Responses of Garlic Quality and Yields to Various Types and Rates of Potassium Fertilizer Applications

Manman Wang, Youliang Ye, Xv Chu, and Yanan Zhao

Agricultural Green Development Engineering Technology Research Centre, Henan Agricultural University, Zhengzhou 450002, China

Shuhong Zhang, Hui Chen, and Wei Qin

Innovation Centre for Efficient Use of Nitrogen Fertilizer, China Nitrogen Fertilizer Industry (Xinlianxin) Technology Research Center, Henan Xinlianxin Chemical Industry Group Co., Ltd. Henan 453731, China

Yang Wang

Agricultural Green Development Engineering Technology Research Centre, Henan Agricultural University, Zhengzhou 450002, China

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Abstract. Potassium (K) is a critical plant nutrient that determines quality in a myriad of crops and increases production yields. However, excessive application of various types of K fertilizers can decrease both the food quality and yields, which translates as economic losses and food safety issues. The objectives of this study were to 1) elucidate the impacts of different application rates of various K fertilizers on garlic, with the aim to identify the optimal and most economical K fertilizer dosage and 2) compare the effects of applying two common K fertilizers (KCl and K_2SO_4) on garlic, to determine the optimal combination. From 2018 to 2020, we utilized two distinct K-fertilized fields to conduct our experiments. The results revealed optimal KCl fertilization increased the biomass and vegetation index in garlic, and promoted the transfer of nitrogen, phosphorus, and potassium nutrients from the stem and leaf to bulb, thereby increasing bulb production. The application of KCl fertilizer increased the number of cloves, the diameters of the cloves and bulbs, and reduced variations in bulb size. In addition, the application of KCl fertilizer improved the nutritional quality (Vitamin C, soluble sugar, soluble protein, and allicin) of the garlic and reduced the accumulation of nitrate. However, excessive KCl fertilizer cause decreased yields, appearance traits, and nutritional quality. Applying the same rate of K fertilizer in the form of K_2SO_4 in isolation increased the garlic yield by only 0.1% to 22.5% when compared with KCl fertilizer. However, the results were not always significant. In this study, the highest yields, appearance traits, and nutritional quality were achieved with the ratio of K_2SO_4 : KCl = 3:1. Consequently, to ensure the highest economic value (considering the market prices of K fertilizer, garlic sprouts, and bulbs), the authors recommend a K fertilizer rate of $252.5 \text{ kg} \cdot \text{ha}^{-1}$ K_2O , with K_2SO_4 accounting for 61.6% for garlic production in field.

Garlic comprises one of the main *Allium* vegetable crops, which is the second most widely grown winter crop after onion (Diriba et al., 2015). Garlic is primarily used for home consumption in various forms for

cooking as either a spice or condiment (Sung et al., 2014). Moreover, garlic has important medicinal values and is used to treat various cardiovascular diseases, stomach diseases, sore eyes, and earache, as it contains significant quantities of minerals, vitamins, and allicin (Elosta et al., 2017; Kamel and Saleh, 2000). Garlic is a healthy food that may also possess antimicrobial properties (Harris et al., 2001). The price of garlic has been rising all over the world during the new coronavirus epidemic (COVID-19). However, there is no evidence from that eating garlic has protected people from COVID-19.

Garlic is highly adaptable and extensively cultivated throughout the world. On a global scale, the leading producers are China, India, Korea, Egypt, Thailand, and Spain. The largest producers of garlic are within Asia (87%), with China and India collectively accounting

for 78% of global production. The garlic yield in China is $23.08 \text{ t} \cdot \text{ha}^{-1}$, which is four times that of India ($5.27 \text{ t} \cdot \text{ha}^{-1}$) and higher than the world average ($16.71 \text{ t} \cdot \text{ha}^{-1}$).

Garlic is sensitive to K during the growth process and absorbs significant nitrogen (N) and K, and limited phosphorus (P) (Jiku et al., 2020). Garlic requires a fertilizer characterized by $N > K > P$. The overall absorption ratio of N, P, and K in garlic is 1:0.3:0.71 (Santos et al., 2016). The ratio implies a high demand for K, which plays a critical role in improving its yield and quality. Although K promotes the transport and distribution of photosynthetic products, its concentration directly affects crop resistance to adverse environmental conditions (Wang et al., 2013).

Because of arbitrary fertilization practices, the fertilizer usage efficiency of garlic in China has always been low, with only $\approx 35\%$ (N), 10% (P), and 40% (K), respectively (Li et al., 2019). Recently, the variable application of N and P fertilizers has caused serious imbalances in N, P, and K in the soil. In most areas of China, soil K is insufficient (He et al., 2015), resulting in the deterioration of garlic quality, aggravated diseases and insect pests, and reduced yields (Ashley and Grabov, 2006). Conversely, excessive K can lead to decreased absorption and utilization of other nutrients by the crops. This includes a decrease in the absorption of cations such as calcium, which leads to crops that are prone to lodging. Additionally, reduced absorption of cations leads to reduced disease resistance, the destruction of the nutrient structure and balance in the soil and soil pollution ensues (El-Nasr and Ibrahim, 2011).

An essential element for plant growth, sulfur (S) (after N, P, and K) plays an indispensable role in plant growth and is an important component of allicin (Jackson, 2000). Multiple studies have observed the effects of K_2SO_4 application is better than KCl for increasing vegetable crop yields and quality (Dennison and Janes, 2015). However, experienced farmers have reported the continuous application of K_2SO_4 did not improve garlic growth. However, no research exists to support their comments. The leading issue for garlic production in China is that farmers apply only KCl or K_2SO_4 in isolation. Because of the higher cost of K_2SO_4 fertilizer, combined with the fact that K_2SO_4 was not considered as effective, the vast majority of farmers apply KCl fertilizer.

Therefore, we hypothesize the economic benefits and quality of garlic may be improved by modifying the field application of K fertilizer. Our objectives were to 1) determine the optimum quantity of K for a customized garlic fertilizer and the optimal ratio within various K fertilizers; 2) determine the most effective KCl application range and provide a scientific basis for the formulation of K fertilizers; and 3) explore the optimum economic returns for K fertilization.

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Y.W. is the corresponding author. E-mail: wangyang1106@henau.edu.cn.

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Materials and Methods

Site description. Field experiments were conducted in Pingcheng (lat. 34°41'N, long. 114°39'E, low soil K concentration) and Peicundian (lat. 34°31'N, long. 114°49'E, high soil K concentration), in Kaifeng City, Henan Province, Central China, during the Oct. 2018 to May 2020 garlic growing season. The area has a subtropical monsoon climate with the mean annual temperatures of 9.6 °C (2018–19) and 10.6 °C (2019–20), whereas the mean winter temperatures were 1.5 °C (2018–19) and 3.5 °C (2019–20) in both the experimental sites during the garlic growing season. The total rainfall during the garlic growing season was 361 mm (2018–19) and 310 mm (2019–20). Before initiating the experiment, soil samples were extracted from the upper 20 cm layer for chemical analyses. The soil type in Pingcheng is a mixed soil with pH 6.6 with an organic matter content of 8.6 g·kg⁻¹, total N of 0.9 g·kg⁻¹, available P of 18.2 mg·kg⁻¹, available K of 69.5 mg·kg⁻¹, and bulk density of 1.23 g·cm⁻³. The soil type in Peicundian was a silt soil with pH 6.8, with an organic matter content of 13.2 g·kg⁻¹, total N of 1.8 g·kg⁻¹, available P of 22.2 mg·kg⁻¹, available K of 147.5 mg·kg⁻¹, and a bulk density of 1.34 g·cm⁻³.

Experimental design and management. The same cultivar (Jinan Daqingke) treatments and crop management were adopted at both study sites. A total of 416,880 seeds per ha were manually sown on 7 Oct. The dimensions of each plot was 6.0 m × 8.0 m. The proposed study was arranged in a randomized complete block design with three replications, and nine K treatments: 1) K0 (no K fertilizer); 2) K75 (75 kg·ha⁻¹ K₂O, KCl); 3) K150 (150 kg·ha⁻¹ K₂O, KCl); 4) K225 (225 kg·ha⁻¹ K₂O, KCl); 5) K375 (375 kg·ha⁻¹ K₂O, KCl); 6) K225 (225 kg·ha⁻¹ K₂O, K₂SO₄); 7) K225 (225 kg·ha⁻¹ K₂O, K₂SO₄:KCl = 1:3); 8) K225 (225 kg·ha⁻¹ K₂O, K₂SO₄:KCl = 1:1); 9) K225 (225 kg·ha⁻¹ K₂O, K₂SO₄:KCl = 3:1).

Nitrogen (300 kg·ha⁻¹ N, urea) was applied at two intervals, at a rate of 50% at basal and 50% at the garlic degeneration stage (≈150 d after sowing; DAS). A basal dose of phosphorus (150 kg·ha⁻¹ P₂O₅), in the form of calcium superphosphate (12% P₂O₅), was applied. The various K treatments, in the form of muriate of potash (or sulphate of potash), were applied as a basal dose. The basal fertilizer was applied before manual sowing, and the N topdressing was applied with water. The field sites employed a garlic-maize rotation system during the experimental period, no fertilizer was applied during the maize growing season. Weeds, diseases, and insects were intensively controlled during the entire growing season to restrict yield losses.

Canopy normalized difference vegetation index (NDVI) measurements. The NDVI readings were measured using a GreenSeeker handheld crop sensor (Trimble's Agriculture Division, Sunnyvale, CA) at the wintering stage (DAS 80), garlic degeneration stage

(DAS 150), flower bud differentiation stage (DAS 170), bolting stage (DAS 190), and maturity stage (DAS 220). The spectral search head was held parallel to the garlic vegetation canopy at a vertical height of ≈0.8 m. We randomly selected three garlic from an area of 3–4 m² in each plot for representative measurement data collection.

Plant nutrient measurements. At the bolting and harvest stage, 10 plants from the double rows in each plot were sampled, and then dissected into stem and leaf, bulb, and sprout. The fresh material was oven dried at 105 °C for 30 min and then at 75 °C until a constant weight was achieved. The plant materials were ground to pass through a 1-mm mesh screen and digested by H₂SO₄ and H₂O₂. The total nitrogen (N) and phosphorus (P) concentration of the digested samples was determined using an automated continuous flow analyzer (Seal, Norderstedt, Germany). The total potassium (K) concentration of the plant was determined with a flame photometer FP-640 (Precision Instrument Co., Ltd., Shanghai, China).

Plant sampling for commodity and nutritional quality measurements. At the bolting and harvest stage, the garlic sprout and bulb yields were manually measured using 50 plants in each plot. Half of the fresh garlic bulb samples were measured for commodity quality, including the bulb diameter, number of cloves, and clove diameter. The fresh material was oven dried at 105 °C for 30 min and then at 75 °C, until a constant (biomass) weight was achieved.

The remaining bulb samples were used for assessing the nutritional quality [vitamin C (Vc), soluble sugar (SS), soluble protein and nitrate]. The Vc concentration was determined following the techniques described in Danbature et al. (2015). The sample extraction was mixed with an ethanol solution (5% trichloroacetic acid, 0.4% H₃PO₄, 0.5% bathophenanthroline, 0.03% FeCl₃), and incubated at 30 °C for 60 min, and the absorbance read at 534 nm.

The soluble sugar content was determined following the method outlined in Zhang et al. (2020). The sample was mixed with 0.15% anthrone in ethanol and then incubated for 15 min in a water bath at 90 °C. The absorbance was measured at 620 nm using a Primag spectrophotometer (SHIMADZU, ultraviolet-1206). The soluble sugar content was determined by assessing the standard curve using gradient D-glucose solutions.

The soluble protein content was quantified according to the method described in Bradford (1976). The samples were homogenized with 25 mL H₂O for 30 min and centrifuged at 4000 g_n for 10 min. The protein extraction was stained using Coomassie brilliant blue G-250 and determined via a spectrophotometer under a wavelength of 464 nm.

The nitrate content was determined according to the method described in Priyanka et al. (2018). The sample homogenate was immersed in double-distilled water and 5% salicylic acid in a sulfuric acid solution was added before incubation for 20 min at room

temperature and 1.8% sodium hydroxide was added. The absorbance was read at 410 nm, and the nitrate level of all samples was calculated according to the standard curves.

The alliin content was determined according to the method of Patricia et al. (2014). Fresh garlic samples (0.5 g) were weighed and added to 25 mL of chilled water (4 °C) and stirred vigorously for 30 s. An additional 25 mL of cold water was added to the sample and it was stirred for another 30 s. The samples were filtered through a 0.45 μm filter membrane for high-performance liquid chromatography analysis. The samples were quantified against an isolated alliin external standard using a calibration curve. The analyses were conducted using a high-performance liquid chromatograph with a reversed-phase column with a LC 300psi gradient pump equipped with a degasifier (DGU-M10A), microvalve injector, and a Shimadzu SPD-M10A diode array detector at a wavelength of 240 nm and a LC-18 reversed-phase column (Prodigy 5μ ODS3 100Å 250 × 4.6 mm, Phenomenex/4097E0), operating at 28 ± 0.5 °C. The mobile phase consisted of methanol and water (50:50) with a flow rate of 1.0 mL/min. The total running time was 20 min.

Data analysis. A one-way analysis of variance was applied to assess the differences within each parameter using the Statistical Software Package for Social Science (SPSS, version 20.0). The mean values of the treatments were compared using the least significant difference test. For all analyses, the significance level was $P < 0.05$. In the binary quadratic equations model, the relative yield was calculated as the ratio of the grain yield obtained for a given K rate or the K₂SO₄/KCl ratio to the highest grain yield in a fixed site and year. All graphs were plotted using the Origin 9.0 software program.

Results

Biomass dynamics. The accumulation of the garlic biomass was slow before 150 DAS, and then accumulated quickly until the garlic bulb was harvested (Fig. 1). When only KCl was applied, the biomass results showed K225 > K375 > K150 > K75 > K0 during the entire growth period, and the difference in biomass between the treatments gradually increased after ≈150 DAS. The addition of K₂SO₄ caused a higher garlic biomass from the beginning of the seedling stage. The garlic biomass was highest with K₂SO₄:KCl = 3:1 treatment regardless of the year or site, and the biomass increased with a higher ratio of K₂SO₄. However, the biomass volume peaked before the proportion of K₂SO₄ reached 100%.

Canopy NDVI. The canopy NDVI gradually increased from 80 DAS to 190 DAS, then the garlic bolted and the leaves began to senesce resulting in a lower NDVI value at the harvest stage (Fig. 2). The canopy NDVI was initially enhanced and then decreased with higher quantities of KCl fertilizer, and attained the maximum value under the K225 treatment. In the K225 treatment, the

Fig. 1. Effects of potassium (K) rate and type on the garlic biomass over the growing period until harvest. (A) Pingcheng site during 2018–19, (B) Peicundian site during 2018–19, (C) Pingcheng site during 2019–20, and (D) Peicundian site during 2019–20. S, K_2SO_4 ; CI, KCl.

increasing proportion of K_2SO_4 enhanced the canopy NDVI. In contrast, at the harvest stage, the NDVI of the K225(S) treatment was significantly lower than the S:CI = 3:1 treatment at the Pingcheng site, which is a similar result to the early growth stage (80 DAS–170 DAS) at the Peicundian site.

Nutrient distribution in different garlic organs. At maturity, the N, P, and K nutrients accumulation in the stem and leaf was significantly higher than the bulb, and the nutrients

accumulation in the bulb was significantly higher than the sprout (Fig. 3). The ratio of N, P, and K nutrients accumulation in the sprout was 4% to 6%, 5% to 11%, and 6% to 8%, respectively. The ratio of nutrients in the sprout was relatively stable in different treatments, sites, and years when compared with the bulb, stem, and leaf results. The ratio of bulb N accumulation was 17% to 37%. The bulb N accumulation ratio increased with higher rates of KCl fertilizer addition, but the ratio of the stem

and leaf N accumulation showed the opposite trend. The addition of K_2SO_4 further increased the ratio of the bulb N accumulation, which reached 33% to 37% in the S:CI = 3:1 treatments. The ratio of the bulb P accumulation was 18% to 39%, and the bulb P accumulation ratio increased with higher KCl fertilizer addition, but the P accumulation ratio of the stem and leaf had an opposite trend. The addition of K_2SO_4 further increased the ratio of bulb P accumulation, which reached 33% to 39% in the S:CI = 3:1 treatments. The ratio of the bulb K accumulation was 10% to 25%, and increased with higher KCl fertilizer addition, but the K accumulation ratio of the stem and leaf showed the opposite trend. The addition of K_2SO_4 further increased the bulb K accumulation ratio, which reached 23% to 25% in the S:CI = 3:1 treatments. It is worth noting the ratios of N, P, and K nutrient accumulation was not the highest in the garlic treated with only potash fertilizer of K_2SO_4 .

Garlic sprout and bulb yield. This 2-year experiment revealed the sprout yield was significantly lower than the bulb yields. The sprouts and bulbs had a significantly higher yield in 2018–19 than in 2019–20. In addition, the yield in the Peicundian experimental site was significantly higher than the Pingcheng site (Fig. 4). When an increasing volume of KCl was applied, the sprout and bulb

Fig. 2. Effects of potassium (K) rate and type on the canopy normalized difference vegetation index (NDVI) of garlic over the growing period until harvest. Different letters in the same column denote significant variations between the different treatments at the same growth stage ($P < 0.05$). (A) Pingcheng site and (B) Peicundian site. Each bar represents the mean $\pm$ SD ($n = 3$). S, K_2SO_4 ; CI, KCl.

Fig. 3. Effects of potassium (K) rate and type on the nitrogen (N), phosphorus (P), and K nutrient distributions in the different garlic organs. (A) N, (B) P, and (C) K accumulation ratio at Pingcheng during 2018–19; (D) N, (E) P, and (F) K accumulation ratio at Peicundian during 2018–19; (G) N, (H) P, and (I) K accumulation ratio at Pingcheng during 2019–20; (J) N, (K) P, and (L) K accumulation ratio at Peicundian during 2019–20. S, K_2SO_4 ; CI, KCl.

yields initially increased and then decreased. The maximum yield occurred in the K225 (CI) treatment. When K225 (CI) was compared with K0, the average sprout yield was from 18.9% to 32.1% higher at both sites over the 2 years, and the average garlic yield was 21.2% to 40.7% higher.

When applying the same amount of K fertilizer, the dynamic trends in sprout yields

were not consistent with the increased ratio of K_2SO_4 and KCl over the 2 years at both sites. During 2018–19, the sprout yield under the K225 (S) treatment was the lowest at the Peicundian site but highest at the Pingcheng site. During 2019–20, the sprout yield increased with an additional ratio of K_2SO_4 , with the highest sprout yield attained in the K_2SO_4 : KCl = 3:1 treatment. When compared with

the sprout yield, the dynamic trend of the bulb yield was more consistent. The highest bulb yield was attained in the K_2SO_4 :KCl = 3:1 treatment for all years and sites, and the highest yields were not obtained when the ratio of K_2SO_4 or KCl reached 100%.

Bulb commodity characteristics. The bulb diameter, number of cloves per bulb, and clove diameter at the Peicundian site were

Fig. 4. Effects of potassium (K) rate and type on sprout and bulb yields. (A) Pingcheng site during 2018–19, (B) Peicundian site during 2018–19, (C) Pingcheng site during 2019–20, and (D) Peicundian site during 2019–20. Different letters denote significant variations between the different treatments for the same organ ($P < 0.05$). Each bar represents the mean $\pm$ SD ($n = 3$). S, K_2SO_4 ; CI, KCl.

higher than those at the Pingcheng site (Table 1; Fig. 5). An increased level of KCl fertilizer resulted in the bulb diameter and number of cloves per bulb initially increasing

to a peak before decreasing. The maximum bulb diameter and number was attained in the K225 (CI) treatment. When compared with the K0 treatment, the bulb diameter and

number of cloves per bulb were increased by 7.1% to 20.2% and 13.5% to 46.9%, respectively. Furthermore, the variation coefficient of the clove diameter was lowest in the K225 (CI) treatment, which indicated that the garlic clove sizes were more uniform.

When supplying the same quantity of K fertilizer, the number of cloves per bulb and clove diameter were higher with the higher ratio of K_2SO_4 . The highest number of cloves per bulb and clove diameter was achieved in the K_2SO_4 :KCl = 3:1 treatment. In contrast to the K225 (CI) treatment, the bulb diameter in the K_2SO_4 :KCl = 3:1 treatment was higher by 4.9% (Pingcheng) and 11.3% (Peicundian), whereas the clove number was higher by 5.3% (Pingcheng) and 30.7% (Peicundian).

Garlic bulb quality. The Vc nutrient content, soluble sugar, soluble protein, and alliin in the garlic bulbs at the Peicundian site were higher than the Pingcheng site. However, the nitrate content in garlic from the Peicundian site was lower than the Pingcheng site during the 2-year study (Table 2). The increased quantity of KCl fertilizer caused the contents of Vc, soluble sugar, soluble protein, and alliin to initially increase and then decrease, with $K0 < K75 < K150 < K375 < K225$. Nevertheless, the nitrate content exhibited the opposite trend with increasing amounts of KCl fertilizer.

When supplying the same amount of K fertilizer, the contents of Vc, soluble sugar, soluble protein, and alliin increased as the ratio of K_2SO_4 increased. The highest values were attributed to the K_2SO_4 :KCl = 3:1 treatment. Conversely, the nitrate content decreased as the K_2SO_4 :KCl increased.

Economic benefits. There was a price reduction of garlic bulbs in 2019–20 and the bulb production was lower in 2019–20 than 2018–19. However, the sprout production was relatively stable throughout the experimental period (Table 3). During 2018–19, when compared with the control, the addition of KCl fertilizer enhanced the net income by as much as 23.4% at the Pingcheng site, and 37.1% at the Peicundian site. In contrast, in the 2019–20 season, the net income increased by up to 56.1% at the Pingcheng site and 101.1% at the Peicundian site. The K225 (KCl) treatment generated the maximum income when only the KCl fertilizer was applied. Using a curve analysis, we concluded that $253.8 \text{ kg} \cdot \text{ha}^{-1}$ was the most economical application of KCl fertilizer (Fig. 6A).

The cost of K_2SO_4 fertilizer was 300 yuan per ton higher than the KCl fertilizer. The cost of K_2SO_4 fertilizer is highly affected by prices and distributors. Therefore, in previous years, farmers have been more willing to select the cheaper KCl fertilizer. When applying the same amount of K fertilizer, the net income was higher with the added K_2SO_4 ratio, with the highest value achieved by the K_2SO_4 :KCl = 3:1 treatment. However, economically, the highest income was generated using the K_2SO_4 :KCl = 1:1 treatment at the Pingcheng site in 2018–19. Further, we concluded that the most economical proportion of K_2SO_4 in the fertilizer was 63.9% (Fig. 6B).

Table 1. Effects of potassium quantity and type on agronomic bulb traits.

Site	Treatment	Bulb diam (mm)	No. of cloves per bulb	Clove diam (mm)	Variation of clove diam
Pingcheng	K0	49.3 e ²	10.8 c	11.7 b	0.34 a
	K75 (CI)	52.4 d	11.0 c	11.9 b	0.36 a
	K150 (CI)	55.4 cd	11.0 c	11.5 b	0.25 bc
	K225 (CI)	59.4 bc	15.2 ab	12.5 ab	0.22 c
	K375 (CI)	57.7 c	14.2 b	12.7 ab	0.26 b
	K225 (S)	61.6 b	15.7 ab	13.2 ab	0.22 c
	S:CI = 1:3	60.5 b	15.3 ab	11.8 b	0.28 b
	S:CI = 1:1	62.5 b	15.7 ab	14.0 a	0.24 bc
	S:CI = 3:1	66.1 a	16.0 a	14.2 a	0.27 b
Peicundian	K0	58.0 f	10.0 d	12.9 c	0.43 a
	K75 (CI)	62.5 e	12.5 cd	14.7 bc	0.46 a
	K150 (CI)	66.8 d	14.2 c	14.7 bc	0.31 b
	K225 (CI)	69.5 bc	15.3 bc	15.4 a	0.25 c
	K375 (CI)	68.8 bc	15.3 bc	14.1 bc	0.31 b
	K225 (S)	70.7 b	16.0 b	15.3 ab	0.24 c
	S:CI = 1:3	67.9 c	16.2 b	14.5 bc	0.24 c
	S:CI = 1:1	69.8 bc	16.8 b	16.1 a	0.31 b
	S:CI = 3:1	72.9 a	20.0 a	15.2 ab	0.20 c

²Different letters within a column denote significant variations between the different treatments at the same experimental site ($P < 0.05$). S, K_2SO_4 ; CI, KCl.

Discussion

Responses of garlic yields and quality to different amounts of K fertilizer. As a K-loving crop, the application of K fertilizer can improve the C and N assimilation in garlic while enhancing the transport of assimilation products from the aboveground leaves to the belowground bulb (Shafeek et al., 2013). In this study, the garlic bulb and sprout yields were increased with higher fertilizer KCl applications ranging from 0 to 225 kg·ha⁻¹ K₂O (Fig. 4). From the seedling stage, the application of KCl effectively increased the garlic biomass when compared with the control, and the differences increased as the garlic grew (Fig. 1). Therefore, the early growth stage had a significant influence on the final garlic yield. An important index that reflects the quality of the canopy in crops is the NDVI because it is intimately correlated with the photosynthetic capacity for crop yields (Abou El-Nasr and Ibrahim, 2011). Our results showed the NDVI variations between the different K treatments were similar to the garlic yields. Therefore, NDVI may be useful indicator for predicting garlic yields (Fig. 2).

From the perspective of plant physiology, the K fertilizer promoted the transport of the photosynthetic products in leaves toward belowground bulbs. In addition, K fertilizer may assist sucrose phosphate synthase and

Fig. 5. The mature garlic clove performance with the different potassium (K) rates and type treatments at (A) Pingcheng and (B) Peicundian. K0, K75, K150, K225, and K375 denote the KCl rate as 0, 75, 150, 225, and 375 kg·ha⁻¹ K₂O, respectively. S, K₂SO₄; C, KCl.

Table 2. Effects of K rate and type on garlic bulb quality.

Yr	Site	Treatment	Vc (mg/100 g)	Soluble sugar (%)	Soluble protein (%)	Nitrate (mg/kg)	Allicin (mg/kg)
2018–19	Pingcheng	K0	6.7 f ²	5.0	5.4 e	1084.4 a	93.7 d
		K75 (Cl)	9.0 e	7.4 e	7.3 d	723.0 b	98.2 cd
		K150 (Cl)	19.1 d	8.9 d	10.2 c	628.5 c	101.5 cd
		K225 (Cl)	25.0 c	12.7 bc	12.2 b	546.7 d	138.3 ab
		K375 (Cl)	19.3 d	10.5 c	11.8 b	662.6 c	98.1 cd
		K225 (S)	26.6 bc	13.7 b	14.4 a	440.6 e	141.1 ab
		S:Cl = 1:3	27.5 ab	12.4 bc	12.5 b	508.0 d	129.2 bc
		S:Cl = 1:1	26.4 bc	13.8 b	14.8 a	474.6 e	133.6 b
		S:Cl = 3:1	29.2 a	15.2 a	15.2 a	428.7 e	167.7 a
	Peicundian	K0	9.6 e	5.1 e	7.8 e	901.2 a	102.8 d
		K75 (Cl)	12.4 d	7.6 d	10.7 d	791.1 b	108.7 d
		K150 (Cl)	24.3 c	8.4 d	11.5 cd	634.0 c	169.9 bc
		K225 (Cl)	30.4 b	12.7 bc	13.8 b	520.0 d	170.5 bc
		K375 (Cl)	25.0 c	10.3 c	12.3 bc	628.2 c	105.3 d
		K225 (S)	32.8 a	14.2 b	16.0 a	471.8 e	192.9 bc
		S:Cl = 1:3	30.0 b	12.7 bc	14.4 b	517.7 d	163.6 c
		S:Cl = 1:1	32.5 a	14.5 b	14.7 ab	474.6 e	215.9 ab
		S:Cl = 3:1	33.8 a	17.8 a	16.4 a	448.2 e	304.4 a
2019–20	Pingcheng	K0	8.2 f	6.0 e	6.3 e	1130.8 a	85.7 d
		K75 (Cl)	11.3 e	7.9 de	8.2 d	861.7 b	94.0 cd
		K150 (Cl)	15.8 d	9.8 d	13.4 c	577.3 c	103.8 c
		K225 (Cl)	21.1 c	14.2 c	14.1 c	548.3 cd	131.3 b
		K375 (Cl)	19.5 c	13.7 c	14.0 c	514.2 d	102.3 c
		K225 (S)	20.4 c	15.2 bc	17.0 b	477.9 e	147.9 ab
		S:Cl = 1:3	23.5 b	15.5 bc	15.0 bc	484.9 de	138.4 ab
		S:Cl = 1:1	24.4 b	16.9 b	18.4 ab	387.3 f	140.3 ab
		S:Cl = 3:1	27.3 a	18.8 a	19.7 a	328.7 g	165.1 a
	Peicundian	K0	11.6 f	5.9 f	11.8 e	938.9 a	93.0 e
		K75 (Cl)	15.1 e	7.6 e	12.7 e	639.2 b	103.3 de
		K150 (Cl)	17.8 d	9.1 de	14.3 d	607.3 bc	119.4 d
		K225 (Cl)	23.0c	14.0 c	16.2 c	496.4 d	174.2 bc
		K375 (Cl)	19.2 d	11.2 d	14.4 d	574.2 c	104.7 de
		K225 (S)	28.1 b	15.2 c	20.2 b	460.02 e	187.3 bc
		S:Cl = 1:3	28.4 b	15.4 c	17.1 c	460.7 e	160.2 c
		S:Cl = 1:1	33.3 a	16.8 b	19.1 bc	402.6 f	201.2 ab
		S:Cl = 3:1	34.0 a	18.1 a	24.1 a	322.9 g	274.0 a

²Different letters within a column denote significant variations between different treatments at the same experimental site in the same year ($P < 0.05$). S, K₂SO₄; Cl, KCl.

Table 3. Effects of K rate and type on the economic benefits of the garlic.^z

Yr	Site	Treatment	Output ($\times 10^4$ yuan/ha)		Fertilizer cost ($\times 10^4$ yuan/ha)	Other production cost ($\times 10^4$ yuan/ha)	Net income ($\times 10^4$ yuan/ha)
			Bulb	Sprout			
2018–19	Pingcheng	K0	15.4 e ^y	1.31 de	0.16	2.10	14.45 e
		K75 (Cl)	17.8 de	1.54 bc	0.20	2.10	17.04 d
		K150 (Cl)	17.8 d	1.58 abc	0.24	2.10	17.04 d
		K225 (Cl)	18.5 d	1.70 a	0.27	2.10	17.83 d
		K375 (Cl)	18.1 d	1.62 ab	0.34	2.10	17.28 d
		K225 (S)	22.6 c	1.46 cd	0.29	2.10	21.67 c
		S:Cl = 1:3	23.5 bc	1.26 e	0.28	2.10	22.38 bc
		S:Cl = 1:1	26.1 a	1.23 e	0.28	2.10	24.95 a
		S:Cl = 3:1	24.8 ab	1.28 e	0.29	2.10	23.69 ab
	Peicundian	K0	22.8 f	2.66 d	0.16	2.10	23.20 f
		K75 (Cl)	25.8 e	2.93 bcd	0.20	2.10	26.43 e
		K150 (Cl)	26.5 d	3.18 abc	0.24	2.10	27.34 d
		K225 (Cl)	30.7 c	3.48 a	0.27	2.10	31.81 c
		K375 (Cl)	28.3 c	3.27 ab	0.34	2.10	29.13 cd
		K225 (S)	32.8 c	2.13 e	0.29	2.10	32.54 c
		S:Cl = 1:3	34.6 b	2.75 cd	0.28	2.10	34.97 b
		S:Cl = 1:1	35.1 b	2.73 cd	0.28	2.10	35.45 b
		S:Cl = 3:1	37.2 a	2.96 bcd	0.29	2.10	37.77 a
2019–20	Pingcheng	K0	6.6 e	0.76 c	0.16	2.10	5.10 e
		K75 (Cl)	7.3 d	1.02 b	0.20	2.10	6.02 d
		K150 (Cl)	8.5 c	1.12 ab	0.24	2.10	7.28 c
		K225 (Cl)	9.1 b	1.23 ab	0.27	2.10	7.96 b
		K375 (Cl)	9.2 b	1.11 ab	0.34	2.10	7.87 bc
		K225 (S)	10.1 ab	1.27 ab	0.29	2.10	8.98 ab
		S:Cl = 1:3	9.2 b	1.24 ab	0.28	2.10	8.06 b
		S:Cl = 1:1	10.2 a	1.28 ab	0.28	2.10	9.10 a
		S:Cl = 3:1	10.6 a	1.38 a	0.29	2.10	9.59 a
	Peicundian	K0	7.1 e	1.41 c	0.16	2.10	6.25 e
		K75 (Cl)	11.1 d	1.42 c	0.20	2.10	10.22 d
		K150 (Cl)	11.7 c	1.71 b	0.24	2.10	11.07 c
		K225 (Cl)	13.1 a	1.84 ab	0.27	2.10	12.57 a
		K375 (Cl)	12.0 c	1.78 b	0.34	2.10	11.34 c
		K225 (S)	13.2 a	2.02 ab	0.29	2.10	12.83 a
		S:Cl = 1:3	12.5 b	1.75 b	0.28	2.10	11.87 b
		S:Cl = 1:1	13.4 a	1.91 ab	0.28	2.10	12.93 a
		S:Cl = 3:1	13.7 a	2.09 a	0.29	2.10	13.40 a

^zThe sale price of the garlic bulbs was 7 yuan/kg in 2019, 3 yuan/kg in 2020, and the sale price of garlic sprouts was 4 yuan/kg in 2019 and 2.6 yuan in 2020. The purchase price of KCl was 2600 yuan/t and 2900 yuan/t for K₂SO₄. Additional production costs included the plastic mulching film, irrigation, pesticides, and labor. S, K₂SO₄; Cl, KCl.

^yDifferent letters within a column denote significant variations between the different treatments at the same experimental site in the same year ($P < 0.05$).

reduce sucrose hydrolysis. Additional K fertilizer may also promote the conversion of starch to soluble sugar (Milford et al., 2000). In our study, the application of K fertilizer increased the ratio of N, P, and K accumulation in the bulb, because K promotes the transfer of nutrients from the stem and leaf to the underground bulb (Fig. 3). In addition, the addition of K fertilizer enhanced the soluble sugar content assisting garlic bulb expansion, which ultimately increased the

bulb yield (Table 2). Furthermore, the application of K fertilizer improved the commodity and nutritional quality.

In our study, the bulb diameter, clove size, and clove numbers were increased with higher K fertilization rates, whereas size variations between the cloves decreased (Table 1). This is advantageous as larger bulbs command a premium internationally. After oral ingestion and entering the human digestive tract, nitrates are easily reduced to nitrites

that are carcinogenic for humans. Therefore, the excessive accumulation of nitrates in a vegetable is a health and safety risk in human consumption (Bian et al., 2020). In this study, the application of K fertilizer significantly decreased the nitrate content of the garlic bulbs (Table 2). In addition, K fertilizer may increase the Vc content, which enhances the antioxidant capacity of garlic. Meanwhile, K promotes the synthesis of N into amino acids to further increase soluble protein, while reducing the accumulation of nitrates (Munir et al., 2019).

We also found a decline in the ratio of bulb N and P nutrients and a decline in the yield and garlic quality with an excessive application of K fertilizer (Figs. 3 and 4; Table 2). Our results support previous findings on other crops (Soliman et al., 2018; Vann et al., 2013). This may be due to excessive K causing salt stress in crops, disturbing the balance between calcium and magnesium ions, and hindering the absorption of other nutrients such as N and P, which overrides the positive effects of K fertilizer (Huu Nguyen et al., 2017).

Responses of garlic yields and quality to different types of K fertilizer. Garlic is a crop that requires the highest quantity of sulfur, and can tolerate sulfur in high concentrations.

Fig. 6. Relationships between the relative net income of garlic and quantity of K fertilizer (A) with the ratio of K₂SO₄ (B).

The accumulated S within garlic can reach 0.3% to 0.6% (Zaman et al., 2012). The appropriate application of S might increase the photosynthetic rate in garlic leaves, while enhancing the antioxidant enzyme and nitrate reductase activities of its leaves (Liu et al., 2010). In addition, S facilitates the transport of the photosynthetic products in garlic plants to the belowground components and promotes the synthesis of proteins (Chandra and Pandey, 2013; Cheng et al., 2015). Previous studies reported the application of K_2SO_4 fertilizer not only increased yields, but also improved the vegetable quality in contrast to KCl fertilizer (Farahani et al., 2020; Kumar and Kumar, 2008).

In this study, when compared with KCl fertilizer, the economic benefits of the application of K_2SO_4 fertilizer increased by 12.8% to 21.5% at the Pingcheng site, and increased by 2.1% to 2.3% at the Peicundian site when comparing the same K fertilization regime (Table 3). The main types of potash fertilizers on the market are KCl and K_2SO_4 . The supply of K_2SO_4 fertilizer is insufficient, and K_2SO_4 is more expensive than KCl (Dennison and Janes, 2015; Katovich et al., 2018). In addition, the effects of K_2SO_4 fertilizer was not consistently significant higher than the KCl fertilizer. Therefore, when K_2SO_4 fertilizer is not available, farmers should use a KCl fertilizer.

Garlic is not sensitive to Cl ions, which are an essential element that directly participates in the Hill reaction and in the regulation of cell osmosis and ion balance. Cl also regulates stomata opening and closing and improves enzyme activity and plant disease resistance. However, excessive Cl can cause imbalances in enzyme activities, inhibit nutrient absorption, and reduce the chloroplast content and photosynthetic capacity. Cl toxicity not only reduces the quality of agricultural products but can also severely reduce crop yields (Greenway and Munns, 1980; White and Broadley, 2001).

In this study, the yields and nutrient quality (Vc, soluble sugar, soluble protein, and allicin) of garlic bulbs were significantly lower with an excessive application of KCl fertilizer (Fig. 4; Table 2). Furthermore, the accumulation of nitrate was greatly increased following the excessive KCl fertilizer (Table 2). Previous studies also identified the effects of K_2SO_4 on garlic were more consistent than KCl, and there are risks of excessive use of KCl in the field. However, as the conservative use of KCl fertilizer will not only not reduce the potential harm to crops and the environment but also promote growth and increased yields.

The present investigation revealed that the application of K_2SO_4 in isolation was not optimal, and that the ratio of the bulb N, P, and K nutrients yields and nutritional quality peaked when K_2SO_4 :KCl = 3:1. We also identified the economic benefits of fertilizer application also peaked when the proportion of K_2SO_4 was 63.9% (Fig. 6B). Potato (Khan et al., 2012), ginger (Haque et al., 2007), and other crops fertilized with an optimized combination of K_2SO_4 and KCl can not only promote the synthesis of crop proteins, starch,

and chlorophyll, but also improve their capacities for photosynthesis and stress resistance, to ultimately improve crop yields and quality (Iqbai et al., 2015).

Conclusion

The application of K fertilizer promoted the transfer of N, P, and K nutrients from the stem and leaf to the bulb, increasing the garlic production. In addition, K fertilization improved the nutritional quality and apparent character of the garlic bulbs. The application of KCl or K_2SO_4 alone did not attain optimal yields, whereas the combination of KCl and K_2SO_4 enhanced the garlic yields and quality, reduced fertilizer input costs, and achieved maximum economic benefits. We recommend for the optimum primary garlic production in these regions, K should be applied at a rate of $252.5 \text{ kg} \cdot \text{ha}^{-1} \text{ K}_2\text{O}$, with K_2SO_4 accounting for 61.6%.

Literature Cited

- Abou El-Nasr, M.E. and E.A. Ibrahim. 2011. Effect of different potassium fertilizer rates and foliar application with some sources of potassium on growth, yield and quality of carrot plants (*Daucus carota* L.). J. Plant Prod. 2:559–569, <https://doi.org/10.21608/jpp.2011.85591>.
- Ashley, M.K. and M.G. Grabov. 2006. Plant responses to potassium deficiencies: A role for potassium transport proteins. J. Expt. Bot. 57:425–436, <https://doi.org/10.1093/jxb/eri034>.
- Bian, Z., Y. Wang, X. Zhang, T. Li, S. Grundy, and Q. Yang. 2020. A review of environmental effects on nitrate accumulation in leafy vegetables grown in controlled environments. Foods 9:732, <https://doi.org/10.3390/foods9060732>.
- Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal. Biochem. 72:248–254, [https://doi.org/10.1016/0003-2697\(76\)90527-3](https://doi.org/10.1016/0003-2697(76)90527-3).
- Chandra, N. and N. Pandey. 2013. Effect of sulfur on the growth, dry matter, tissue sulfur and carbohydrate concentration of *Allium sativum* L. and *Allium cepa* L. Indian J. Agr. Biochem. 26:182–186.
- Cheng, B., H.F. Lian, S.Q. Liu, H.P. Guo, and Y.L. Sun. 2015. Effects of sulfur and selenium combination fertilizing on the growth, quality and antioxidant ability of allium sativum during senescence. Plant Physiol. J. 51:44–50, <https://doi.org/10.13592/j.cnki.pj.2014.0414>.
- Danbature, W.L., F.F. Yirankinyuki, B. Magaji, and Z. Ibrahim. 2015. Comparative determination of vitamin C and iron in ten (10) locally consumed fruits in Gombe State, Nigeria. Int. J. Adv. Res. Chem. Sci. 2:14–18.
- Dennison, R.A. and B.E. Janes. 2015. Quality of vegetables as related to fertilizer materials with emphasis on potash salts. Auk 130:21–29, <https://doi.org/10.1525/auk.2012.12006>.
- Diriba, S.G., D.R. Nigussie, K. Woldetsadik, G. Tabor, and J.J. Sharma. 2015. Effect of nitrogen, phosphorus, and sulphur fertilizers on growth yield, and economic returns of garlic (*Allium sativum*). Sci. Technol. Arts Res. J. 4:10–22, <https://doi.org/10.4314/star.v4i2.2>.
- El-Nasr, M.A. and E. Ibrahim. 2011. Effect of different potassium fertilizer rates and foliar application with some sources of potassium on growth, yield and quality of carrot plants (*Daucus carota* L.). J. Plant Prod. 2:559–569, <https://doi.org/10.21608/jpp.2011.85591>.
- Elosta, A., M. Slevin, K. Rahman, and N. Ahmed. 2017. Aged garlic has more potent antiglycation and antioxidant properties compared to fresh garlic extract in vitro. Sci. Rep. 7:39613, <https://doi.org/10.1038/srep39613>.
- Farahani, S., N. Shahsavari, and M.M. Arasteh. 2020. Effect of potassium sulfate on the physiological characteristics of canola cultivars in late season drought stress conditions. J. Plant Nutr. 43:1–12, <https://doi.org/10.1080/01904167.2020.1727507>.
- Greenway, H. and R.A. Munns. 1980. Mechanisms of salt tolerance in nonhalophytes. Annu. Rev. Plant Physiol. 31:149–190, <https://doi.org/10.1146/annurev.pp.31.060180.001053>.
- Haque, M.M., A.K.M.M. Rahman, M. Ahmed, M.M. Masud, and M.M.R. Sarker. 2007. Effect of nitrogen and potassium on the yield and quality of ginger in hill slope. J. Soil Nat. 1:36–39.
- Harris, J.C., S.L. Cottrell, S. Plummer, and D. Lloyd. 2001. Antimicrobial properties of allium sativum (garlic). Appl. Microbiol. Biotechnol. 57:282–286, <https://doi.org/10.1007/s002530100722>.
- He, P., L. Yang, X. Xu, S. Zhao, F. Chen, and S. Li. 2015. Temporal and spatial variation of soil available potassium in china (1990–2012). Field Crops Res. 173:49–56, <https://doi.org/10.1016/j.fcr.2015.01.003>.
- Huu Nguyen, H., S. Maneepong, and P. Suraninpong. 2017. Effects of potassium, calcium, and magnesium ratios in soil on their uptake and fruit quality of pummelo. J. Agr. Sci. 9:110, <https://doi.org/10.5539/jas.v9n12p110>.
- Iqbai, A., A. Amanuiiah, and M. Iqbai. 2015. Impact of potassium rates and their application time on dry matter partitioning, biomass and harvest index of maize (*Zea mays*) with and without cattle dung application. Emir. J. Food Agr. 27:447–453, <https://doi.org/10.9755/ejfa.2015.04.042>.
- Jackson, G. D. 2000. Effects of nitrogen and sulfur on canola yield and nutrient uptake. Agron. J. 92:644–649, <https://doi.org/10.2134/agronj2000.924644x>.
- Jiku, M.A.S., M. Alimuzzaman, A. Singha, M.A. Rahaman, and S.R. Sinha. 2020. Response and productivity of garlic (*Allium sativum*) by different levels of potassium fertilizer in farm soils. Bull. Natl. Res. Cent. 44:9, <https://doi.org/10.1186/s42269-020-0267-7>.
- Kamel, A. and M. Saleh. 2000. Recent studied on the chemistry and biological activities of the organosulfur compounds of garlic (*Allium sativum*). Stud. Nat. Prod. Chem. 23:455–485, [https://doi.org/10.1016/S1572-5995\(00\)80135-0](https://doi.org/10.1016/S1572-5995(00)80135-0).
- Katovich, V., F. Thabtah, and C. Day. 2018. Potash fertilizer to agricultural based economies. Int. J. Agr. Manage. 6:123–130, <https://doi.org/10.5836/ijam/2017-06-123>.
- Khan, M.Z., M.E. Akhtar, M. Mahmood-Ul-Hassan, M.M. Mahmood, and M.N. Safdar. 2012. Potato tuber yield and quality as affected by rates and sources of potassium fertilizer. J. Plant Nutr. 35:664–677, <https://doi.org/10.1080/01904167.2012.653072>.
- Kumar, A.R. and N. Kumar. 2008. Studies on the efficacy of sulfate of potash on physiological, yield and quality parameters of Banana cv. Robusta (Cavendish-AAA). EurAsian J. BioSci. 2:102–109.
- Li, Y.T., W.B. Liu, X.Z. Liu, M. Zhang, Y.H. Wang, W. Zhang, and X.L. Gao. 2019. Effects of abundance and deficiency of nitrogen, phosphorus and potassium fertilizers on yield and

- nPK utilization efficiency of garlic (In Chinese). Shandong Agr. Sci. 51:106–168.
- Liu, Z.L., S.Q. Liu, and Z.K. Zhang. 2010. Effects of sulfur on physiological characteristics and main mineral elements absorption in garlic (In Chinese). China Vegetables 10:46–50, <https://doi.org/10.1016/j.cognition.2011.01.014>.
- Milford, G. F. J., M. J. Armstrong, P. J. Jarvis, B. J. Houghton, D. M. Bellett-Travers, and J. Jones. 2000. Effect of potassium fertilizer on the yield, quality and potassium offtake of sugar beet crops grown on soils of different potassium status. J. Agr. Sci. 1:1–10, <https://doi.org/10.1017/s0021859699007881>.
- Munir, A., M.T. Shehzad, A.A. Qadir, G. Murtaza, and H.I. Khalid. 2019. Use of potassium fertilization to ameliorate the adverse effects of saline-sodic stress condition (EC w: SAR w levels) in rice (*Oryza Sativa* L.). Commun. Soil Sci. Plant Anal. 50:1–11, <https://doi.org/10.1080/00103624.2019.1648657>.
- Patricia, P., H.C. Maria, S.A.S. De, S.V.S.N. Da, and P.M.T. Bertoldo. 2014. Evaluation of allicin stability in processed garlic of different cultivars. Food Sci. Technol. (Campinas) 34:623–628.
- Priyanka, S., K.S. Manish, R.B. Younus, and R.N. Gokul. 2018. A review on spectroscopic methods for determination of nitrite and nitrate in environmental samples. Talanta 191:364–381, <https://doi.org/10.1016/j.talanta.2018.08.028>.
- Santos, L.P.D.D., M.L.P. Cunha, J.M. Clemente, and T.F. Oliveira. 2016. Recovery efficiencies of nitrogen, phosphorus and potassium of the garlic crop. J. Plant Nutr. 40:624–631, <https://doi.org/10.1080/01904167.2016.1240201>.
- Shafeek, M.R., M.K. Hassan Nagwa, S.M. Singer, and N.H.M. El-Greadly. 2013. Effect of potassium fertilizer and foliar spraying with Etherel on plant development, yield and bulb quality of onion plants (*Allium cepa* L.). J. Appl. Sci. Res. 9:1140–1146.
- Soliman, S.S., A.I. Alebidi, R.S. Al-Obeed, and A.M. Al-Saif. 2018. Effect of potassium fertilizer on fruit quality and mineral composition of fig (*Ficus carica* L. cv. Brown Turkey). Pak. J. Bot. 50:1753–1758.
- Sung, S.Y., L.T. Sin, T.T. Tee, S.T. Bee, and W.A.W.A. Rahman. 2014. Control of bacteria growth on ready-to-eat beef loaves by antimicrobial plastic packaging incorporated with garlic oil. Food Control 39:214–221, <https://doi.org/10.1016/j.foodcont.2013.11.020>.
- Vann, M.C., L.R. Fisher, D.L. Jordan, S.W. David, D.H. Hardy, and A.M. Stewart. 2013. Potassium rate and application effect on flue-cured tobacco. Agron. J. 105:304–310, <https://doi.org/10.2134/agronj2012.0259>.
- Wang, M., Q.S. Zheng, and Q.R. Shen. 2013. The critical role of potassium in plant stress response. Int. J. Mol. Sci. 14:7370–7390, <https://doi.org/10.3390/ijms14047370>.
- White, P.J. and M.R. Broadley. 2001. Chloride in soils and its uptake and movement within the plant: A review. Ann. Bot. 6:967–988, <https://doi.org/10.1006/anbo.2001.1540>.
- Zaman, M., M. Hashem, M. Jahiruddin, and M. Rahim. 2012. Effect of sulphur fertilization on the growth and yield of garlic (*Allium sativum* L.). Bangl. J. Agr. Res. 36:647–656, <https://doi.org/10.3329/bjar.v36i4.11751>.
- Zhang, S.W., Y.j. Zong, and C.Y. Fang. 2020. Optimization of anthrone colorimetric method for rapid determination of soluble sugar in barley leaves. Food Res. Dev. 41:196–200.