Relationship between plant type and canopy apparent photosynthesis in maize (*Zea mays* L.)

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Abstract

Experiments were conducted to study the effect of plant type on canopy photosynthesis under field conditions. A chamber made of aluminium frame covered with clear plastic material was used to estimate canopy CO_2-exchange rates over a land area of 1.33 m^2. The plant type of maize "Shendan 7" [planophile type, original-type (OT)] was changed to erectophile type [altered-type (AT)] at silking stage. The rates of canopy apparent photosynthesis (CAP) were measured in both types of maize grown at five plant densities during the reproductive phase. It was shown that AT canopies had greater rates (about 17.2 %) of CAP than did OT canopies and the yield increased by about 5.9 - 8.6 % in AT canopies. The vertical distribution of photosynthetic photon flux density and CO_2 concentration in AT canopies were more uniform than those in OT ones. It was suggested that the compact architecture of maize canopy was excellent for photosynthesis and yield formation.

Key words: erectophile type, light interception, light penetration, planophile type, yield formation

Introduction

Maize (*Zea mays* L.) can be of two different morphological types, planophile and erectophile, according to the angle between the upper leaves and stem. Field practice of maize production showed that cultivars of the erectophile type had higher yield potential than those of the planophile type. All high yielding records at present were established by using erectophile type of maize cultivars. On the contrary, there are opposite opinions among investigators using different experimental methods. To study the reletionship between plant type and canopy apparent photosynthesis may be helpful for understanding the effect of plant type on grain yield.

One available method for studying the effect of plant type on grain yield is to use planophile type hybrid in which angles between stem and leaves were artificially

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Abbreviations: CAP - canopy apparent photosynthesis; LAI - leaf area index; LOV - leaf orientation value; PAR - photosynthetic active radiation; PPFD - photosynthetic photon flux density.

changed to the erectophile type. An experiment conducted in pots with various plant types and planting densities indicated that at low densities CAP rates were not significantly different, and in high densities, higher CAP rates were observed with more erect leaves (Xu, Wang and Niu 1992, unpublished). Whether this result could be found in field conditions is still unclear. Therefore, we conducted the present experiment to analyse the relationship between plant type and CAP rate in the field.

Materials and methods

This experiment was conducted in the farm field of Shandong Academy of Agricultural Sciences, Jinan, People's Republic of China. Soil properties were as follow: Organic mater 2.5 %, total soil N 0.11 %, water soluble N 85 µg g^{-1}, P_2O_5 93 µg g^{-1}, K_2O 284.6 µg g^{-1}. Shendan 7, a planophile type hybrid, was used for observations. Five planting densities ranged as 30 000, 45 000, 60 000, 75 000 and 90 000 plants per hectare, respectively. Sowing date was June 20, 1993. Eight rows of maize was planted in each plot at 5 m in row lenght and 0.67 m row spacing. Three replications were arranged. Within the whole growth season, 345 kg N ha^{-1} was applied in the soil. Irrigation, insect pest control, weed control and other useful management were conducted regularly to meet the needs of high-yielding maize.

At silking stage, half of the plants in each density were altered from planophile type (original-type) to erectophile type (altered-type). The method used to change the plant type was to use strings to alter the angle between stem and leaves to 10 ° and even less. Leaf orientation value (LOV) was calculated by using an equation suggested by Pepper (1974):

$$\mathrm{LOV} = \sum_{i=1}^{n} [\theta (l_f/l)]i/n$$

Where θ is the angle degree of leaf from horizontal plane, l_f is the length from the base of leaf blade to the flagged point of leaf [cm], l is length of leaf [cm], and n is the number of samples. LOV in each treatment is shown in Table 1.

Table 1. Leaf orientation value (LOV) of leaves above the ear of maize in different treatments.

Plant density [plants ha^{-1}]	Planophile	Erectophile
30 000	46.9	70.0
45 000	53.7	70.1
60 000	54.3	70.1
75 000	55.0	70.1
90 000	61.5	70.2

At silking stage, vertical distribution of PPFD in maize canopy was measured by using a *Li-188B* integrating quantum/radiometer/photometer (*Li-Cor,* Lincoln, NE, USA). The vertical distribution of CO_2 concentration was measured on a clear day with a model *GXH-305* infrared CO_2 analyser (BAIF, Beejing, P.R. China).

CAP rates were measured by using the modified closed chamber system (Wells *et al.* 1982, Garrity *et al.* 1984). The dimensions of the aluminium framed assimilation chamber were 1.33 × 1 × 1~2.9 m (length × width × height). The chamber was covered with clear plastic material that transmitted approximately 90 % of PAR. One or two 35 W electronic fans were fixed in the chamber for mixing. The infrared CO_2 analyser monitored changes in CO_2 concentration in the chamber. The readings were taken after 1 - 2 min of measurement. CAP rates were expressed per ground area basis. A micro computer was used for data calculation and analysis. samples for grain yield were collected at harvest.

Results

Effect of plant type on PPFD and CO_2 concentration: PAR is an important factor influencing photosynthesis. Investigating the effect of plant type on PPFD distribution is useful for analyzing the role of plant type in CAP rates. Fig. 1 shows

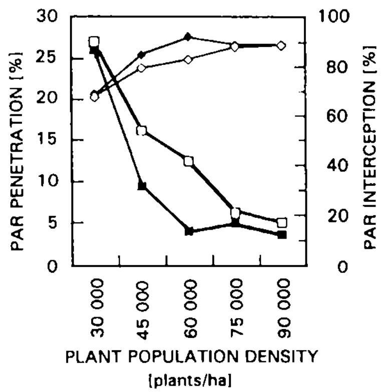

Fig. 1. The effect of plant type on PAR penetration (*squares*) and PAR interception (*rhombs*). *Full points* - original type, *open points* - altered type.

that at the same density under 75 000 plants ha^{-1}; the percentage PAR penetration within erectophile type canopies is higher, and percentage PAR interception is lower than that in planophile type canopies. Under high density conditions (above 75 000 plants ha^{-1}), the percentage PAR interception in two plant types is similar. The results also indicated that layer of ear-leaf and base-leaf obtained significant increases of PPFD (data not shown). This is to say erectophile type canopies improved their radiation condition compared to planophile type canopies. It was most obvious at moderate planting densities, and altered plant type is helpful for photosynthesis.

The observations of canopy CO_2 concentration in different densities showed that differences of CO_2 concentration in different heights of altered-type plant canopies became smaller (Fig. 2), indicating the decline of diffusive resistance in gas exchange between soil CO_2 and that above the plant canopy. Contrary to this, in original type canopies - particularly in high plant densities, because of less radiation and poor gases exchange - CO_2 used for photosynthesis is insufficient. This will cause a low photosynthetic rate.

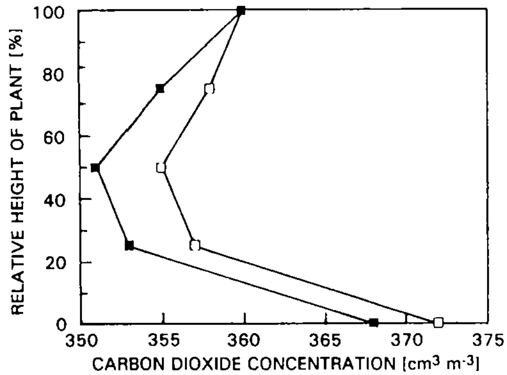

Fig. 2. The effect of plant type on distribution of CO_2 concentration within maize canopy (45 000 plants ha^{-1}). *Full points*: original type, *open points*: altered type.

Seasonal changes of CAP rates: Seasonal changes of CAP rates in maize is a single peak curve that is similar to that found in a previous study (Hu *et al.* 1993). The equations of different plant densities describe as follow:

$$Y_{30\,000} = -2.54019 + 1.34340X + 0.00014X^2 - 0.00009X^3$$
$$Y_{45\,000} = -2.96437 + 1.60778X - 0.00145X^2 - 0.00011X^3$$
$$Y_{60\,000} = -3.29426 + 2.03472X - 0.01234X^2 - 0.00004X^3$$
$$Y_{75\,000} = -1.61751 + 2.37602X - 0.02253X^2 + 0.00002X^3$$
$$Y_{90\,000} = 0.45793 + 2.31610X - 0.02462X^2 + 0.00003X^3$$

Where X is the days from sowing, Y is CAP rate [μmol(CO_2) m^{-2} s^{-1}], and 30 000 - 90 000 are planting densities [plants ha^{-1}].

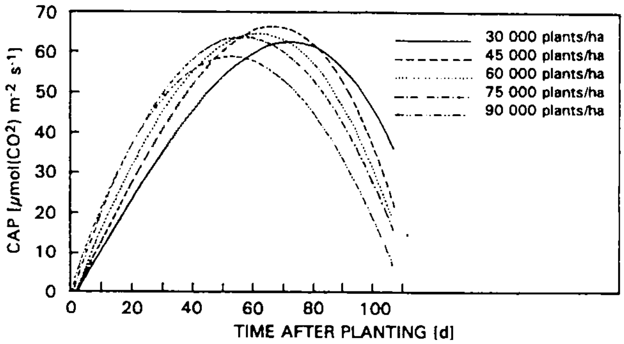

Fig. 3. Seasonal trend of canopy apparent photosynthesis rate for different plant densities in maize (original type).

Based on statistics, the highest CAP rate in five planting densities ranging from 30 000 - 90 000 plants ha^{-1} occurred 72 d, 67 d, 62 d, 56 d and 53 d from sowing (7 d before silking to 12 d after silking) respectively. The peak values were 62.6, 66.4, 64.7, 63.9 and 59.0 μmol CO_2 m^{-2} s^{-1}. Fig. 3 also shows the sequences of peak value occurrence for different planting densities, and the results is that peak value at higher density comes much earlier than that in lower density. The effect of planting densities on CAP rate before silking was less than that after silking. After 3 weeks of silking, 45 000 plants ha^{-1} had the highest CAP rate, and 90 000 plants ha^{-1} decreased its CAP capacity to the lowest. Among all treatments, the order is 45 000 > 60 000 > 30 000 > 75 000 > 90 000 plants ha^{-1}. Based on CAP rate, 45 000 plants ha^{-1} is the best planting density for maize hybrid Shendan 7.

Effects of plant type on maize CAP rates: Comparison of CAP rates between original and altered type at different densities indicated that canopy apparent photosynthesis rate in altered type was greatly improved compared with that of original type at the same planting density (Fig.4). Both this result and experiments conducted in pots (Xu *et al.* 1992) have proved that changing the planophile type to erectophile type can increase the CAP rate. It is helpful for the production and accumulation of dry matter.

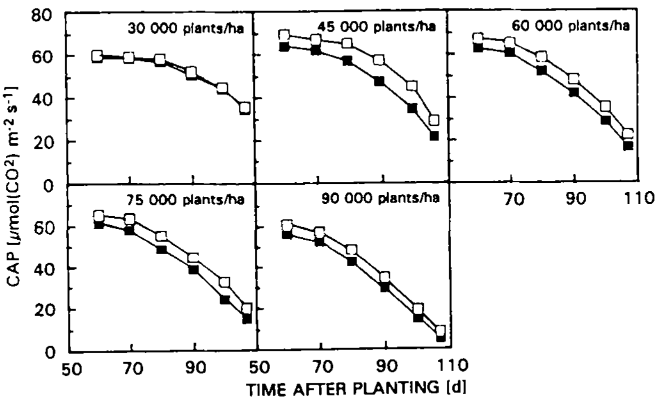

Fig. 4. The effect of plant type on canopy apparent photosynthesis rate in maize. *Full points* - original type, *open points* - altered type.

In low planting density such as 30 000 plants ha^{-1}, a small difference can be seen between the two plant types. This comes from less competition for light and nutrition among plants. Additional details tell us CAP rate of altered type was about 17.2 % higher than original type on average. Judging from the absolute value, a density with 45 000 plants ha^{-1} had the highest increase of CAP rate. Its total CAP rate was also the highest and peak value reached 69.5 μmol CO_2 m^{-2} s^{-1}.

Effect of plant type on grain yield of maize: A major goal in growing crops is to obtain a higher yield. Table 2 showed the difference in yield between two plant types. The results proved that the grain yield of erectophile type increased to some degree in all densities than planophile type. Yield increase of erectophile type is associated with improvement in CAP capacities. The results also concluded that with the increase of plant densities over 45 000 plants ha^{-1}, the grain yield decreased. Between the two plant types at the lowest density, grain yield was almost the same. Under high plant densities, the grain yield of erectophile type was higher by 5.9 - 8.6 %.

Table 2. Grain yield of maize in different treatments.

Plant density [plants ha^{-1}]	Planophile [kg ha^{-1}]	Erectophile [kg ha^{-1}]	Increase [%]
30 000	6474.0	6528.0	0.8
45 000	8091.0	8635.5	6.7
60 000	7846.8	8524.8	8.6
75 000	7687.5	8266.5	7.5
90 000	7106.4	7528.5	5.9

Discussion

The method of changing type in maize to investigate the effect of plant type on grain yield has been used previously (Gardner *et al.* 1985). Whether changed plant type can increase yield mainly depends on LAI. When LAI ≥ 5, changing plant type leads to the increase of grain yield (Gu *et al.* 1979). Our experiment indicates that when LAI ≥ 3.6, grain yield can be increased significantly. This might correlate with cultivar characteristics. While other studies only suggested that changing plant type can be increase yield, this present research investigated the "source" under field conditions, and concluded that improved CAP capacity in erectophile type is an important factor foryield increase. Some scientists believed that if the PAR distributed uniformly in plant canopies, photosynthesis rate can be increased by a larger LAI. We analysed the vertical distribution of PPFD and CO_2 concentrations. The results proved that a higher CAP rate in erectophile type canopies was not only related to the uniform distribution of PAR, but also to the uniform distribution of CO_2 within canopies. Based on these results, we concluded that producing erectophile type, along with other excellent characteristics of maize cultivars, can effectively reduce the competitions among plants and among organs. It also can improve the enviromental conditions for assimilation source and increase CAP rates. Furthermore, a good cultivar can produce a large "sink" and obtain high yield.

Establishment of a high yield and high efficiency maize population includes the problem of suitable angle of leaves. theoretically, under high LAI condition, the smaller the angles between leaves and stem, the higher the CAP rate (Gardner *et al.* 1985). Some researchers suggest that the best angles should be 10 °. Many other scientist belive the more erect leaves, the higher the grain yield. Therefore, we believe that the optimal density of a maize crop should be set up based on quality of plant types. A question is rising how erect should plant leaves be not clear in maize crop for optimal field production. At this point, further studies need to be done.

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