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Optimizing the Growth of Silage Maize by Adjusting Planting Density and Nitrogen Application Rate Based on Farmers' Conventional Planting Habits

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Abstract: Silage maize is cultivated due to its high nutritional value as a forage. China's recent agricultural policy promotes the popularization and cultivation of silage maize. The production of silage maize is affected by planting density and nitrogen application. Based on investigating the planting habits of local farmers, we adjusted the planting density and nitrogen application rate to optimize the growth of silage maize. This study was conducted to investigate the effects of planting density (65,000 plant ha^{-1} (D1), 80,000 plant ha^{-1} (D2), and 95,000 plant ha^{-1} (D3)) and nitrogen rate (150 kg ha^{-1} (N1), 230 kg ha^{-1} (N2), and 310 kg ha^{-1} (N3)) on growth, yield, and quality of silage maize using a two-factor random block design. Planting density and nitrogen fertilizer significantly affected plant height, stem diameter, leaf area index, crude protein, neutral detergent fiber, acid detergent fiber, and starch of silage maize. In summary, the combination of a planting density of 80,000 plants ha^{-1} and a nitrogen application rate of 310 kg ha^{-1} produced a higher crude protein and starch yield and better palatability and quality; this result can aid silage maize growth.

Keywords: silage maize; planting density; nitrogen; growth attributes; biomass yield; quality

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1. Introduction

Silage maize is a special type of maize that is harvested from the milk stage to the dough stage and can be processed directly into animal feed. Silage maize outperforms other forage crops regarding biomass yield, crude fiber content, sugar content, protein quality, and nutritional value in stems and leaves [1,2]. Due to its high yield and quality, silage maize is one of the main feeds used in animal production [3]. Silage maize was planted in a very small area in China. Since 2015, when China issued a policy promoting animal feed production, the production of silage maize has been increasingly popular [4]. The planting acreage reached 2.33 million ha in 2022 due to favorable policies and financial subsidies.

Planting density and nitrogen rate are two important factors affecting the yield and quality of crops [5]. The right combination of planting density and nitrogen rate can improve the fertilizer absorption and utilization of silage maize, thus promoting yield and quality.

Planting density affects plant growth and development by changing light, water, and nutrient conditions during the process of growth [6], thus affecting the yield and quality of silage maize [7]. At a high planting density, the competition between individual plants intensifies, and the yield potential of the crop population cannot be fully achieved [5]. Limited nutrient, water, and light availability usually leads to increased competition between individual plants, which results in a decreased photosynthetic rate, growth rate, and grain-filling rate [8]. The optimal density often varies depending on the end use of maize, and high density is usually more beneficial to forage production than to grain production [9]. However, the effect of planting density on the yield and quality of silage maize is still controversial. As the planting density increased, Cusicanqui et al. found that the forage maize increased in yield but decreased in quality [1]. Salama reported that crude protein (CP) content decreased slightly with the increase in density, but the contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were not affected [9]. Arpici et al. found that planting density affected the dry biomass yield of forage maize, but it had no significant effect on quality-related indicators [10]. The optimal planting density of silage maize is affected by a variety of factors. The differences in temperature, soil property, fertility, variety, and moisture content are all factors affecting planting density.

Nitrogen is one of the most important macronutrients for crop production and development [11]. Nitrogen fertilization significantly impacts plant growth, yield components, and quality [12]. Nitrogen can improve the dry biomass yield of forage maize by affecting the leaf area index (LAI), leaf area duration, and photosynthetic efficiency [13]. However, the average recovery rate of nitrogen fertilizer is very low [14]. Unreasonable application of nitrogen fertilizer will reduce the utilization efficiency and damage the environment [15]. A rational nitrogen rate can improve nitrogen use efficiency and protect the environment via increasing yield [16]. However, a one-time application of nitrogen fertilization cannot provide sufficient nutrients for silage maize during the peak stage of nitrogen absorption [17]. Studies have shown that repeated application of nitrogen to C4 grain crops can improve the use efficiency of fertilizer and ensure reasonable productivity [18]. Additional amendment of the urea can increase the yield of silage maize and improve the quality of the stalk with less lodging. Fang et al. and Qu et al. found that with the increase in nitrogen rate, the ADF and NDF contents decreased [11,19]. Sheaffer et al. found that nitrogen only increased CP content and did not affect other quality parameters [20]. The results of the above studies have not reached a consensus, and the effect of nitrogen application on the quality of silage maize needs more research.

China is wide in its north–south span and has varying latitudes, leading to diverse differences in climate temperature and precipitation. Most of the Chinese pastoral areas are in the north, so the development of forage crops in the north is better than that in the south [21,22]. The Middle–Lower Yangtze Plain is an important grain and oil production base in China. The richest water resources in China in this region make it one of the best places for crop production. However, few studies have been reported on how to improve the yield and nutritional value of silage maize by optimizing planting density and nitrogen application. Based on the common fertilization methods used by local farmers, this study optimized the planting density and adjusted the nitrogen application rate to balance the relationship between yield and the quality of silage maize. This study aimed to identify a reasonable combination of planting density and nitrogen application rate to optimize the growth of silage maize.

2. Materials and Methods

2.1. Plant Material, Site, and Condition

A field experiment was conducted on the Yueming Farm (32°37 N, 119°68 E), Yangzhou City, Jiangsu Province, China, in 2021. Yangqingchuyu 01, a silage maize variety bred for the middle and lower reaches of the Yangtze River, was used. The preceding crop of the field was wheat. The soil in the experimental field was sandy loam, containing 12.64 g kg^{-1} of organic matter, 1.12 g kg^{-1} of total nitrogen, 60.72 mg kg^{-1} of available nitrogen, 35.28 mg kg^{-1} of available phosphorus, and 65.64 mg kg^{-1} of available potassium in the 0−20 cm soil layer.

2.2. Experimental Design and Field Practice Management

Before our experiment, we investigated the planting situation of silage maize in Yangzhou to develop a full understanding of the fertilization strategy commonly used by local farmers. The field experiment was conducted in a two-factor randomized block design with three replicates. The two factors are planting density and nitrogen rate.

2.2.1. Planting Density

The three planting densities used were 65,000 plant ha^{-1} (D1), 80,000 plant ha^{-1} (D2), and 95,000 plant ha^{-1} (D3). The point-seeding planting method was used, where the different densities were determined by different intervals of points on the string and by manually sowing two seeds at each point. The spacing between plants for D1, D2, and D3 were 30.8 cm, 25 cm, and 21 cm, respectively. At the V1 stage, the condition of seedlings was checked, and the excess seedlings were manually removed.

2.2.2. Fertilizer Application

The local conventional nitrogen (N) fertilization strategy is to apply 230 kg ha^{-1} nitrogen in the form of urea (46% N). Thirty percent was incorporated as a basal fertilizer, while the remainder was broadcast as a split application topdressing, with 50% at the jointing stage (V6 stage) and 20% at the trumpet stage (V12 stage). In this study, we set 230 kg ha^{-1} N as the medium level of nitrogen rate. In order to explore the possibility of lowering or increasing the nitrogen rate and maintaining an acceptable level of silage yield, we set a lower nitrogen rate of 150 kg ha^{-1} (65.0% of the medium level) and a higher nitrogen rate of 310 kg ha^{-1}(135.0% of the medium level). The experiment plan is shown in Table 1. The three rates were designated N1 (150 kg ha^{-1}), N2 (230 kg ha^{-1}), and N3 (310 kg ha^{-1}). The timing and proportion of nitrogen fertilizer application followed the usual application pattern of local investigations. Phosphate and potassium fertilizers were applied as basal fertilizers, with P_2O_5 80 kg ha^{-1} and K_2O 100 kg ha^{-1} applied in the form of $(NH_4)\ _2HPO_4$ and KCl, respectively, before seeding.

Table 1. The combination of planting density and nitrogen fertilizer application rate in the experimental design.

Treatments	Planting Density (ha^{-1})	Nitrogen Application Rate (ha^{-1})
D1 × N1	65,000 plant	150 kg
D1 × N2	65,000 plant	230 kg
D1 × N3	65,000 plant	310 kg
D2 × N1	80,000 plant	150 kg
D2 × N2	80,000 plant	230 kg
D2 × N3	80,000 plant	310 kg
D3 × N1	95,000 plant	150 kg
D3 × N2	95,000 plant	230 kg
D3 × N3	95,000 plant	310 kg

2.2.3. Planting and Field Management

There were 9 treatments and 27 plots in total. The area of each plot was 14 m^2 (7 m × 2 m). The wide and narrow rows planting method was adopted, with a wide row of 0.6 m and a narrow row of 0.4 m. The sowing date was 31 May, and the harvest date was September 3. Weeding, pest control, and other field practices were conducted with local recommendations. The meteorological data of the growth period are shown in Figure 1.

2.3. Sampling and Measurements

At different growth stages, 3 plants of each plot were randomly sampled for the measurement of morphological indicators, including plant height, stem diameter, and LAI.

At the harvest stage (R5.5, 1/2 mike line), 10 plants of each plot were taken continuously to determine the yield. After measuring the samples' fresh weight, all the samples were dried at 105 °C in an oven for 30 min for enzyme inactivation and then dried at 80 °C to constant weight for dry biomass determination.

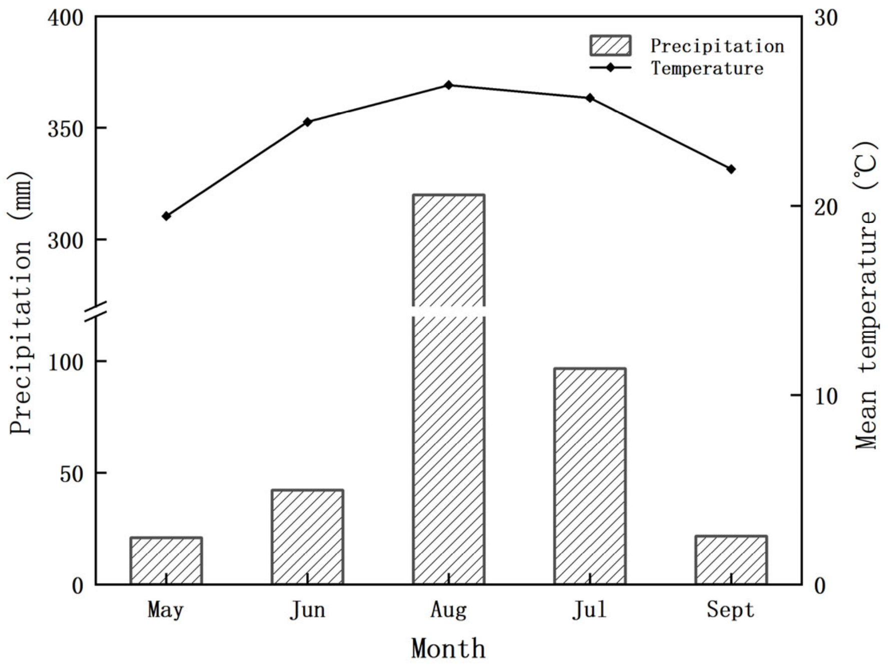


Figure 1. Monthly mean temperature and total precipitation during the growth period of silage maize in 2021.

The dried sample was crushed and passed through a 1 mm screen. The quality indexes of the powder were determined. Crude protein (N content * 6.25) was determined by using the H_2SO_4–H_2O_2 digestion method [23]. Starch content was determined by hydrochloric acid hydrolysis anthrone colorimetry [24]. NDF, ADF, and water-soluble carbohydrate (WSC) contents were determined according to the method of Van Soest et al. and Smith et al. [25,26].

According to the relative feeding value (RFV) calculation method proposed by the Hay Market Working Group of the American Forage and Grassland Council, the feed quality and expected intake of different feeds were compared. The specific calculation formulas are as follows:

$$\text{DDM} = 88.90 - 0.799 \times \text{ADF}$$

$$\text{DMI} = 120/\text{NDF}$$

$$\text{RFV} = (\text{DDM} \times \text{DMI})/1.29$$

In the formula, ADF, NDF, DDM, and DMI are acid detergent fiber content (%), neutral detergent fiber content (%), digestible dry matter (% DW), and roughage dry matter intake (% BW), respectively.

2.4. Statistical Analysis

The package SPSS 24.0 (SPSS, IBM Statistics, Armonk, NY, USA) was used to analyze variance (ANOVA). The mean was compared at the level of $p < 0.05$ by Duncan's multiple range test after the F value test was conducted. Origin 2022 (OriginLab, Northampton, MA, USA) was used to draw graphs and conduct correlation tests.

3. Results

3.1. Growth Attributes

3.1.1. Stem Diameter

Stem diameter was significantly affected by planting density at the jointing and trumpet stages and by nitrogen at the trumpet and maturity stages (Table 2). At the jointing and trumpet stages, the stem diameter of D1 was significantly larger than that of the D3 treatments (Table S1). With the increase in planting density, the stem diameter of silage maize gradually decreased. The stem diameter of D1 was the largest at different growth stages. With the increase in nitrogen rate, the stem diameter of silage maize gradually increased. The N3 treatments were significantly higher than the N1 and N2 treatments in stem diameter at the trumpet stage and maturity stage.

Table 2. Effects of planting density and nitrogen rate on stem diameter, plant height, and LAI at three growth stages.

Treatments	Stem Diameter (mm plant^{-1})			Plant Height (cm plant^{-1})			LAI		
	Jointing Stage	Trumpet Stage	Maturity Stage	Jointing Stage	Trumpet Stage	Maturity Stage	Jointing Stage	Trumpet Stage	Maturity Stage
D1 × N1	24.55 a–d	24.42 ab	22.03 abc	74.75 cd	197 e	257 de	2.39 cd	4.45 c	4.70 d
D1 × N2	24.87 ab	24.06 abc	22.13 abc	79.55 bc	203 cde	285 ab	2.35 d	4.79 c	6.15 abc
D1 × N3	25.72 a	25.28 a	23.33 a	78.55 bcd	209 bcd	276 abc	2.65 bcd	5.05 c	4.75 d
D2 × N1	22.90 b–e	21.81 de	21.16 c	77.15 bcd	201 de	266 cd	2.53 cd	5.17 c	5.03 cd
D2 × N2	24.75 abc	21.49 de	21.83 bc	79.60 bc	210 bcd	272 bcd	3.00 bc	6.25 b	5.47 bcd
D2 × N3	22.51 cde	24.54 ab	22.83 ab	85.65 a	222 a	281 abc	3.20 ab	7.81 a	6.68 a
D3 × N1	22.39 de	22.14 cde	20.73 c	72.65 d	204 cde	244 e	2.90 bcd	6.99 b	5.96 abc
D3 × N2	21.48 e	20.48 e	22.03 abc	75.3 cd	212 abc	275 abc	2.97 bcd	6.99 b	6.59 ab
D3 × N3	23.79 a–d	22.94 bcd	22.03 abc	81.85 ab	219 ab	288 a	3.64 a	7.96 a	6.61 ab
D	**	**	ns	*	*	ns	**	**	**
N	ns	**	**	**	**	**	**	**	*
D × N	ns	ns	ns	ns	ns	*	ns	*	*

Different letters represent significant differences at $p < 0.05$. * and ** mean significance level $p < 0.05$ and significance level $p < 0.01$, respectively; ns means not significant. D, N, and D × N represent planting density, nitrogen fertilizer, and the interaction between planting density and nitrogen fertilizer, respectively. D1, D2, and D3 represent 65,000, 80,000, and 95,000 plants ha^{-1}, respectively, and N1, N2, and N3 represent 150, 230, and 310 kg ha^{-1} nitrogen, respectively

3.1.2. Plant Height

Plant height was significantly affected by planting density at the jointing and trumpet stages (Table 2). The effect of planting density on plant height varies at different stages. The D2 treatment at the jointing stage has the highest plant height among all density treatments, while the D3 treatment has the highest plant height during the trumpet stage (Table S1). However, at the mature stage, the plant height of D1N3 treatment decreased compared with D1N2. The plant height of the D3N1 treatment was significantly lower than that of other treatments. Nitrogen rate had a significant effect on plant height at all growth stages, and the plant height increased with the increase in nitrogen rate. At the mature stage, the plant height of the N2 and N3 treatments was significantly higher than that of the N1 treatment. Compared with the N1 treatment, the plant height of N2 and N3 increased by 8.6% and 10.3%, respectively.

3.1.3. LAI

Planting density and nitrogen application had significant effects on the LAI of silage maize at all the growth stages, and the interaction had a significant effect on the trumpet and maturity stages (Table 2). At the three growth stages, when planting density increased from D1 to D2, LAI increased by 17.8%, 34.6%, and 10.2%, respectively; when planting density increased from D2 to D3, LAI increased by 8.9%, 14.0%, and 11.5%, respectively (Table S1). The LAI of the D3 treatment was the highest among the three planting density treatments. The LAI of the N3 treatment was significantly higher than that of other nitrogen treatments at the jointing stage and trumpet stage, but the LAI of the N2 treatment was the highest at the maturity stage. At the trumpet stage and maturity stage, the LAI of D3N3 was the largest, but the difference between D3N3 and D2N3 was not significant.

3.2. Biomass Yield

Planting density significantly affected the number of silage maize cobs, with D2 and D3 significantly higher than D1, and D2 and D3 increased by 21.5% and 25.7% compared to D1. There was no significant difference between nitrogen fertilizer treatments.

Planting density, nitrogen, and the interactions affected the fresh and dry biomass yield of silage maize (Figure 2). The fresh biomass yield increased from 65.6 to 71.5 t ha^{-1} as the planting density increased from D1 to D2, while the yield increased by 6 t ha^{-1} as the planting density increased from D2 to D3. With the increase of nitrogen fertilizer from N1 to N2, the fresh biomass yield increased from 61.4 t ha^{-1} to 74.1 t ha^{-1}. The fresh biomass yield increased by 5.0 t ha^{-1} when the nitrogen rate increased from N2 to N3. The highest yield of fresh biomass yield was 87.1 t ha^{-1} in the D3N3 treatment, but there was no significant difference with the D2N3 treatment.

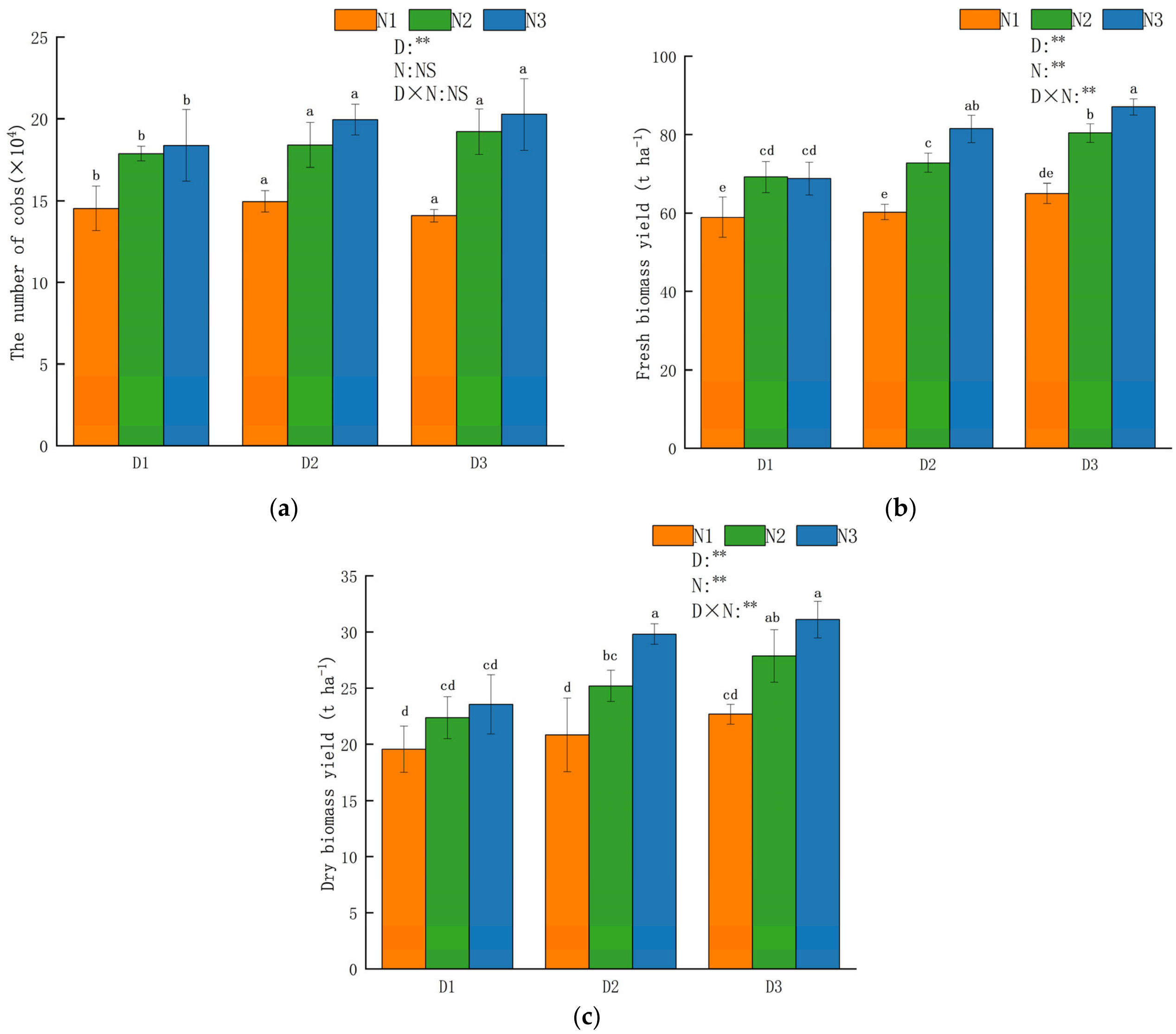


Figure 2. Effects of nitrogen fertilizer and planting density on fresh and dry biomass yields. (**a**) The number of cobs; (**b**) fresh biomass yield; and (**c**) dry biomass yield. Different letters represent significant differences at $p < 0.05$. ** and NS mean significance level $p < 0.01$ and not significant, respectively. D, N, and D × N represent planting density, nitrogen fertilizer, and the interaction between planting density and nitrogen fertilizer, respectively. D1, D2, and D3 represent 65,000, 80,000, and 95,000 plants ha^{-1}, respectively, and N1, N2, and N3 represent 150, 230, and 310 kg ha^{-1} nitrogen, respectively.

With the increase in planting density and nitrogen rate, dry biomass yield increased gradually. Compared with D1, the dry biomass yield of D2 and D3 increased by 13.6% and 19.8%, respectively. But, there was no significant difference between D3 and D2. The yield was significantly higher than that of D1. Dry biomass yield increased by 16.3% with an increasing nitrogen rate from N1 to N2 and increased by 10.7% from N2 to N3.

3.3. Quality Attributes

Planting density and nitrogen application significantly affected the content of CP, ADF, NDF, and starch (Table 3).

Table 3. Effects of planting density and nitrogen application on CP, ADF, NDF, starch, and WSC.

Treatments	CP (%)	ADF (%)	NDF (%)	Starch (%)	WSC (%)
D1 × N1	8.43 cd	31.40 a	52.93 a	20.43 c	9.40 cd
D1 × N2	9.06 a	29.16 bcd	49.33 bc	22.33 bc	12.80 ab
D1 × N3	8.96 ab	28.96 bcd	48.40 bc	20.76 c	11.30 bc
D2 × N1	8.30 d	28.66 cd	49.60 b	22.43 abc	8.66 d
D2 × N2	8.53 cd	26.66 e	46.96 c	25.03 a	11.30 bc
D2 × N3	8.7 bc	27.86 cde	48.16 bc	23.80 ab	13.33 ab
D3 × N1	8.33 cd	29.46 bc	49.30 bc	20.53 c	9.86 cd
D3 × N2	8.5 cd	27.36 de	48.06 bc	22.86 abc	12.36 ab
D3 × N3	8.63 bcd	30.73 ab	50.06 b	21.03 c	13.90 a
D	**	**	*	**	ns
N	**	**	**	*	**
D × N	ns	**	*	ns	ns

CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; WSC: water-soluble carbohydrate. Different letters represent significant differences at $p < 0.05$. * and ** mean significance level $p < 0.05$ and significance level $p < 0.01$, respectively; ns means not significant. D, N, and D × N represent planting density, nitrogen fertilizer, and the interaction between planting density and nitrogen fertilizer, respectively. D1, D2, and D3 represent 65,000, 80,000, and 95,000 plants ha^{-1}, respectively, and N1, N2, and N3 represent 150, 230, and 310 kg ha^{-1} nitrogen, respectively.

3.3.1. CP

The CP content gradually increased with the increase in nitrogen rate. With the increase in planting density, CP content gradually decreased. The CP content under the N2 and N3 nitrogen rates was significantly higher than that under the N1 nitrogen rate (Table S1). The CP content of D1 planting density was significantly higher than that of D2 and D3.

3.3.2. ADF and NDF

With the increase in planting density and nitrogen rate, ADF and NDF contents decreased in the D2 treatments but increased in the D3 treatments. The contents of ADF and NDF were the highest in the D1N1 treatment and the lowest in the D2N2 treatment. Under the N2 treatment, the contents of ADF and NDF were lower than those of other nitrogen treatments (Table S1). In the D2 treatments, the content was significantly lower than that of other planting densities.

3.3.3. Starch

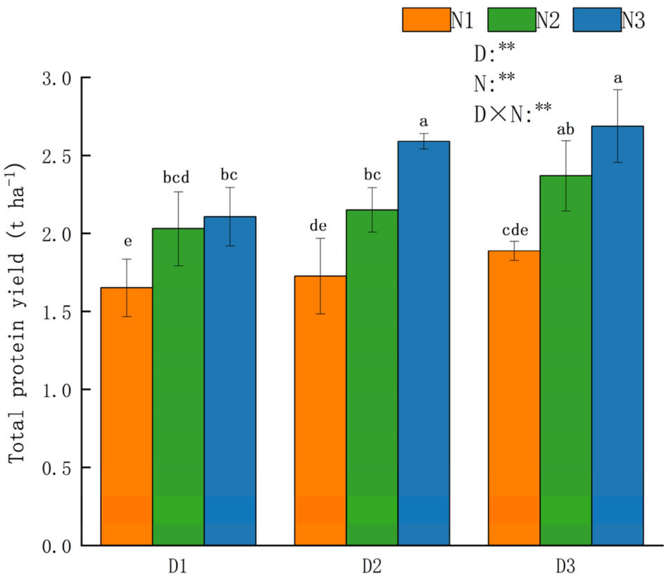
The starch content increased from 20.5% to 24.3% as the planting density increased from D1 to D2 and decreased from 24.3% to 22.1% as the planting density increased from D2 to D3 (Table S1). The starch content increased from 21.0% to 23.1% with the increase in nitrogen rate from N1 to N2 and decreased from 23.1% to 22.8% with the increase in nitrogen rate from N2 to N3.

3.3.4. WSC

Nitrogen rate had a significant effect on WSC content, but planting density had no significant effect. The content of WSC increased gradually with the increase in nitrogen application, and there was no significant difference in the content of WSC among different planting densities. The WSC content in N3 and N2 treatments was 37.6% and 30.5% higher than that in the N1 treatment (Table S2).

3.3.5. Crude Protein Yield and Total Starch Yield

With the increase in planting density and nitrogen rate, the total crude protein yield increased gradually (Figure 3). The maximum value was reached in the D3N3 treatment, but there was no significant difference with D2N3. Compared with the D1 planting density, the crude protein yield increased by 16.6% under the D3 density. Compared with N1, the crude protein yield of N3 increased by 28.7%. With the increase in planting density, the total starch yield increased first in the D2 treatments and then decreased in the D3 treatments. The total starch yield increased gradually with the increase in nitrogen rate. The maximum value was reached in the D2N3 treatment, but there was no significant difference with D3N3. Compared with the D1 planting density, the total starch yield increased by 27.3% under the D2 planting density. Compared with N1, the total starch yield of N3 increased by 31.6%.



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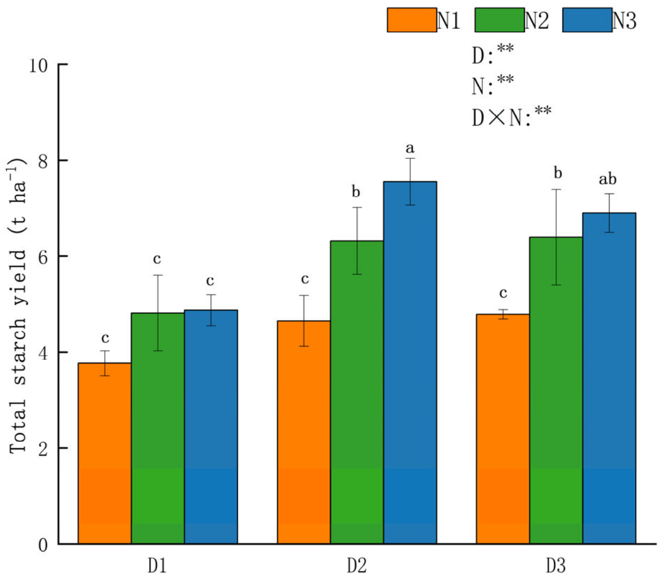

(**b**)

Figure 3. Effects of planting density and nitrogen application on crude protein yield and starch yield. (**a**) Total crude protein yield; (**b**) total starch yield. Different letters represent significant differences at $p < 0.05$. ** mean significance level $p < 0.01$. D, N, and D × N represent planting density, nitrogen fertilizer, and the interaction between planting density and nitrogen fertilizer, respectively. D1, D2, and D3 represent 65,000, 80,000, and 95,000 plants ha^{-1}, respectively, and N1, N2, and N3 represent 150, 230, and 310 kg ha^{-1} nitrogen, respectively.

3.3.6. RFV

Planting density and nitrogen application significantly affected the RFV (Figure 4). With the increase in planting density and nitrogen application, RFV increased first and then decreased. As planting density increased from D1 to D2, RFV increased by 6.3%, and as planting density increased from D2 to D3, RFV decreased by 3.6%. With the increase of nitrogen application from N1 to N2, RFV increased by 7.3%, and with the increase of nitrogen application from N1 to N2, RFV decreased by 3.4%. The maximum value was obtained in the D2N2 treatment, which was not significantly different from D2N3 and D3N2.

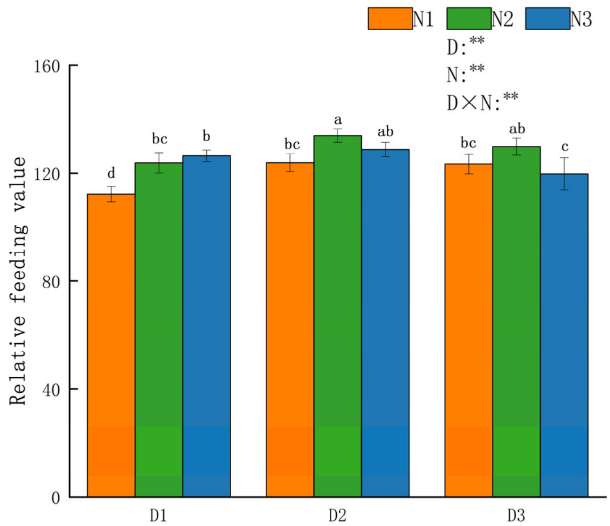

Figure 4. Effects of planting density and nitrogen application on RFV. Different letters represent significant differences at $p < 0.05$. ** means significance level $p < 0.01$. D, N, and D × N represent planting density, nitrogen fertilizer, and the interaction between planting density and nitrogen fertilizer, respectively. D1, D2, and D3 represent 65,000, 80,000, and 95,000 plants ha^{-1}, respectively, and N1, N2, and N3 represent 150, 230, and 310 kg ha^{-1} nitrogen, respectively.

4. Discussion

4.1. Effects of Planting Density and Nitrogen Application on Growth Characteristics of Silage Maize

The stem is important for transporting nutrients and supporting plant growth [27]. In our experiment, the stem diameter of plants decreased with increased planting density and increased with increased nitrogen rate during the three growth stages. As the growth period progressed, the trend of decreasing stem diameter caused by increased density gradually decreased, and the effect of nitrogen fertilizer on stem diameter was gradually greater than that of planting density; this is consistent with previous studies [28–30]. At high planting density levels, individual plants seek higher heights to obtain sufficient light, resulting in thinning of the culm and increased risk of lodging [31]. However, with the increase in nitrogen rate, the content of lignin in the stem also increased, which increased the stem diameter and enhanced the lodging resistance of the stem (but may affect the quality of silage maize) [32].

The height of a plant is often used as an indicator of plant vigor, which depends on the growth ability and habits of the plant [33]. Plant height is closely related to yield in forage crop production [34]. In this study, there was no significant difference in plant height between D1 and D3 densities at the jointing stage, and plant height increased gradually with the increased planting density at the trumpet stage, while there was no significant effect of planting density on plant height at the maturity stage; this showed that with the advance of the growth period, the effect of density on the plant height of silage maize declines, which may be due to the competition for nutrients and light among individuals. Nitrogen fertilizer significantly affected the height of silage maize in the whole growth period, and the plant height increased with the increase of nitrogen fertilizer application. However, the plant height of the mature D3N1 treatment was significantly lower than other treatments, indicating that supplementary nutrition may have been lacking, resulting in the imbalance of group nutrition. The increased supply of nitrogen fertilizer meets the needs of silage maize for nutrients, but excessive nitrogen fertilizer will not always promote plant growth. Similar results were found in the study of oats [35].

LAI can represent the crop production status of the whole growth period. The optimal LAI is the basis for improving light use efficiency and obtaining high yield [36]. In our study, we found that increasing the plant density and nitrogen rate increased LAI, which is consistent with previous studies [37–39]. As a forage crop, silage maize differs from maize for grain production. The optimal LAI of silage maize is often greater than grain maize's [40]. In previous studies, a model was used to analyze the decreasing trend of the optimal LAI of maize from west to east in northern China [41]. In this study, the LAI at the trumpet stage is the largest. The LAI of the D3N3 treatment was the highest in the whole growth period, but there was no significant difference compared with D2N3. However, at the D1 density, the LAI of the D1N2 treatment was significantly higher than that of D1N3, indicating that excessive nitrogen fertilizer did not further increase population development at the late growth stage. There was a significant positive correlation between LAI and dry matter yield in three periods (correlation coefficients: 0.91^{**}, 0.88^{**}, 0.79^{**}, respectively), meaning LAI was the key basis for high biomass yield.

4.2. Response of Silage Maize Biomass Yield to Planting Density and Nitrogen Fertilizer

In this study, the fresh biomass and dry matter yield increased by increasing planting density, but there was no significant difference between D2 and D3 levels. A similar conclusion was reached by Liu et al. [42]: the yield difference between the planting densities of 90,000 plants ha^{-1} and 105,000 plants ha^{-1} was insignificant but significantly higher than the planting density of 75,000 plants ha^{-1}. Although high planting density can increase the LAI, the effect of ventilation and light transmission between individual plants becomes worse, and the quality of silage maize is affected. In this study, the fresh biomass yield and dry matter yield increased gradually with the increase in nitrogen application, which is consistent with Ma et al. [43]. In the previous planting of grain maize, the grain yield, under a certain density level, would not further increase beyond a certain level of nitrogen [44]. However, in the study of Li et al., under the treatment of eight nitrogen gradients, the yield of silage maize may decrease if the nitrogen application rate continues to increase after reaching the highest yield [45].

The biggest difference between silage maize and grain maize is the purpose of harvesting. The whole plant is harvested for silage production, while only the ear is harvested for grain production. For silage maize, nitrogen is transported to the stem, leaf, and ear to increase the biomass yield. For grain maize, nitrogen is transported to the ear to improve grain yield. The differences are caused by the position of nitrogen absorption and accumulation. The differences between varieties may also have an impact. In this study, the fresh biomass yield and dry matter yield of the D3N3 treatment were the highest, followed by the D2N3. Exploring which treatment is the best still needs to be further combined with quality analysis.

4.3. Effects of Planting Density and Nitrogen Fertilizer on the Quality of Silage Maize

The crude protein (CP) content is an important parameter in dairy rations, providing N to rumen microorganisms and amino acids to the small intestine for absorption and utilization by ruminants [46]. While forage maize has a high energy content, it is low in CP content. Increasing the content of CP is important to enhance the nutritional value of feed maize. In our study, the content of CP increased with the increase of nitrogen application, indicating that the increase in nitrogen application promoted the nitrogen absorption of silage maize. Under high-density conditions, the CP content decreased, but according to the results of Wang et al. [47], the density did not affect the CP content of silage maize. The difference from our experiment might be caused by water supply in different climate zones, as water deficit could lead to individual competition for nutrients, thus affecting CP content.

The standard for measuring excellent silage maize is high CP content and low ADF and NDF content, resulting in better palatability of the forage [48]. In our study, the contents of ADF and NDF in the D1 treatment decreased with the increase of nitrogen application rate, while the contents in the D2 and D3 treatment decreased with the increase of nitrogen application rate initially but then increased. We believe that under the three nitrogen fertilizer application rates set in this study, it is a definite fact that CP content increases with the increase of nitrogen application rate, but NDF and ADF show lower content under the

N2 treatment. Overall, although excessive nitrogen fertilizer promotes the increase of CP content in our experiment, it may lead to an increase in NDF and ADF content, thereby affecting the feeding value of silage maize; this is also in agreement with Baghdadi et al. [49]. Wang et al. found that CP, starch, and crude fat content decreased with increasing plant density, but the content of ADF and NDF increased with increasing plant density [50]. In our study, the results of CP content gradually decreasing with increasing planting density were similar, but ADF and NDF content first decreased and then increased with increasing planting density. So, we believe that an increase in planting density does not necessarily lead to an increase in fiber content. An appropriate planting density promotes improving fiber quality, achieving a balance between yield and quality. In the study of Marsalis et al., both density and nitrogen fertilizer did not affect the NDF content of crops, which may be due to differences in crop varieties and regional precipitation [51]. Due to the high water consumption of silage maize, water deficit can limit factors in its yield and quality [52]. It is also worth noting that abnormally high rainfall in August may have a negative impact on yield and quality results, as this is the reproductive growth stage of maize, and excessive water can lead to stress.

Starch is the main source of metabolizable energy for silage maize and is also a product of photosynthesis. Except for a portion consumed during growth and respiration, the rest is preserved in plant organs [24]. In our study, the starch content of D2 treatments was significantly higher than D1 and D3, indicating that either too high or too low planting density would affect the reduction of starch content. Our results showed that the application of nitrogen fertilizer could increase the starch content and improve the nutritional value. With the increase in nitrogen fertilizer usage, silage maize obtains more nutrients, leading to vigorous growth and a gradual increase in plant starch accumulation. In a previous study, the starch concentration of silage maize was positively correlated with dry matter weight but negatively correlated with fiber concentration [53]; this is consistent with the present study, which showed a significant negative correlation between starch content and ADF (−0.793 *) and NDF (−0.763 *).

WSC refers to monosaccharides and oligosaccharides that are soluble in water and ethanol. It is an important osmotic regulator in plants and the main form of carbohydrate metabolism and storage [54]. Planting density did not affect WSC content in this study, and WSC content increased with the increase of nitrogen application, which was the same as found in the study of four grassland plants [55]. In our study, the WSC content was lower at the N1 level and significantly increased under N2 and N3 nitrogen treatments, but there was no significant difference between the two groups. Nitrogen application at low nitrogen levels may lead to the transfer of WSC from the aboveground part of the plants to the roots, which first promotes the growth of roots and then shows a lower content. With the increase of nitrogen, WSC could participate in growth regulation and metabolism, and the content of WSC in the aboveground part also increased. However, with the further increase of nitrogen fertilizer, the increasing trend of WSC content gradually slowed down.

4.4. Synergistic Balance of Quality Indexes and Biomass Yield in Silage Maize

In previous studies, Wang et al. found that increasing planting density and nitrogen application increased crude protein yield and starch yield [47]. The results of our study were the same: the crude protein yield and starch yield reached the maximum in the D3N3 and D2N3 combinations, but there was no significant difference between them. However, the starch yield of D2 was significantly higher than that of D3. Although increasing density can improve yield, too high a density can reduce total starch yield. There was no significant difference between D2 and D3 in the total yield of crude protein, which indicated that too high planting density could not always improve the crude protein yield, and increasing the amount of nitrogen application under suitable planting density could significantly improve the crude protein yield.

For the yield results, there was no significant difference in dry matter yield between D2 and D3, and the treatment of D2N3 and D3N3 had an advantage in dry matter yield.

Although there was no significant difference in crude protein yield, starch yield, and WSC content between D3N3 and D2N3, the RFV of D2N3 was significantly higher than that of D3N3.

5. Conclusions

Our study provides assistance for optimizing the growth of silage maize by adjusting planting density and nitrogen application rate. The planting density and nitrogen application rate have a significant impact on the agronomic traits, yield, and quality characteristics of silage maize. Based on the results of yield and quality, the D2N3 combination had higher crude protein and starch yield, better palatability, and quality. So, according to our results, the planting density of 80,000 plants ha^{-1} and the nitrogen application rate of 310 kg ha^{-1} can balance silage maize yield and quality and optimize the growth of silage maize.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13112785/s1, Table S1: The main effect result values of planting density and nitrogen application rate on stem diameter, plant height and LAI at three growth stages; Table S2: The main effect result values of planting density and nitrogen application rate on CP, ADF, NDF, starch, and WSC.

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