Potassium extracting power, a key factor determine the efficiency of the sodium tetraphenlylboron method to evaluate soil K availability to plant

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Abstract
The ($NaBPh_4$) method was improved to evaluate potassium (K) plant availablity in various soils in the current study. The amount of soil K extracted by the $NaBPh_4$ method was significantly influenced by K extracting power (KEP) of the method which is determined by salt concentration and extracting period used. At lowest KEP, the $NaBPh_4$ method can only extract soluble and exchangeable K in soils, which was equivalent to the K extracted sequentially by three times of conventional NH_4OAc method. With increased KEP, the $NaBPh_4$ method not only extracted all NH_4OAc-extracted K, but also an increased portion of easy releasable non-exchangeable K (NEK) which contributed significantly to the K uptake by ryegrass (*Lolium perenne* L.) from soils. The soil available K extracted by the $NaBPh_4$ method with a proper KEP correlated well to the K removed by 1-8 crops of ryegrass. By adjusting the KEP to a proper level, the $NaBPh_4$ method is assumed suitable for evaluating K availability in various soils to plants.

Key Words
Soil available K, NaCl, K buffering capacity, critical K level

Introduction
Many chemical methods such as 1M NH_4OAc, Mehlich3, salts and dilute acids had been proposed by researchers for evaluation of available potassium (K) in soils (Mehlich, 1984; Salmon, 1998; Hosseinpur and Samavati, 2008). The NH_4OAc method is the most widely used, but it was not suitable for soils that possess substantial amount of plant-available NEK because that the NH_4OAc method can only extract water soluble and exchangeable but not non-exchangeable K (NEK) in soils and minerals (Cox *et al.,* 1999). The sodium tetraphenlylboron ($NaBPh_4$) method seems to be better than the NH_4OAc method to predict soil K availability to plants because of its ability to extract both exchangeable and non-exchangeable K in soils (Schulte and Corey 1965; Wentworth and Rossi, 1972; Husin *et al*., 1986; Cox *et al*., 1996; Cox and Joern, 1997; Cox *et al*., 1999). However, some researchers found that the $NaBPh_4$ methods did not show much advantage as compared with traditional NH_4OAc method for assessment of soil available K to plants (Schindler *et al*. 2002; Fernandez *et al*. 2008). The effectiveness of $NaBPh_4$ method for assessment of soil available K seems largely dependent on the K extracting power (KEP) and extraction period of the method that different researchers employed.
The objectives of this study were (i) to evaluate the effect of the factors on the KEP of the $NaBPh_4$ method, and (ii) to modify $NaBPh_4$ method to a proper KEP to get the method suitable for evaluating K availability in various soils to ryegrass (*Lolium perenne* L.).

Materials and methods
Soils

Table 1. Locations and basic properties for the soils tested.

Soil location	Soil type	CEC ($cmol\ kg^{-1}$)	OM ($g\ kg^{-1}$)	pH	$CaCO_3$ (%)	Clay (%)	AK ($mg\ kg^{-1}$)	SAK ($mg\ kg^{-1}$)	T K (%)
Laiyang, Shandong (LY)	Aquic Inceptisol	9.20	10.0	6.80	—	12.2	93.0	1068	1.63
Wangcheng, Hunan (WC)	Ultisol	9.97	40.2	5.14	—	30.5	73.1	334	1.41
Fengqiu, Henan (FQ)	Calcic Aquic Inceptisol	8.31	6.5	8.65	7.36	21.8	126.0	1092	2.18
Changshu, Jiangsu (CS)	Entisol	27.33	46.6	6.65	1.08	34.3	149.5	582	1.61

OM: organic metter; Clay: particles <0.002 mm; AK: Available K; SAK: slow available K; TK: total K

Four topsoils (0-20 cm) with different soil properties and K buffering capacity were used (Table 1). Soil pH, CEC, $CaCO_3$, organic matter, clay content, available K, slow available K and total K were all measured by conventional methods (Lu, 1999).

Extraction of soil K with $NaBPh_4$ method under various conditions
The general procedure of $NaBPh_4$ method used for extracting soil K was similar to that described by Cox *et al*. (1999). Different NaCl and $NaBPh_4$ concentrations in extracting solution ($NaBPh_4$ + NaCl + 0.01 M EDTA) were set. After shaking at 200 rpm for intended periods, 25 mL of quenching solution (0.5 M NH_4Cl + 0.14 M $CuCl_2$) was added to stop the extraction. Three replicates were set for all soil extraction tests.

Establish different K status in soils and evaluation of soil K availability to ryegrass
KCl was applied to each type of soil at rates of 0, 100, 200, 300 and 400 mg K kg^{-1} to obtain soils with different K status. Each pot contained 5.00 kg soil, each treatment had four replicates. A pre-cropping of rice was initiated to make fertilizer K balanced with the native K in soil. After the rice season, 50 g soil was sampled from each pot for soil K test. Soil available K was measured by NH_4OAc method and the modified $NaBPh_4$ method (0.2 M $NaBPh_4$ + 0.01 M EDTA) with different extracting period (30, 60 and 120 min). The left soil was used for perennial ryegrass cropping with sufficient supply of water and all nutrients other than K. The ryegrass was harvested at 8-week intervals, and totally 8 crops of ryegrass were harvested. Dry matter (DM) yield and K uptake by each crop of the ryegrass were determined.

Analysis
K concentration in solutions were measured with a flame photometer using an internal standard procedure employing 3 mM lithium chloride. The differences among means was statistically evaluated with SAS 6.12, using analyses of variance (ANOVA) taking *P* value <0.05 as significant.

Results

Amount of soil K extracted by $NaBPh_4$ method under different extracting conditions
Increase NaCl concentration in extracting solution significantly increased K extracted from soils, and the effect was related to soil types and also the $NaBPh_4$ concentration (Figure 1). At lower $NaBPh_4$ concentration (0.01 M), amount of K extracted increased linearly as the NaCl concentration increased from zero to 3.0 M (Figure 1a). While the positive effect of NaCl on K release from three of four soils reach to a top point at 2.0 M when higher $NaBPh_4$ (0.2 M) was used (Figure 1b). It indicated that the KEP of the $NaBPh_4$ method was greatly increased by increased concentration of NaCl, and then also increased by a higher concentration of $NaBPh_4$ in extracting solution. To get KEP of the $NaBPh_4$ method lower, omission of NaCl from the extracting solution is suggested.

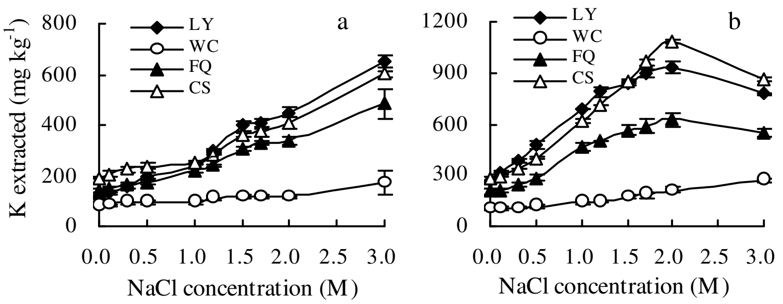

Figure 1. Effect of NaCl in extracting solution on K extracted from 4 soils with a 30-min extraction (a -0.01 M $NaBPh_4$; b- 0.2 M $NaBPh_4$). Vertical bars represent standard deviation (n=3).

Without NaCl, the K extracted from soils did not changed by the $NaBPh_4$ (0.001 and 0.003 M) method even the extracting period increased up to 30 min (Figure 2), which reflecting the lowest KEP of the $NaBPh_4$ method used. Soil K extracted by the $NaBPh_4$ method with lowest KEP and by 3 times sequential extraction of conventional NH_4OAc method was compared in Figure 3. Similar amount of K extracted by both methods indicated that the $NaBPh_4$ method with lowest KEP can only extracted soluble and exchangeable K in soils. As $NaBPh_4$ concentration increased to 0.03 and 0.2 M, the K extracted from soils was increased gradually, but the effect differed among soils (Figure 2). Without NaCl, to extract a small portion of NEK from soils, based on the data in Figure 2, 0.2 M $NaBPh_4$ is recommended for evaluation of soil available K to plants.

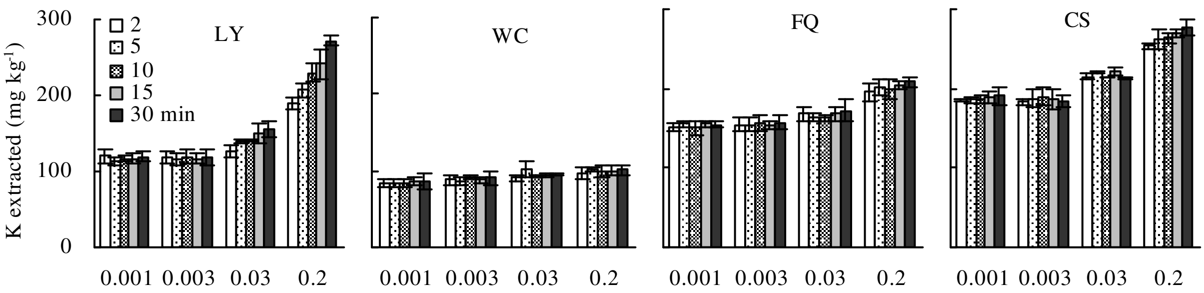

Figure 2. Effect of $NaBPh_4$ concentration and extraction period on K extracted with $NaBPh_4$ method in absence of NaCl from 4 soils. Vertical bars represent standard deviation (n=3).

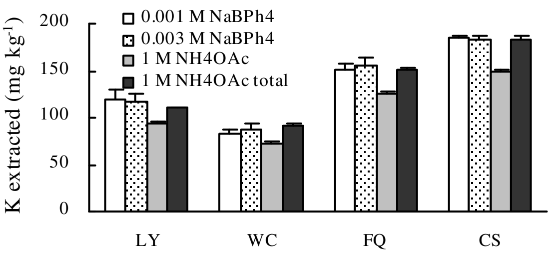

Figure 3. Comparing K extracted from 4 soils by $NaBPh_4$ method with lowest K extracting power and by NH_4OAc method ("1 M NH_4OAc total" was made by 3 times successive extraction). Vertical bars represent standard deviation (n=3).

Evaluating soil K availability to ryegrass

The correlation coefficient indicating the linear relationship between soil K removed by 1 to 8 crops of ryegrass and K extracted by NH_4OAc and $NaBPh_4$ methods was shown in Table 2. The results indicated that the NH_4OAc method was not suitable for evaluation of K availability to ryegrass in soils used in current study. While both 60- and 120-min $NaBPh_4$ method are suitable and better than the 30-min $NaBPh_4$ method to estimate soil K availability to 1-8 crops of ryegrass.

Table 2. Correlation coefficient (r^2)of simple linear regression equations describing the relationship of soil K removed by 1 to 8 crops of ryegrass and K extracted by different chemical methods (n=80).

Crops		1	2	3	4	5	6	7	8
1 M NH_4OAc		0.68**	0.61**	0.40**	0.36**	0.35**	0.34**	0.32**	0.28**
0.2 M	30 min	0.84**	0.84**	0.68**	0.64**	0.64**	0.63**	0.60**	0.57**
$NaBPh_4$	60 min	0.83**	0.92**	0.89**	0.87**	0.87**	0.86**	0.85**	0.83**
	120 min	0.84**	0.94**	0.91**	0.89**	0.89**	0.89**	0.88**	0.86**

** Correlation coefficient is significant at level of $p < 0.01$.

The data in Figure 4 clearly showed the difference between NH_4OAc and $NaBPh_4$ 60-min methods for their ability to predictive K availability to one and eight crops of ryegrass in different soils. For each type of the soil, a good linear correlation between NH_4OAc extractable-K (AK) and K removed by one or eight crop of ryegrass was indicated by the linearly assembled points in Fig. 4a, 4c. When taking four type soils as a whole, the points scattered on the plot (Figure 4a, 4c). It was related to the different K buffering capacity of the soils tested. The soil LY has a very high K buffering capacity, which “fixed” most of the K added and got very low levels of AK in soil samples (Figure 4a). The K removed by first crop of ryegrass exceeded the content of AK in some soil samples of LY(Figure 4a), and the K removed by 8 crops of ryegrass (245-438 mg kg^{-1}) was much higher than the AK values (39-63 mg kg^{-1}), indicating that the NEK contributed to most of ryegrass K uptake and was not evaluated by the NH_4OAc method, thus lead to the line scattered upward in Figure 4a, 4c. While for the soil WC, the K removed by ryegrass is close to the AK in soil (Figure 4c), which suggested that almost no NEK contributed to ryegrass K uptake, and the line scattered downward in Figure 4c. The results suggested that the NH_4OAc method was only suitable for evaluating K availability in soils belong to same soil type or with similar K buffering capacity, but not in soils that have different K buffering capacity and contribute various portion of NEK to plant K uptake.

In Figure 4b, 4d, the scattered points assembled along a line in plots of $NaBPh_4$-60 min methods. It suggested that the $NaBPh_4$ method with a proper KEP is suitable for evaluating K availability in various soils to plants because that soil K including all AK and a proper portion of easy release NEK which is actually available to plants was well evaluated by the method.

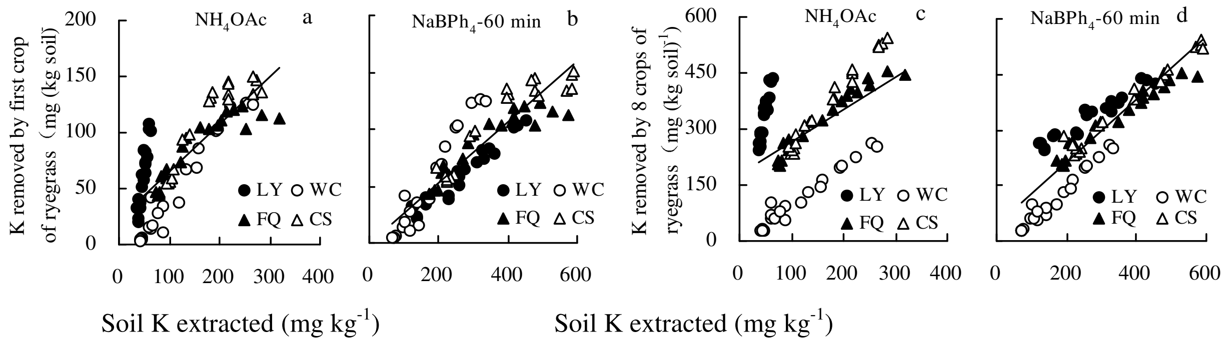

Figure 4. Comparing K removed by 1st and 8 crops of ryegrass and K extracted by NH_4OAc and modified $NaBPh_4$ methods from 4 soils.

Conclusion

The amount of soil K extracted by $NaBPh_4$ method is largely dependent on the KEP of the method which determined by components of the extracting solution and extracting peroid. Increasing NaCl concentration in extracting solution (in presence of some level of $NaBPh_4$) make biggest increment of KEP of the $NaBPh_4$ method, followed by increasing of $NaBPh_4$ concentration and by extracting period. With lowest KEP, the $NaBPh_4$ mothod can only extract water soluble and exchangeable K from soils. With proper KEP, the $NaBPh_4$ with 60- or 120-min extracting period are much better than the NH_4OAc method to estimate soil K availability to 1-8 crops of ryegrass.

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