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Biotransformation of Earthworm Activity on Potassium-Bearing Mineral Powder

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ABSTRACT: This study analyzes the biotransformation of earthworms on K in potassium-bearing mineral powder (PBMP) under different PBMP recruitments. A mixture of PBMP (10% to 60% mass fraction) and decaying cow dung was used as feed for breeding the earthworms to study the potassium-releasing ability of earthworms on PBMP in soil. The mixture containing 20% and 30% PBMP resulted in good growth and propagation of the earthworms as well as higher conversion rates of potassium. Therefore, the optimum recruitments of mineral powder are 20% and 30%. The mixture of cow dung and PBMP was compared with the mixture of cow dung and corresponding proportions of quartz powder to analyze the conversion rate of earthworms on PBMP in different combinations. After the earthworms were raised with the mixture of cow dung and PBMP (8 : 2 and 7 : 3) for 30 d, the contents of rapidly available K and effective K were 10 824.3±35.9 and 11 688.4±16.1 mg·kg^{-1} as well as 10 079.6±62.2 and 10 247.5±172.7 mg·kg^{-1}, respectively. After the earthworms were raised with the mixture of cow dung and quartz powder (8 : 2 and 7 : 3) for 30 d, the contents of rapidly available K and effective K were 10 623.3±41.1 and 11 385.5±13.5 mg·kg^{-1} as well as 9 834.2±51.8 and 9 907.6±11.4 mg·kg^{-1}, respectively. Thus, the contents of rapidly available K and effective K in the mixture of cow dung and PBMP were significantly higher compared with those in the mixture of cow dung and quartz

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powder (P<0.05). The increment contents of rapidly available K and effective K were 201.0 and 302.9 mg·kg^{-1} as well as 245.4 and 339.9 mg·kg^{-1}, respectively. Therefore, earthworms can activate and trans-form K into effective K through feeding, digestion, absorption, and excretion. The results provided a new idea of using earthworms to release potassium in low-grade potassium-bearing rocks and obtain the rapidly available K and effective K needed by plants.

KEY WORDS: earthworm, potassium-bearing mineral powder, mineral K, rapidly available K, effective K, activation.

INTRODUCTION

Potassium is one of the nutrient elements essential for plant growth and metabolism (Chen et al., 2011; Zhang et al., 2011; Huang and Jing, 1995). Soil is the main source of potassium in plants. However, potassium in soil has different forms and thus exhibits different effectiveness. In terms of effectiveness, potassium in soil can be divided into the mineral K, slowly available K, rapidly available K, and water soluble K. Rapidly available K is the main indicator of the seasonal potassium-supplying capacity of soils, which usually accounts for 0.05% to 0.15% of the total amount of potassium in soil. Slowly available K is an indicator of the potassium-supplying potential of soils (Xie and Zhou, 1999). Effective K is the sum of rapidly available K and slowly available K. Therefore, the content of effective K in soils reflects the potassium-supplying ability of soils (Bao, 2000). Since the 1980s, potassium deficiency in soils has been intensified in China (Xie and Zhou, 1999), and soluble potassium fertilizer are mainly obtained from imports because of scarcity in such ore resources. The discovery of other potassium sources is important because of the large imbalance in the production and demand of potash fertilizer in the world, as well as the monopoly in international potassium ore resources (Manning, 2010; Sun et al., 2009).

Low-grade potassium-bearing rocks are widely distributed in China, India, and other countries where potassium is extremely deficient. Insoluble K cannot be directly absorbed by plants. However, certain processing and conversion methods can activate part of K. Therefore, the development and utilization of these low-grade potassium-bearing rock resources as potassium fertilizer has become an important issue in several countries. The physical and chemical methods employed to produce potassium fertilizer using potassium-bearing rocks are mainly divided into three categories: direct crushing, high-temperature calcinations, and wet chemical methods (Lian, 2011; Wang et al., 2010). However, the long process flows, huge investment, high cost, more tailings, poor economic efficiency, and environmental pollution associated with these technologies prevent their industrial use. Researchers have paid more attention on biological methods because of their low cost, low energy consumption, and environmental-friendly features. The current biotransformation methods of potassium-bearing minerals include the activation of microorganisms (Xiao et al., 2012a, b; Basak and Biswas, 2010, 2009; Liu et al., 2006), the direct activation of plants (Wang H Y et al., 2011; Wu et al., 2011; Wang J G et al., 2000a), and the activation of organic acids (Wang and Duan, 2004; Wang J G et al., 2000b).

To date, no study has reported on the use of soil animals for the activation and release of K. However, several studies (Amador et al., 2003; Li et al., 2002; Helling and Larink, 1998; Blair et al., 1997; Subler et al., 1997; Basker et al., 1992) have shown that earthworm activity affects the physical and chemical properties as well as the fertility status of soils. Earthworm activity can also promote organic matter decomposition and nitrogen mineralization in soils and expand the microbial biomass, which is helpful in the transformation of phosphorus and potassium into effective phosphorus and potassium to improve the nutrient content and fertility of soils. Liu et al. (2011) studied the degradation of potassium rock by earthworms and the responses of bacterial communities in their guts and surrounding substrates after being fed with mineral. Their results indicated that earthworms can accelerate the degradation of silicate. In addition, earthworms play important roles in ecosystem processes. They elicit positive effects on soil structure and promote nutrient cycling by enhancing mineral weathering. These results prove that earthworms could be used to activate K in potassium-bearing mineral powder (PBMP). However, systematic research and quantitative analysis on the ability of earthworms to transform and release potassium from potassium-bearing minerals are still lacking.

This study aims to broaden the channels of the biotransformation of K and quantitatively analyze the effect of earthworm activity on this transformation. A mixture of PBMP and different proportions of cow dung was used as feed for earthworms to explore their biotransformation of K in PBMP. The results of this study may provide more data and scientific basis for the feasibility and practical application of using earthworms in activating K in soil.

MATERIALS AND METHODS

Materials

Earthworm

Earthworms (*Eisenia foetida*) or "Ohira II" from the family Lumbricidae was purchased from the breeding base in Yangchang dairy farm, Guiyang. Healthy adult earthworms with clear clitellum and well-balanced growth vigor (weight: 300 to 400 mg; length: 50 to 70 mm) were used in the experiments.

Potassium-bearing mineral powder

Potassium-bearing minerals collected from Fuquan in Guizhou Province were ground into powders using a grinder (PCS0808, China). The powders were filtered through 100 mesh sieves and will be used as substrate for earthworm feed. X-ray fluorescence analysis revealed that the PBMP is composed of the following chemical compounds in weight percent: K_2O (9.29%), SiO_2 (54.14%), Al_2O_3 (17.25%), Fe_2O_3 (4.8%), MgO (3.96%), CaO (3.26%), Na_2O (0.16%), and others (7.14%). X-ray diffraction analysis demonstrated that the PBMP is composed of the following minerals: K-feldspar (75.52%), mica (9.25%), dolomite (7.15%), montmorillonite (4.10%), kaolinite (3.46%), and hornblende (0.52%).

Cow dung

Cow dung samples collected from the Yangchang dairy farm were pretreated through compost fermentation for one month. The basic chemical properties of the decomposed cow dung are shown in Table 1.

Table 1 Basic chemical properties of decomposed cow dung

Material	pH	Total N (%)	Total P (%)	Total K (%)	Effective P ($g·kg^{-1}$)	Effective K ($g·kg^{-1}$)	Rapidly available K ($g·kg^{-1}$)
Decomposed cow dung	8.54	1.540	0.92	1.77	1.64	14.56	13.09

Quartz powder

The particle size of quartz powder (CP, Hunan Xiangzhong Institute of Geological Experiment) is 0.15 mm (100 mesh). A mixture of quartz powder and different proportions of cow dung was considered as the test control in feeding the earthworms.

Methods

Selecting the recruitments of PBMP

The experiment set up eight treatments with two duplicates, producing a total of 16 containers. The total dry weight of each feed was 1 kg. The mass percentages of the additive PBMP are as follows: 0 (group A), 10% (group B), 20% (group C), 30% (group D), 40% (group E), 50% (group F), and 60% (group G). A control group was also set (group H). The feed formulation for each group is shown in Table 2. The test vessel is a 35 cm × 25 cm × 20 cm carton with a layer of plastic film at the bottom to prevent feed nutrient loss and earthworm escape. The feed was placed into the carton after being uniformly mixed, and 100 uniformly sized earthworms were inoculated in each group (no earthworms were added in the control group). Moisture content and temperature were

Table 2 Feed formulation for the earthworms

Material	Group							
	A	B	C	D	E	F	G	H
Potassium-bearing mineral powder (%)	0	10	20	30	40	50	60	0
Cow dung (%)	100	90	80	70	60	50	40	100

controlled at approximately 70% and 25 ℃, respectively. The earthworms were raised for 50 d in a dark room.

The feed mixture was sampled thrice every 14 d (i.e., after 14, 28, and 42 d of growth). The sample was uniformly mixed, and then multi-point samplings were conducted. The samples were air-dried, ground, and then filtered through 60 mesh sieves. The contents of effective K and rapidly available K were then determined (see Sample analysis).

The daily growth weight adding (DGWA) rate and the daily propagation adding (DPA) rate of the earthworms were measured every 10 d (i.e., after 10, 20, 30, 40, and 50 d of growth) (Li et al., 2004). Adult earthworms, earthworm eggs, and young earthworms were carefully selected and counted. The adult earthworms were weighed. The DGWA and DPA rates of the earthworms were calculated through the following formula to select the more appropriate PBMP recruitments.

DGWA rate=(total weight after being raised for a certain period–initial weight)/initial weight×raising days.

DPA rate=(total number of articles after being raised for a certain period-initial number of articles)/initial number of articles×raising days.

In the above formulas, the total number of earthworms includes adult earthworms, young earthworms, and earthworm eggs, in which an earthworm egg represents three earthworms because an earthworm Ohira II egg can hatch 2 to 7 earthworms (Pan, 2009).

Transformation amount of PBMP

After selecting the appropriate PBMP recruitment (i.e., 20% and 30% or 8 : 2 and 7 : 3 cow dung-to-PBMP ratios, respectively), four treatments and two replicates were set up, yielding a total of eight containers. The total dry weight of each container was 50 g, and the feed formulation was as follows: ① 80% cow dung+20% PBMP (8 : 2); ② 70% cow dung+ 30% PBMP (7 : 3); ③ 80% cow dung+20% quartz powder (8 : 2, control 1); and ④ 70% cow dung+30% quartz powder (7 : 3, control 2).

After being uniformly mixed, the feed was placed into a plastic bowl with a diameter of 8 cm and a height of 7 cm. Ten earthworms were inoculated in each container (ibid) at 70% moisture and 25 ℃ temperature for 30 d in a dark room. The earthworms were picked out after 30 d of growth. The feed mixture was air-dried, weighed, ground, and then sieved (60 mesh) to determine the contents of effective K and rapidly available K (see Sample analysis). The conversion rate of K can be calculated as follows

$$T = \frac{C_1 \times M_1 - C_2 \times M_2}{M_3 \times A \times 10^6} \times 100\%$$

where T is the conversion rate of K, %; C_1 is the content of rapidly available K or effective K in the experimental group with PBMP, mg·kg^{-1}; M_1 is the total mass of the experimental group with PBMP, kg; C_2 is the content of rapidly available K or effective K in the control group with quartz powder, mg·kg^{-1}; M_2 is the total mass of the control group with quartz powder, kg; M_3 is the PBMP recruitment, kg; A is the content of K in PBMP, which is 9.29% (in form of K_2O, hereinafter); and 10^6 is the coefficient of kg when converted to mg.

Sample analysis

The air-dried samples were used to determine the contents of effective K and rapidly available K.

The cold 2 mol·L^{-1} HNO_3 solution extraction method was used to determine the content of effective K. Approximately 0.5 g of samples (accurate to 0.000 1 g) was mixed and oscillated with 50 mL cold 2 mol·L^{-1} HNO_3 for 30 min. The mixture was filtrated immediately, and the filtrate was collected for testing. A blank control was also conducted.

The 1 mol·L^{-1} ammonium acetate extraction method was used to determine the content of rapidly available K. Approximately 0.5 g of air-dried samples and 50 mL of 1 mol·L^{-1} ammonium acetate solution were mixed in an extraction bottle (flask). The bottle was stoppered and oscillated for 30 min. The mixture was filtrated with a filter paper, and the filtrate was collected for testing. A blank control was also conducted.

The filtrates from the above two experiments were diluted 10 times after the pretreatment. A full-spectrum direct-reading plasma emission spectrometer (Thermo Fisher Scientific, UK) was used for the determination.

Statistical analysis

Excel was used for establishing the sample database and diagram. Chinese version SPSS 17.0 was used for the statistical analysis.

RESULTS AND DISCUSSION

Comparison of the Growth and Reproduction of Earthworms during the Breeding Process

The growth and reproduction of earthworms directly affect the transformation of PBMP. Therefore, a statistical analysis was conducted on the DGWA and DPA rates of the earthworms in each treatment group. The better PBMP recruitment was selected to improve the transformation efficiency of PBMP in the systems.

The DGWA rates of the earthworms with different PBMP recruitments are shown in Fig. 1.

The DGWA rates in groups A (100% cow dung), B (90% cow dung+10% PBMP), C (80% cow dung+20% PBMP), and D (70% cow dung+30% PBMP) initially increased and then decreased with increasing breeding time. By contrast, those in groups E (60% cow dung+40% PBMP), F (50% cow dung+50% PBMP), and G (40% cow dung+60% PBMP) gradually decreased. At the same feeding time, the DGWA rate decreased or even had a negative growth with increasing PBMP recruitment. These results may be attributed to the continuous consumption of organic matter and the gradual decrease in the DGWA rate of the tested scatophagic earthworms as breeding time was increased. Furthermore, the weight of the tested earthworms was not infinitely increased and remained in a steady state with increasing time. The higher the PBMP recruitment, the lower the content of the corresponding organic matter will be. Therefore, at the same breeding time, the DGWA rate in the different treatments decreased with increasing PBMP recruitment. The DGWA rate in group A reached the maximum value of 0.037 after 20 d of growth and then slowly decreased afterwards. The DGWA rates in groups B, C, and D also reached the maximum value after 20 d of growth and then slowly decreased afterwards. After 0 to 10 d of growth, the DGWA rate in group B was higher than that in group A. This finding indicates that the added PBMP did not affect the growth of earthworms within 10 d. Moreover, the DGWA rates in groups E, F, and G reached the maximum value after 10 d of growth and then gradually decreased afterwards. The DGWA rates in

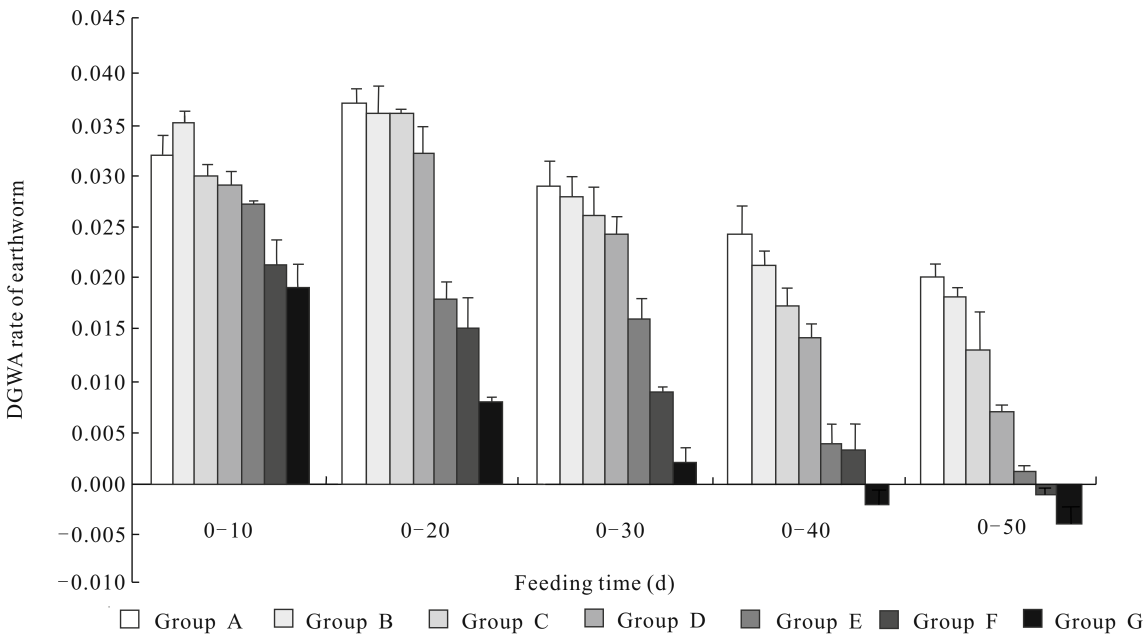

Figure 1. DGWA rate of earthworms with different mineral powder recruitments in the feed mixture. Group A. 100% cow dung; group B. 90% cow dung+10% PBMP; group C. 80% cow dung+20% PBMP; group D. 70% cow dung+30% PBMP; group E. 60% cow dung+40% PBMP; group F. 50% cow dung+50% PBMP; and group G. 40% cow dung+60% PBMP.

groups F and G exhibited negative growth after 40 and 50 d of growth, respectively. This finding indicates that the materials in the feed were no longer able to meet the growth requirements of the earthworms. At the same time, some of the earthworms escaped and died. Therefore, the higher the PBMP recruitment, the lower the DWGA rate of the earthworms will be.

The DPA rates of the earthworms with different PBMP recruitments are shown in Fig. 2.

As shown in Fig. 2, the DPA rate in each breeding period gradually decreased with increasing PBMP. The DPA rate in group A reached the maximum value of 0.102 after 30 d of growth and then gradually decreased afterwards. The DPA rates in the other groups reached the maximum value after 20 d of growth and then gradually decreased afterwards. This result indicates that the content of cow dung eaten by the earthworms was gradually reduced and that the earthworms were allowed to adapt to the system.

Based on the growth and propagation of the earthworms in different feed ratios, the DGWA and DPA rates in group A were higher than those in the other groups. However, the earthworms in groups B, C, and D exhibited good growth and vigorous propagation. The two indices reached the maximum value after 20 d of growth.

Variable Quantity of Rapidly Available K and Effective K in Each Treatment at Different Times

The contents of rapidly available K and effective K in feed mixtures at different times are shown in Table 3.

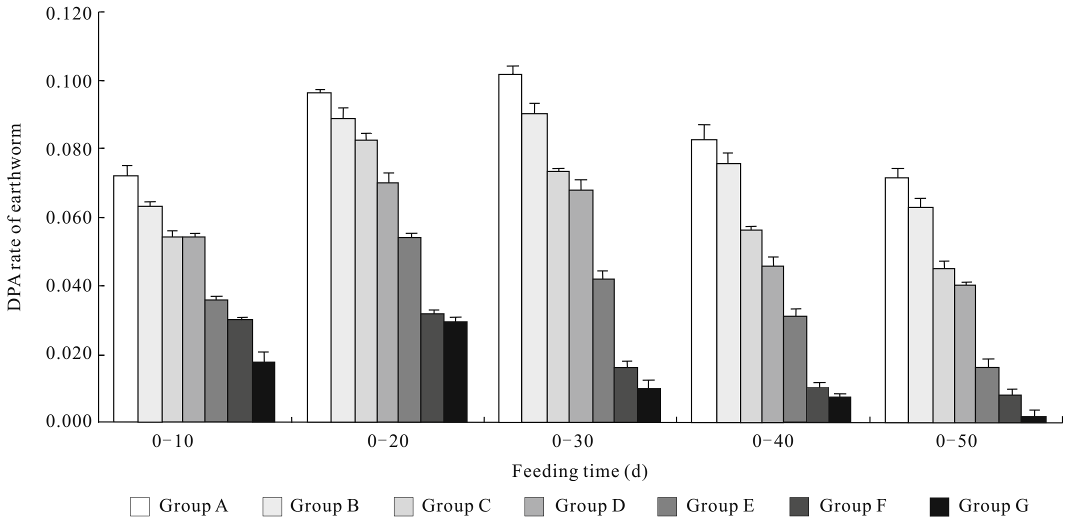

Figure 2. DPA rate of earthworms with different mineral powder recruitments in the feed mixture. The formulation of each group is the same as the one in Fig. 1.

Table 3 Contents of rapidly available K and effective K in feed mixtures at different times

Group	Available K (mg·kg^{-1})				Effective K (mg·kg^{-1})			
	0 d	14 d	28 d	42 d	0 d	14 d	28 d	42 d
A	13 094.8	13 614.2±18.5	13 730.4±58.6	14 032.4±102.3	14 569.6	15 274.8±231.7	15 852.3±354.2	16 350.2±58.4
B	11 790.9	12 187.0±40.3	12 661.4±320.9	13 309.5±192.1	13 138.7	13 502.2±325.7	14 292.7±339.1	15 362.7±759.2
C	10 487.1	10 599.1±236.7	10 832.1±0.5	11 558.9±193.6	11 705.8	11 740.0±238.4	11 847.0±389.8	12 882.7±43.1
D	9 183.2	9 653.8±369.4	9 894.8±467.1	11 023.7±505.4	10 276.8	9 899.7±120.4	10 349.6±6.4	11 280.7±119.9
E	7 879.4	7 564.8±614.1	7 557.6±624.1	8 603.7±334.7	8 793.2	8 620.9±92.8	8 243.6±107.3	9 403.2±35.4
F	6 533.1	6 433.8±321.1	6 517.9±164.3	7 154.5±40.1	7 284.8	6 734.5±11.7	7 130.7±209.8	7 436.3±533.5
G	5 248.6	4 412.3±227.4	4 832.2±48.6	5 385.3±105.4	5 827.8	5 084.1±260.8	5 486.4±42.8	6 104.0±92.9
H	13 094.8	13 085.2±251.0	13 028.40±68.5	13 062.4±54.7	14 569.6	14 589.2±254.4	14 753.6±458.0	14 621.0±94.3

The formulation in each group is the same as the one in Fig. 1; mean±standard deviation; similarly hereinafter.

The contents of rapidly available K and effective K in group A were higher compared with those in the other groups at different times. The reason is that the contents of rapidly available K and effective K in the initial cow dung were up to 13 094.8 and 14 569.6 $mg \cdot kg^{-1}$, respectively, which were much higher than the contents of rapidly available K (56.2 $mg \cdot kg^{-1}$) and effective K (260.4 $mg \cdot kg^{-1}$) in PBMP. After the influence of earthworms, the contents of rapidly available K and effective K in each group gradually increased, but none of them surpassed the ones in group A. The results indicate that most of the potassium in PBMP was difficult to be released. The contents of rapidly available K and effective K in each treatment gradually decreased with increasing PBMP recruitments. After 50 d of growth, the contents of rapidly available K and effective K in group A increased from 13 094.8 to 14 032.4 $mg \cdot kg^{-1}$ and from 14 569.6 to 16 350.2 $mg \cdot kg^{-1}$, respectively. However, those in the control group (group H; 100% cow dung with no earthworms) did not exhibit significant changes. Therefore, earthworm activity significantly affected the contents of rapidly available K and effective K in the systems. At the same time, the effects of microorganisms from the cow dung and other factors on this experiment were negligible after 50 d. The contents of rapidly available K and effective K in the other groups increased with increasing breeding time. The contents of rapidly available K and effective K in groups B, C, and D significantly increased, whereas those in groups E, F, and G did not show any significant change. This finding may be attributed to the reduction in organic matter contents in the growth environment, which affected the growth and activity of the earthworms. The increase in the contents of rapidly available K and effective K in the reaction systems may be attributed to two reasons. First, the growth and propagation of earthworms reduced the total amount of feed, thereby relatively increasing the contents of rapidly available K and effective K. Second, the earthworms transformed K into available K and effective K through feeding, digestion, absorption, and excretion of vermicompost. The factors involved in this experiment are complex. Thus, further experiments are needed to verify whether earthworms can promote the transformation of K in PBMP.

The growth and propagation of *E. foetida* in the reaction systems were compared, and the changes in the contents of rapidly available K and effective K were studied. Overall, earthworm activity under 10%, 20%, and 30% PBMP recruitments evidently affected the whole system. However, the treatment of 10% PBMP has a little PBMP recruitments. Therefore, the combinations with 20% and 30% PBMP recruitments were selected for the subsequent experiments on the conversion of earthworms on PBMP.

Changes in the Contents of Rapidly Available K and Effective K in the Transformation of PBMP

Based on the above experiment, 80% cow dung+20% PBMP and 70% cow dung+30% PBMP were selected as experimental groups. At the same time, control groups (i.e., 80% cow dung+20% quartz powder and 70% cow dung+30% quartz powder) were also set up. Quartz powder is a mineral powder without potassium, which is difficult to be decomposed. Quartz powder was selected in the control group to illustrate clearly that the increase in rapidly available K and effective K is related to the bio-weathering from PBMP in the experimental groups. The contents of rapidly available K and effective K in the feed were determined after 30 d under the same experimental conditions. The changes in the contents of rapidly available K and effective K in each treatment are shown in Table 4.

As shown in Table 4, the differences between the contents of rapidly available K and effective K in the experimental (80% cow dung+20% PBMP) and control groups (80% cow dung+20% quartz powder) were not significant before the treatment ($P>0.05$). After the treatment, the contents of rapidly available K and effective K in the experimental group (80% cow dung+20% PBMP) were 201.0 and 302.9 $mg \cdot kg^{-1}$ higher compared with those in the control group (80% cow dung+20% quartz powder), respectively. At the same time, the contents of rapidly available K and effective K in the experimental group (70% cow dung+30% PBMP) were 245.4 and 339.9 $mg \cdot kg^{-1}$ higher compared with those in the control group (70% cow dung+30% quartz powder), respectively.

The content of potassium in the tested PBMP was 9.29% (in the form of K_2O). Thirty days after the

Table 4 Contents of rapidly available K and effective K in the feed mixture with different PBMP recruitments

Treatment	Before treatment		After treatment			
	Available K ($mg \cdot kg^{-1}$)	Effective K ($mg \cdot kg^{-1}$)	Available K ($mg \cdot kg^{-1}$)	Effective K ($mg \cdot kg^{-1}$)	Available K increment ($mg \cdot kg^{-1}$)	Effective K increment ($mg \cdot kg^{-1}$)
80% cow dung +20% quartz powder	10 247.2±16.1a	11 063.7±80.9a	10 623.3±41.1b	11 385.5±13.5b	201.0	302.9
80% cow dung +20% PBMP	10 356.9±43.0a	11 140.4±7.5a	10 824.3±35.9a	11 688.4±16.1a		
70% cow dung +30% quartz powder	8 408.6±213.6b	10 054.8±46.1b	9 834.2±51.8d	9 907.6±11.4d	245.4	339.9
70% cow dung +30% PBMP	8 464.2±323.9b	10 089.5±49.3b	10 079.6±62.2c	10 247.5±172.7c		

The values with different lowercase letters in the same list are significantly different ($P<0.05$).

addition of 20% (10 g) PBMP, the total masses of the feed mixture in the experimental (80% cow dung+ 20% PBMP) and control groups (80% cow dung+20% quartz powder) were 46.26 and 46.19 g, respectively. The conversion rates of K into rapidly available K and effective K were 1.08% and 1.59%, respectively, according to the transformation formula of K in PBMP. After the addition of 30% (15 g) PBMP, the total masses of the feed mixture in the experimental (70% cow dung+30% PBMP) and control groups (70% cow dung+30% quartz powder) were 47.01 and 47.23 g, respectively, and the conversion rates of K into rapidly available K and effective K were 0.67% and 0.99%, respectively. The conversion rate of K was higher when 20% of PBMP was added than when 30% PBMP was added. *E. foetida* can activate K in PBMP, which can transform K into rapidly available K and effective K. However, the conversion rate was low, which may be attributed to the following reasons. First, the tested earthworms were fond of livestock dung and only took a slight amount of PBMP. Therefore, the earthworms were domesticated or selected from local soils to improve the amount of transformation. Second, the experimental time was short and thus the ingestion of earthworms may be not completed. Third, the optimum inoculation density, humidity, temperature, pH, and other factors were selected to obtain the best results on the growth and propagation of the earthworms, which also greatly affected the whole system.

The use of soil animals such as earthworms to activate K is a simple and practical technique. The adaptability and propagation of earthworms are strong, and earthworms themselves can be considered as high-protein feed. A mixture of cow dung and PBMP was used as feed for earthworms in this experiment. This technique can process a large amount of organic waste (i.e., cow dung), reduce environmental influence, and release part of K from PBMP to obtain K-rich organic fertilizers (Yu et al., 2011; Hao et al., 2004).

CONCLUSIONS

Different proportions of PBMP were added to cow dung for feeding the earthworms. The earthworms fed with the mixture containing 20% and 30% PBMP exhibited good growth and propagation. Therefore, the optimum recruitments of mineral powder are 20% and 30%.

In this study, 20% and 30% PBMP were added into the cow dung as *E. foetida* feed for 30 d. Compared with the control groups, the contents of rapidly available K and effective K transformed from PBMP were 201.0 and 302.9 $mg \cdot kg^{-1}$, respectively, when PBMP recruitment was 20%. The conversion rates of K into rapidly available K and effective K were 1.08% and 1.59%, respectively. The contents of rapidly available K and effective K transformed from PBMP were 245.4 and 339.9 $mg \cdot kg^{-1}$, respectively, when PBMP recruitment was 30%. The conversion rates of

K into rapidly available K and effective K were 0.67% and 0.99%, respectively. Therefore, the biotransformation on PBMP exists for earthworms. At the same time, the earthworms activated and transformed the K in PBMP into rapidly available K and effective K. However, the conversion rate of earthworms on PBMP was still lower, and a certain distance was found from the practical application. Therefore, the conversion rate must be increased by improving the formulations and optimizing the earthworm species. According to existing laboratory studies, the use of pre-treated PBMP (e.g., composting) improves the conversion rate of K (to be published).

The results of the current study provided a new idea of using earthworms to release potassium in low-grade potassium-bearing rocks and obtain the available K needed by plants.

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