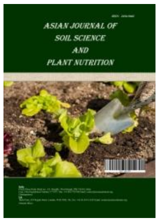

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# The Effect of Si Fertilizer and Si Fertilizer with Straw Return on Soil K Availability and Grain Yield on Spring Maize (*Zea mays* L) in Northeast China

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author MFS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors YG and MZ managed the analyses of the study. Author MFS managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** To investigate the effect of silicon (Si) fertilizer and Si fertilizer with straw return in potassium (K) and maize grain yield.
**Methods:** In 2018 and 2019, two field experiments were established in Nong'an county, Jilin province. Four treatments were arranged in a randomized block design: JS3 (straw return + Si), WS3 (no straw return + Si), JS0 (straw return + no Si) and WS0 (no straw return + no Si).
**Results:** In comparison with WS3, the average soil available K for WS0 was 22.1% lower. Similarly, compared with JS3, the average soil available K for WS3 was even decreased by 3.1%. The plots amended with Si fertilizer (15.9% WS3) significantly increased K uptake than that of WS0, and the total uptake of K under JS3 increased by 7.5% compared with that under WS3. The total dry matter and grain yield were significantly higher under WS3, which increased by 6.5% and 4.8% respectively, and JS3 significantly outperformed WS3 by 2.9% and 1.3% for total dry matter and grain yield.
**Conclusions:** Our results indicate that the application of Si fertilizer improves K availability, uptake and crop yield, and the use of Si fertilizer with straw return sustainably improves K release to meet crop requirements while increasing crop productivity.

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*Keywords: Crop straw; Si-based fertilizer; spring maize; K utilization; grain yield.*

## 1. INTRODUCTION

Potassium (K) is one of the essential nutrients for crop production, which constitutes up to ten percent of dry plant mass. K plays critical physiological processes such as enzyme activity, homeostasis, osmoregulation, protein metabolism and membrane polarization [1]. Furthermore, the essential plant processes such as photosynthesis, growth and photorespiration largely depend on the concentration of K. Farmers have adopted the practice of applying excessive fertilizer to achieve more yield. Improper chemical fertilization can pose severe problems, including water pollution, soil pollution, and air pollution [2]. Intensive long time use of chemical fertilizer may lead to change is soil fertility and soil nutrient imbalance [3].

Silicon (Si) is the most abundant element on the earth's surface, which has proved to have many beneficial effects on crops [4]. In 2006, the French researcher Desplanques et al. [5] revealed that the biogenic silica is significantly applied to the soil contributing to 1-3% of the whole Si in the earth. Greger et al. [6] studied the influences of Si on soil nutrient availability, in the study, they found that Si-maintained increased availability of nutrients in the soil solution which payback for the depletion in tissue concentration of those nutrient elements. They also figured out that Si also improves the uptake of nutrients in non-stressed crops. The possible reasons why Si increases the amount of some elements could be that Si helps the binding of them in plant tissues. Previous research has discovered that Si can stimulate various plants to take up more macronutrients and micronutrients (K, Ca, P, S, Mn, Zn, Cu, Cl, Fe) from the soil [7]. Crop straw return to the field after harvest is positively encouraged in China to decrease the environmental pollution that comes out from straw burning [8]. Straw return is a best management practice for tackling and helping soil nutrient conservation and improving crop yield; it also decreases soil degradation, improving soil physical characteristics, and enhancing soil fertility indices [9]. However, unsuitable methods of the straw application might depreciate soil quality and unbalance nutrients distribution [10]. Organic manure contains essential macronutrients nitrogen, phosphorus, potassium, and micronutrients such as calcium, magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron, and molybdenum [11]. Several field experiments have confirmed that combining crop straw return and chemical fertilizer can help to attain the optimum crop grain yield similar to inorganic fertilizer alone [12,13]. In the experiment conducted in Pakistan, the effects of inorganic and organic manures of soil physical and chemical properties. The plots received fertilizers alongside organic manure revealed that the growth and yield of maize crops were significantly improved. The K content was enhanced. They concluded that the integration of organic fertilizers with organic manure could be used with a reduced rate to improve crop productivity sustainably [14].

Many studies have focused on the effect of straw incorporation and Si fertilizer separately on the availability of K, uptake, dry matter, and grain yield. There are few reported cases on the use of combined Si fertilizer and straw return on K availability, dry matter, and grain yield. The use of combined Si with the straw return will, even more, increase soil availability of K, dry matter, and grain yield. Hence an experiment was conducted to investigate the effects of Si fertilizer under the straw condition on soil K, K uptake, total dry matter and grain yield.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Area

The field study was carried out at Dong Fang Hong village (124°31'E, 43°55'), Nong'an County, Changchun city, Jilin Province, in the 2018 and 2019 farming seasons. It is located in the Platteland of Songliao Plain, with a plane landscape having four different seasons with a mean yearly temperature of 4.7°C, a frost-free period of 145 days and average precipitation of 507.7 mm per annum. The experimental area is the spring maize continuous cropping area, and the tested soil was Chernozem soil (Soil classification is based on the Canadian system of soil classification). The fundamental physical and chemical parameters were measured before the experiment commenced at a soil depth 0-20 cm in 2018 and 2019, respectively, of the studied soil, were shown in Table 1. The elemental composition of straws was 8.7 g $kg^{-1}$ of N, 1.7 g $kg^{-1}$ of K, 9.0 g $kg^{-1}$ of K, and 6.2 g $kg^{-1}$ of Si.

## 2.2 Experimental Design

The trials had a two-way factorial design in which 12000 kg ha$^{-1}$ (J) of straw was returned to the field in one part, and the other part had no straw returned to the field (W). The Si treatments included the S0 treatment (0 kg ha$^{-1}$, no Si fertilizer) and the S3 treatment (45 kg ha$^{-1}$ of Si fertilizer). There were four treatments: WS0 (no Si fertilizer + no straw), WS3 (Si fertilizer + no straw), JS0 (no Si fertilizer + straw) and JS3 (Si fertilizer + straw). The treatments were arranged in a randomized block design (RBD) with four replications.

Sodium silicate ($Na_2SiO_3$) was applied as Si fertilizer. The area of each plot was 35 m$^2$. The maize variety Fumin 985 (produced by Jilin Fumin Seed Leaf Co., Ltd) was planted on May 7, 2018, and May 10, 2019, and then harvested on September 28, 2018, and October 2, 2019, respectively. The planting density was 65000 plants ha$^{-1}$. Macronutrients (N, P, and K) were used in all experimental plots. The rate of N application was 240 kg ha$^{-1}$ in each treatment, in which the base fertilizer accounted for 40% of the total N application rate, the topdressing fertilizer at the jointing stage accounted for 30% of the total N application rate, and the topdressing fertilizer accounted for 30% of the total N application rate. All plots were treated with P pentoxide ($P_2O_5$, 100 kg ha$^{-1}$) and K oxide ($K_2O$, 100 kg ha$^{-1}$), which were applied once as the base fertilizers. The remainder of the management was based on the local standard of field production.

## 2.3 Soil and Plant Sample Collection and Soil Analyses

Both soil and plant samples from each plot were collected during the experiment at the V6 (six leaves), V12 (twelve leaves), VT (tasselling), R2 (blister aging), R3 (milking) and R6 (maturity) stages (40, 59, 68, 94,110 and 130 days after emergence in 2018 and 55, 64, 73, 94,113 and 130 days after emergence in 2019, respectively). From each plot, soil samples were collected from a depth of 0–20 cm with a soil auger at three randomly selected points and were mixed entirely to prepare a uniform soil sample. After air-dried, the soil samples were crushed with a mortar and pestle and passed through a 2-mm sieve for analysis of the soil chemical properties. The plant-available K was determined using the flame photometry method.

## 2.4 Plant Tissue Nutrient Analysis

Three samples of fresh plants of uniform growth size were collected from each plot. Plant samples were divided into two components (stem and leaf) for V6 and V12 stages and four parts: stem (including the stem, leaf sheath, and bract leaf), leaf (excluding the leaf sheath, bounded by the leaf ring), cob, and grain for VT, R2, and R3 stages. Plant samples were heated at a constant temperature in a blast oven at 105 °C for 30 min and dried to a uniform weight at 80 °C. Each plant piece was weighed to obtain its dry weight (DW). The total K content of the different plant organs was extracted by the flame photometry method. The K uptake (kg$^{-1}$) in the plant segments was computed by multiplying the segment K concentration (%) by the dry matter fraction (DM) (t ha$^{-1}$).

## 2.5 Grain Yield and Straw Yield Components

At maize maturity, the yield was measured in each experimental plot with a representative area of 10 m$^2$, and ten ears were selected according to the weight mean method to measure the grain number per ear and the 1000-grain weight. The economic yield was calculated by the air-dry weight (14% water content) of 10 grains in each plot. The total dry matter was computed based on the fresh straw yield in the two sampled rows and the proportional oven-dried yield in the 3-plant subsample. The total dry matter was computed by multiplying the DM (t ha$^{-1}$) by the plant population.

## 2.6 Statistical Data Analysis

Soil available K (mg kg$^{-1}$), total K uptake (kg hm$^{-1}$), REK (%), AEK (Kg kg$^{-1}$), PFPK (Kg ha$^{-1}$), total straw yield (kg ha$^{-1}$) and the grain yield (kg ha$^{-1}$) were analyzed using SPSS Statistics 25.0 (SPSS, Inc., Chicago, IL, USA). The means differences were compared by Duncan's test at the 0.05 significance level. Figures and the means and standard errors (S.E) were created in Origin.

**Table 1. Fundamental characteristics of studied soils before planting of maize**

| Site | Years | Organic matter mg.kg-1 | Alkaline nitrogen mg.kg-1 | Available phosphorus mg.kg-1 | Available potassium mg.kg-1 | Available silicon mg.kg-1 | Soil pH |
|---|---|---|---|---|---|---|---|
| Nong'an | 2018 | 27.9 | 107.3 | 50.7 | 163.5 | 350.1 | 8.0 |
| | 2019 | 25.0 | 109.2 | 33.9 | 114.1 | 357 | 7.7 |

## 3. RESULTS AND DISCUSSION

### 3.1 Dynamic Change of Available Potassium (K) During Maize Growth

As shown in Fig. 1, the Si fertilizer application significantly increased soil available K. Averaged over two years, the WS3 treatment accounted for 22.1% less than did the WS0 treatment at the maturity period. The addition of Si fertilizer attributed to an increased concentration of K+ in the soil solution, which led one to high plant uptake of K [15]. Our results were in line with that of [16], who demonstrated that in two experimental years, Si application significantly increased available K, which is consequently enhanced yield. These findings are essential at adding insights into the integration of micronutrients-based fertilizer, especially Si, for increased crop productivity.

Our current study specified that the use of straw in our experiment improved the soil availability of K. The JS3 treatment at maturity R6 stage contained 3.1% available K lower than did the WS0 treatment averaged over two years (Fig. 1). This is because the more K comes from the mineralization of organic matter delivered from the crop residues [17]. Our results are in good agreement with Zhao et al. [18], who showed that straw return increased available K in the top of the 30cm soil layer. These findings are valuable at adding knowledge on the integration of crop straw and chemical-based fertilizer for sustainable agriculture.

### 3.2 Effect of Straw Returning with Si Fertilizer on K Accumulation in Spring Maize

In the present study, averaged over two growing seasons, the total K uptake in the whole plant was higher (15.9%) in Si treated (WS3) treatments than in non-Si treated (WS0) individuals at the R2 stage (Fig. 2). Accumulation of more K in the crop was associated with the influences of Si in the physiological process of the plant [19]. This finding is consistent with Pati et al. [16], who reported that Si fertilizer at 600kg $ha^{-1}$ improved K uptake in the rice crop. Hence, Si fertilizer application should have contributed to the plant to accumulate more K during the whole maize growth.

In the present research, the addition of straw in Si fertilizer improved the total K uptake in the plants, as we hypothesized. The plants registered under JS3 plots showed to take up 7.5% over the average higher compared to those under WS3 treatment (Fig. 2). This is due to that straw materials contribute to the release of K and

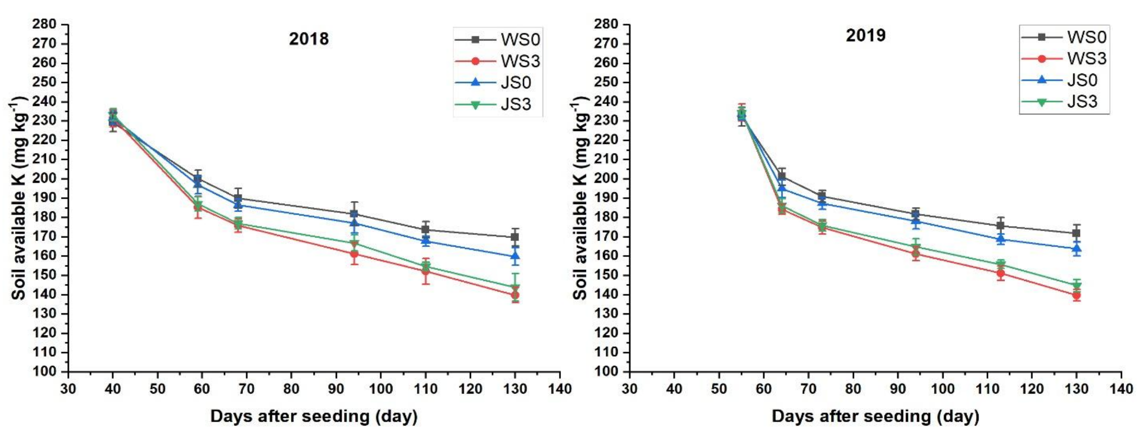


**Fig. 1. Changes in soil available K across different plant growth stages. Vertical bars show the standard error based on three replicates**

other plant nutrients [20]. Similar increases of K absorption in the crop as the result of straw incorporation were also observed by Bai et al. [21]. Therefore, straw return with Si fertilizer can be used as an alternative practice to improve K uptake in crops.

### 3.3 The Effect of Si Fertilizer and Straw on Dry Matter Accumulation in Spring Maize

The results present in Table 1 illustrate that the maize grain significantly influenced by Si application. The substantially higher grain (11685 kg $ha^{-1}$) and 11657 kg ha-1) in 2018 and 2019, respectively yields per plot were recorded due to basal application of 45kg $ha^{-1}$ of $Na_2SiO_3$, while the lower grain (11196 kg $ha^{-1}$) and 11052 kg $ha^{-1}$) per plot were registered under the conventional practice plot (Table 2). Furthermore, Si fertilizer significantly affected the total dry matter accumulation. The treatment WS3 gave a 6.5% higher dry matter over the control (WS0) (Fig.3). The increase in maize yield and straw might be due to improvements in fertilizer efficiency [22]. The lower return in the control treatment (WS0) relative to Si treated plots, was probably due to less Si and N interactions, which resulted in inadequate N for the crop to produce a higher yield. A similar observation was reported by Xu et al. [23], who found that the application of Si improved maize grain yield and dry matter accumulation. These findings could contribute to the further understanding Si fertilizer enhances dry matter production and grain yield.

The findings from this experiment demonstrate that the addition of Si fertilizer and straw increases grain yield and dry matter of maize in two years of study. The significantly higher grain (11881 kg $ha^{-1}$) and 11777 kg $ha^{-1}$) in 2018 and 2019, respectively yields per plot were recorded due to addition of organic matter by straw

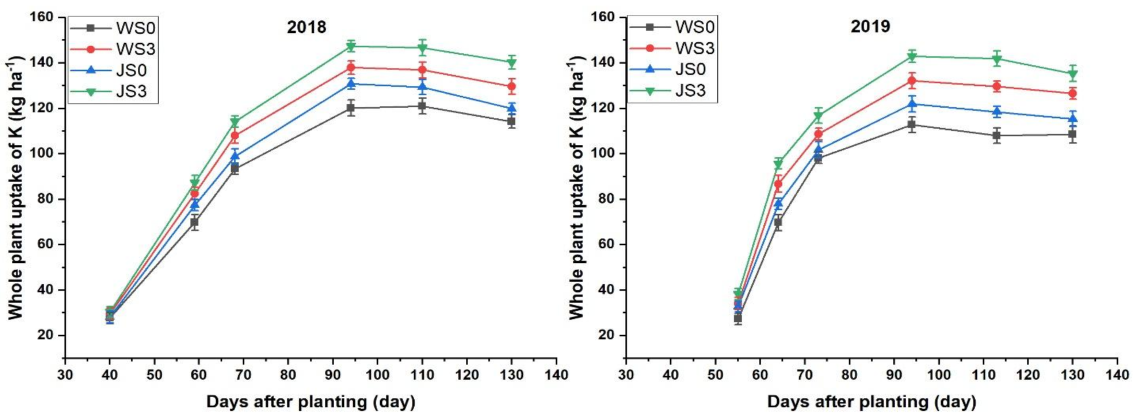


**Fig. 2. The response of maize total plant K uptake for two years, 2018 and 2019. Each data point is the mean ± S.E. of three replications**

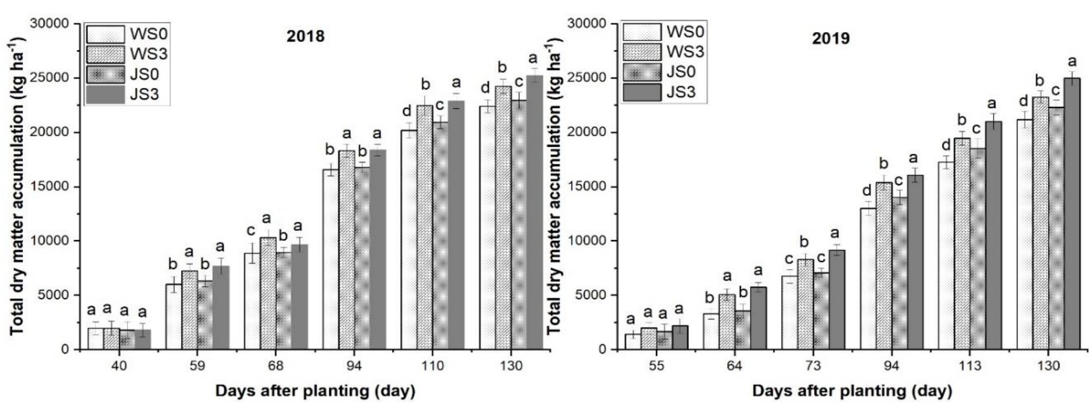


**Fig. 3. The seasonal total dry matter accumulation of plant evaluated for two years, 2018 and 2019. Bars with different lowercase letters indicate significant differences at *P* < 0.05**

**Table 2. Showing variance analysis of grain number (per$^{ear}$), 1000-grain weight (g) and yield (kg ha$^{-1}$), of maize in two consecutive years of 2018-2019**

| Year | Treatment | Grain Number (per Ear) | 1000-Grain Weight (g) | Yield (kg ha$^{-1}$) |
|---|---|---|---|---|
| 2018 | WS0 | 597±4b | 300±11c | 11196±359c |
| | WS3 | 597±14b | 330±7a | 11685±221a |
| | JS0 | 635±5c | 314±2b | 11345±11b |
| | JS3 | 693±33a | 330±4a | 11881±107a |
| 2019 | WS0 | 329±6b | 527±3c | 11052±155c |
| | WS3 | 336±4ab | 550±8a | 11657±30a |
| | JS0 | 333±21ab | 542±62b | 11067±24b |
| | JS3 | 346±4a | 556±2a | 11777±134a |

application [24] under the JS3 treatment, while the lower grain (11685 kg ha$^{-1}$) and 11657 kg ha$^{-1}$) per plot were recorded under without straw treatment (Table 2). The treatment JS3 gave a 2.9% higher dry matter over the WS3 treatment (Fig. 3). The increases in grain yield and dry matter was probably due to improved organic matter and nutrients such as N.P.K and others [25]. Our findings agree with Zhang et al. [26], who have found that straw incorporation increased grain yield and biomass yield. Therefore, the straw application should be considered an essential practice in maize farming for improving yield and promoting sustainable soil systems.

## 4. CONCLUSION

The central objectives of this research were to explore the effect of Si fertilizer and Si fertilizer with straw return on K soil availability, total plant uptake, total dry matter uptake, and grain yield in spring maize. The benefit of Si fertilization and Si fertilizer with straw return on soil available K, uptake, dry matter, and grain yield were systematically analyzed. The results showed that Si fertilizer positively influences K availability, dry matter, and grain yield. Si fertilizer with straw practice was the most important since it involved straw fraction to maintaining relatively high crop yield and attaining remarkably high K utilization. Therefore, combined Si fertilizer with straw return can be regarded as an optimal K management practice to achieve reasonable maize yield in northeast China sustainably.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Shin R. Strategies for improving potassium use efficiency in plants. Molecules and Cells. 2014;37:575.
2. Savci S. An agricultural pollutant: Chemical fertilizer. International Journal of Environmental Science and Development. 2012;3:73.
3. Benbi D, Biswas C. Nutrient budgeting for phosphorus and potassium in a long-term fertilizer trial. Nutrient Cycling in Agroecosystems.1999;54:125-132.
4. Deshmukh RK, Ma JF. Bélanger RR. Role of silicon in plants. Frontiers in Plant Science. 2017;8:1858.
5. Desplanques V, Cary L, Mouret JC, Trolard F, Bourrié G, Grauby O, Meunier JD. Silicon transfers in a rice field in Camargue (France). Journal of Geochemical Exploration. 2006;88:190-193.
6. Greger M, Landberg T, Vaculík M. Silicon influences soil availability and accumulation of mineral nutrients in various plant species. Plants. 2018;7:41.
7. Owino-Gerroh C, Gascho G. Effect of silicon on low pH soil phosphorus sorption and uptake and growth of maize. Communications in Soil Science and Plant Analysis. 2005;35:2369-2378.
8. Mehmood K, Chang S, Yu S, Wang L, Li P, Li Z, Liu W, Rosenfeld D, Seinfeld JH. Spatial and temporal distributions of air pollutant emissions from open crop straw and biomass burnings in China from 2002 to 2016. Environmental chemistry letters. 2018;16:301-309.
9. Jin C, Zheng MJ, Pang DW, Yin YP, Han MM, Li YX, Luo YI, Xu X, Yong L, Wang ZI. Straw return and appropriate tillage method improve grain yield and nitrogen efficiency of winter wheat. Journal of Integrative Agriculture. 2017;16:1708-1719.
10. Pang D, Chen J, Tang Y, Yin Y, Yang D, Cui Z, Zheng M, Li Y, Wang Z. Effect of returning methods of maize straw and N treatments on soil physicochemical

property and yield of winter wheat. Acta Agronomic Sinica. 2016;42:1689-1699.
11. Ahmad M, El-Saeid MH, Akram MA, Ahmad H, Haroon H, Hussain A. Use of organic fertilizers to enhance soil fertility, plant growth and yield in a tropical environment. Organic Fertilizers-From Basic Concepts to Applied Outcomes. 2016;85-108.
12. Wang Y, Zhu Y, Zhang S, Wang Y. What could promote farmers to replace chemical fertilizers with organic fertilizers. Journal of cleaner production. 2018;199:882-890.
13. Zhao J, Ni T, Li J, Lu Q, Fang Z, Huang Q, Zhang R, Li R, Shen B, Shen Q. Effects of organic-inorganic compound fertilizer with reduced chemical fertilizer application on crop yields, soil biological activity, and bacterial community structure in a rice-wheat cropping system. Applied Soil Ecology. 2016;99:1-12.
14. Mahmood F, Khan I, Ashraf U, Shahzad T, Hussain S, Shahid M, Abid M, Ullah S. Effects of organic and inorganic manures on maize and their residual impact on soil Physico-chemical properties. Journal of Soil Science and Plant Nutrition. 2017;17:22-32.
15. Ahmad AA, Radovich TJ, Nguyen HV, Uyeda J, Arakaki A, Cadby J, Paull R, Sugano J, Teves G. Silicon fertilization–A tool to boost up drought tolerance in wheat (*Triticum aestivum* L.) crop for better yield. Journal of Plant Nutrition. 2016;39:1283-1291.
16. Pati S, Pal B, Badole S, Hazra GC, Mandal B. Effect of silicon fertilization on growth, yield and nutrient uptake of rice. Communications in Soil Science and Plant Analysis. 2016;47(3):284-290.
17. Wei T, Zhang P, Wang K, Ding R, Yang B, Nie J, Jia Z, Han Q. Effects of wheat straw incorporation on the availability of soil nutrients and enzyme activities in semiarid areas. PLoS One. 2015;10:4.
18. Zhao S, He P, Qiu S, Jia L, Liu M, Jin J, Johnston AM. Long-term effects of potassium fertilization and straw return on soil potassium levels and crop yields in north-central China. Field Crops Research. 2014;169:116-122.
19. Dantas Júnior EE, Chaves LHG, Costa FA Md, Gheyi HR. Silicate fertilizer and irrigation depth in corn production. Revista Ceres. 2013;60:563-568.
20. Tan D. Jin J. Huang S. Liu Z. Jiang L. Effect of long-term potassium application on irrigated soil potassium and the yield and nutrient of crops. Zhongguo Shengtai Nongye Xuebao/Chinese Journal of Eco-Agriculture. 2009;17:625-629.
21. Bai YL, Lei W, Lu YL, Yang LP, Zhou LP, Lu N, Cheng MF. Effects of long-term full straw return on yield and potassium response in wheat-maize rotation. Journal of Integrative Agriculture. 2015;14:2467-2476.
22. Qingfeng M, Shanchao Y, Peng H, Zhenling C, Xinping C. Improving yield, and nitrogen use efficiency simultaneously for maize and wheat in China: A review. Pedosphere. 2016;26:137-147.
23. Xu H, Lu Y, Xie Z. Effects of silicon on maize photosynthesis and grain yield in black soils. Emirates Journal of Food and Agriculture. 2016;779-785.
24. Christensen BT. Straw incorporation, and soil organic matter in macro-aggregates and particle size separation. Journal of Soil Science. 1986;37:125-135.
25. Memon MS, Guo J, Tagar AA, Perveen N, Ji C, Memon SA, Memon N. The effects of tillage and straw incorporation on soil organic carbon status, rice crop productivity, and sustainability in the rice-wheat cropping system of eastern China. Sustainability. 2018;10:961.
26. Zhang P, Wei T, Li Y, Wang K, Jia Z, Han Q, Ren X. Effects of straw incorporation on the stratification of the soil organic C, total NPhysico-chemical and C: N ratio in a semiarid region of China. Soil and Tillage Research. 2015;153:28-35.



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