Research Findings

Potassium Extracting Power: A Key Factor in Determining the Efficiency of the Sodium Tetraphenylboron Method in the Evaluation of Plant Available Soil K as Assessed by Sequential Ryegrass Cropping

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Abstract

The sodium tetraphenylboron ($NaBPh_4$) method for evaluating K availability in soil was modified to improve evaluation of plant available K in four different soil types in China. The amount of soil K extracted in this method is dependent on the K extracting power (KEP), which is determined by concentrations of $NaBPh_4$, NaCl and the extraction period used. At lowest KEP, only soluble and exchangeable K are extracted, which is equivalent to the K obtained from three successive extractions using the conventional ammonium acetate (NH_4OAc) method. Increasing KEP in the $NaBPh_4$ method resulted not only in an equivalent extraction of K as obtained by NH_4OAc, but also in an increase in the amount of the easily releasable non-exchangeable K (NEK), which contributed significantly to the K uptake by ryegrass (*Lolium perenne* L.) from the soils. The results suggest that the NH_4OAc method was only suitable for evaluating K availability in soils of the same soil type or with similar K buffering capacities, but not in soils in which K buffer capacity varies and in which NEK contributes, to a varying extent, to plant K uptake. The soil available K extracted by the $NaBPh_4$ method with suitable KEP, correlated well to K removal by eight sequential crops of ryegrass. By adjusting the KEP to a suitable level, the modified $NaBPh_4$ method was shown to be suitable for evaluating plant available K.

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Materials and methods

Soils

Four topsoils (0-20 cm) with different soil properties such as pH, cation exchange capacity (CEC) $CaCO_3$, organic matter, clay content and K buffering capacity were used (Table 1). Two soils, LY and WC, contrasting in potassium availability, were included. Soil LY contained a low level of readily available K (soil solution and exchangeable K), with K plant supply being dependent on K release from the NEK pool. Whereas in soil WC, release of K from this pool was very low, with the readily exchangeable K pool being the main source for plant uptake. 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). Varying concentrations of NaCl and $NaBPh_4$ concentrations in extracting solution ($NaBPh_4$ + NaCl + 0.01 M EDTA) were selected after shaking at 200 rpm for specific 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 taken 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 of soil and each treatment had four replicates. A pre-cropping of rice was initiated to allow equilibration of fertilizer K with native K in the soil under the wet-dry courses during the rice season.

After the rice season, 50 g of 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 remaining soil was used for sequential cropping of perennial ryegrass in which adequate water was supplied together with all required mineral nutrients other than K. The ryegrass was harvested at eight-week intervals, and a total of eight crops of ryegrass were taken. Dry matter (DM) yield and K uptake (in the above

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

Soil location (village, province)	Soil type	CEC	OM	pH	$CaCO_3$	Clay	AK	SAK	TK
		cmol kg^{-1}	*g kg^{-1}*		------ % ------		-- *mg kg^{-1}* --		%
Laiyang, Shandong (LY)	Aquic Inceptisol	9.20	10.0	6.80	NA	12.2	93.0	1,068	1.63
Wangcheng, Hunan (WC)	Ultisol	9.97	40.2	5.14	NA	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	1,092	2.18
Changshu, Jiangsu (CS)	Entisol	27.33	46.6	6.65	1.08	34.3	149.5	582	1.61

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

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ground parts) by each crop of the ryegrass were determined.

Analysis

K concentration in solution was 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.

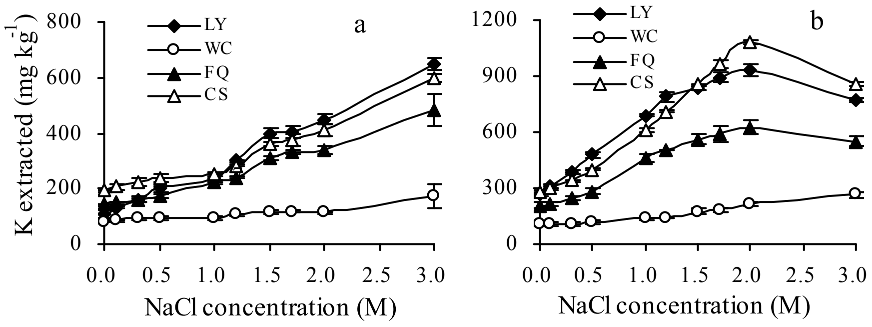

Fig. 1. Effect of NaCl in extracting solution on K extracted from four soils with a 30 min extraction (a -0.01 M $NaBPh_4$; b- 0.2 M $NaBPh_4$). Vertical bars represent standard deviation (n=3), the same as below.

Results and Discussion

Amount of soil K extracted by $NaBPh_4$ method under different extracting conditions

It has been reported that the K extracted from K-bearing minerals by NaBPh4 method was significantly affected by the presence of Na in extraction solution (Scott *et al.*, 1960; Smith and Scott, 1966), and a combination of 1.7 M NaCl with 0.2 M NaBPh4 was frequently used by many researchers (Cox *et al.*, 1996, 1999; Schindler *et al.*, 2002; Fernandez *et al.*, 2008). However, the detailed effect of NaCl concentration on K release from different soils is still unknown. Increasing NaCl concentration in the extracting solution significantly increased the K extracted from soils; the effect being related to soil type and also to $NaBPh_4$ concentration (Fig. 1). At the lower $NaBPh_4$ concentration (0.01 M), the amount of K extracted increased linearly as the NaCl concentration increased from 0 to 3.0 M (Fig. 1a). With the higher $NaBPh_4$ concentration (0.2 M), the positive effect of NaCl on K release from three of the four soils reached a maximum at 2.0 M (Fig. 1b). These findings indicate that the KEP of the $NaBPh_4$ method was greatly increased by increased concentration of NaCl, and raised by a higher concentration of $NaBPh_4$ in the extracting solution. To retain KEP lower in the $NaBPh_4$ method, omission of NaCl from the extracting solution is suggested.

In the absence of NaCl, the K extracted from soils did not differ significantly between the two lower concentrations of $NaBPh_4$ (0.001 and 0.003 M) even though the extracting period increased up to 30 min (Fig. 2), reflecting the lowest KEP in this method. Soil K extracted by the $NaBPh_4$ method, with lowest KEP, was compared with the conventional NH_4OAc method using a single or a total of three successive extractions (Fig. 3). The relatively similar amount of K extracted by both methods indicates that the $NaBPh_4$ method with lowest KEP is only capable of extracting 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 (Fig. 2). In the absence of NaCl, to extract a small portion of NEK from soils, as based on the data in Fig. 2, 0.2 M $NaBPh_4$ is recommended for evaluation of soil available K to plants.

Evaluating soil K availability to ryegrass

The correlation coefficient indicating the linear relationship between soil K removed by the eight sequential crops of ryegrass, and K extracted by NH_4OAc and $NaBPh_4$ methods, are

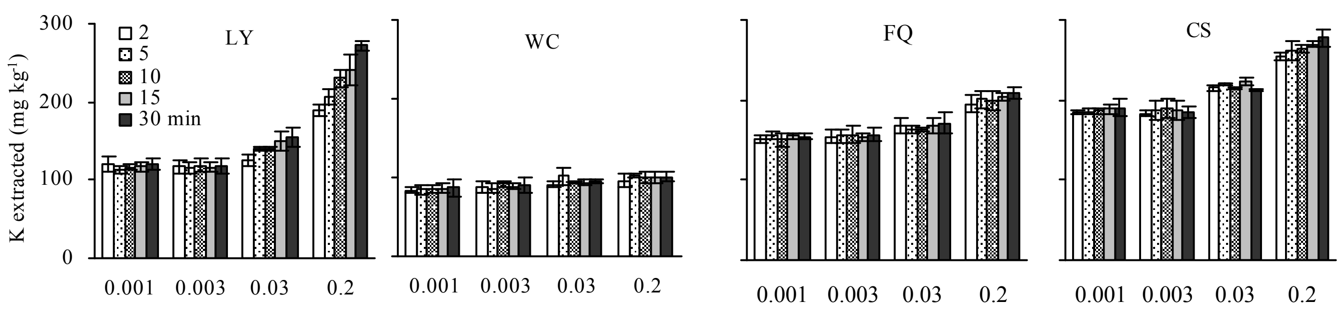

Fig 2. Effect of $NaBPh_4$ concentration and extraction period on K extracted with the $NaBPh_4$ method in the absence of NaCl from four soils.

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shown in Table 2. The results indicate that the NH_4OAc method was not suitable for evaluation of K availability to ryegrass in soils used in the current study. By contrast both 60- and 120-min $NaBPh_4$ method are suitable and much better than the NH_4OAc method in estimating soil K availability in the eight sequential crops of ryegrass.

The data in Fig. 4 clearly show the difference between NH_4OAc and $NaBPh_4$ 60-min methods in their ability to predict K availability to the first and eighth crops of ryegrass in different soils. For each soil type, a reasonably linear correlation between NH_4OAc extractable-K (AK) and K removed by the first or eighth crop of ryegrass is indicated by the linearly assembled points in Fig. 4a, 4c. When considering the four soil types, together however, the points are scattered on the plot (Fig. 4a, 4c) which relates to the different K buffering capacities of the soils tested.

The soil LY has a very high K buffering capacity, which "fixes" most of the K added and with low levels of AK in the soil samples (Fig. 4a). The K removed by eight crops of ryegrass (245-438 mg kg^{-1}; Fig. 4c) was much higher than the AK values (39-63 mg kg^{-1}; Fig. 4c) indicating that the NEK contributed to most of ryegrass K uptake which was not evaluated by the NH_4OAc method, thus accounting for the line scattered upward in Fig. 4a, 4c.

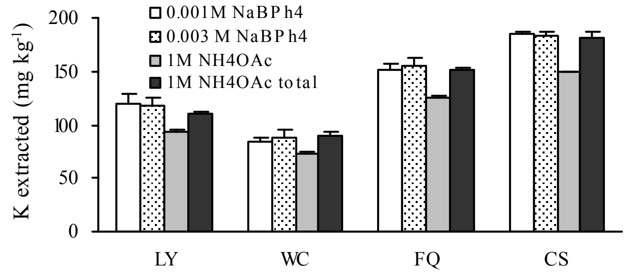

Fig. 3. A comparison of K extracted from four soils by the $NaBPh_4$ method (at two $NaBPh_4$ concentrations with lowest KEP) and the NH4OAc method (with either a single extraction or with three successive extractions).

Table 2. The correlation coefficient (r^2) of simple linear regression equations describing the relationship of soil K removed by the eight 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.

For the soil WC, the K removed by the ryegrass is close to the AK in the soil (Fig. 4c), which suggests that almost no NEK contributed to ryegrass K uptake, and this is similarly so for the line scattered downward in Fig. 4c. The results suggest that the NH_4OAc method was only suitable for evaluating K availability in soils of the same soil type or with similar K buffering capacities, but not in soils in which K buffer capacity varies and in which NEK contributes to varying extent to plant K uptake.

In Fig. 4b, 4d, the reasonably close assemblage of scattered points along a line of the plots for both crops of ryegrass is indicative of the suitability of the modified $NaBPh_4$ method in evaluating the availability of K of the soils to the ryegrass crop. These findings confirm the $NaBPh_4$-60 min method with modified KEP for evaluating K availability allowed the inclusion of that proportion of NEK which is actually available to plants in addition to water soluble and readily exchangeable AK.

Conclusion

The amount of soil K extracted by the

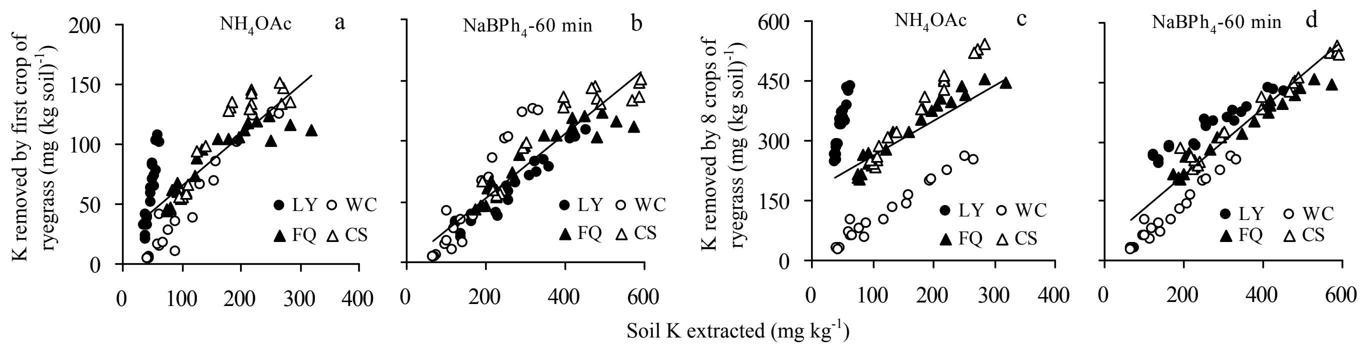

Fig. 4. Comparing K removed by first crop of ryegrass and K extracted by conventional NH_4OAc and modified $NaBPh_4$ methods from four soils (a - NH_4OAc method; b - modified $NaBPh_4$ method).

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$NaBPh_4$ method is largely dependent on KEP of the method, which is determined by components of the extracting solution and extracting period. Increasing NaCl concentration in the extracting solution has the greatest effect in increasing the KEP, followed by increasing $NaBPh_4$ concentration, and by length of extracting period. At the lowest KEP, the $NaBPh_4$ method can only extract water soluble and exchangeable K from soils. Modifying the KEP, by increasing the concentration of $NaBPh_4$ in the absence of NaCl and raising the extracting period to 60- or 120-min allowed an estimation of soil K availibility, which was much more accurate than the NH_4OAc method as assessed by K uptake of eight sequential crops of ryegrass. The latter method was only suitable for evaluating K availability in soils of the same soil type or with similar K buffering capacities, but not for soils in which K buffer capacity varies and in which NEK contributes, to a varying extent, to plant K uptake.

Acknowledgements

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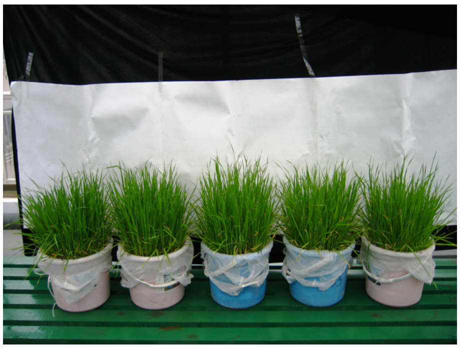

Rice grown in pots to allow equilibration of fertilizer K with native K in the soil under the wet-dry courses during the rice season. Photo by H.Y. Wang.

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