# Potentials of straw return and potassium supply on maize (*Zea mays* L.) photosynthesis, dry matter accumulation and yield

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# Abstract

Maize (*Zea mays* L.) is considered one of the most important grains in the world. Straw return and potassium fertilization can enhance the maize yield. Therefore, three field experiments were carried out in the three years (2018–2020) to study the effects of straw return at two methods and four levels of potassium fertilization on photosynthesis, dry matter accumulation and yield of the maize ‘Xianyu 335’. To conduct the field trials, a split plot system in five replications was established. Two straw return methods (straw return with deep tillage and straw mulching with no tillage) were in the main plots, and four potassium fertilization levels (0, 30, 45 and 60 kg/ha) were in the subplots. Each sub-plot consisted of 10 rows with 5 m length and 0.6 m width, and each sub-plot area was 30 $m^2$ in the three years. The results indicated that the straw return methods and the potassium supply significantly affected the maize photosynthesis, dry matter accumulation and yield in the three years. Under the same potassium supply, straw return with deep tillage significantly improved the maize photosynthesis, dry matter accumulation and yield compared to straw mulching with no tillage. The above characteristics improved with increased potassium supply. The treatment of SFK60 recorded the highest values for the parameters of maize photosynthesis, dry matter accumulation and yield during the three harvest seasons. The treatment of SFK45 reached maximum profit of maize planting, which was 12088.77 yuan/ha. Therefore, SFK45 was an effective way to ensure the stable and higher yields of maize and to maximize the income of farmers.


# Introduction

Maize is consumed as an important strategic material with multiple purposes such as grain, economy, feed and energy [1]. The maize yield is regulated not only by its own photosynthesis and dry matter accumulation [2, 3], but also by external cultivation measures and fertilizer supply [4–6]. Straw return is a green and sustainable agricultural cultivation technology. China produced the most crop residue in the world, approximately $8.4\times10^8$ t [7]. Rational use of straw resources is an important way to realize the sustainable development of agriculture [8]. Straw mulching with no tillage considers a traditional conservation measure for improving crop microclimate [9, 10]. Continuous straw mulching with no tillage is not conducive to changing soil plough bottom and even causes the problem of poor sowing quality [11, 12]. Straw return with deep tillage is one of the most important agricultural management measures to break soil plough bottom and improve sowing quality in order to increase maize photosynthesis and yield [13]. Fertilizer also plays an important role in the process of achieving stable and high maize yield, just like cultivation measures. Potassium fertilizer made an important contribution to ensure the steady increase of maize yield [14, 15]. Different potassium supply influenced the maize yield variously. Studies have shown that the high maize yield was mainly concentrated in the potassium supply of 40–80 kg/ha [16]. Yan [17] reported that the optimum potassium supply for high maize yield in medium fertility soil was 39.5 kg/ha. Zhao [18] considered that the interaction between straw return and potassium fertilizer was the best potassium fertilizer management mode to achieve high yield of maize. Therefore, the regulations of straw return methods and potassium supply will become an important cultivation and management measure for high maize yield.

In conclusion, previous studies have focused on the effects of straw return on maize photosynthesis and yield, and also on the analyses of potassium fertilizer on maize growth and yield. However, there was a lack of research on the cooperation of different straw return methods and potassium fertilization levels. Therefore, on the basis of previous studies, a three-year field experiments were conducted to determine the effects of straw return and potassium supply on maize photosynthesis, dry matter and yield in Tumochuan Plain irrigation area in Midwestern Inner Mongolia of China. The main objective of this study was to understand how different straw return methods and potassium fertilization levels could influence maize growth and yield. Specifically, we tested 1) how different straw return methods and potassium fertilization levels influenced maize photosynthesis, dry matter and yield? 2) what was the best treatment for obtaining a high yield? 3) what was the best method for maximizing the income of farmers? 4) whether the effects of the treatments varied among the three years? The information generated in this study will be helpful to select the best agricultural measure that can maintain a high yield and obtain the maximum profit.

# Materials And Methods

### *Site description.*

Three field experiments were carried out at the experimental base of Inner Mongolia Agricultural University (40°33' N, 110°31' E) located in the Midwestern Inner Mongolia of China during the seasons from 2018 to 2020. The three-year experiments were carried out in the same plot, and the test of straw return and potash fertilizer started in 2016. The surface soil fertility (0–20 cm) and the climatic conditions during the growth period of maize were shown in Table 1. The maize was seeded on April 25, 26 and 24, and was harvested on October 3, 5 and 2 in 2018, 2019 and 2020, respectively. Base fertilizer applied at the seeding included $P_2O_5$ at the rate of 105 kg/ha, and $K_2O$ of different application levels of 0, 30, 45 and 60 kg/ha. In addition, 300 kg/ha of N was top-dressed during the jointing stage. A series of cultivation and management measures such as irrigation and weeding were carried out according to the local high-yield cultivation [19].

**Table 1.** Soil fertility and climatic conditions.

| Year | Organic matter (g/kg) | Total N (g/kg) | Available N (mg/kg) | Available P (mg/kg) | Available K (mg/kg) | pH | Sunshine hour (h) | Average temperature (°C) | Average rainfall (mm) |
|---|---|---|---|---|---|---|---|---|---|
| 2018 | 25.53 | 1.1 | 92.35 | 9.8 | 117.37 | 7.6 | 1869.2 | 20.9 | 215.2 |
| 2019 | 25.96 | 1.1 | 93.65 | 9.7 | 120.95 | 7.6 | 1893.6 | 20.7 | 213.5 |
| 2020 | 26.29 | 1.1 | 91.28 | 10.2 | 124.53 | 7.6 | 1825.7 | 21.2 | 235.7 |

The field study was carried out on the official land which belonged to the key laboratory of crop cultivation and genetic improvement of Inner Mongolia Autonomous Region, permission was given after research application passing verification. During the field study none of endangered or protected species were involved. No specific permissions were required for conducting the field study because it was not carried out in protected area.

### *Experimental design.*

The test material was maize 'Xianyu 335'. A split plot design with five replications was used. The two straw return methods (straw return with deep tillage and straw mulching with no tillage) were assigned in the main plots, which were expressed by SF and FG. The four potassium fertilization levels (0, 30, 45 and 60 kg/ha) were allocated in the sub-plots, which were expressed by K0, K30, K45 and K60. CK was the control treatment which straw was not returned and without potash supply. The treatments of this experiment were as follows: SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60. Each sub-plot consisted of 10 rows with 5 m length and 0.6 m width, and each sub-plot area was 30 $m^2$ in the three years. The designated tillage practices were performed each autumn after the harvest of maize. The straw return with deep tillage (SF) crushed straws (less than 10 cm) and returned the straws into the field by subsoiling to a depth of 40 cm. The straw mulching with no tillage (FG) involved mechanically chopping straw into 3–5 cm long pieces and mulched on the soil surface.

Economic analysis of results were used to determine the variances between different factors to obtain the greatest profitability of straw return methods and potassium supply. The profit of maize planting was calculated according to the local market price of maize (1yaun/kg) and the harvest time of the production. The production costs included the expenses of different straw return methods, potassium supply, seeds, hoeing and watering, which were calculated in Renminbi (RMB) at the local market price (Table 2).

**Table 2.** Itemization of maize planting cost of different treatments during 2018 to 2020.

| Treatment | Straw return methods | Potassium fertilization levels | Cost (yuan/ha) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Straw return | Potash fertilizer | Seeds | Hoeing and watering | Total cost |
| CK | — | 0 | 0 | 0 | 950 | 750 | 1700 |
| SFK0 | SF | 0 | 750 | 0 | 950 | 750 | 2450 |
| SFK30 | SF | 30 | 750 | 120 | 950 | 750 | 2570 |
| SFK45 | SF | 45 | 750 | 180 | 950 | 750 | 2630 |
| SFK60 | SF | 60 | 750 | 240 | 950 | 750 | 2690 |
| FGK0 | FG | 0 | 450 | 0 | 950 | 750 | 2150 |
| FGK30 | FG | 30 | 450 | 120 | 950 | 750 | 2270 |
| FGK45 | FG | 45 | 450 | 180 | 950 | 750 | 2330 |
| FGK60 | FG | 60 | 450 | 240 | 950 | 750 | 2390 |

***Measurements.***

Photosynthetic parameters [20]. In the silking stage (R1), the net photosynthetic rate (Pn),stomatal conductance (Gs),transpiration rate (Tr),intercellular $CO_2$ concentration (Ci) of ear leaves from five healthy and uniform plants in each plot were measured by using a portable photosynthesis system (LI-6400XT, USA) . The measurements were conducted at 1500 μmol $CO_2$ $m^2$ $s^{-1}$ on clear days using an open system.

Dry matter accumulation [21, 22]. Maize plants were taken in each plot during R1 and R6 stage with five replicates. Maize plants were dried at 105 °C for 30 minutes, then dried at 80 °C to constant weight, and weighed the dry matter weight.

Yield and yield component [23, 24]. At the physiological maturity stage (R6), four rows in the middle of the measured production area were selected, and all plants in these rows were harvested after removal of the side plants. Ten plants with uniform ear growth were selected for determination of ear rows, row grains, 1000-grain weight, and grain water content (measured with an LDS-1G moisture content detector), then calculated the maize yield.

***Statistics analysis.***

Data SPSS window version 17 (SPSS Inc., Chicago, USA) was used to finishing statistical analysis and correlation analysis. Under straw return methods, potassium fertilization levels, and test years, we examined photosynthetic characteristics, dry matter accumulation and yield using GLM based on the model for a split-plot design [25, 26]. The values were all the F-values of the ANOVA. Straw return methods, potassium fertilization levels, and test years were the independent variables, and the photosynthetic characteristics, dry matter accumulation and yield were dependent variables in this test. In order to determine the impact of independent variables on dependent variables, statistically significant variance was tested using two-way analysis of variance, and multiple comparisons were made using the least significant difference (LSD) test with $\alpha = 0.05$ [27]. Histograms were conducted by using Sigma Plot 12.5. And different letters on histograms indicated that means statistically different at $P<0.05$ level.

# Results

***Significance tests of straw return methods, potassium fertilization levels and their interactions.***

Analysis of variance (ANOVA) results showed that straw return methods and potassium fertilization levels had significant effects on maize photosynthesis, dry matter and yield from 2018 to 2020 (Table 3). Significant interactions between straw return methods and potassium fertilization levels were only found on Pn of 2018 and 2020, and Tr of 2018-2020. Through the comparison of three-year F-values, it could be found that the effect of potassium fertilization levels on maize photosynthesis, dry matter and yield was greater than that of straw return methods.

**Table 3.** Significance of the effects of straw return methods, potassium fertilization levels and their interactions on maize growth and yield using ANOVA.

| Year | Source | Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$) | Gs ($mmol \cdot m^{-2} \cdot s^{-1}$) | Tr ($mmol \cdot m^{-2} \cdot s^{-1}$) | Ci ($\mu mol \cdot mol^{-1}$) | Dry matter in R1 (g/plant) | Dry matter in R6(g/plant) | Yield (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| 2018 | S | 31.2** | 24.28** | 76.15** | 6.6* | 9.24** | 11.01** | 2.21ns |
| | K | 51.14** | 67.78** | 195.24** | 10.74** | 20.21** | 34.07** | 7.71** |
| | S×K | 5.93** | 1.09ns | 9.13** | 0.34ns | 0.79ns | 0.24ns | 0.07ns |
| 2019 | S | 12.45** | 27.71** | 45.74** | 4.66* | 5.55* | 9.46** | 4.89* |
| | K | 14.49** | 114.66** | 115.35** | 14.14** | 13.76** | 28.22** | 14.59** |
| | S×K | 2.13ns | 0.53ns | 4.17* | 0.32ns | 0.54ns | 0.22ns | 0.24ns |
| 2020 | S | 27.55** | 22.23** | 38.02** | 6.91* | 6.48* | 13.93** | 6.29* |
| | K | 40.02** | 92.37** | 77.3** | 22.09** | 19.06** | 45.56** | 16.02** |
| | S×K | 4.03* | 0.17ns | 3.27* | 0.32ns | 1.23ns | 0.89ns | 0.26ns |

Note: Numbers were F-values. Stars indicated the level of significance (*= $p<0.05$, **= $p<0.01$), ns represented insignificant. S represented straw return methods, including SF and FG; K represented potassium fertilization levels, including K0, K30, K45, K60 kg/ha.

***Effects of straw return and potassium fertilizer on photosynthesis of maize.***

The straw return methods and potassium fertilization levels significantly influenced ($p \leq 0.05$) the maize photosynthesis compared to control (CK), resulting in Pn, Gs and Tr values that were higher than those of CK, and Ci value that was lower than that of CK. Straw return and potassium supply increased Pn, Gs and Tr. Compared with CK, under the treatments of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60, Pn in 2018 increased by 1.70, 2.65, 5.21, 7.31, 0.63, 2.50, 3.60, 3.97$\mu mol \cdot m^{-2} \cdot s^{-1}$; Pn in 2019 increased by 3.12, 4.55, 6.33, 8.85, 2.11, 4.07, 4.68, 5.13$\mu mol \cdot m^{-2} \cdot s^{-1}$; and Pn in 2020 increased by 4.09, 5.77, 8.48, 11.44, 3.20, 5.11, 5.79, 7.47 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Fig. 1a). Gs in 2018 increased by 0.06, 0.10, 0.18, 0.20, 0.02, 0.08, 0.13, 0.15 $mmol \cdot m^{-2} \cdot s^{-1}$; Gs in 2019 increased by 0.07, 0.11, 0.19, 0.22, 0.03, 0.08, 0.17, 0.17 $mmol \cdot m^{-2} \cdot s^{-1}$; and Gs in 2020 increased by 0.09, 0.13, 0.19, 0.21, 0.06, 0.09, 0.17, 0.19 $mmol \cdot m^{-2} \cdot s^{-1}$ (Fig. 1b). Tr in 2018 increased by 0.55, 1.02, 1.51, 1.74, 0.49, 0.86, 1.12, 1.27 $mmol \cdot m^{-2} \cdot s^{-1}$; Tr in 2019 increased by 0.71, 1.24, 1.61, 1.92, 0.61, 1.01, 1.34, 1.41 $mmol \cdot m^{-2} \cdot s^{-1}$; and Tr in 2020 increased by 0.87, 1.30, 1.67, 1.99, 0.71, 1.13, 1.38, 1.47 $mmol \cdot m^{-2} \cdot s^{-1}$ (Fig. 1c).

Straw return and potassium supply decreased Ci. Compared with CK, under the treatments of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60, Ci in 2018 decreased by 0.55, 1.02, 1.51, 1.74, 0.49, 0.86, 1.12, 1.27$\mu mol \cdot mol^{-1}$; Ci in 2019 decreased by 0.71, 1.24, 1.61, 1.92, 0.61, 1.01, 1.34, 1.41$\mu mol \cdot mol^{-1}$; and Ci in 2020 decreased by 0.87, 1.30, 1.67, 1.99, 0.71, 1.13, 1.38, 1.47$\mu mol \cdot mol^{-1}$ (Fig. 1d).

Comprehensive analysis showed that Pn, Gs, Tr increased and Ci decreased significantly after the treatment of SF under the same potassium supply. Under the same straw return method, Pn, Gs and Tr values increased significantly with the potassium fertilization levels, while Ci decreased. The effects of straw return and potassium fertilizer on maize photosynthesis increased gradually from year to year.

***Effects of straw return and potassium fertilizer on dry matter of maize.***

We can see from Fig 2, the straw return methods and potassium fertilization levels significantly influenced ($p \leq 0.05$) the maize dry matter accumulation compared to CK, resulting in the dry matter values that were higher than that of CK. Straw return and potassium supply increased dry matter accumulation. Compared with CK, under the treatments of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60, the dry matter of R1 and R6 stage increased by 17.63, 27.74, 48.28, 60.13, 12.64, 21.15, 35.04, 41.31 and 26.09, 53.74, 81.54, 97.59, 14.49, 40.46, 62.08, 75.73 g/plant in 2018; the dry matter increased by 21.97, 35.87, 52.97, 68.07, 18.73, 27.13, 41.47, 48.83 and 31.38, 64.48, 90.92, 108.03, 20.00, 46.45, 73.53, 83.20 g/plant in 2019; the dry matter increased by 30.73, 43.79, 67.20, 81.46, 29.99, 34.28, 57.57, 57.81 and 39.21, 70.29, 103.97, 122.08, 30.49, 53.17, 87.96, 91.36 g/plant in 2020.

In short, under the same straw return method, the increase of maize dry matter from R1 to R6 improved significantly with the potassium level, potassium fertilizer could improve the maize dry matter accumulation ability. The maize dry matter of R1 to R6 increased significantly after the treatment of SF compared to FG under the same potassium supply. The promotion effect of straw return and potassium fertilizer on maize dry matter increased from year to year.

### *Effects of straw return and potassium fertilizer on maize yield.*

The straw return methods and potassium fertilization levels significantly influenced ($p \leq 0.05$) the maize yield compared to CK, resulting in maize yield values that were higher than those of CK. Straw return and potassium supply increased maize yield. Compared to CK, under the treatments of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60, maize yield in 2018 increased by 9.73%, 15.74%, 24.02%, 24.46%, 5.84%, 13.51%, 18.64%, 21.19% (Fig. 3a); maize yield in 2019 increased by 9.79%, 15.68%, 25.44%, 25.47%, 5.79%, 13.67%, 18.86%, 21.29% (Fig. 3b); and maize yield in 2020 increased by 10.32%, 17.47%, 25.58%, 25.76%, 7.83%, 13.72%, 19.01%, 21.69% (Fig. 3c).

The maize yield among treatments was as follows: SFK60>SFK45>FGK60>FGK45> SFK30>FGK30>SFK0>FGK0>CK. Compared to FG, the effect of SF on maize yield was more obvious. The maize yield increased significantly with the potassium fertilization levels under the potassium fertilization levels of 0-60kg/ha in this test. The treatment of SFK60 recorded the highest average yield in the three-year test, which was 14744.39kg/ha. The maize yield in different planting years showed as follows: 2020>2019>2018, which indicated that the promotion effect of straw return and potassium fertilizer on maize yield increased from year to year.

### *Correlation analysis of photosynthesis, dry matter accumulation and yield of maize.*

Pn, Gs, Tr and Ci were significantly correlated with dry matter accumulation. Pn, Gs and Tr were positively correlated with dry matter, while Ci was negatively correlated with dry matter (Table 4). The results showed that the increase of Pn, Gs, Tr and the decrease of Ci could significantly improve maize dry matter. Dry matter was positively correlated with maize yield, indicating that the increase of dry matter accumulation could significantly improve maize yield. The increase of Pn, Gs, Tr and dry matter accumulation,as well as the decrease of Ci could significantly increase maize yield.

Under the method of SF, the correlation coefficients of Pn, Gs, Tr, dry matter at R1 stage, dry matter at R6 stage and Ci with yield were 0.862, 0.988, 0.962, 0.948, 0.971 and -0.978;the correlation coefficients were 0.838,0.975,0.970,0.930,0.979 and -0.973 under the method of FG. The results showed that, under the method of SF, the correlation coefficients between dry matter of R1 stage, Pn, Gs, Ci with yield were higher than that under the method of FG, which indicated that SF could promote the correlation between dry matter of R1 stage, Pn, Gs, Ci with yield. Under the method of FG, the correlation coefficients between dry matter of R6 stage, Tr with yield were higher than that under the method of SF, which indicated that FG could promote the correlation between dry matter of R6 stage, Tr with yield.

**Table 4**. Correlation analysis of photosynthesis, dry matter accumulation and yield of maize under two straw return methods.

| Method | Index | Pn (μmol·m-2·s-1) | Gs (mmol·m-2·s-1) | Tr (mmol·m-2·s-1) | Ci (μmol·mol-1) | Dry matter in R1(g/plant) | Dry matter in R6 (g/plant) | Yield (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| SF | Pn (μmol·m-2·s-1) | 1 | | | | | | |
| | Gs (mmol·m-2·s-1) | 0.900** | 1 | | | | | |
| | Tr (mmol·m-2·s-1) | 0.939** | 0.982** | 1 | | | | |
| | Ci (μmol·mol-1) | -0.933** | -0.995** | -0.989** | 1 | | | |
| | Dry matter in R1 (g/plant) | 0.965** | 0.971** | 0.978** | -0.981** | 1 | | |
| | Dry matter in R6 (g/plant) | 0.945** | 0.980** | 0.992** | -0.986** | 0.989** | 1 | |
| | Yield (kg/ha) | 0.862** | 0.988** | 0.962** | -0.978** | 0.948** | 0.971** | 1 |
| FG | Pn (μmol·m-2·s-1) | 1 | | | | | | |
| | Gs (mmol·m-2·s-1) | 0.873** | 1 | | | | | |
| | Tr (mmol·m-2·s-1) | 0.923** | 0.978** | 1 | | | | |
| | Ci (μmol·mol-1) | -0.912** | -0.970** | -0.986** | 1 | | | |
| | Dry matter in R1 (g/plant) | 0.881** | 0.971** | 0.948** | -0.948** | 1 | | |
| | Dry matter in R6 (g/plant) | 0.887** | 0.989** | 0.984** | -0.978** | 0.981** | 1 | |
| | Yield (kg/ha) | 0.838** | 0.975** | 0.970** | -0.973** | 0.930** | 0.979** | 1 |

***Effects of straw return and potassium fertilizer on the profit of maize planting.***

Gross income is an important economic index that determines the profit or benefit that a farmer can obtain. On the other hand, net return reflects the actual income of farmer. According to the average selling price of maize (1 yuan/kg) from 2018 to 2020, the net income of maize planting of different treatments was as follows: SFK45>SFK60>FGK60>FGK45>SFK30>FGK30>SFK0>FGK0>CK (Table 5). Compared to CK. the average net profit of maize planting in the three-year test increased by 421.26, 1049.07, 2014.82, 1980.44, 313.58, 1035.34, 1587.44, 1828.69 yuan/ha between the treatments of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60. Straw return and potassium supply increased the net profit of maize planting. The net profit of maize planting increased significantly after SF compared to FG under the same potassium supply. The treatment of SFK45 reached maximum profit of maize planting, which was 2014.82 yuan/ha.

**Table 5.** Effects of straw return methods and potassium fertilization levels on the profit of maize planting.

| Treatment | Expenditure（yuan/ha） | | | Total expenditure（yuan/ha） | Yield (kg/ha) | Gross income（yuan/ha） | Net profit（yuan/ha） |
|---|---|---|---|---|---|---|---|
| | Straw returning | Potash fertilizer | Other | | | | |
| CK | 0 | 0 | 1700 | 1700 | 11773.95 | 11773.95 | 10073.95 |
| SFK0 | 750 | 0 | 1700 | 2450 | 12945.21 | 12945.21 | 10495.21 |
| SFK30 | 750 | 120 | 1700 | 2570 | 13693.02 | 13693.02 | 11123.02 |
| SFK45 | 750 | 180 | 1700 | 2630 | 14718.77 | 14718.77 | 12088.77 |
| SFK60 | 750 | 240 | 1700 | 2690 | 14744.39 | 14744.39 | 12054.39 |
| FGK0 | 450 | 0 | 1700 | 2150 | 12537.53 | 12537.53 | 10387.53 |
| FGK30 | 450 | 120 | 1700 | 2270 | 13379.29 | 13379.29 | 11109.29 |
| FGK45 | 450 | 180 | 1700 | 2330 | 13991.39 | 13991.39 | 11661.39 |
| FGK60 | 450 | 240 | 1700 | 2390 | 14292.64 | 14292.64 | 11902.64 |

## Discussion

Photosynthesis is the physiological basis for crop growth and yield formation [28]. Higher yield and biomass can be obtained by maintaining higher leaf physiological activity and improving photosynthetic efficiency [29-31]. The photosynthesis of maize was mainly controlled by the cultivation measures and fertilizer [32, 33]. Studies have found that straw return can improve the photosynthetic capacity of maize, and the effect of SF was better [34, 35]. Xia [36] showed that potassium fertilizer can promote the maize photosynthetic characteristics and achieve the purpose of improving maize yield by the increase of Pn, Gs, Tr and the decrease of Ci. In the research presented here, compared with CK, Pn of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60 treatments increased by 1.70-4.09, 2.65-5.77, 5.21-8.48, 7.31-11.44, 0.63-3.20, 2.50-5.11, 3.60-5.79, 3.97-7.47$\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively. The photosynthesis increased after the treatment of SF under the same potassium supply. The photosynthesis increased significantly with the potassium fertilization levels under the same straw return method.

Dry matter accumulation is the key to yield formation of maize [37]. Studies have shown that straw return promoted dry matter accumulation of maize, and different straw return methods had different effects on dry matter and yield [38-40]. Potassium is one of the essential nutrients for maize growth, which plays an important role in promoting the accumulation of dry matter [41]. Du [42] showed that potassium deficiency affected the dry matter accumulation of maize. Han [43] found that there was a significant positive correlation between maize dry matter and yield. In a certain range of potassium fertilizer application, dry matter accumulation and yield of maize improved with the increase of potassium fertilizer application. In this study, compared with CK, dry matter in R1 stage of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60 treatments increased by 17.63-30.73, 27.74-43.79, 48.28-67.20, 60.13-81.46, 12.64-29.99, 21.15-34.28, 35.04-57.57, 41.31-57.81 g/plant, respectively. Compared with CK, dry matter in R6 stage of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60 treatments increased by 26.09-39.21, 53.74-70.29, 81.54-103.97, 97.59-122.08, 14.49-30.49, 40.46-53.17, 62.08-87.96, 75.73-91.36 g/plant, respectively. The results showed that SF promoted the dry matter accumulation of maize at R1 and R6 stage. The improving effect of dry matter improved significantly with the increase of potassium fertilization levels.

Sun [44] showed that straw return can significantly increase maize yield through continuous years of straw return experiment. Some studies have found that the potassium fertilizer can increase the yield and income of maize [45, 46]. In this paper, compared with CK, yield of SFK0, SFK30, SFK45, SFK60, FGK0, FGK30, FGK45 and FGK60 treatments increased by 9.73%-10.32%, 15.74%-17.47%, 24.02%-25.58%, 24.46%-25.76%, 5.84%-7.83%, 13.51%-13.72%, 18.64%-19.01% and 21.19%-21.69, respectively. The yield of different treatments was as follows: SFK60>SFK45>FGK60>FGK45>SFK30>FGK30>SFK0>FGK0>CK. The yield increased significantly after the treatment of SF under the same potassium supply. The yield improved with the increase of potassium fertilization levels (0-60kg/ha) under the same straw return method.

In conclusion, this experiment focused on the effects of straw return methods and potassium fertilization levels on photosynthesis, dry matter and yield of maize in 2018-2020. The results showed that the response of photosynthesis, dry matter and yield of maize to straw return methods and potassium supply were significantly different, and the effect of potassium supply was more significant. The promotion effect of straw return and potassium fertilizer on the above indexes increased from year to year. The maize photosynthesis, dry matter accumulation and yield among different treatments were as follows: SFK60>SFK45>FGK60>FGK45>SFK30>FGK30>SFK0>FGK0>CK. The effect of SF was greater than FG. The values of the above indexes were positively correlated with potassium supply. Considering the income and expenditure of maize planting, the treatment of SFK45 reached maximum profit of maize planting. The maximum profit of maize was 12088.77 yuan/ha, which was 2014.82 yuan more than that of CK.

## Conclusion

On average, the maize photosynthesis, dry matter accumulation, yield and net profit of maize planting were significantly increased by straw return and potassium supply. The promotion effect of straw return and potassium fertilizer on the above indexes increased from year to year. In this experiment, SFK60 was selected as the most effective treatment to improve the maize photosynthesis, dry matter accumulation and yield. However, considering the income and expenditure of maize planting, this test analyzed the cost difference of different straw return methods and potassium fertilization levels in maize planting, the treatment of SFK45 reached the maximum profit of maize planting, which was 12088.77 yuan/ha. The photosynthesis, dry matter accumulation and yield of SFK45 treatment were only a little smaller than SFK60. Therefore, SFK45 was an effective way to ensure the stable and higher yields of maize and to maximize the income of farmers.

## Declarations

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Writing – review & editing: Julin Gao, Jiying Sun.

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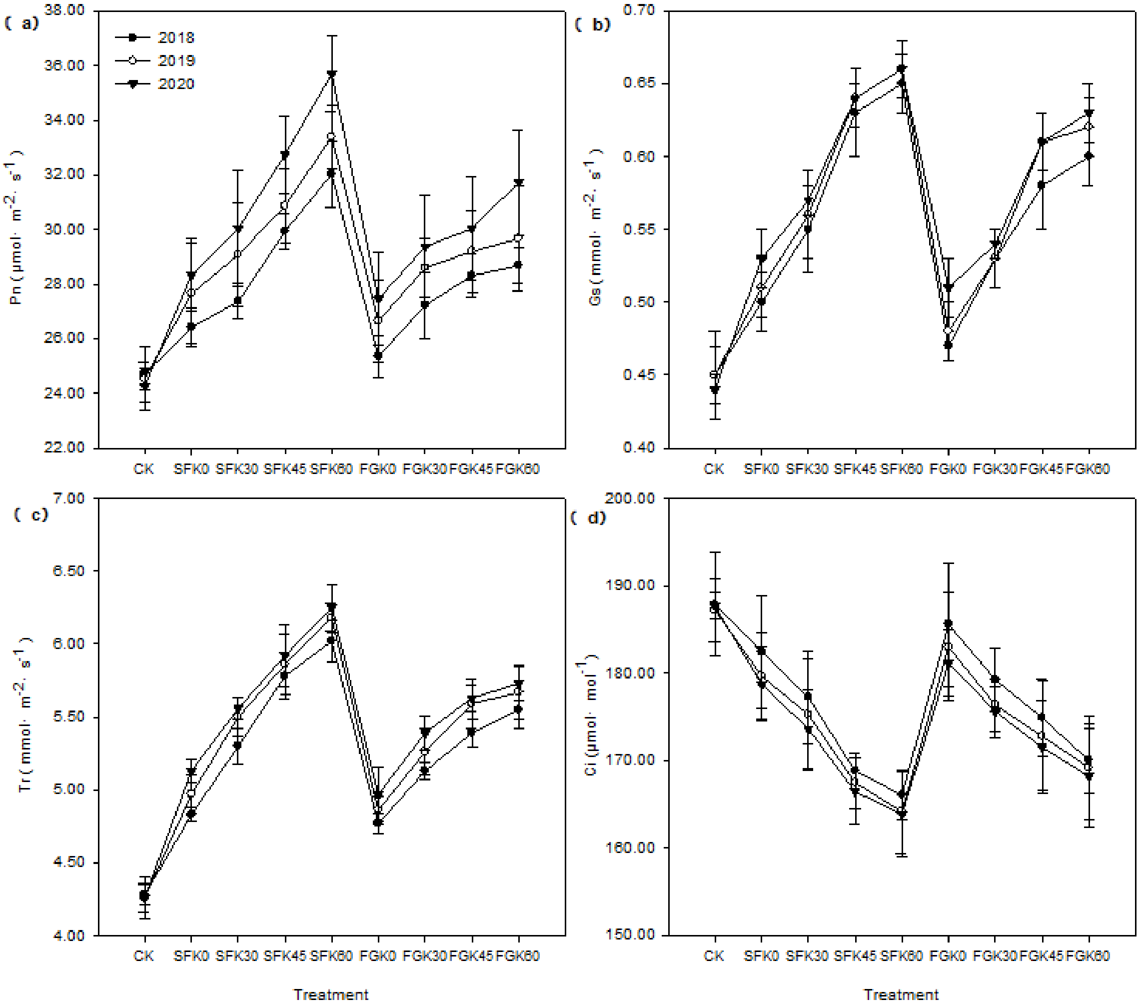
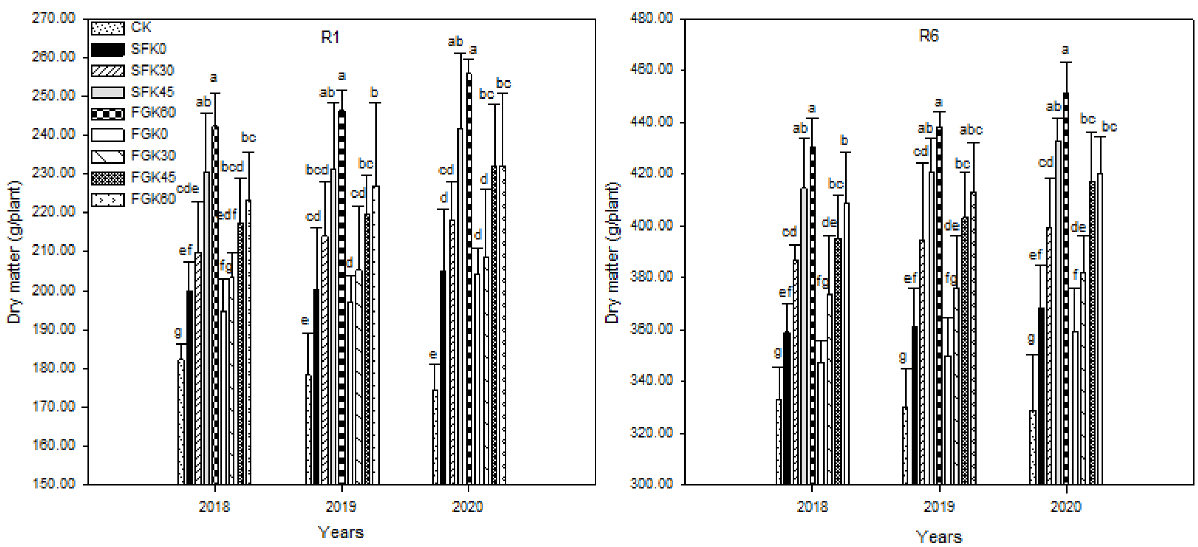
## Figures



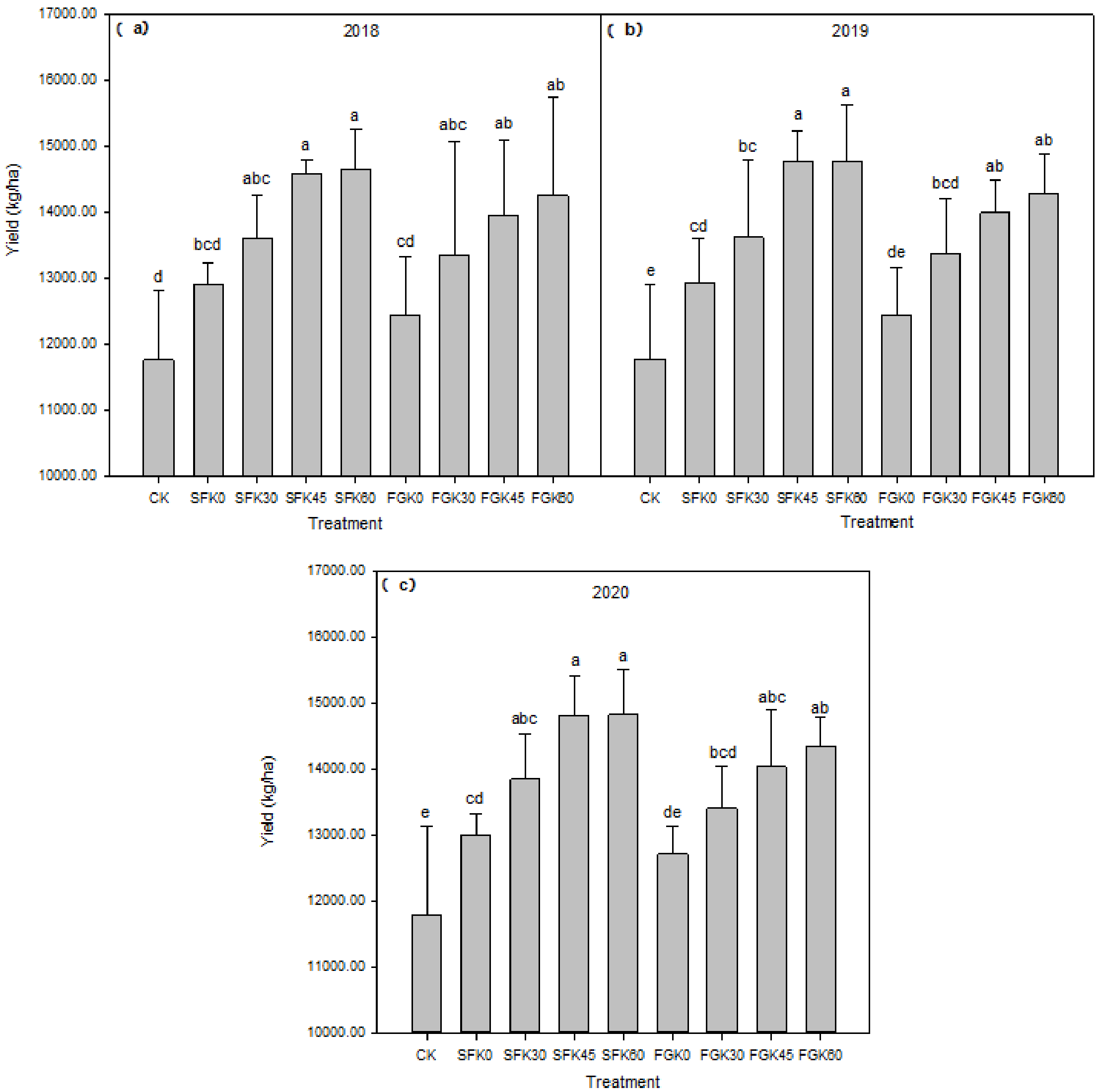

## Figure 1

Effects of straw return methods and potassium fertilization levels on maize photosynthesis.




## Figure 2

Effects of straw return methods and potassium fertilization levels on maize dry matter. Note: Values followed by different letters in the same year indicated indicate statistical significance at α = 0.05 under different treatments. The same below.




## Figure 3

Effects of straw return methods and potassium fertilization levels on maize yield.