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Different Mechanized Fertilization Methods in Nutrient Utilization and Summer Maize Yield

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Abstract: In the production of summer maize, the problems of excessive fertilizer input and low fertilizer utilization rate are common, resulting in the waste of resources and environmental pollution. In order to explore the optimal fertilization mode of summer maize, a field experiment with eight treatments was designed in which sowing and fertilization were carried out by different machines. The effects of the two fertilization methods, i.e., hole fertilization and strip fertilization; two fertilization positions, i.e., side-position fertilization and positive-position fertilization; and two fertilization depths, i.e., 10 cm and 15 cm, on the summer maize yield, plant nitrogen, phosphorus, and potassium nutrient accumulation, and aboveground biomass were studied. The results show that different fertilization modes had significant effects on summer maize yield, nitrogen, phosphorus, and potassium nutrient accumulation, and aboveground biomass. In general, when the strip fertilization method was used, 15 cm deep positive-position fertilization was superior. When the hole fertilization method was used, 15 cm deep side-position fertilization was superior.

Keywords: location of fertilization; fertilizer application depth; hole-fertilization; summer maize; yield

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1. Introduction

Zea mays L. is the most common food crop in China. In 2020, China's maize production reached 261 million tons, accounting for 38.9% of total grain production [1]. Fertilizer is important for crop yield, but as a result of excessive fertilizer application, resources are wasted, and the environment is impacted. In recent years, government departments have proposed a "double reduction" in chemical fertilizers and pesticides, and agricultural researchers have developed many agronomic measures to reduce the amount of chemical fertilizers used. In 2016, China's planting industry achieved zero growth in fertilizer use for the first time, and significant progress was made in reducing fertilizer use. However, there are still many problems, including unbalanced regional nutrient supplies and unbalanced fertilization of different crops. Among them, there are still problems related to excessive fertilizer input and low fertilizer utilization rate in maize production [2].

The utilization rate of fertilizer is closely related to the fertilization method. Intelligent fertilization methods and positions are the basis for improving crop yields and fertilizer utilization efficiency [3,4]. According to different fertilization periods, the types of fertilization are divided into base fertilizer, seed fertilizer, top-dressing, and so on. Among them, seed fertilizer is a fertilizer used at the same time as sowing, which mainly provides nutrients for early crop growth and lays a foundation for later growth. Thus, seed fertilizer plays an important role in crop growth [5]. Commonly, the fertilization methods of seed fertilizer include surface fertilization and mechanical deep fertilization. Depending on the location of the fertilizer, mechanical deep fertilization is used, which includes seed and fertilizer mixed-sowing fertilization, side-position deep fertilization, positive-position deep fertilization, opposite-hole fertilization, and so on. Maize is a hole-seeding crop; thus, fertilization methods mainly include strip fertilization and hole fertilization. The fertilization position includes the side position and positive position. Reasonable fertilization methods can increase crop yield and improve crop quality. Unreasonable fertilization methods and fertilization locations cause deterioration of the soil quality, reduced fertilizer utilization, waste of resources, and pollution of the environment [5–7]. The application position of fertilizer affects the absorption, utilization, and assimilation of nitrogen, phosphorus, and potassium in summer maize, which directly affects its growth and development, and then affects the yield of summer maize and the fertilizer utilization rate [4,8]. Therefore, studying the effects of different fertilization methods on nutrient utilization and the yield of summer maize is of great significance for improving the fertilizer utilization rate, reducing production costs, and guiding the development of fertilization machinery technology.

At present, most of the fertilization methods on the seeder are side-position strip fertilization. Hole fertilization technology is generally in the research stage, and there is a lack of sophisticated machinery [9,10]. Wu et al. designed a duckbill-valve-type fertilizer hole-forming mechanism, which is driven by a stepping motor using a rocker mechanism. The duckbill valve intermittently opens and closes to introduce the granular fertilizer, which is discharged by the outer groove wheel fertilizer discharger into the soil. The test results show that the distance accuracy and hole fertilization accuracy meet the requirements of precision applications with corn [11]. Du et al. designed an inclined trapezoidal hole-type hole fertilizer applicator. The effects of operating speed, filling hole length, and airflow speed on the hole length error and hole fertilizer discharge were studied in simulation and bench tests. Further field experiments showed that the fertilizer applicator exhibited superior hole formation performance [12]. Liu et al. designed a cavity-type precision hole fertilization device, which relies on the fertilizer cavity of the fertilizer plate to divide the amount of granular fertilizer required for each hole. When the fertilizer cavity is transferred to the bottom, the fertilizer is quickly blown into the fertilizer pipe by airflow, and the fertilizer is applied to the soil by hole fertilization. In order to address the problem of granular fertilizer easily becoming stuck in the fertilizer tray and fertilizer cavity, a flexible fertilizer protection mechanism was also designed. Through simulation and bench tests, the design parameters, such as optimal forward speed and optimal airflow speed, were determined, and the hole-forming performance met operational requirements [13–15]. Wang et al. designed several different pricking hole mechanisms for liquid fertilizer hole applications, such as a crank-rocker-type system, an elliptical gear planetary system, and a full elliptical planetary system. A simulation test, dynamic analysis, and working parameter optimization of the mechanism were carried out to improve fertilization efficiency and meet the agronomic requirements [16–18]. Yuan et al. designed a hole fertilization system and fertilizer discharger by referring to the structural principle of the spoon-wheel seed metering device. The simulation and bench test results show that the device can realize hole fertilization and meet production requirements, but the efficiency of the fertilizer discharger is lower than that used in the traditional strip fertilization method [5].

Studies have shown that concentrated positioning deep fertilization can improve maize yield, nutrient uptake, and utilization efficiency. The apparent characteristics of inter-plant hole application are improved compared with ditching strips [4]. Concentrated deep application beside each corn plant with fertilizer tablets increased yield and fertilizer utilization rate [19]. The yield and nitrogen utilization efficiency of summer maize were improved by limited area and quantitative fertilization per plant compared with conventional fertilization [20]. One-time root-zone fertilization can achieve a high yield in crops and a high efficiency in fertilization [21]. However, as a result of the lack of positioning hole fertilization equipment, in comparative tests of different fertilization methods, hole fertilization is usually completed manually, and the strip fertilization comparison test is completed using common production equipment. During the implementation of these experiments, different people have different qualities of fertilization operations, and there is a big gap between the effect of manual and machine operations. Therefore, the experiment is greatly influenced by human factors, and the credibility of the results is affected. In this study, the commonly used strip fertilization corn seeder and the specially developed hole fertilization seeder were selected as fertilization machines. Comparative experiments to assess strip fertilization, hole fertilization, the side position, positive position, and different depths were designed. The summer maize yield, the accumulation of nitrogen, phosphorus, and potassium nutrients in plants, and the aboveground biomass were tested under different fertilization methods. The best mechanized fertilization method was established in order to improve maize fertilization and to provide a basis for the design of a corn fertilization seeder.

In this study, an experiment with eight treatments is carried out. Each treatment covers an area of 36 m^2 and is repeated three times. Therefore, the objective of this study is to determine the response of different fertilization methods on nutrient utilization and yield of summer maize. The results provide new ideas for the selection of fertilization methods and the design of sowing and fertilization machinery.

2. Materials and Methods

2.1. Outline of Test Area and Test Materials

The test site was located in Juqiao Town Liuzhai Village, Qibin District, Hebi City, Henan Province (114°17′57″ E, 35°40′03″ N, altitude 72 m). The tests were conducted in June–October 2017 and June–October 2018, respectively. The test area was located in the northern part of Henan Province, which was characterized by a temperate semi-humid monsoon climate. The four seasons were distinct, the summer was hot and humid, the annual average temperature was 14.2–15.5 °C, the annual precipitation was 349.2–970.1 mm, and the annual sunshine duration was 1787.2–2566.7 h. The annual precipitation in the test area was 506.9 mm in 2017 and 557.3 mm in 2018. The average temperature was 14.7 °C in 2017 and 14.9 °C in 2018. The average sunshine time was 2179.3 h in 2017 and 2206.4 h in 2018. The soil used in this experiment was clay loam with 28, 48, and 24% sand, silt, and clay, respectively. The planting pattern was wheat–maize rotation. The basic properties of the tested soil are shown in Table 1.

Table 1. Basic properties of the tested soil.

Year	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Organic Matter (g·kg^{-1})	pH Value
2017	102.91	36.84	181.00	22.98	7.31
2018	101.34	36.15	178.64	24.38	7.44

The experimental plot area was 36 m^2. The length and width of each plot were 6 m. Each treatment was repeated three times and was randomly arranged. The tested variety was “Yu an No. 3”, which was produced by Henan Ping An Seed Industry Co., Ltd. (Zhengzhou, China). The plant was compact, with a total number of 18–19 leaves and a plant height of 250–261 cm. The planting density was 67,500 plants ha^{-1}. The distance between seed rows was 0.55 m, and the distance between plants was 0.27 m. The tested fertilizer was a special formula fertilizer for summer maize (28-10-12) developed by Henan Agricultural University. In this, 50% of the total nitrogen was slow-release nitrogen, urea, and coated urea (the slow-release nitrogen was resin, with a sulfur double membrane, double control, coated urea, with a release period of about 80 days). Large particles of potassium chloride and monoammonium phosphate were used as raw materials for blending. The amount of nitrogen (N) was 210 kg ha^{-1}, phosphorus (P_2O_5) was 75 kg ha^{-1}, and potassium (K_2O) was 90 kg ha^{-1}. All the fertilizers were applied once during sowing, and no additional fertilizer was applied later.

The preceding crop was wheat, with straw bales after the field treatment and no-tillage sowing. Protective rows were set up around the whole test area, and field management was carried out in combination with local production measures. It was first sown on 15 June 2017 and harvested on 4 October. Then, it was sown again on 13 June 2018 and harvested on 2 October. Each hole contained 1–2 seeds at a sowing depth of 4 cm.

2.2. Fertilization Methods and Machines

In this experiment, experimental treatments using positive-position hole fertilization, positive-position strip fertilization, side-position hole fertilization, and side-position strip fertilization were designed. The relative position of seed fertilizer is shown in Figure 1. Positive-position hole fertilization is used to apply the fertilizer right below the seed. In this way, the seed and fertilizer are separated by soil to prevent burning seedlings (Figure 1a). Positive-position strip fertilization is used to apply fertilizer directly below the seed row (Figure 1b). Side-position hole fertilization is used to apply the fertilizer in a hole to the side of the seed line, with the seeds corresponding to the fertilizer holes one to one (Figure 1c). Side-position strip fertilization is a common fertilization method at present, and the fertilizer is applied to the side of the seed row (Figure 1d). A sowing depth of 4 cm was used. The fertilization depths *D* were 10 cm and 15 cm from the ground level. Side-position fertilization was applied 5 cm to the side of the seed row.

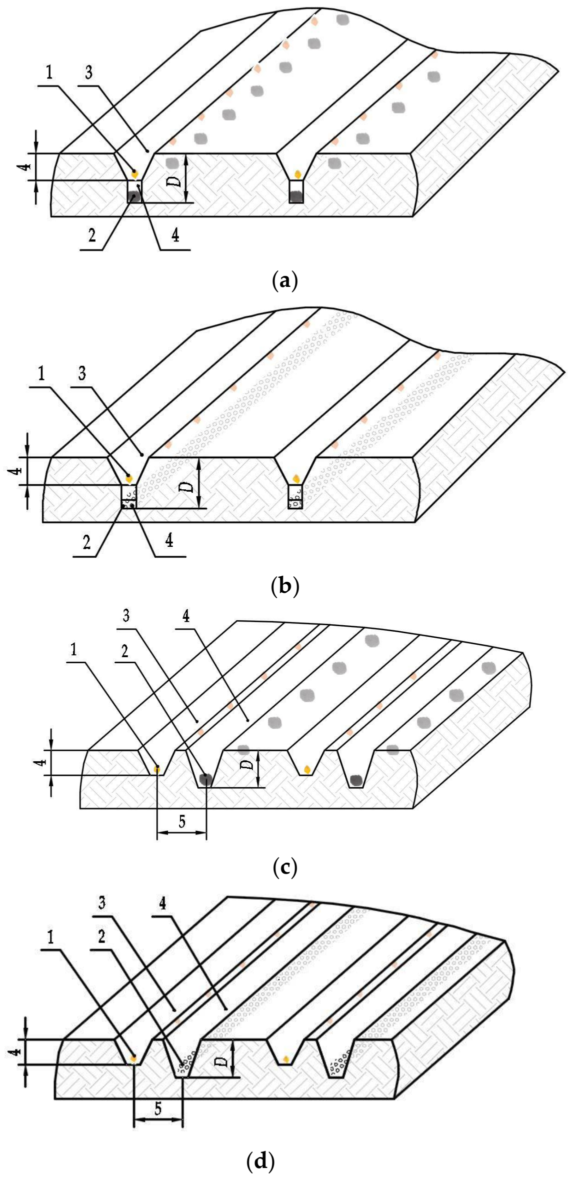


Figure 1. Schematic diagram of fertilization location. (1) Seed; (2) fertilizer; (3) seed furrow; (4) fertilizer furrow. (**a**) Positive-position hole fertilization; (**b**) positive-position strip fertilization; (**c**) side-position hole fertilization; (**d**) side-position strip fertilization. The number "4" in the figure represents the seeding depth. The number "5" in the figure represents the horizontal distance between seeds and fertilizer. The letter "*D*" in the figure represents the depth of fertilization.

The strip fertilization treatment was performed using a commonly used strip fertilization corn planter, which is shown in Figure 2a. The machine has two front and rear beams. A fertilizing opener is installed on the front beam, and the fertilizer is applied to the soil through the fertilizing opener. The seeding parts are installed on the rear beam, including a spoon wheel metering device, a seed box, a seeding opener, a ground wheel, a transmission system, and so on. In side-position strip fertilization, the fertilizer opener and the corresponding line of sowing opener were staggered 5 cm horizontally, and the level of the fertilizer opener was adjusted to achieve the change in fertilization depth. In positive-position strip fertilization, the same straight-line position with the seeding opener was utilized, and the ditching depth was adjusted according to the test requirements. After the fertilizer was applied, the soil was returned and covered, and the sowing opener was furrowed again.

(**a**) (**b**)

Figure 2. Two types of fertilization seeder. (**a**) Seeder with strip fertilization; (**b**) seeder with hole fertilization.

The hole fertilization seeder is shown in Figure 2b. The machine has two beams. The front beam carries a fertilization opener, a fertilizer box, a large slot outside the slot wheel fertilizer, a cam splitter, a stepper motor, and other components. A spoon wheel metering device, a seed box, a sowing opener, a ground wheel, a transmission system, and other parts are installed on the rear beam. The step motor drives the cam splitter, and the cam splitter drives the outer groove wheel-type fertilizer distributor. Through the intermittent rotation of the cam splitter, the outer groove wheel of the fertilizer distributor rotates a groove to realize the intermittent discharge of the fertilizer into the hole. By adjusting the effective width of the groove wheel by adjusting the handle, the amount of fertilization per hole can be adjusted. The Hall sensor is used to detect the rotation angle of the seeding shaft, to calculate the time difference between the fertilizer entering the soil and the seed entering the soil, and to accurately control the rotation speed of the stepping motor. This is performed to ensure the fertilizer and seed positions correspond precisely. In side-position hole fertilization, the fertilizer opener and the corresponding line of the sowing opener in were staggered 5 cm horizontally, and the level of the fertilizer opener was adjusted to change the fertilization depth. For positive-position hole fertilization, the same straight-line position with the seeding opener was utilized, and the ditching depth was adjusted according to the test requirements. After the fertilizer was applied, the soil was returned and covered, and the sowing opener was furrowed again.

2.3. Design of Experiment

The experiments were designed considering three factors: fertilization method, fertilization location, and fertilization depth. The fertilization method is divided into hole fertilization and strip fertilization, the fertilization position is divided into the positive position and side position, and the fertilization depth is divided into 10 cm and 15 cm. There were eight treatments in the experiment (Table 2). T1 was side-position hole fertilization at a depth of 10 cm: the hole fertilizer was located at a horizontal distance of 5 cm from the row at a depth of 10 cm from the ground level, and seed holes and fertilizer holes corresponded one to one. T2 was positive-position hole fertilization at a depth of 15 cm: the hole fertilizer was located 11 cm below the seed hole, and seed holes and fertilizer holes corresponded one to one. T3 was positive-position hole fertilization at a depth of 10 cm: the hole fertilizer was located 6 cm below the seed hole, and seed holes and fertilizer holes corresponded one to one. T4 was side-position hole fertilization at a depth of 15 cm: the hole fertilizer was located on the row side at 5 cm, at a depth of 15 cm from the ground level, and seed holes and fertilizer holes corresponded one to one. T5 was side-position strip fertilization at a depth of 10 cm: strip fertilizer was located at the horizontal distance of 5 cm, at a depth of 10 cm from the ground level. T6 was positive-position strip fertilization at a depth of 10 cm: strip fertilizer was located at 6 cm below the row position. T7 was side-position strip fertilization at a depth of 15 cm: the strip fertilizer application was located at a horizontal distance of 5 cm, at a depth of 15 cm from the ground level. T8 was positive-position strip fertilization at a depth of 15 cm: strip fertilizer application was located 11 cm below the seed line position.

Table 2. Experimental treatments.

Treatments	Fertilization Method	Fertilization Location	Fertilization Depth (cm)
T1	hole fertilization	side position	10
T2		positive position	15
T3		positive position	10
T4		side position	15
T5	strip fertilization	side position	10
T6		positive position	10
T7		side position	15
T8		positive position	15

2.4. Sample Collection and Determination Method

2.4.1. Determination of Basic Soil Nutrients

Soil samples of 0–20 cm were collected before maize sowing to determine the basic fertility of the soil. Soil-available phosphorus was determined by $NaHCO_3$ extraction using the molybdenum blue colorimetric method, and soil-available potassium was determined by NH_4OAc extraction using flame spectrophotometry. The soil organic matter was determined using the potassium dichromate volumetric method and the external heating method, and the soil alkali-hydrolyzable nitrogen was determined using the alkali solution diffusion method [22]. The pH value of the soil was evaluated by the combined pH/moisture meter AMTAST AMT-300 (Amtast USA Inc., Lakeland, FL, USA) based on the potentiometry.

2.4.2. Mature Plant Dry Matter and Nutrient Determination

During the harvest period, two summer maize plants were collected from each plot. They were killed at 105 °C for 15 min and dried to constant weight at 65 °C. The dry matter weight of straw and grain was weighed using an electronic balance. All samples were dried, smashed, and digested with concentrated H_2SO_4–H_2O_2. The total nitrogen of the plants was determined by continuous flow analysis, the total phosphorus of the plants was determined by molybdenum blue colorimetry, and the total potassium of the plants was determined by flame spectrophotometry.

2.5. Determination of Yield and Determination of Seeds Quality

For harvest period sampling, 2 rows of corn in the middle of each plot, 10 cobs per row, were bagged, dried, and weighed, with 14% water content being converted into plot yield. In addition, 10 consecutive cobs of corn were taken to measure the quality, grain number per cob, 1000-grain weight, cob length, etc.

2.6. Data Processing and Statistics

The main data were calculated as follows:

Nutrient accumulation (kg ha^{-1}) = [straw dry weight (kg ha^{-1}) × straw nutrient content (g kg^{-1}) + grain dry weight (kg ha^{-1}) × grain nutrient content (g kg^{-1})]/1000.

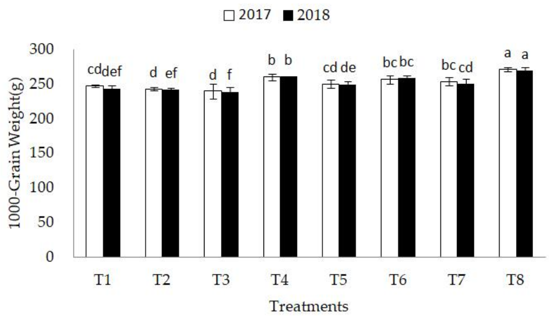
Aboveground biomass (kg ha^{-1}) = straw dry weight (kg ha^{-1}) + grain dry weight (kg ha^{-1}).

Statistical analysis of variance and the tests for the homogeneity of variances and the normality of the data were performed using Microsoft Excel 2007 (Microsoft Inc., Redmond, WA, USA) and the SPSS22.0 (SPSS Inc., Chicago, IL, USA) software. Duncan's new complex range method was used for multiple comparisons between different treatments ($p < 0.05$).

3. Results

3.1. Effects of Different Fertilization Treatments

The effects of different fertilization treatments on summer maize yield are shown in Figure 3. It can be seen that different fertilization treatments had significant effects on 1000-grain weight and yield but had no significant effects on cob length and grain number per cob. In terms of 1000-grain weight, the T8 treatment produced the highest values in 2017 and 2018, which were 271.48 g and 269.79 g, respectively, significantly higher than the other treatments. The second highest value was recorded for the T4 treatment, which was significantly higher than the values for the T1, T2, and T3 treatments, in 2017, and significantly higher than those for the other treatments, except T8, in 2018. The lowest 1000-grain weight values in 2017 were recorded for the T3 and T2 treatments, which were 240.01 and 243.07 g, respectively. The lowest grain weight value in 2018 was for the T3, T2, and T1 treatments, which were 239.02, 241.85, and 243.95, respectively.



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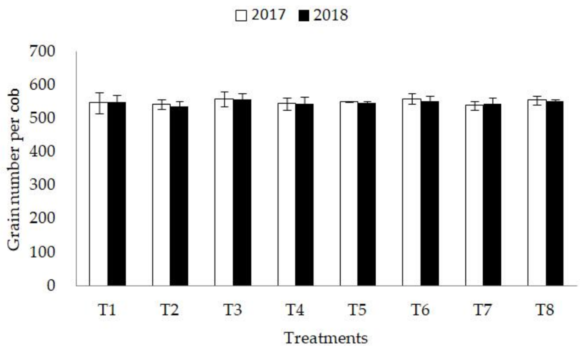
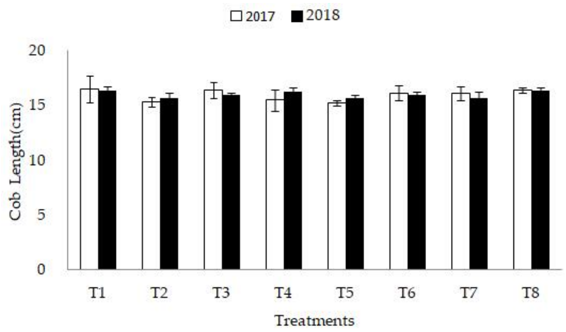


(**b**)

Figure 3. *Cont.*



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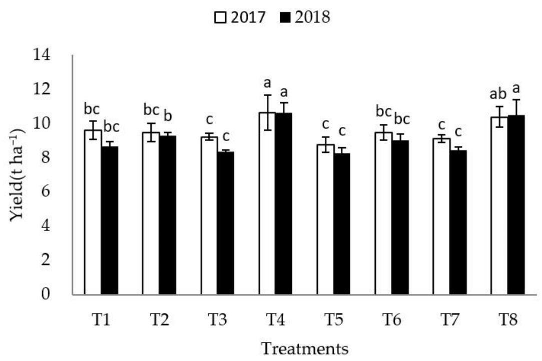


(**d**)

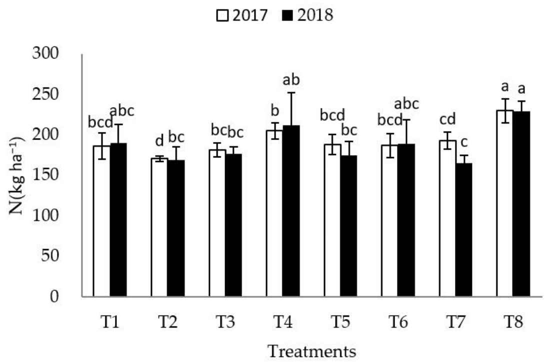
Figure 3. Effects of different fertilization treatments on yield of summer maize. (**a**) The 1000-grain weight; (**b**) grain number per cob; (**c**) cob length; (**d**) yield. Error bars indicate standard deviations of the means. Within a year for a given dependent variable, different letters indicate treatment means that are significantly different ($p \leq 0.05$).

In terms of yield, the T4 and T8 treatments produced the highest values in 2017 and 2018. The yields of the two treatments in 2017 were 10.62 and 10.37 t ha^{-1}, respectively, and the yields of the two treatments in 2018 were 10.63 and 10.51 t ha^{-1}, respectively. Except for the T8 treatment in 2017, the yields of the T4 and T8 treatments in the 2 years were significantly higher than those of other treatments. When the hole application fertilization method was used, lateral fertilization was superior to positive fertilization at the same depth. In 2017, the yield of T4 was 12.08% higher than that of T2. In 2018, the T4 treatment significantly increased by 14.48% as compared with the T2 treatment, and the T1 treatment increased its yield by 4.23% as compared with the T3 treatment. When the strip fertilization method was used, the effect of positive fertilization was superior to that of lateral fertilization at the same depth. In 2017, the yield of T8 was 13.74% higher than that of T7, and the yield of T6 was 8.33% higher than that of T5. In 2018, the T8 treatment significantly increased by 24.75% as compared with the T7 treatment. Under the same fertilization method and fertilization position, and different fertilization depths, the yield difference in each corresponding treatment was not significant in 2017. In 2018, excluding the T7 and T5 treatments, the treatments at a depth of 15 cm produced significantly higher values than the corresponding treatments at a depth of 10 cm.

In general, when the hole fertilization method was used, side fertilization was superior in terms of increasing yield. When the fertilization method was used, positive-position fertilization was superior in terms of increasing yield. Using the same fertilization method and fertilization position, the 15 cm depth was better.

3.2. Effects of Different Fertilization Treatments on Nutrient Accumulation of Summer Maize

As shown in Figure 4, different fertilization treatments had significant effects on the nutrient accumulation of summer maize. In 2017 and 2018, the nutrient accumulation produced by the T8, T4, and T6 treatments was higher. Except for potassium in 2017, the difference between these three treatments was not significant. In 2017 and 2018, the highest nitrogen accumulation values were recorded for the T8 treatment, which were 226.73 kg ha^{-1} and 226.64 kg ha^{-1}, respectively, followed by the values for the T4 treatment, which were 202.11 kg ha^{-1} and 212.05 kg ha^{-1}, respectively. The accumulation of phosphorus was similar to that of nitrogen, and the highest accumulation was produced by the T8 treatment, followed by the T4 treatment. The accumulation of potassium was slightly different from the accumulation of nitrogen and phosphorus. In 2017 and 2018, the T4 treatment produced the highest values, 252.31 kg ha^{-1} and 256.35 kg ha^{-1}, respectively, followed by the T8 treatment, 246.44 kg ha^{-1} and 242.34 kg ha^{-1}, respectively. Except for potassium in 2017, the accumulation values of nitrogen, phosphorus, and potassium for the T8, T4, and T6 treatments were significantly higher than for the T7 treatment.



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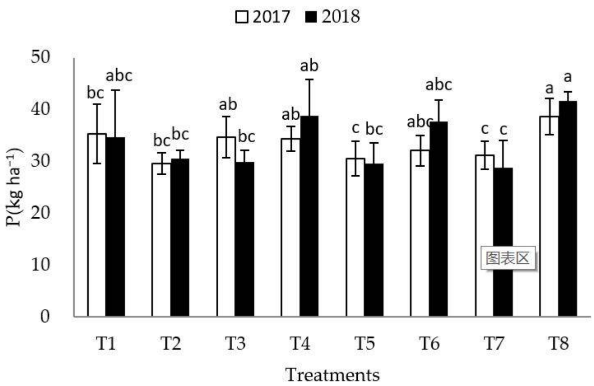

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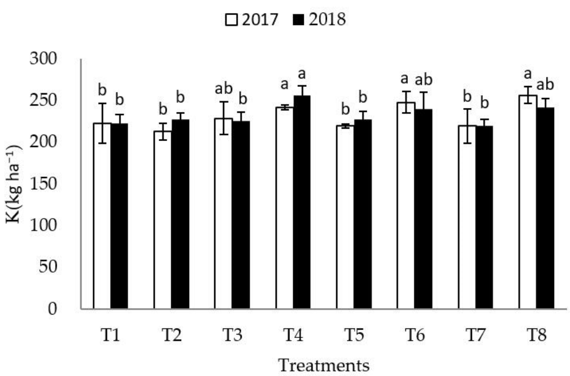

(**c**)

Figure 4. Effects of different fertilization treatments on nutrient accumulation of summer maize. (**a**) Effect on nitrogen accumulation; (**b**) effect on phosphorus accumulation; (**c**) effect on potassium accumulation. Error bars indicate standard deviations of the means. Within a year for a given dependent variable, different letters indicate treatment means that are significantly different ($p \leq 0.05$).

When the hole fertilization method was used, the difference in nutrient accumulation between side-position fertilization and positive-position fertilization was not significant when the fertilization depth was 10 cm. When the fertilization depth was 15 cm, except for nitrogen and phosphorus accumulation in 2018, the nutrient accumulation from side-position fertilization was significantly higher than that of positive-position fertilization. When the strip fertilization method was used, and the fertilization depth was 10 cm, there was no significant difference in nutrient accumulation between side-position fertilization and positive-position fertilization, except for potassium, in 2017. When the fertilization depth was 15 cm, except for potassium, in 2018, the nutrient accumulation for positive-position fertilization was significantly higher than that of side-position fertilization.

In general, when the hole fertilization method was used, side-position fertilization was superior as regards plant nutrient accumulation. When the strip fertilization method was used, positive-position fertilization was superior as regards plant nutrient accumulation. For the same fertilization method and position, the depth of 15 cm was better.

3.3. Effects of Different Fertilization Treatments on Aboveground Biomass

As shown in Figure 5, different fertilization treatments had significant effects on the aboveground biomass accumulation of summer maize. Among the eight treatments, the aboveground biomass accumulation of summer maize for the T8 and T4 treatments was significantly higher than those of the other treatments in 2017 and 2018, which indicated that the aboveground biomass accumulation of summer maize was better at a 15 cm depth using side-position hole fertilization and at a 15 cm depth using positive-position strip fertilization.

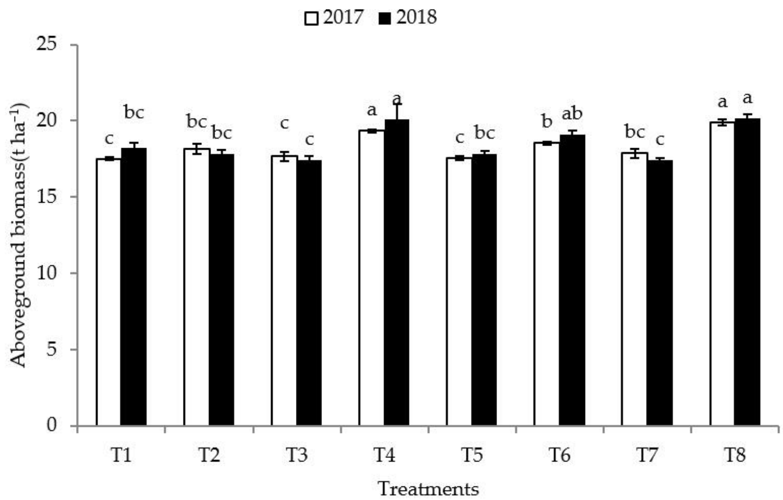

Figure 5. Effects of different fertilization treatments on aboveground biomass. Different letters indicate treatment means that are significantly different ($p \leq 0.05$).

When the hole fertilization method was used at a fertilization depth of 10 cm, the difference in aboveground biomass accumulation between side-position fertilization and positive-position fertilization was not significant. When the fertilization depth was 15 cm, the nutrient accumulation of side-position fertilization was significantly higher than that of positive-position fertilization. In 2017, the T4 treatment increased by 6.55% as compared with the T2 treatment. In 2018, the T4 treatment increased by 12.76% as compared with the T2 treatment. When the strip fertilization method was used at a depth of 10 cm, the aboveground biomass accumulation of positive-position fertilization was 5.63% higher than that of side-position fertilization in 2017, and there was no significant difference between side-position fertilization and positive-position fertilization in 2018. In the case of the fertilization depth of 15 cm, the aboveground biomass accumulation of positive-position fertilization in 2017 was 11.22% higher than that of side-position fertilization, and the aboveground biomass accumulation of positive-position fertilization in 2018 was 15.53% higher than that of side-position fertilization.

In general, when the hole fertilization method was used, side-position fertilization was superior in terms of aboveground biomass accumulation. When the strip fertilization method was used, positive-position fertilization was superior in terms of aboveground biomass accumulation.

4. Discussion

This study aimed to find out the optimal fertilization mode for summer maize. The research showed that the nutrient utilization and yield of summer maize were closely related to fertilization methods. With the same amount of fertilizer applied per unit area, the concentration of fertilizer and the distance between roots and seeds significantly affected the nutrient utilization and yield of summer maize. In this study, among the eight different treatments, when the strip fertilization method was used, 15 cm deep positive-position fertilization was superior. When the hole fertilization method was used, 15 cm deep side-position fertilization was superior. It can also be concluded from this experiment that the current common side-position strip fertilization method is not the best fertilization method.

The results of many studies on fertilization methods are consistent with the conclusions of this study. A reasonable fertilization period and an appropriate fertilization location are the basis for improving crop yield, the quality of agricultural products, and fertilizer use efficiency. Incorrect fertilization methods lead to the deterioration of soil quality, the reduction in fertilizer utilization, the waste of resources, and environmental pollution [23]. Fertilizer application methods affect the migration and transformation of fertilizer nutrients in the soil and affect crop root growth and nutrient absorption and utilization, thereby impacting the growth and yield of summer maize [3]. Therefore, it is important to study intelligent fertilization methods and the growth characteristics of summer maize, according to the fertilizer requirements, to realize high yields. At present, the common fertilization method is to apply fertilizer on the side of the crop row. Different machines have different fertilization depths and distances. Blind fertilization cannot guarantee that the fertilizer is fully absorbed by the root system, and it also causes fertilizer waste [24,25].

The yield and nutrient uptake, and utilization of summer maize are closely related to the absorption of nutrients in the soil by roots. Roots can absorb sufficient nutrients for the growth of aboveground parts of plants and achieve high yields. The research shows that most of the roots of summer maize are distributed in the 0–40 cm soil layer, and the amount of deep roots increases with the growth of the plant [26]. Nutrient uptake by roots is related to the distribution of nutrients in the soil, so different fertilization positions and fertilization depths are closely related to nutrient uptake by roots. Studies have shown that crop yield is related to the temporal and spatial distribution of roots [27]. The change in phosphorus fertilizer application depth can change the distribution of maize roots in the soil. Different phosphorus application depths have obvious effects on the soil available phosphorus content, maize root length at different soil depths, nitrogen and phosphorus uptake in maize aboveground, and summer maize yield [28]. The deep application of nitrogen fertilizer can improve nitrogen use efficiency and crop yield. Applying nitrogen fertilizer to the soil can inhibit ammonia volatilization and improve its utilization rate. The results show that the ammonia volatilization rate of a 10 cm deep application of nitrogen fertilizer is far lower than that of surface application and a 5 cm deep application, and the ammonia volatilization rate of a 20 cm deep application is very low [29]. Deep fertilization of nitrogen fertilizer has a significant effect on maize growth and yield. The results of pot tracer tests showed that the fertilizer utilization rates of corn urea surface fertilization for deep fertilization at 5 cm, deep fertilization at 10 cm, and deep fertilization at 15 cm were 39.67%, 44.92%, 53.11%, and 52.65%, respectively [30]. The effects of the basal application depth of nitrogen fertilizer on the yield, nitrogen utilization, and nitrogen residue of summer maize in the North China Plain region were studied. The results showed that the yield of summer maize with a deep application in the ridge was higher than that with a side strip application, and the suitable basal application depth of urea for summer maize in this area was 8–16 cm [31]. In another experiment, it was demonstrated that different fertilizer spacings and fertilization depths had significant effects on the summer maize yield. In the Huang-Huai-Hai summer sowing area, when the horizontal distance of seed fertilizer was 10 cm, the appropriate fertilizer depth was 8–16 cm; when the horizontal distance was 15 cm, the appropriate fertilization depth was 8 cm [32]. In this experiment, under the same other conditions, the effect of most 15 cm deep fertilization treatments is significantly better than that of 10 cm deep treatment. These results show that reasonable mechanized fertilization methods and proper fertilization depth can achieve higher nutrient utilization and yield of summer maize.

This experiment is not sufficient, and further research is needed. In this experiment, strip fertilization and hole fertilization were used, but the total amount of fertilizer per unit area was the same; however, hole fertilization was more concentrated around the seeds than strip fertilization. Under the positive-position hole fertilization method, the plant growth was not very good. The possible reason is that the fertilizer concentration around the root system is too large, and a certain degree of seedling burning occurs. Therefore, from the test results, it can be seen that the depth of 15 cm using positive-position hole fertilization is better than 10 cm using positive-effect fertilization. Moreover, side-position hole fertilization is better than positive-position hole fertilization. Therefore, for the hole fertilization mode, the spacing between seeds and fertilizers should be appropriately large to be more conducive to plant growth. For the strip fertilization mode, because the fertilizer is more dispersed, fertilizer spacing should be appropriately small but not too small. In this experiment, when the positive-position strip fertilization method was used, a 15 cm depth was better than a 10 cm depth, and positive-position strip fertilization was superior to side-position strip fertilization. However, because the depth of fertilization in this experiment only included two gradients, the best fertilization depth was not found. Therefore, further research is needed to explore more fertilization depth gradients to determine the optimal fertilization depth so that the roots can absorb nutrients at the most suitable depth and the fertilizer can be fully absorbed and utilized by the roots.

Exploring the best fertilization method so that the roots can better absorb the nutrients in the soil, on the one hand, can promote the absorption of nutrients in the soil by the crop roots and, on the other, can improve the fertilizer utilization rate. Considering the influence of various factors on the high yield of maize and the high utilization rate of fertilizer, various fertilization methods were studied in order to reduce fertilizer input while achieving high yields of summer maize. In addition, in the study of new fertilization methods, the requirements of agricultural machinery operations should also be considered. Only fertilization methods that can be performed by agricultural machinery can be promoted and applied in production. The next research direction is to determine the best fertilization mode and amount, provide a reference for agricultural machinery design, and promote its application in agricultural production. It is of great significance to reduce the amount of fertilizer application while obtaining a high yield of summer maize.

5. Conclusions

Different fertilization modes had significant effects on summer maize yield, nitrogen, phosphorus, and potassium nutrient accumulation, and aboveground biomass. The results of this study showed that when the strip fertilization method was used, 15 cm deep positive-position fertilization was superior, and when the hole fertilization method was used, 15 cm deep side-position fertilization was superior. Furthermore, in this study, the level of factors is not enough. Further experimental research is recommended to determine the best fertilization method.

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