Effects of Multi-plant per Hill Planting on Population Quality and Yield of Summer Maize (Postprint)

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Abstract

Increasing planting density is a key strategy for high yield of maize; however, continuous increase in planting density also brings a series of problems, among which canopy closure in high-density populations has become one of the main factors limiting further density increase. To alleviate canopy closure in high-density summer maize populations and improve population quality and yield formation under high-density planting, this experiment established three treatments at a density of 82,500 plants $\cdot$ hm^{-2}: one plant per hole (P1), two plants per hole (P2), and three plants per hole (P3), and analyzed the effects of multiple plants per hole on leaf area, dry matter, photosynthetic potential, relative growth rate, net assimilation rate, crop growth rate, grain-to-leaf ratio, and yield at various developmental stages of summer maize. The results showed that, compared with the control P1, P2 and P3 increased leaf area per plant by 10.7%~21.9% and 7.3%~16.7% at silking stage, respectively, and by 13.5%~21.9% and 9.4%~12.7% at 20 days after silking, respectively; dry matter accumulation at silking and maturity stages in P2 and P3 was significantly higher than that in P1 ($P<0.05$). Multiple plants per hole planting increased the photosynthetic potential of summer maize after the 6-leaf stage, with the magnitude of increase in P2 being smaller than that in P3; the relative growth rate from 20 days after silking to maturity in P2 and P3 was 30.4%~190.7% and 33.9%~183.5% higher than that in P1, respectively, and the net assimilation rate was 16.1%~161.9% and 30.7%~155.8% higher, respectively. The adoption of multiple plants per hole planting increased crop growth rate, grain-to-leaf ratio, and grain yield, with P2 and P3 increasing yield by 5.8%~23.5% and 4.9%~18.9% compared with P1, respectively. Grain weight/leaf area and grain number/leaf area showed significant linear positive correlations with grain yield ($R^2=0.94$, $P<0.0001$ and $R^2=0.76$, $P<0.001$). These results indicate that under high-density planting conditions, multiple plants per hole planting can improve summer maize population quality and increase yield. This study recommends the two plants per hole planting method under high density.

Full Text

Effects of More Plants per Hill on Population Quality and Yield of Summer Maize

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Abstract

Increasing planting density is an important means to achieve high maize yield, but continuous increases in density also bring a series of problems. Canopy closure in high-density populations has become one of the main factors limiting further density increases. To alleviate canopy closure in high-density summer maize populations and improve population quality and yield formation under dense planting, this experiment established three treatments at a density of 82,500 plants$\cdot$hm^{-2}: one plant per hill (P1), two plants per hill (P2), and three plants per hill (P3). The study analyzed the effects of multiple plants per hill on leaf area, dry matter, photosynthetic potential (PP), relative growth rate (RGR), net assimilation rate (NAR), crop growth rate (CGR), grain-leaf ratio, and yield at various growth stages. Compared with the control P1, P2 and P3 increased individual plant leaf area by 10.7%-21.9% and 7.3%-16.7% at silking stage, respectively, and by 13.5%-21.9% and 9.4%-12.7% at 20 days after silking. Dry matter accumulation at silking and maturity stages under P2 and P3 was significantly higher than under P1 ($P < 0.05$). Planting multiple plants per hill increased photosynthetic potential after the 6-leaf stage, with P2 showing a smaller increase than P3. From 20 days after silking to maturity, RGR under P2 and P3 was 30.4%-190.7% and 33.9%-183.5% higher than P1, respectively, while NAR was 16.1%-161.9% and 30.7%-155.8% higher, respectively. The multiple plants per hill planting pattern enhanced crop growth rate, grain-leaf ratio, and grain yield, with P2 and P3 increasing yield by 5.8%-23.5% and 4.9%-18.9% compared with P1, respectively. Grain weight per leaf area and grain number per leaf area showed significant positive linear correlations with grain yield ($R^2 = 0.94$, $P < 0.0001$ and $R^2 = 0.76$, $P < 0.001$, respectively). These results demonstrate that under high-density conditions, multiple plants per hill planting can improve summer maize population quality and increase yield. This study recommends the two plants per hill planting pattern under high density.

Keywords: More plants per hill; Summer maize; Population quality; Net as-

similation rate; Yield

Introduction

High-density planting is currently an important approach to further exploit the high-yield potential of summer maize. Planting density determines ear number and grain number per ear among the three yield components [1-3], so increasing planting density means increasing ear number. However, as planting density increases, the canopy becomes more closed, light transmittance deteriorates [4-6], middle and lower leaves senesce prematurely, photosynthetic efficiency decreases [7], grain number per ear, thousand-grain weight, and kernel rate decline, and barren tip length increases, ultimately affecting post-anthesis dry matter accumulation and grain yield. Previous studies have shown that the relationship between yield and density follows a parabolic curve; when planting density increases beyond a certain value, yield gradually declines [8-10]. In North China, the hot and humid environment during the summer maize season exacerbates these disadvantages of high-density planting. Therefore, how to compensate for the shortcomings generated during the maize densification process through planting patterns is a worthwhile research topic.

High-yielding population structure is a prerequisite for achieving high yield. Population structural characteristics affect crop canopy light distribution and photosynthetic properties through the interception, absorption, and transmission of photosynthetically active radiation, ultimately influencing photosynthesis, dry matter accumulation, and yield formation [11]. Therefore, improving photosynthetic efficiency and material production capacity in high-density summer maize populations mainly depends on optimizing population structure, improving canopy ventilation and light penetration, increasing leaf area before anthesis, and delaying leaf senescence after anthesis. Planting pattern is one of the factors that coordinate individual ventilation and light conditions and nutritional status under high-density conditions and ultimately affect yield [12], as it can regulate maize population structure, improve field microclimate, and enhance resource use efficiency. Current maize planting patterns in China include equal row spacing, wide-narrow row spacing, double-plant cultivation, precision cultivation, and multiple plants per hill [13-14]. Among these, multiple plants per hill refers to planting two or more maize plants in one hill. Previous research has extensively investigated measures to optimize population structure through wide-narrow row planting [15], chemical regulation [16], and intercropping [17], but systematic studies on population quality and yield of summer maize under high-density multiple plants per hill planting are still rare. This study, at a relatively high planting density (82,500 plants $\cdot$ hm^{-2}), used multiple plants per hill (two and three plants per hill) planting patterns to alter summer maize population structure and examined population quality, including quantitative indicators characterizing canopy structure (population quality) such as photosynthetic potential (PP), net assimilation rate (NAR), relative growth rate (RGR), crop growth rate (CGR), and grain-leaf ratio [18], as well as changes in yield and yield components, aiming to provide a theoretical basis for the application of high-yield technology with multiple plants per hill in summer maize.

Materials and Methods

1.1 Experimental Site and Design

The experiment was conducted in 2013 and 2014 at the Wuqiao Experimental Station of China Agricultural University (37°41 02 N, 116°37 23 E, elevation 14–22 m). The region has 2,724.8 hours of annual sunshine, mean annual temperature of 12.9 °C, and a frost-free period of 201 days. The experimental area is located in the central Heilonggang Basin of the Haihe Plain, with a warm temperate monsoon climate. Average annual precipitation is 562 mm, mainly distributed from June to August. The soil is alluvial salinized fluvo-aquic soil with a loamy texture and clay bottom, groundwater depth of 7–9 m, and effective water storage of 420 m^3 in the 2 m soil profile. The topsoil pH was 8.12, organic matter content 11.1 $g \cdot kg^{-1}$, total nitrogen 0.9 $g \cdot kg^{-1}$, available phosphorus 18.0 $mg \cdot kg^{-1}$, and available potassium 78.8 $mg \cdot kg^{-1}$, indicating medium soil fertility. Weather conditions during the experimental years are shown in

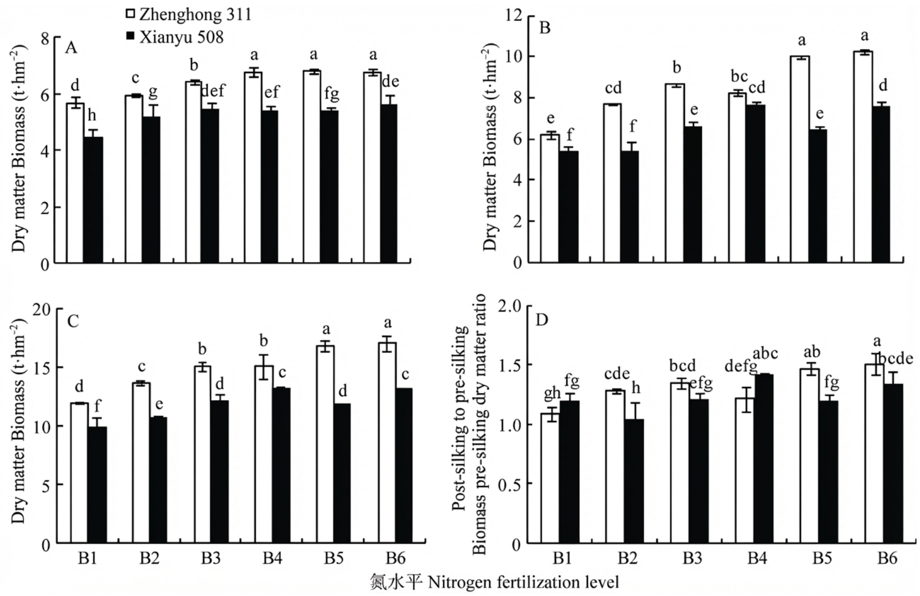

Figure 1: Figure 1

. Severe droughts occurred in the region in mid-to-late June, mid-to-late August, and mid-September 2013 (from maize seedling stage to 12-leaf stage, silking to 15 days after silking, and 25–35 days after silking).

The summer maize cultivar 'Zhengdan 958' was used. Phosphorus, potassium, and nitrogen fertilizers were applied as basal fertilizers before sowing at rates of 240 kg(N)$\cdot$hm^{-2} as urea, 105 kg$\cdot$hm^{-2} as calcium superphosphate, and 120 kg$\cdot$hm^{-2} as potassium sulfate. No topdressing was applied during the growth period. A randomized block design was used with a planting density of 82,500 plants$\cdot$hm^{-2} and three treatments: one plant per hill (P1), two plants per hill (P2), and three plants per hill (P3), with three replications per treatment. Plot size was 6 m × 10 m with 60 cm row spacing. Seeds were sun-dried before sowing to remove shriveled and broken kernels. Manual sowing was conducted on June 16 each year (two seeds per hill for P1, four seeds for P2, and five seeds for P3), followed by irrigation after sowing. No irrigation was applied during the entire growth period. At the 4-leaf stage, the weakest seedling in each hill was removed, and final thinning was conducted at the 7-leaf stage (retaining uniform seedlings). Weeds and pests were well controlled. At the 8-leaf stage, 20 hills with uniform stem diameter, plant height, and growth vigor were selected and tagged in each plot for dry matter and leaf area measurements.

1.2 Measurement Items and Methods

Individual plant leaf area and dry matter measurement: At seedling stage (VE), 6-leaf stage (V6), 12-leaf stage (V12), silking stage (R1), 20 days after silking (DAS20), and physiological maturity stage (M), three representative hills were selected from each plot. The length and width of each green leaf were measured, and leaf area was calculated as: leaf area = length × width × 0.75. Individual plant leaf area was obtained by summing the area of all leaves on each plant. Plants were then separated into stem and leaf parts, killed at 105 °C for 15-20 minutes, and oven-dried at 80 °C to constant weight for dry matter measurement.

Empty stalk ratio measurement: At maturity, four middle rows in each plot were selected to investigate total plant number and empty stalk number (ears with fewer than 50 kernels were considered empty stalks). Empty stalk ratio was calculated as: empty stalk ratio = empty stalk number / total plant number.

Yield measurement: At maturity, actual ear number per plot was surveyed, and four middle rows (4 m per row) were harvested. Total fresh ear weight was recorded, and 20 ears were randomly selected based on average fresh ear weight to investigate kernels per ear, thousand-grain weight, kernel rate, and moisture content. Actual yield was calculated (converted to 14% moisture content).

1.3 Calculation Methods

Photosynthetic potential (PP, $×10^{4}$ m$^2\cdot$d$\cdot$hm^{-2}) = (L_1 × 10,000 + L_2 × 10,000) / 2 × (t_2 - t_1)
Relative growth rate (RGR, d^{-1}) = (lnW_2 - lnW_1) / (t_2 - t_1)
Net assimilation rate (NAR, mg$\cdot$m$^{-2}\cdot$d^{-1}) = [(lnL_2 - lnL_1) / (L_2 - L_1)] × (W_2

- W_1) / (t_2 - t_1)
Crop growth rate (CGR, $g \cdot m^{-2} \cdot d^{-1}$) = ($W_2$ - W_1) / [A × (t_2 - t_1)]
Grain weight/leaf area ($mg \cdot cm^{-2}$) = grain yield / leaf area at silking
Grain number/leaf area ($grain \cdot cm^{-2}$) = total grain number / leaf area at silking

Where: L_1 and L_2 are population leaf area index (individual plant leaf area × planting density) at times t_1 and t_2, respectively; W_2 and W_1 are dry weight ($kg \cdot hm^{-2}$) at times t_1 and t_2, respectively; A is land area (hm^2).

1.4 Data Statistics and Analysis

Microsoft Excel 2010 was used for data calculation and graphing. SAS 9.0 software GLM and Duncan procedures were used for F-test and multiple comparisons ($P < 0.05$) [19]. SAS 9.0 PROC CORR procedure was used for correlation analysis between yield, yield components, and photosynthetic potential, relative growth rate, net assimilation rate, and crop growth rate at various growth stages across two years [19].

Results

2.1 Effects of Multiple Plants per Hill on Summer Maize Leaf Area

Multiple plants per hill treatment (T) had significant effects on leaf area at various stages ($P < 0.0001$). In 2013, P1 had the largest leaf area at V6 while P3 had the smallest; at V12, P2 was significantly higher than P1 and P3 ($P < 0.05$) with no significant difference between P1 and P3; at silking, 20 days after silking, and maturity, leaf area showed a trend of P2 > P3 > P1 with significant differences among treatments (Table 1). In 2014, P1 was significantly larger than P2 and P3 at V6 ($P < 0.05$), while the pattern at silking and 20 days after silking was similar to 2013; at V12 and maturity, leaf area showed P2 > P1 > P3 (Table 1). These results indicate that multiple plants per hill planting had positive effects on leaf area from V12 to silking and delayed leaf area decline after silking, with these effects diminishing as plant number per hill increased. Year (Y) had significant effects on leaf area at V6, V12, silking, and maturity ($P < 0.0001$). Except for similar average leaf area at silking and 20 days after silking between 2014 and 2013, all other stages were larger in 2014 than in 2013. Treatment × year (T×Y) interactions had significant effects on leaf area at V12 ($P < 0.0001$), silking ($P < 0.0001$), 20 days after silking ($P < 0.001$), and maturity ($P < 0.001$) (Table 1). These results demonstrate that weather conditions (rainfall, temperature, light) were the main factors causing inter-annual differences in leaf area and generating treatment × year interaction effects (Table 1).

2.2 Effects of Multiple Plants per Hill on Summer Maize Dry Matter Accumulation

Multiple plants per hill treatment (T) had significant effects on dry matter weight at various stages. In 2013, dry matter weight at V6 and V12 under P2 and P3 was significantly higher than under P1 ($P < 0.05$) with no significant difference between P2 and P3; at silking, P2 was highest and P1 lowest; at 20 days after silking, P2 was highest and P3 lowest; at maturity, P2 was significantly higher than P1 and P3 ($P < 0.05$) with no significant difference between P1 and P3 (Table 2). In 2014, dry matter at V6, silking, and maturity showed similar patterns to 2013; at V12, P2 was highest and P3 lowest; at 20 days after silking, P2 was highest and P1 lowest (Table 2). These results show that multiple plants per hill planting significantly increased dry matter accumulation at various growth stages, with the enhancement effect diminishing as plant number per hill increased. Year (Y) had significant effects on dry matter at V6, V12, silking, 20 days after silking, and maturity ($P < 0.0001$). Average dry matter accumulation at V6 and 20 days after silking in 2014 was similar to 2013, while other stages were larger in 2014 than in 2013 (Table 2). Treatment × year (T×Y) interactions had significant effects on dry matter at V12 ($P < 0.0001$), silking ($P < 0.01$), 20 days after silking ($P < 0.0001$), and maturity ($P < 0.0001$) (Table 2).

2.3 Effects of Multiple Plants per Hill on Photosynthetic Potential

In 2013, photosynthetic potential of all treatments showed an increasing trend from emergence to maturity; PP was similar among three treatments during emergence-V6; P2 had the highest PP during V6-V12 while P1 and P3 were similar; during V12-maturity, PP showed an increasing trend of P1, P3, and P2 (Figure 2

). The pattern in 2014 was consistent with 2013 (Figure 2). These results indicate that multiple plants per hill planting had positive effects on photosynthetic potential after V6, with the effect diminishing as plant number per hill increased, and no effect before V6.

2.4 Effects of Multiple Plants per Hill on Relative Growth Rate, Net Assimilation Rate, and Crop Growth Rate

In 2013, relative growth rate of all treatments showed a decreasing trend from emergence to maturity; RGR was similar among treatments during emergence-V6; during V6-V12, P2 was highest and P3 lowest; during V12-silking, RGR increased in the order of P3, P2, and P1; during silking-20 days after silking, P1 was highest with P2 and P3 similar; during 20 days after silking-maturity, P2 and P3 were 2.9 and 2.8 times higher than P1, respectively (Figure 3a). In 2014, RGR of all treatments increased gradually from emergence to V12, decreased sharply from V12 to 20 days after silking, then increased slowly from 20 days after silking to maturity; inter-treatment patterns at each stage were similar to

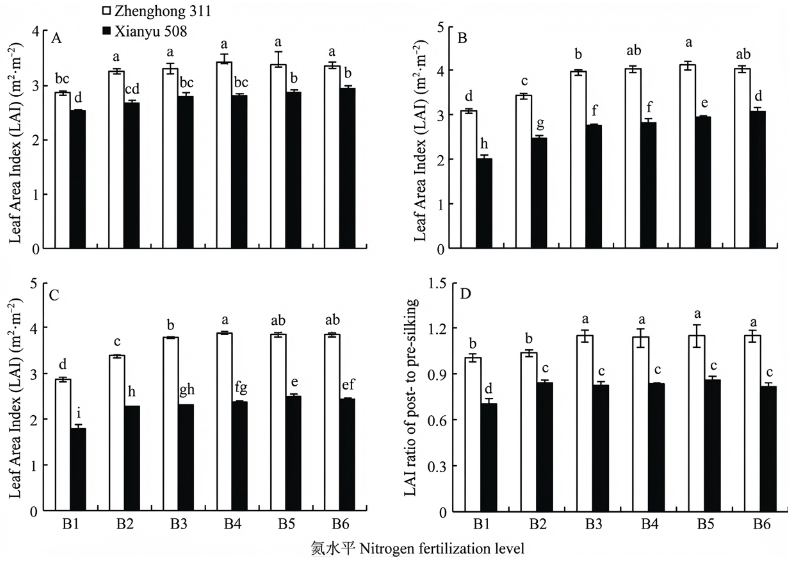

Figure 2: Figure 2

2013 (Figure 3a [FIGURE:3]). These analyses indicate that multiple plants per hill planting had significant promoting effects on relative growth rate during the late grain-filling period.

For net assimilation rate, in 2013, P1 and P3 showed decreasing trends from emergence to maturity; P2 showed a decreasing trend from emergence to silking, an increasing trend from V12 to 20 days after silking, and a decreasing trend from silking to maturity. NAR during emergence-V6 increased in the order of P1, P2, and P3; NAR was similar among treatments during V6-V12; during V12-silking, P1 was highest and P2 lowest; during silking-20 days after silking and 20 days after silking-maturity, P2 was highest (Figure 3b). In 2014, NAR of P1 decreased from emergence to silking, increased from V12 to 20 days after silking, and decreased from silking to maturity; NAR of P2 and P3 decreased from emergence to 20 days after silking and increased gradually from silking to maturity; NAR was similar among treatments during emergence-V6 and V6-V12; during V12-silking, NAR increased in the order of P1, P2, and P3; during silking-20 days after silking, P1 was highest and P2 lowest; during 20 days after silking-maturity, P2 and P3 were 16.1% and 30.7% higher than P1, respectively (Figure 3b). Two-year experimental results demonstrated that multiple plants per hill planting could increase net assimilation rate during the late grain-filling period.

For crop growth rate, in 2013, all treatments showed an increasing trend from emergence to silking followed by a slow decline; CGR increased in the order of P1, P2, and P3 during emergence-V6; during V6-V12 and 20 days after silking-maturity, P2 was highest and P1 lowest; during V12–silking, P2 was highest with P1 and P3 similar; during silking–20 days after silking, CGR increased in the order of P3, P2, and P1 (Figure 3c). In 2014, CGR of all treatments increased from emergence to V12 (or silking), decreased from V12 (or silking) to 20 days after silking, then increased slowly; absolute growth rate at each stage was higher under P2 than P1 (Figure 3c). These results indicate that multiple plants per hill planting can increase crop growth rate.

2.5 Effects of Multiple Plants per Hill on Grain-Leaf Ratio

In both 2013 and 2014, grain weight per leaf area increased in the order of P1, P3, and P2 (Figure 4a [FIGURE:4]). In 2013, grain number per leaf area under P2 and P3 was 4.7% and 2.4% higher than under P1, respectively, while in 2014, it increased by 27.1% and 5.4%, respectively (Figure 4b). These results demonstrate that the grain-leaf ratio of summer maize was improved under both two plants per hill and three plants per hill planting patterns.

2.6 Effects of Multiple Plants per Hill on Yield and Yield Components

In 2013, ear number under P2 was significantly higher than under P1 and P3 ($P < 0.05$), while P3 was significantly lower than P1 ($P < 0.05$); grain number per ear under P2 was 8.3% and 5.6% higher than under P1 and P3, respectively; thousand-grain weight under P2 was significantly higher than under P1 and P3 ($P < 0.05$) with no significant difference between P1 and P3; yield under P2 and P3 was 5.8% and 4.9% higher than under P1, respectively; empty stalk ratio increased in the order of P2, P1, and P3 (Table 3). In 2014, P2 had the highest ear number and grain number per ear while P3 had the lowest; thousand-grain weight under P2 and P3 was significantly higher than under P1 ($P < 0.05$); yield and empty stalk ratio patterns were consistent with 2013 (Table 3). In 2014, except for lower mean empty stalk ratio than in 2013, yield and yield components were all higher than in 2013. Treatment (T) and year (Y) had significant effects on ear number, grain number per ear, thousand-grain weight, yield, and empty stalk ratio ($P < 0.0001$); treatment × year (T×Y) interactions had significant effects on ear number ($P < 0.0001$), grain number per ear ($P < 0.001$), thousand-grain weight ($P < 0.001$), yield ($P < 0.01$), and empty stalk ratio ($P < 0.001$) (Table 3). These results indicate that temperature, light hours, precipitation, and other weather conditions were the main causes of inter-annual differences in yield and yield components, and that treatment and its interaction with year had significant effects on yield and yield components (Table 3). Evidently, two plants per hill planting can significantly increase yield and improve yield components; three plants per hill planting had negative effects on harvested ear number but positive effects on yield, grain weight, and empty stalk ratio.

Discussion

Maize is China’ s largest grain crop, accounting for one-third of China’ s total cereal production and 19% of world maize export trade [20]. Therefore, research on maize high yield has always been a scientific hotspot. The increase in modern maize hybrid yield per unit area is mainly attributed to increased optimal planting density rather than increased individual plant yield [21]. Many scholars believe that further high yield of maize can only be achieved through high-density planting [4, 22–23]. However, ideal yields are not obtained at higher planting densities; instead, yield is reduced because excessive density leads to extended anthesis-silking interval, increased kernel abortion, reduced grain number per ear, and increased empty stalk ratio [21]. Additionally, high-density planting can lead to insufficient assimilate supply, resulting in increased barren tip length [24]. However, under high-density conditions, the two plants per hill pattern significantly reduces barren tip length and markedly increases kernels per row and ear length compared with one plant per hill [25], improving ear traits and increasing yield. Two plants per hill increased yield by 5.8%–23.5% compared with one plant per hill.

Table 4 shows that yield and yield components had significant correlations with photosynthetic potential, relative growth rate, net assimilation rate, and crop growth rate during V6–V12 and DAS20–maturity. Therefore, yield improvement may be related to improved population structure and function.

Leaves are the main component of the canopy and the primary organ for photosynthesis. Leaf area size, functional duration, photosynthetic efficiency, and accumulation and distribution of photosynthetic products determine crop population yield [26]. As planting density increases, individual plant leaf area decreases while population leaf area increases, with large differences between high and low densities. This experiment demonstrated that under constant planting density, using two or three plants per hill planting patterns could increase pre-silking leaf area, delay post-silking leaf area decline, and ensure sufficient photosynthetic leaf area for pre-anthesis material accumulation and post-anthesis grain filling.

Population photosynthetic characteristics are directly affected by the interception and absorption of photosynthetically active radiation at each growth stage, which directly affects net assimilation rate [4]. Two-year experimental results showed that photosynthetic potential during the post-silking period under two and three plants per hill was significantly higher than under one plant per hill, resulting in higher net assimilation rate (NAR), crop growth rate (CGR), and relative growth rate (RGR) during mid-to-late grain filling. Ear number, grain number per ear, thousand-grain weight, and yield were significantly positively correlated with PP, NAR, CGR, and RGR from 20 days after silking to maturity. Thus, two plants per hill increased grain weight and consequently grain yield by increasing late-stage dry matter accumulation. Wei et al. [27] reported that under 75,000 plants $\cdot$ hm^{-2} density, wide-narrow row planting with two plants per hill improved internal canopy light conditions, increased net photosynthetic rate and leaf area index, alleviated contradictions between individual plants and the population, enhanced grain filling capacity, and increased dry matter accumulation. Our study using equal row spacing with two plants per hill also significantly increased grain filling rate and grain weight [25]. Zhu et al. [28] found that for ‘Xianyu 335’ , three plants per hill could promote post-anthesis dry matter accumulation but did not improve canopy light transmittance or leaf area. However, Li et al. [29] reported that at 60,000 plants $\cdot$ hm^{-2}, double-plant planting could alleviate canopy competition for ‘Ludan 981’ with optimal root-shoot coordination and yield performance; at 90,000 plants $\cdot$ hm^{-2}, double-plant planting could alleviate root competition for ‘Ludan 818’ , partially improve canopy population structure quality and function, maintain root-shoot coordination, and show yield increase.

Grain-leaf ratio is a comprehensive indicator measuring the source-sink coordination level in summer maize populations. High-yielding populations require dynamic balance between source and sink at high levels [30–31]. Two-year experiments found that grain weight per leaf area under two and three plants per hill was 9.7%-22.5% and 3.6%-15.3% higher than under one plant per hill, respectively, while grain number per leaf area was 4.7%-27.1% and 2.4%-5.4% higher, respectively (Table 4), leading to significantly higher yields than the control. Additionally, grain yield showed significant positive linear correlations with grain weight per leaf area ($R^2 = 0.94$, $P < 0.0001$) and grain number per leaf area ($R^2 = 0.76$, $P < 0.001$) (Figure 5 [FIGURE:5]). Ding et al. [32] found similar patterns in rice. This indicates that high grain-leaf ratio is one reason for the higher grain yields obtained with two and three plants per hill planting. Thus, yield improvements with two and three plants per hill should be attributed to improved population quality (leaf area, photosynthetic potential, relative growth rate, net assimilation rate, crop growth rate, and grain-leaf ratio).

Conclusion

This two-year field experiment demonstrated that multiple plants per hill planting can increase pre-silking leaf area, delay post-silking leaf area decline, increase dry matter accumulation at silking and maturity, enhance photosynthetic potential after the 6-leaf stage, promote growth, increase grain weight and grain-leaf ratio, and ultimately increase grain yield. The improvement effects of multiple plants per hill on summer maize population quality and yield diminished with increasing plant number per hill. Therefore, this study concludes that the two plants per hill planting pattern can achieve higher yield under high-density conditions.

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