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Yield-increase effects via improving soil phosphorus availability by applying K_2SO_4 fertilizer in calcareous–alkaline soils in a semi-arid agroecosystem

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ABSTRACT

Many studies have reported evidence describing the effects of K_2SO_4 fertilizer on crop productivity, but there is scant information about the yield-increasing mechanisms when influencing soil properties by K_2SO_4 application in calcareous and alkaline soils. In this study, one field and incubation experiments were conducted to investigate the effects of K_2SO_4 fertilizer on crop yields and soil properties in calcareous and alkaline soils on the Loess Plateau of Northwestern China. In field experiments, four K_2SO_4 treatments were applied to potato (*Solanum tuberosum* L.) in 2007 and spring wheat (*Triticum aestivum* L.) in 2008: (1) CK: no K_2SO_4; (2) T1: K_2SO_4 @ 100 kg ha^{-1} in 2007 and 50 kg ha^{-1} in 2008; (3) T2: K_2SO_4 @ 200 kg ha^{-1} in 2007 and 100 kg ha^{-1} in 2008; and (4) T3: K_2SO_4 @ 300 kg ha^{-1} in 2007 and 150 kg ha^{-1} in 2008. In 2007, potato yield increased by 17.4% in T2 and 21.5% in T3 compared with CK, but did not significantly increase in T1. In 2008, spring wheat yields increased by 10.0%, 15.8% and 18.7% in T1, T2 and T3 treatments, respectively, compared with CK. Stepwise regression ($P \leq 0.05$) revealed that soil-available K at tuber formation and starch accumulation stage, and available P at starch accumulation stage correlated well with potato yield. Soil available P before sowing and at anthesis correlated well with spring wheat yield. Soil available P content was mostly higher in T1, T2 and T3 than in CK from June 2007 to August 2008 when the same dose P fertilizer was applied in all plots. Applying K_2SO_4 decreased soil pH. Soil available P was significantly negatively correlated with soil pH ($R = -0.5721$, $P = 0.0015$). In an incubation experiment, the four K_2SO_4 treatments were designed: (1) CK: no K_2SO_4; (2) S1: K_2SO_4 @ 0.44 g kg^{-1} dry soil; (3) S2: K_2SO_4 @ 0.88 g kg^{-1} dry soil; (4) S3: K_2SO_4 @ 1.32 g kg^{-1} dry soil. The results also showed that addition of K_2SO_4 significantly decreased soil pH and increased available P in calcareous and alkaline soils. Our study suggests that K_2SO_4 is desirable for improving crop productivity by increasing soil P availability via decreasing soil pH in calcareous and alkaline soils besides K effect in a low input dryland agroecosystem.

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1. Introduction

Nitrogen, P and K are the most essential plant nutrients with respect to increasing yield. In recent years, much attention has been paid to the effects of N and P fertilizers on crop yields, soil quality and the environment, as high amounts of N and P fertilizers are applied all over the world (Halitligil et al., 2002; Malhi and Lemke, 2007; Halajnia et al., 2009; Ma et al., 2009; Valkama et al., 2009; Ferrise et al., 2010; Liang et al., 2011); less attention has been paid to changes in soil parameters and increased crop yields by K_2SO_4 fertilizer.

Compared to individual inorganic N and P fertilization, combined inorganic NPK fertilization significantly increased grain yields of wheat and maize in alkaline soils in four distinctive agroecological zones across China (Zhang et al., 2011). We found that that K_2SO_4 fertilizer may increase soil Ca_2-P and Ca_8-P in alkaline soils by analyzing the report of Zhou and Zhang (2005). Potato is a K-favoring crop, and many researchers have reported evidence describing the significant effect of K_2SO_4 fertilizer on increased yield in calcareous–alkaline soils (Li et al., 2002; Qin, 2003; Wang and Lu, 2005; Ierna et al., 2011). K_2SO_4 fertilizer has been recently introduced into rainfed farming systems on the Loess Plateau of

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China as the production of potato and spring wheat has increased. However, there is scant information about the effects of K_2SO_4 fertilizer on soil properties, and no information is available on the yield-increasing mechanism when influencing soil properties by K_2SO_4application in calcareous and alkaline soils.

Soil becomes more acidic after applying sulfur-containing fertilizers (Li and Wang, 2004; Zou et al., 2004). P fertilizer added to calcareous soils was mostly converted to relatively less soluble Ca_8-P within a very short time due to high soil Ca^{2+} content (Wang et al., 2005; Jalali and Ranjbar, 2010). Decreased soil pH favored increased available P content in calcareous–alkaline soils (Qin et al., 2006).

Potato and wheat are the two major crops grown in semi-arid regions of China (Xiao et al., 2007). From the above mentioned information, we have a hypothesis that $SO_4{}^{2-}$ of K_2SO_4 application would decline soil pH, which may improve soil phosphorus availability and then be favorable to crop yield improvement. Therefore, the primary objectives of this study were to investigate: (1) the effect of K_2SO_4 application on soil pH and P availability; (2) the relationship among crop yields, available K and available P; and (3) the principal mechanism of yield-increase of crops by K_2SO_4 application in calcareous–alkaline soils.

2. Materials and methods

2.1. Field experiment

2.1.1. Description of study site

The field experiment was conducted for two growing seasons in 2007 and 2008 at the Semiarid Ecosystem Research Station of Lanzhou University on the Loess Plateau (36°02′N, 104°25′E, 2400 m above sea level) in Zhongliangchuan of Yuzhong County, Gansu Province, China. The site has a medium-temperate semi-arid climate, with a mean annual air temperature of 6.5 °C and mean maximum and minimum temperatures of 19.0 °C (July) and −8.0 °C (January). Average annual open-pan evaporation is about 1300 mm. Average annual precipitation is 320 mm, of which approximately 56% is received from June to September. The water table lies about 60 m deep and is not available to plants. The soil has a mean soil bulk density of 1.15 g cm^{-3}, pH 7.8, 145.0 g kg^{-1} $CaCO_3$, 65.3 mg kg^{-1} mineral N (NO_3—N + NH_4—N), 7.7 mg kg^{-1} available P and 89.6 mg kg^{-1} available K. The soil is Heima (Calcic Kastanozems, according to the FAO taxonomy), with a field water holding capacity of 22.9% and a permanent wilting coefficient of 6.2% (Shi et al., 2003). In 2006, prior to the experiment, the site was planted with field pea followed by a fallow of 260 days before potato was sown in 2007.

2.1.2. Experimental design and field management

One crop was grown each year: potato (*S. tuberosum* L.) in 2007 and spring wheat (*T. aestivum* L.) in 2008. Considering that 100–300 kg K_2SO_4 ha^{-1} for potato and 50–150 kg K_2SO_4 ha^{-1} for spring wheat are generally applied by farmers in the region, the experiment had four K_2SO_4 treatments: (1) CK: no K_2SO_4; (2) T1: K_2SO_4 @ 100 kg ha^{-1} in 2007 and 50 kg ha^{-1} in 2008; (3) T2: K_2SO_4 @ 200 kg ha^{-1} in 2007 and 100 kg ha^{-1} in 2008; and (4) T3: K_2SO_4 @ 300 kg ha^{-1} in 2007 and 150 kg ha^{-1} in 2008. In addition, 70 kg N ha^{-1} as urea, 20 kg P ha^{-1} as single superphosphate and 1.5 t ha^{-1} sheep manure were applied to every plot each year. The composition of sheep manure varied from year to year, with average values (as g kg^{-1}) of 219 organic C, 10 total N, 0.85 total P, 21 total K, 0.09 N (NH_4—N + NO_3—N) and 0.16 available P. All K_2SO_4, N and P fertilizers were applied 20 cm deep by rotary tillage and harrowing at the time of sowing. Manure was applied using the same method at the time of sowing and after potato harvest in October 2007. The experiment had a randomized block design with three replications.

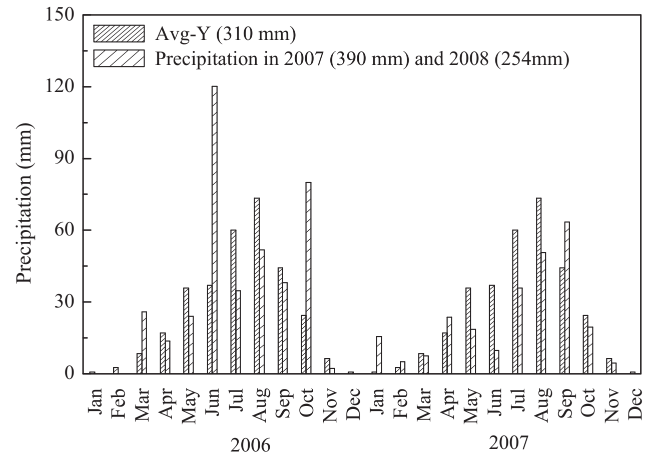

Fig. 1. Precipitation (mm) in 2007 and 2008, monthly average precipitation in past 30 years in Yuzhong (Avg-Y).

Each plot was 6 m × 6 m, separated by a ridge 0.4 m high and 1 m wide. These treatments were repeated in the same plots for 2 years.

The seeding rate was 180 kg ha^{-1} for spring wheat and 300 kg ha^{-1} for potato. Spring wheat was grown from early April to early August, and potato was grown from late April to late September. Precipitation at the site was measured using an automatic weather station (WS-STD1, England). Precipitation during the growing season was 293.3 mm in 2007 and 94.7 mm in 2008 (Fig. 1). Potato had the longer growing season of 155 days and spring wheat had 122 days. Precipitation in the potato growing period accounted for 75.2% total annual precipitation. The corresponding value for spring wheat was 37.3%.

2.2. Incubation experiment

An incubation experiment was undertaken to confirm whether addition of K_2SO_4 decreases soil pH and soluble Ca, and then increases available P. Soil from 0 to 20 cm depth was collected from the Semiarid Ecosystem Research Station of Lanzhou University on the Loess Plateau. The soil has a mean 7.8 g kg^{-1} organic C, 0.8 g kg^{-1} total N, 2.2 mg kg^{-1} available P, pH 8.2 and 148.0 g kg^{-1} $CaCO_3$. The samples were air-dried, ground and sieved (2 mm) before incubation. The laboratory incubations were performed in 250-mL glass jars using a completely randomized experimental design with four treatments. Three replicates from each treatment were assigned to each of 3 sampling dates for a total of 36 incubation jars. The four K_2SO_4 treatments: (1) CK: no K_2SO_4; (2) S1: K_2SO_4 @ 0.44 g kg^{-1} dry soil; (3) S2: K_2SO_4 @ 0.88 g kg^{-1} dry soil; (4) S3: K_2SO_4 @ 1.32 g kg^{-1} dry soil. Air dried soil (50 g) was weighed into each jar and adjusted to moisture content of 0.22 g H_2O g^{-1} soil [~80% water holding capacity (WHC)] with deionized water in dark at 28 ± 1 °C. Sampling dates were at day 0 prior to incubation and at 7, 14 and 42 d during the incubation period.

2.3. Soil pH buffer capacity

Soil samples (5 g, 2 mm) from 0 to 20 cm depth was collected in the same site for the incubation experiment were weighed into each of 18 plastic containers (100 mL), the 18 plastic containers were divided into 3 groups, and incremental amounts (0, 0.5, 1, 2, and 4 mL) of standardized hydrochloric acid (HCl) (0.1 mol L^{-1}) were added, the final volume of suspension after acid addition was equal to 25 mL, and then sealed the containers tightly and arranged randomly. The suspensions were equilibrated for 24 h on an isothermal

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