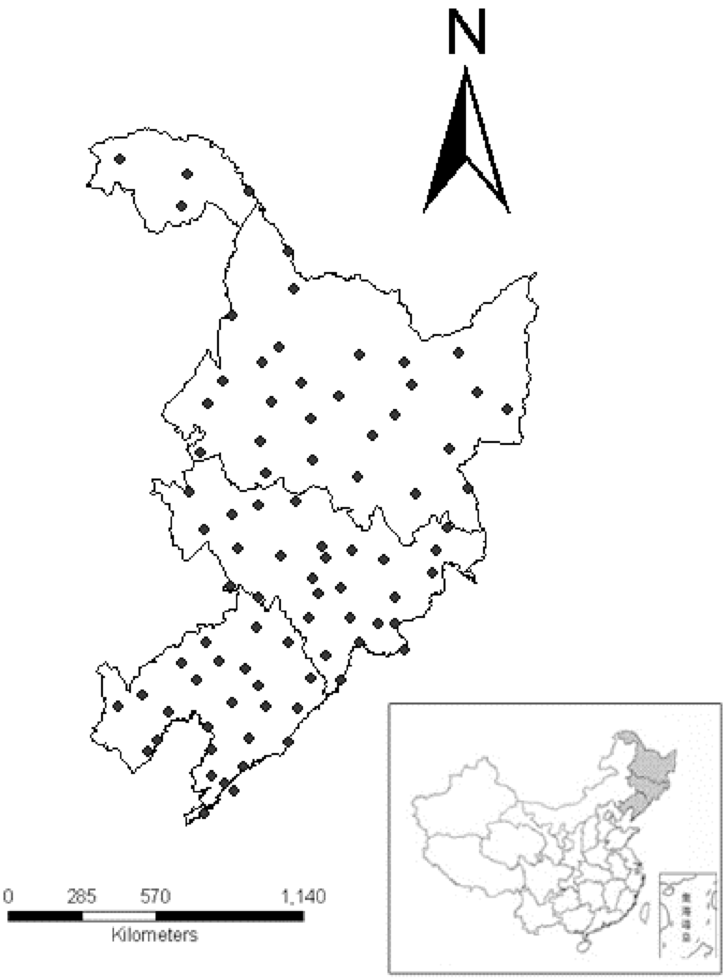

Fig. 1: Location of the study area in China (Dots indicate the location of weather stations)

Meteorological data and processing: Light distribution was calculated using a data set that included meteorological data, an administrative map and grain cultivation area statistics for North-Eastern China. Temperature, longitude, latitude and altitude data were obtained from the Data Centre of the National Meteorological Bureau of China. Daily weather data were collected at 87 stations distributed the provinces of Heilongjiang, Jilin and Liaoning from 1981-2010 (Fig. 1) at a wide range of elevations.

Method for predicting solar radiation: Solar Radiation (Q_M) can be calculated as:

$$Q_M = Q_o(a+b_S) \tag{1}$$

Q_M is the monthly astronomical total solar throughout radiation, S is the monthly sunshine percentage and a and b are regression coefficients calculated using a least-squares method and data from the nearest weather station.

Experimental design: The study was carried out between 2009 and 2011. It was a split-plot experiment based on a randomized complete block design with three replicates. Ten open-pollinated maize cultivars (Table 1), Baihe (Bh), Yinglizi (Ylz), Jidan101 (Jd101), Zhongdan2 (Zhd2), Sidan8 (Sd8), Danyu13(Dy13), Yedan13 (Yd13), Jidan180 (Jd180), Zhengdan958 (Zhd958) and Xianyu335 (Xy335), were used. In the split-plot design, cultivars were used as main plots and maize densities were included as subplots. The subplots measured 12×12 m with maize planted at a spacing of 60 cm between rows, producing plant populations of approximately 37, 500, 52, 500, 67, 500 and 82500 (d1, d2, d3 and d4) pl ha^{-1}, respectively.

Table 1: TPAR/IPAR in lays among varieties at two densities and regression of TPAR/IPAR among varieties

	TPAR/IPAR Ear stratum		TPAR/IPAR Below the ear		TPAR/IPAR On ground	
Varieties	d1	d4	d1	d4	d1	d4
Bh	0.197	0.116	0.110	0.049	0.055	0.032
Ylz	0.229	0.098	0.104	0.053	0.070	0.034
Jd101	0.192	0.097	0.125	0.047	0.057	0.032
Sd8	0.231	0.100	0.165	0.059	0.054	0.035
Zhd2	0.248	0.105	0.149	0.051	0.075	0.037
Dy13	0.252	0.101	0.162	0.087	0.067	0.038
Yd13	0.263	0.118	0.141	0.098	0.079	0.049
Jd180	0.252	0.140	0.131	0.128	0.085	0.045
Zhd958	0.358	0.182	0.168	0.112	0.099	0.046
Xy335	0.382	0.198	0.193	0.139	0.143	0.049
R^2	0.758**	0.638**	0.585**	0.859**	0.674 **	0.847**

The following calculations were performed:

$$\text{Leaf area per plant} = \text{length}\times\text{width}\times 0.75\ (\text{cm}^2) \quad (2)$$

$$\text{LAI} = \text{Leaf area per plant}\times\text{density}\times 10^{-8} \quad (3)$$

Solar radiation interception: Incoming Photosynthetically Active Radiation (IPAR) was calculated from Photosynthetically Active Radiation (PAR) measured above the canopy and Transmitted Photosynthetically Active Radiation (TPAR) measurements at three locations: ear leaves, below ear leaves but above senesced leaves and the bottom of the anopy. The fraction intercepted was measured at 9:00 to 11:00 AM on clear days during the first 10 days of the grain-filling period using a line quantum-sensor (SunScan, Delta, UK). Three measurements were taken within each plot. TPAR/IPAR is used to estimate the distribution of solar radiation in the maize canopy.

The attenuation coefficient(k) can then be calculated as:

$$K = \frac{-\ln(\text{TPAR}/\text{IPAR})}{\text{LAI}} \quad (4)$$

We also measured the leaf area of different cultivars at the silking stage under different plant densities and constructed three regression equations between leaf area and density for the three types. According to the assumption that density is equal to the ratio between reasonable LAI and leaf area, we established a unary quadratic equation and estimated reasonable densities for local populations using Eq. 5.

$$\text{Density (plant/m}^2) = \text{Reasonable LAI/ leaf area of plant at the silking stage} \quad (5)$$

RESULTS

Light distribution in north-eastern China: Average solar radiation over 30 years varied from 1800 to 2700 MJ/m^2 in North-Eastern China which shows that solar radiation was higher in the west than in the east, exhibiting a zonal distribution with a gradual decrease from west to east (Fig. 2).

Light extinction coefficient (K): We measured TPAR and IPAR for the 10 varieties (Table 1) at densities of 37, 500, 52, 500, 67, 500 and 82, 500 pl ha^{-1} (d1, d2, d3 and d4). From Table 1, we can conclude that TPAR/IPAR decreased with increasing density and that TPAR/IPAR values for different cultivars changed by different degrees. Also, TPAR/IPAR was shown to decline with decreasing height which means that less and less light reaches the bottom of the plant as height decreases. The light extinction coefficient (k) was then calculated using Eq. 4; k was determined by group structure and showed no relationship with light intensity. The 10 maize cultivars were classified using a hierarchical cluster analysis which calculates between-group linkage measurements by Euclidean distance, according to their k-values under different densities. Figure 3 shows the results.We defined these three types as spreading leaf, intermediate type and upright leaf, according to their k-values.

Reasonable leaf area index (LAI) values in north-eastern China: Using the spreading-leaf type, intermediate type and upright-leaf type groups from the cluster analysis, we constructed three regression equations between the k-value and LAI for the three types, respectively. The initial regression analyses indicated that k-value and LAI were highly significantly correlated ($p<0.01$). The resulting equations were Spreading leaf:

$$K = -0.113\text{LAI}+1.241$$

Intermediate type: $K = -0.078\text{LAI}+1.01$

Upright leaf: $K = -0.037\text{LAI}+0.705$

Based on the assumption that the light compensation point to ensure normal maize growth is close to 1000 lux, we back-stepped the suitable LAI of local maize according to Equation 4 using IPAR values for 87 weather stations in North-Eastern China. The spreading-leaf maize LAI ranged from 2.94 to 3.52, the intermediate type LAI ranged from 3.73 to 4.51 and the upright-leaf type LAI ranged from 5.22 to 6.28.

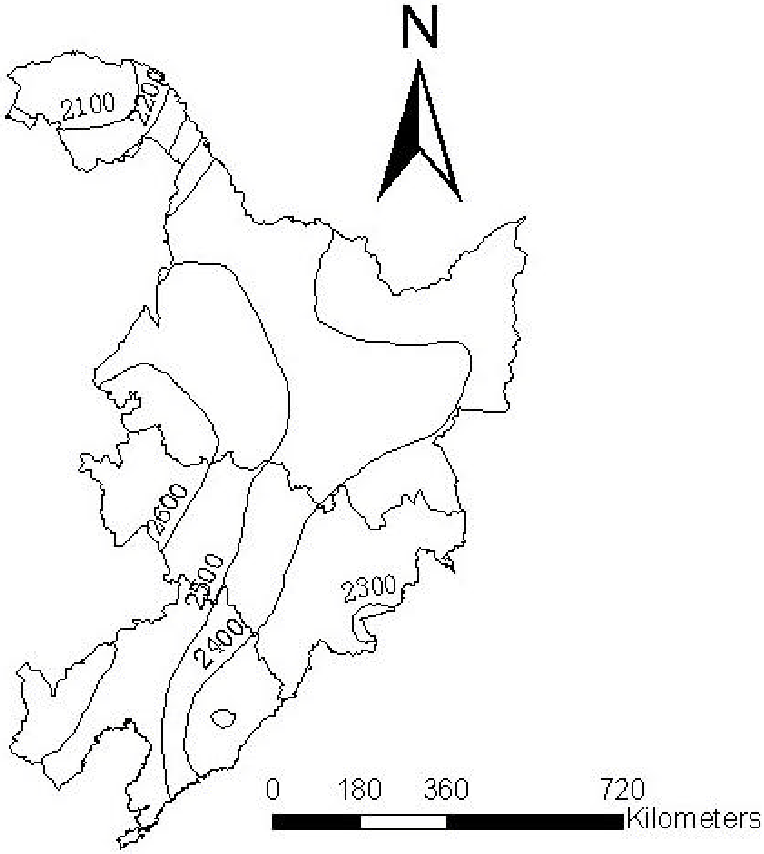

Fig. 2: Distribution of annual global solar radiation in Northeastern, China

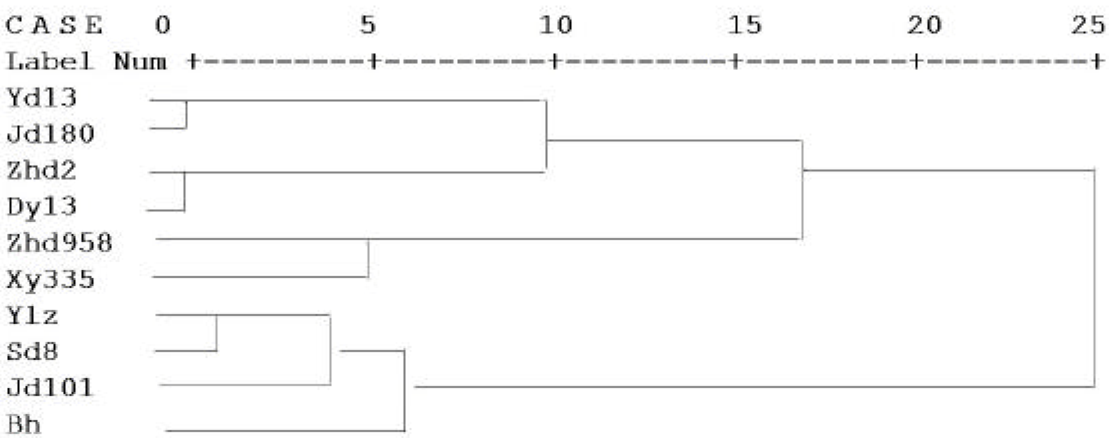

Fig. 3: Hierarchical cluster analysis dendrogramusing average linkage (between groups)

According to the assumption that density is equal to the ratio between suitable LAI and leaf area, we established a unary quadratic equation. Suitable densities for the stations can be estimated. The three following equations were obtained:

y = leaf area(m^2/pl); x = density (pl/m^2)

Spreading leaf: $y = -0.045x+1.103$

Intermediate type: $y = -0.042x+1.101$

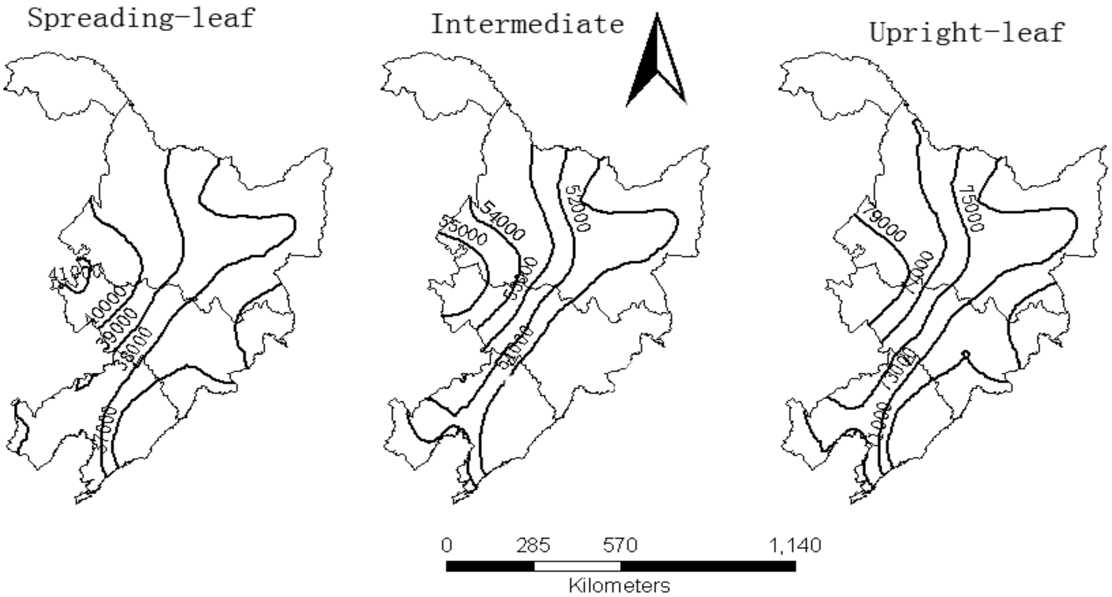

Fig. 4: Maize plant density distribution under light limitation in Northeast, China

Table 2: Yield performance at different density

Varietis	dx	dy
Bh	52500	43578.26
Ylz	37500	63196.90
Jd101	37500	42654.20
Sd8	72500	56345.80
Zd2	52500	62325.10
Dy13	72500	65738.40
Yd13	82500	68128.85
Jd180	82500	76875.25
Xy335	82500	79482.46
Zd958	82500	72352.42

Dx: Maximum yield density (Measured), Dy: Simulation optimal density

$$\text{Upright leaf: } y = -0.041x+1.092$$

Reasonable density in north-eastern China: We created a map of maize density in North-Eastern China (Fig. 4), excluding the area mentioned above. Figure 4 shows that the density of spreading leaf maize ranged from 33, 381 to 41, 736 pl ha^{-1}, the density of the intermediate type ranged from 44, 629 to 56, 584 pl ha^{-1} and the density of the upright-leaf type ranged from 62, 573 to 82, 969 pl ha^{-1}. The reasonable density increased from east to west and different cultivars showed similar patterns. The area of high density was distributed in the southwest in Heilongjiang Province and to the west in Jilin Province; the area of low decreased.

Yield performance: Table 2 shows the yield performance of the different varieties under different densities and simulated values of optimal density. Using Bh as an example, the experimental yield performance was 52, 500 pl ha^{-1} and the simulation value was 43, 578.26 pl ha^{-1} which was close to the measured value. However, yield in the upright-leaf type increased with plant density. Using Xianyu335 as an example, the experimental optimal yield was 82, 500 pl ha^{-1} and the simulation value was 79482.46 pl ha^{-1} which was also close to the measured value. Yield in the intermediate type depended on the specific variety. As a result, the simulated values were reliable.

DISCUSSION AND CONCLUSION

Discussion: The light extinction coefficient (k) kept changing. The relationship between the k-value and LAI differed significantly among varieties and with plant density. The extinction coefficient decreased significantly as the solar angle increased during the day. The k-value was smallest at noon, the only time when the sun's rays were in the same plane as the rows. RUE was affected by the group structure.

Maize populations that achieve maximum economic grain yield vary from 30, 000 to over 80, 000 pl ha^{-1}, depending on water availability, soil fertility, maturity rating, planting date, row spacing and solar radiation. In this paper, we only discussed the influence of solar radiation on plant density. In a subsequent paper, we will discuss the effects of water and other factors on plant density.

Conclusion: The density of cultivars was affected by light interception and the reasonable density was determined by the scientific group structure. The suitable planting density was between 30, 000 and 80, 000 pl ha^{-1}, with different types having different predicted reasonable planting densities.

The reasonable plant density within the study area decreased from west to east. The mid-west area in North-Eastern China was more suitable for planting high-density maize crops and the suitable density was lower in the east. Consequently, by growing maize at the optimum plant density for dry matter yield, farmers should achieve maximum grain yields.

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