Movement and transformation of potassium in fertiliser micro-sites in latosol

Y D He¹,², X B Cui³, L X Wang¹,², Y X Liu¹,², T Jing¹,² and B Z Wang¹,²,⁴

¹ Haikou Experimental Station, Chinese Academy of Tropical Agricultural Sciences, Haikou 570102, China
² Hainan Key Laboratory of Banana Genetic Improvement, Haikou, 570102, China
³ Environment and Plant Protection College, Hainan University, Haikou 570228, China

E-mail: 13807615366@163.com

Abstract: A soil column method was used to analyse the characteristics of the movement and transformation of potassium (K) in a latosol. The internal temperature was maintained at 28 to 30 °C. The distances moved by the added K were 50 to 100 mm after 7 and 28 d, respectively. Potassium moved faster within 7 d during the incubation time of 28 d. The concentrations of water-extractable K, and exchangeable K, had significant negative linear relationships with distance from fertiliser placement in the region of K movement. In incubation time, water-extractable K and exchangeable K had significant effects on the concentration distributions for fertiliser micro-sites, but had no significant effects on non-exchangeable K. Most of K was still in an available form at fertiliser micro-sites after moving into the soil except that 4.22% to 11.19% of all applied K was fixed by soil.

1. Introduction

Potassium (K) is one of the three essential factors in plant growing. The amount of potassium necessary for plant growth is matched with nitrogen, and higher than phosphorus [1]. A deficiency of potassium causes a severe reduction in crop yield, and crop quality, and reduces the effectiveness of other inputs. In recent years, crops have removed more K from the soil with the expansion in the number of varieties of high-yield crops, increases in multiple cropping indices, and the development of more intensive agriculture. This causes increasing potassium deficient soil areas to appear: soil potassium depletion is becoming increasingly serious [2]. Potassium fertiliser application is an
important way of alleviating this soil potassium deficit. China, the world’s top consumer of potash fertiliser, is deficient in raw potash resources. Potash supply is realised by imports given China’s less developed potash industry [3]. Plants can attain their full potential by improving the utilisation of potassium in this kind of situation. So an accurate assessment of the supply of potassium to different soils, and guidelines for rational fertilisation, are becoming more important. In order to improve utilization efficiency of K fertilisers, the investigation not only the amounts of different K fractions that other fertilisers may have on the K balance in soils, but also the movement and transformation of K in soils were required.

Most researchers have focused on leaching and transporting potassium in field experiments. However, there is little research available which examines the diffusion and transformation of potassium in fertiliser micro-sites. Dong Yuanyan studied the transport and diffusive coefficients of phosphate and potassium in red soils by using a soil column method, which did not involve the effectiveness and distribution of K, when KH₂PO₄ is applied [4]. The movement and transformation of K in fertiliser micro-sites in fluvo-aquatic soil and red earth were investigated through an incubation experiment using a soil column by Zhenyu Du and Jianmin Zhou when KCl was applied [5,6]. There have been no reports on the diffusion and transformation of potassium in latosols in Hainan, China, to date. To provide support for scientific management and to guide a rational use of fertiliser, for this study try to provide novel insight into the effects of the application of low (0.2 g) and high (0.5 g) concentrations of K₂SO₄ on the K⁺ movement and transformation profile at 7 and 28 d in a latosol, by using a laboratory experiment in soil column.

2. Materials and methods

2.1. The condition of test point

The soil (litosol) used in this study was calcareous, and belonged to those Ustic Argosoils according to the Chinese soil classification system, and was approximately equivalent to a luvisol in the FAOUNESCO system. The soil sample was obtained from the top 15 cm of a cultivated layer in a field located near Chengmai city, Hainan Province, China (N 19° 56´ 22.71˝, E 109° 54´ 06.33˝). The soil texture was silt loam, and some selected chemical and physical properties index were as follows: organic matter content 17.4 g/kg, pH 5.42, hydrolysed nitrogen 62.7 mg/kg, effective phosphorus 16.69 mg/kg, and available potassium 11 mg/kg. After removing visible plant residues, stones, and other material, when the soil was air-dried, ground to pass a 0.9mm aperture sieve of soil. The K fertiliser used in this study was an analytically pure grade of K₂SO₄, which had been the soil before being used in these experiments.

2.2. Methods

Laboratory soil column experiments were conducted to evaluate the movement and transformation of potassium in fertiliser micro-sites. The wax columns (Patent No: zl201320728057.4), 150 mm in height with a cylindrical cavity have an internal diameter of 50 mm were used for soil incubation [7]. It was use that jelly melted and mixed to make the wax column was 2:1(Two parts of paraffin wax,1 part petroleum). Two pieces of filter paper were used to close the bottom of the wax column: the 360 g.
of soil was packed into each column to obtain a final bulk density of 1.22 g/cm$^3$. One filter paper (approximately 49 mm in diameter) was placed on the soil surface to separate the soil from the fertiliser, and to ensure that the fertiliser solution could be evenly spread over the soil. The packed soil columns were placed vertically on the fine sand disc, and become wetted by capillary rise to a moisture content of 401 g/kg. After abandoning a filter papers covering the bottom, the top and bottom of the packed wax blocks prevent moisture lose that were covered with plastic film. The packed wax blocks were allowed to equilibrate for 48 h at 25 °C before K treatments were applied.

The K fertiliser treatments were 0.2 g and 0.5 g of K$_2$SO$_4$, respectively. The K fertilisers were added at a rate of 0.09 g and 0.224 g per column, respectively. Which were equivalent to the addition of 55 kg K$_2$O hm$^{-2}$ and 138 kg K$_2$O hm$^{-2}$ in field, respectively. Along one side of crop rows spaced 45 cm apart. This application device was intended to simulate field conditions similar to those near fertiliser granules or banding. A soil column with application of K was used as the control trial. Different incubation times (1 w and 4 w) were also used for two different K concentration treatments, respectively. Three replicates were used in a completely randomised design for experiment. The wax blocks were covered, then incubated vertically condition at 28 °C. After 1 w or 4 w, the filter paper on the soil cylinder was removed for K analysis to evaluate the amount of K retained. It use for blade to cut the cylinder into 30 slices, 5 mm thick.

Soil samples of each slice were analysed to find the concentrations of different potassium, and soil moisture.

Water-soluble K (WSK) was determined as follow: 1.8 g of soil, which was equivalent to 1 g of water-free soil, and 10 mL distilled water were added to 50 mL centrifuge tube and shaken on a reciprocating shaker at 25 °C , and 30 min. The mixture was centrifuged for 10 min, and the suspension was separated and the K concentration in the solution was determined by flame spectrometry.

Exchangeable K (EK) was extracted from 1.8 g of soil, 10ml of 1 M ammonium acetate solution at pH 7.0 in 50 mL centrifuge tubes and shaken at 25 °C for 1 h [8]. The mixture was centrifuged for 10 min, the suspension separated and the K$^+$ concentration in the solution was determined by flame spectrometry. it is difference that between WSK and the NH$_4$OAc-extracted for K Exchangeable calculated.

Non-exchangeable K (NEK) was determined as follow: 1.8 g of soil, and 10 mL of 1M HNO$_3$ were mixed in glass beaker (which was covered with a watch glass, size 250 mL). The mixture was boiled for 10 min, filtered, and then made up to 100 mL. The K$^+$ concentration was determined by flame spectrometry. NEK was calculated by subtracting the K extracted with NH$_4$OAc from that extracted with HNO$_3$ method [9].

All results presented were the means of three replicates. The statistical analysis of the data was based on MS-Excel™ 2003 and SAS 9.1 software.

3. Results and discussion

3.1. Movement of K and water-soluble K in fertiliser micro-sites in a latosol

Water-soluble K is the available potassium in a soil solution that is immediately available to plants and is potentially subject to leaching. The amount of WSK should dependent on the equilibrium among the
different forms of K in the soil and the application, or removal of K from the soil. Keeping the balance of WSK should be dependent on soil properties such as pH, CEC, clay mineralogy, and could be influenced by the alteration of ion concentrations in soil solution and the total concentration of soluble anions.

The depths of K movement can be slightly changed by the concentration of fertiliser applied: here they were 50 mm (for 0.2 g K$_2$SO$_4$) and 55 mm (for 0.5 g K$_2$SO$_4$) after 1 w, and 80 mm (for 0.2 g K$_2$SO$_4$) and 100 mm (for 0.5 g K$_2$SO$_4$) after 4 w (Fig. 1). The migration rate of K in earlier stages was faster than in later stages. This was because the potassium content in earlier stage was higher. When the soil water content was 150 g/kg and its bulk density was 1.60 g cm$^{-3}$, the distances moved by the added K were 18 to 34 mm after three to 14 d in red soil, according to Dong et al. [4] The movement and transformation of K in fertiliser micro-sites on a red soil were studied through an incubation experiment using a soil column. When the soil water content was 370 g·kg$^{-1}$ and bulk density was 1122 g cm$^{-3}$, the distances moved by the added K were 60 to 110 mm after 7 d and 28 d [5]. There were large differences between the results in the two different experiments, possibly because the physico-chemical properties of the soil were different.

The concentration of WSK contained in soil section gradually decreased with increasing distance from the fertiliser application site (Figure 1). It showed a negative linear relationship between the contents of water-soluble K and distance (Table 1). The concentration of WSK, cultivated for 1 w, was higher than that when cultivated for 4 w at 0 to 30 mm distance in the soil column. At distances greater than 30 mm, the results were the opposite. This showed that the WSK was migrating downwards at between 1 w and 4 w.

![Figure 1. The water-extracted potassium content in the soil sample.](image-url)
To analyse the effects of fertilisation and cultivation time on the water-soluble potassium content distribution, we used a linear best-fit between the water-soluble potassium contents produced by the four treatments and distance: analysis of variance and multiple comparisons were then used to find the coefficients of the regression equation. The results showed that water-soluble potassium content decreased with distance from the point of fertilisation under high fertiliser doses; meanwhile, the rate of decline \( (b_1) \) was significantly increased (Table 1). For the same amount of fertilisation, the rate of decline at 7 d was bigger than that at 28 d. The intercept \( (b_0) \) and regression coefficient \( (b_1) \) of the four regression equations were significantly different. This showed that the amount of fertiliser and time affected the distribution of water-soluble potassium content at fertiliser micro-sites.

### Table 1. The relationship between the water-soluble K \((y, \text{mg/kg})\) and the depth \((x, \text{mm})\) was determined by one-dimensional linear regression \((y = b_0 + b_1x)\).

| Amount of K\(_2\)SO\(_4\) (g) | Incubation time (w) | Regression coefficient |  
|-----------------------------|---------------------|------------------------|
|                             |                     | \(b_0\)     | \(b_1\)     | \(R^2\) |
| 0.2                         | 1                   | 1160.13     | -25.38      | 0.963** |
| 0.2                         | 4                   | 610.5       | -7.94       | 0.949** |
| 0.5                         | 1                   | 2344.78     | -45.65      | 0.980** |
| 0.5                         | 4                   | 1314.56     | -14.01      | 0.986** |

Notes: Different lower case letters indicate significant liming effects at a 0.05 probability level; ** stands for very significant \((P < 0.01)\).

3.2. The content distribution of exchangeable K at fertiliser micro-sites in a latosol

Exchangeable K is the total K adsorbed by the organic matter, or clay minerals that can easily be exchanged with other cations. The distribution pattern of exchangeable K is the same as that of water-soluble K. From Figure 2, it was seen that the exchangeable K content gradually decreased with increasing distance. It showed a negative linear relationship between the exchangeable K contents and distance (Table 2). The results showed that exchangeable K content increased as the distance from the point of fertilisation decreased: the rate of decline \( (b_1) \) was also significantly increased: when the amount of fertiliser was the same, the rate of decline at 7 d was bigger than that at 28 d. The intercept \( (b_0) \) and regression coefficient \( (b_1) \) of the four regression equations were markedly different. This showed that the amount of fertiliser and application time on the distribution of exchangeable K content were significantly affected at such fertiliser micro-sites.
Figure 2. The exchangeable K content in the soil sample.

Table 2. The relationship between the exchangeable K \((y, \text{mg/kg})\) and depth \((x, \text{mm})\) was determined by one-dimensional linear regression \((y = b_0 + b_1x)\).

| Amount of K\(_2\)SO\(_4\) (g) | Incubation time (w) | Regression coefficient | \(R^2\) |
|-------------------------------|---------------------|------------------------|---------|
| 0.2                           | 1                   | 563.69                 | -10.67  | 0.965** |
| 0.2                           | 4                   | 403.69                 | -5.14   | 0.940** |
| 0.5                           | 1                   | 1353.84                | -27.56  | 0.958** |
| 0.5                           | 4                   | 606.78                 | -5.69   | 0.832** |

Notes: Different lower case letters indicate significant limiting effects at a 0.05 probability level; ** represents very significant \((P < 0.01)\).

3.3. The content distribution of non-exchangeable K at fertilizer micro-sites in a latosoll

Figure 3 showed that the non-exchangeable K contents gradually decreased with soil depth. There was no significant difference in transfer volume of non-exchangeable K under different treatment times at these fertiliser micro-sites. Rate of fertiliser addition was another important factor affecting potassium fixation in latosols. The NEK contents of treatments subjected to the addition of added 0.5 g K\(_2\)SO\(_4\), under the same conditions, was higher than that when adding 0.2 g. The latosol had a lower ability to fix potassium (albeit with local, micro-regional differences therein).
3.4. The migration of different forms of K at fertiliser micro-sites in a latosol

When 0.2 g of K was applied, the migration distance was 50 mm after 1 w. The average forward speed was 7.14 mm/d. The distance moved by the K was 80 mm after 4 w. The average forward speed was 1.43 mm/d in the final 3 weeks. The average forward speed in the first week was over five times faster than in the final three weeks. The migration distance of K, when applying 0.5 g, was 55 mm after 1 w. The average speed of its movement was 7.86 mm/d. The migration distance of K was 100 mm after 4 w and its average forward speed was 2.14 mm/d in the final three weeks. The average speed in the first week was over four times faster than the final three weeks, thus it can be seen that potassium moved faster within the first 7 d of the 28 d incubation period.

From Table 4, the recovery rate of K was between 97.1% and 101.1% due to possible errors and over-extraction of chemically bound K in the soil’s structure. Recycled K was used in lower amounts than would otherwise have been the case.

**Table 3.** The migration of K fertilisers at fertiliser micro-sites in a latosol.

| Amount of K2SO4 (g) | Incubation time (d) | Migration amount (mg) |
|---------------------|---------------------|-----------------------|
|                     |                     | WSK       | EK      | NEK      | available K | TK       |
| 0.2                 | 7d                  | 55.45b    | 30.43a  | 3.78a    | 85.88a      | 89.66a   |
| 0.2                 | 28d                 | 50.79d    | 34.79a  | 5.17a    | 85.57a      | 90.75a   |
| 0.5                 | 7d                  | 128.75a   | 68.23b  | 17.65b   | 196.98b     | 217.42b  |
| 0.5                 | 28d                 | 130.71c   | 71.66b  | 25.51b   | 202.37b     | 227.88b  |
Different lower case letters indicate significant limiting effects at a 0.05 probability level.

One week later, 34.21 mg (38.16%) and 88.67 mg (40.78%) of K was transformed into other forms with K doses of 0.2 g and 0.5 g, respectively. After 4 w, there were 39.96 mg (44.03%) and 97.17 mg (42.64%) of K, respectively, which had transformed into other forms thus proving that the rate of movement of K and the inversion quantity and transformation rate were significantly improved by extending the diffusion time. Along with the rise of fertiliser dose, the rate of movement of K and the inversion quantity were significantly increased (albeit the rule governing the transformation rate was not obvious).

4. Conclusions
Fertiliser has a significant impact on the various forms of potassium migration volume. The internal temperatures remained at between 28 and 30 °C. The distances moved by the added K were 50 to 100 mm after 7 d and 28 d. Potassium moved faster within the first 7 d of the 28 d incubation time. The average forward speed in the first week was over four to five times faster than in the final three weeks.

The balance between WSK and EK finished instantaneously, but the balance between EK and NEK finished slowly [10]. Most of the K was still in an available form (89.24% to 95.78%) at these fertiliser micro-sites after moving into the soil except that 4.22% to 11.19% of the applied K was fixed by the soil. About 40% of the K was transformed into other forms in all treatments.

EK and WSK showed similar distribution patterns. The concentrations had significant negative linear relationships with distance from fertiliser placement in the region of K movement.

Both K application amount, and incubation time, had significant effects on the concentration distributions of WSK and EK in fertiliser micro-sites. With extended diffusion time, the rate of movement of K, the inversion quantity, and the transformation rate were significantly improved. Along with increased dose, the rate of movement of K and the inversion quantity were significantly improved (albeit the changing trend of the rate of transformation was not obvious).

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