Aboveground dry matter and grain yield of summer maize under different varieties and densities in North China Plain

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Abstract

To increase summer maize grain yield in North China Plain, we conducted field experiments with three densities (3, 6, and 9 plants m^{-2}) on two plant types (a flat type, LD981, and a compact type, LD818) during 2010 and 2011 summer maize growing seasons to study leaf area index (LAI), above ground dry matter accumulation, grain filling rate, and grain yield. The results indicated that with the density increased, the LAI in the both varieties enhanced; however, plant density at the rate of 9 plants m^{-2} significantly (LSD, $P < 0.05$) increased LAI in LD818. Increasing densities enhanced the above ground dry matter of LD818, but not of LD981. With the density increased, the grain filling rate in the both varieties declined, but during the later growing season, the grain filling rate in LD818 was higher than that in LD919. Irrespective of plant density at the rate of from 3 to 6 or 6 to 9 plants m^{-2}, the grain No. per ear, 1,000-kernel weight, and ears No. per m^2 in LD981 were all lower than those in LD818; this was the main reason why with the increased density, the population yield in LD981 was lower than that in LD818. These results indicate that in North China Plain, increasing plant density could enhance the grain yield of compact type summer maize.

Keywords: summer maize, leaf area index, grain filling rate, variety, density

Introduction

North China Plain, covers an area of 1,445 million hectare, was reported to provide about one-fifth of the total state food (Chen and Wu, 1997). In this region, the widely planted crops are winter wheat and summer maize, and adopted winter wheat and summer maize double cropping system in a year. However, the Plain has only 7.2% of the total national water resources (Zhang et al, 2007). The evapotranspiration during the winter wheat growing season is approximately 400–500 mm, but annual precipitation typically does not exceeded 200 mm (Li et al, 2007). Therefore, additional irrigation is required for the winter wheat yield, so sustainably increase winter wheat grain yield is restrained. However, summer maize growing season is in a rainy season, so there're enough water resources to support sustainably increase grain yield. Wang et al (2011) indicated that the actual yield of summer maize only about 70% of the potential yield, implying that the region has room to increase yield by improving crop management.

In recent year, many results indicate that improve plant densities could result in higher summer maize grain yield. Begna et al (1997) showed that rapid growth of the first ear and higher harvest index values were indications that leafy reduced-stature hybrids were more tolerant of higher population densities than the conventional hybrids. Mehdi (2011) concluded that growing maize at density with application of 350 kg ha^{-1} N rate that could result in maximum grain yield of maize and hence increase productivity of maize crop. However, Amanullah et al (2009) showed that the grain yield, harvest index, shelling percentage, 1,000-grain weight, and grains per ear were maximized at 80,000 plants ha^{-1} and with application of P fertilizer. Liu and Tollenaar (2009) found that increasing plant density from 4 to 12 plants m^{-2} resulted in an increase in heterosis for grain yield and harvest index, but did not affect heterosis for dry matter at maturity. Emine et al (2010) reported that 180,000 plants ha^{-1} may be recommended for cultivation of silage maize under drip irrigation at Southern Marmara Region in Turkish. Maize responds differently to plant densities under different cultivation practices which influence maize yield greatly. Hence, the relationship between maize yield and plant density is not well established.

Variety is one of the most important agronomic practices and therefore there are numerous studies conducted with maize variety. Chen et al (2012) reported that in the Huanghuaihai Region of China, variety change has played a critical role in increasing maize yields, over the past 50 years, the contribution of variety to yield is from 21.0% to 44.3%. Since the 1980S, yield per unit area and grain yield per plant greatly increased and ear diameter, ear length, grain depth, grains per spike, and kernel weight showed an upward trend with the evolution of cultivars (Wang

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et al, 2011). Chen et al (2012) suggested that in dryland area, it was the effective way to obtain high yield with increasing grain weight per plant, based on this principle, kernels per row, 1,000-grain weight, ear row number, and ear width should be considered. Because it would be difficult to further increase the maize yield dramatically (Muhammad et al, 2012), as growers did in the past, it has been proposed in China that breeding better varieties would be critical.

In recent years, management studies on maize in China have focused primarily on densities and varieties. Results of these studies indicated somewhat differences due to different ecological conditions and genotypes. In North China Plain, two types of summer maize are widely grown, i.e., compact and flat. In the aforementioned reports, only one type of plant was studied. Further, the influences of densities and varieties are often entangled with one another, making it difficult to determine whether density or variety has a decisive effect on future yield increase. Hence, this study aims to determine the effect of plant densities and varieties on the aboveground dry matter accumulation and grain yield of summer maize, with the aim of establishing theoretical and practical maize cultivation techniques in North China Plain.

Materials and Methods

Experimental Site

The experiment was conducted during the 2010 and 2011 summer maize growing seasons at the Bayi Experimental Station of Shandong Academy of Agricultural Science (37°1”N, 117°1”E) in the North China Plain. Each experimental plot is 40 m × 3 m in size with a light loamy soil. The levels of Olsen P, K min% on CEC, and mineral nitrogen in the 0 – 20 cm soil layer were 29.38, 87.17, and 65.2 mg kg^{-1}, respectively. Agriculture in this area is intensified by using a winter wheat and summer maize double cropping system consisting of high-yielding cultivars, high amounts of fertilizer, and water input. The site is characterized by a summer monsoon climate with mean annual precipitation of 690 mm, of which approximately 65% falls from June to September, and thus no irrigation is applied during the summer maize growing season. In 2010 and 2011 summer maize growing seasons, the precipitation was 441.1 and 411.7 mm, respectively, as shown in Table 1.

Experimental Design

The experiment involving 2 summer maize types: flat type “LD981” and compact type “LD818”. 3 plant densities were employed throughout the summer maize growth cycle as follows: 3, 6, and 9 plants m^{-2}. Treatments were randomized using a complete factorial design and treatments were replicated 3 times. At the sowing time, diammonium hydrogen phosphate, potassium sulfate, and urea were applied at a rate of 7.5, 11.5, and 15.0 g m^{-2}, respectively, additional 15.0 g m^{-2} of urea was applied at maletetrad stage. The maize plants were manually planted after harvesting winter wheat on June 10 and June 12 in 2010 and 2011, respectively. Plants were harvested on October 13, 2010 and October 9, 2011, respectively.

Measurements and Sampling Procedures

Leaf length and the maximum width of crops from each treatment were measured by a ruler at jointing (JO), maletetrad (MT), flowering (FL), milky (MI), and maturity (MA). The total leaf area (cm^2) for summer maize leaves was obtained with the relationship

$$A = 0.759 \sum_{i=1}^{m} Li \times Wi$$

(Kang et al, 2003), where A is leaf area, L is leaf length, and W is the maximum leaf width. The LAI was obtained by the ratio of total leaf area of per unit ground area.

Above-ground dry matter was determined by sampling consisting of 3 consecutive plants from the central rows at JO, MT, FL, MI, and MA. The sampling areas were spaced to avoid the effects of previous samplings. The 3 sampled plants were weighted (fresh weight). Dry matter was determined after drying at 80°C for 72 h.

Grain filling measurements were carried out by randomly sampling 3 selected plants per treatment and per each genotype at 10, 20, 30, 40, and 50 days after pollination. Harvested spikes were dried at 80°C for 2 days, and the grains were removed by hand, counted and weighed. Grain dry weight and numbers were used to calculate the average grain weight for each sample.

Grain yield and yield components were measured at maturity on an area of 8 m^2 corresponding to the two central rows of each plot. The number of maize ears per m^2 and the number of rows per ear were measured. The 1,000-kernels weight was estimated by counting and weighting 100 grains on 3 replicates per plot.

Table 1 - Mean monthly precipitation and air temperature in 2010 and 2011 summer maize growing season.

Growing seasons	Climatic variables	Jun[a]	Jul	Aug	Sep	Oct[b]
2010	Precipitation (mm)	15.1	174.1	207.5	40.2	4.2
	Air temperature (°C)	26.2	28.7	25.6	21.5	14.8
2011	Precipitation (mm)	42.6	92.9	171.0	97.7	7.5
	Air temperature (°C)	27.0	28.0	25.8	19.8	15.6

[a]precipitation and air temperature in June was the mean monthly from sown day to Jun 30; [b]precipitation and air temperature in October was the mean monthly from Oct 1 to harvested day.

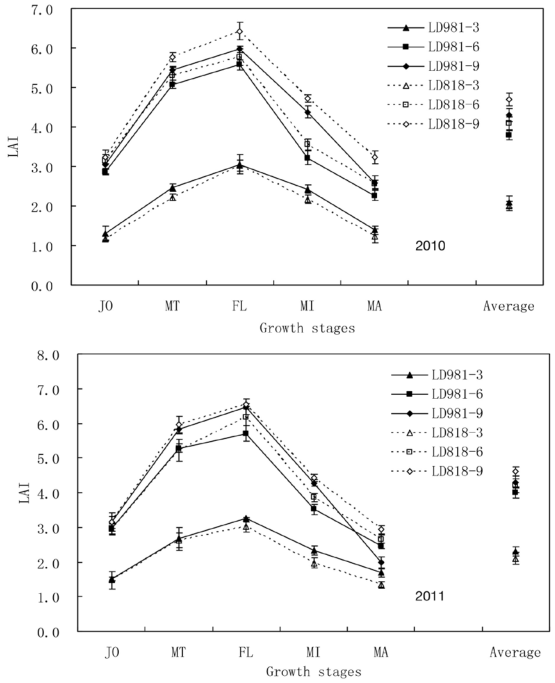

Figure 1 - The dynamic variation of LAI. JO, MT, FL, MI, and MA represent jointing, maletetrad, flowering, milky, and maturity stages. Vertical bars are standard errors.

Statistical Analysis

Data were analyzed using the SPSS 12.0 software. Analysis of variance (ANOVA) was performed separately for each trial according to the complete factorial design to assess varietal differences. The effect of varieties and densities interactions were assessed by analysis of variance of combined data from all trials. Differences between means were compared by Fisher's least-significant-difference (LSD) tests at the 5% probability level. Since treatments were the same over the 2 year, year was retained as a factor for ANOVA analyses.

Results

Leaf Area Index

The leaf area index (LAI) is a critical biophysical variable that describes canopy geometric structures and growth conditions. As shown in Figure 1, under different plant densities, the variation trend of LAI in the two varieties is consistent, with the developing of growth stages and presenting an odd peak curve. From jointing to maletetrad stages, the LAI increased greatly, and at flowing stage reached the maximum value, then declined rapidly. With the density increased, the LAI in the both varieties enhanced; the mean LAI at the rate of 6 and 9 plants m^{-2} were higher than that at the rate of 3 plants m^{-2} by 86.36% and 102.27% in 2010, and 96.68% and 97.56% in 2011, respectively. The result indicated that the amplification of LAI in LD818 is higher than that in LD981. At the rate of 3 plants m^{-2}, the mean LAI in LD981 was higher than that in LD818 by 5.00% and 9.52% in 2010 and 2011, respectively; at the rate of 6 plants m^{-2}, there were no significantly (LSD, P = 0.058) differences between them; however, at the rate of 9 plants m^{-2}, the latter was significantly higher than the former by 9.30% and 6.98% in 2010 and 2011 growing seasons, respectively. Further analysis found that after milking stage, the LAI in LD981 was decreased greatly, especially at the rate of 9 plants m^{-2}; at maturity, the highest LAI in LD981 was found at the rate of 6 plants m^{-2}, followed by at the rate of 9 plants m^{-2}, and the lowest LAI was found at the rate of 3 plants m^{-2}. As for LD981, the highest LAI was found at the rate of 9 plants m^{-2}, followed by at the rate of 6 plants m^{-2}, and the lowest LAI was found at the rate of 3 plants m^{-2}. Therefore, the LAI of summer maize was affected simultaneously by variety and density. The LAI was positively related to density within a threshold, and the relations no longer hold beyond that threshold.

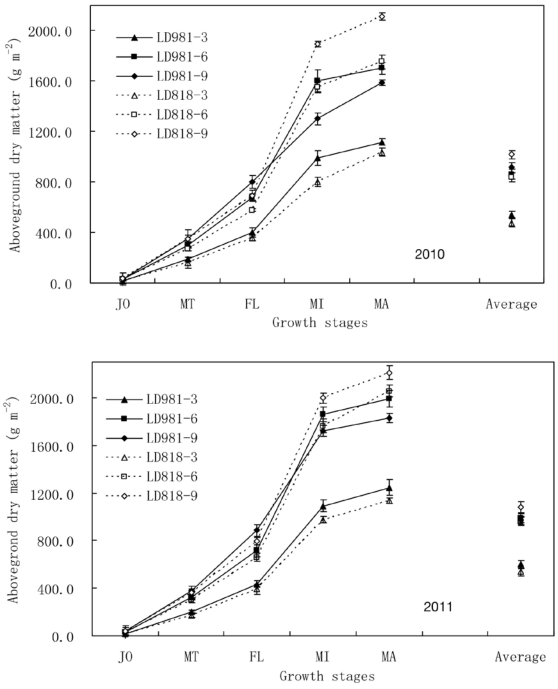

Figure 2 - The dynamic variation of aboveground dry matter. JO, MT, FL, MI, and MA represent jointing, maletetrad, flowering, milky, and maturity stages. Vertical bars are standard errors.

Aboveground Dry Matter

As shown in Figure 2, from jointing to flowering stage, for the both summer maize varieties, with the density increased, the aboveground dry matter was enhanced, too. However, after flowering stage, as for LD981, the aboveground dry matter at the rate of 6 plants m^{-2} was higher than that at the rate of 9 plants m^{-2}.

Compared with the both varieties, at the rate of 3 and 6 plants m^{-2}, the mean aboveground dry matter in LD981 was higher than those in LD818 by 64.7

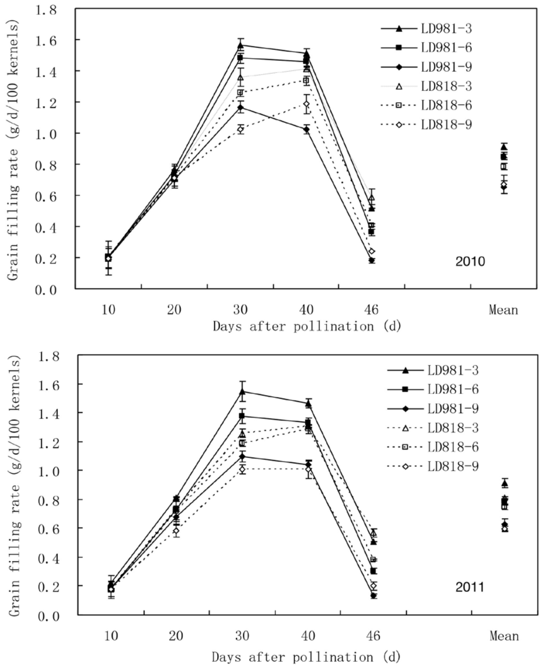

Figure 3 - The dynamic variation of grain filling rate. Vertical bars are standard errors.

and 25.0 g m^{-2} in 2010, and 61.6 and 24.4 g m^{-2} in 2011, respectively; however, at the rate of 9 plants m^{-2}, the mean aboveground dry matter in LD818 was higher than those in LD981 by 102.4 and 109.6 g m^{-2} in 2010 and 2011, respectively. Hence, as for flat variety LD981, increasing density could not effectively enhance aboveground dry matter; however, as for compact variety LD818, increasing density is an effective measure to improve aboveground dry matter.

Grain Filling Rate

With the density increased, the grain filling rate in the both varieties declined (Figure 3). There're not significantly (LSD, $P = 0.061$) differences among any densities in 20 days after pollination, then the differences were gradually increased, this showed that the densities mainly affected the grain filling rate in the later summer maize growing season. The result also showed that the grain filling rate in LD981 was faster than that in LD818, therefore, the maximum value of grain filling rate in LD981 was earlier than that in LD818. After that point, the grain filling rate was decreased in the both varieties, and with the density increased, the magnitude of the drop was increased. Grain filling period of the both varieties was the same, but during the later growing season, the grain filling rate in LD818 was higher than that in LD981, and the grain filling active time in LD818 is longer than that in LD981.

Grain Yield

As shown in Table 2, with the density increased, both grains No. per ear and 1,000-kernel weight were all significantly (LSD, $P < 0.05$) decreased, which resulted to significantly (LSD, $P < 0.05$) drop grain yield per plant, therefore, these 2 yield compositions showed the negative effect on the grain yield; moreover, with the density increased, ears No. per m^2 significantly (LSD, $P < 0.05$) enhanced, which showed the positive effect on the grain yield. The result of the combination effect with negative and positive on the both varieties was not consistent, the highest population yield in LD981 was found at the rate of 6 plants m^{-2}, which was not significantly (LSD, $P = 0.060$) higher than that at the rate of 9 plants m^{-2}, but significantly (LSD, $P < 0.05$) higher than that at the rate of 3 plants m^{-2} by 408.65 g m^{-2}. The highest population yield in LD818 was found at the rate of 9 plants m^{-2}, followed by at the rate of 6 plants m^{-2}, and the lowest was found at the rate of 3 plants m^{-2}, which was only 664.14 g m^{-2}.

Compared with the both varieties, at the rate of 3 plants m^{-2}, both grains No. per ear and 1,000-kernel weight were all significantly (LSD, $P < 0.05$) higher than those in LD818, and there're not significant (LSD, $P = 0.059$) difference between ears No. per m^2, which resulted to grain yield per plant and population grain yield in LD981 were all significantly (LSD, $P < 0.05$) higher than those in LD818; at the rate of 6 plants m^{-2}, although grains No. per ear in LD981 was significantly (LSD, $P < 0.05$) higher than that in LD818, 1,000-kernel weight and ears No. per m^2 in LD818 were all significantly (LSD, $P < 0.05$) higher than those in LD981, resulted to there're not significant (LSD, $P = 0.067$) differences between the both varieties; at the rate of 9 plants m^{-2}, the grains No. per ear, 1000-kernel weight, and ears No. m^{-2} in LD818 were all significantly (LSD, $P < 0.05$) higher than those in LD981, which resulted in the highest population yield. Plant density at the rate of from 3 to 6 plants m^{-2}, the grain No. per ear, 1,000-kernel weight, and ears No. m^{-2} in LD981 were all lower than those in LD818 by 3.87%, 3.56%, and 2.58%, respectively; however, at the rate of from 6 to 9 plants m^{-2}, were lower by 13.17%, 5.62%, and 10.55%, respectively, these are the main reason why with the increased plant density, the population yield in LD981 was lower than that in LD818.

Discussion

In North China Plain, two types of summer maize are widely cultivated, i.e., compact and flat. Many results reported that compared to flat variety, compact variety could significantly increase grain yield, and suggested that it's an effective measure to achieve super-high-yield (Wang et al, 2011; Shen et al, 2012); the results presented in this paper are in accordance with these results.

The increase in grain yield can be explained by the increase in LAI and net crop assimilation (Franc and Martina, 2002). In this study, plant density at the rate of from 6 to 9 plants m^{-2}, the LAI in LD818 was higher than that in LD981. The amount of incoming photosynthetic active radiation (PAR) that is absorbed by

Table 2 - Grain yield and yield components of summer maize.

Treatments	Grains No. per ear	1000-kernel Weight (g)	Ears No. per m^2	Grain yield (g plant^{-1})	Population yield (g m^{-2})
LD981-3	686.08a	402.67a	4.89f	228.86a	736.56c
LD981-6	632.51b	376.43d	6.41d	193.25c	1145.21b
LD981-9	474.96e	313.57f	8.53b	107.97e	933.72b
LD818-3	629.49b	396.92b	5.02e	213.71b	664.14d
LD818-6	604.73c	383.58c	6.71c	195.85c	1173.71b
LD818-9	533.84d	341.08e	9.00a	145.06d	1302.39a
By year					
2010	611.07	379.85	6.84	198.50	1006.31
2011	576.13	358.23	6.68	163.06	978.93
P value	0.0001	0.0001	0.0001	0.0001	0.0001
By variety					
LD981	597.33	375.15	6.92	184.87	1046.75
LD818	589.00	364.09	6.61	176.69	905.16
P value	0.1589	0.0276	0.0069	0.0014	0.1789
By density					
3	658.00	402.31	8.78	221.29	1159.46
6	618.00	379.50	6.56	194.55	1068.06
9	503.50	327.06	5.95	126.51	700.35
P value	0.0001	0.0001	0.0001	0.0001	0.0271
Interactions					
Variety×density	0.0074	0.0165	0.0069	0.0002	0.0094

Different letters within a column indicate significant differences (LSD, $P < 0.05$). All P values significant at $P < 0.05$.

the canopy primarily depends on LAI. However, the differences in PAR capture ratios for the summer maize canopies were not only due to dynamic LAI variations, but also due to alterations in vertical distributions (Li et al, 2012). Fang et al (2006) showed that improving the PAR capture ratio and amount of interception in the upper canopy of winter wheat had a great impact on grain yield, for approximately 60% more photosynthate was produced by the flag leaves and spikes during the later winter wheat growing season. As for summer maize, most of the green organ photosynthetic matter was produced by the three spike leaves; hence, an increase in the PAR capture ratio in this part would aid in the accumulation and transportation of photosynthetic products in the later summer maize growing season. Therefore, the improved PAR capture ratio in these parts was very important for increasing the grain yield. Not only the LAI values affect the intercepted radiation, but also the angle of plant leaves (Mu et al, 2010). For this reason, different summer maize varieties may differ in their ability to benefit from densities. This topic requires further exploration.

In recent years, the ability of the North China Plain to sustain its contribution to China's food supply is at risk because available water resources and cultivable land are diminishing. Under these conditions, super-high-yield summer maize is very necessary. Compact summer maize variety combined with high density, may be a useful method for developing super-high-yield in the North China Plain.

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