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A New Chemical Grading System for Plant-Available Potassium in soils

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Forms of soil K

Chemical form	Structure K (very stable)	Non-exchangeable K (K difficult to be exchanged and fixed K)	Exchangeable K	Water soluble K
Plant availability	Hard to be used K	Slow available K	Available K	
Where it exists	Structure of feldspar and mica	2:1 layer silicates like illite, vermiculite, biotite	Outer surface of particles	Soil solution
Retaining ability	Couple affinity	Interlayer affinity,	Static affinity	Free ion
Balance relationship	Weathering →	Slow ⇄	Quick ⇄	
Diffusion coefficient	10^{-23}～10^{-15}		～10^{-7}	
Determination methods	Total-K – HNO_3-K	HNO_3-K – NH_4Ac-K	NH_4Ac-K	
Relative content	90%～98%	2%～8%	0.1%～2%	

（Xie *et al.*，2000）

How much is the NEK in soil?

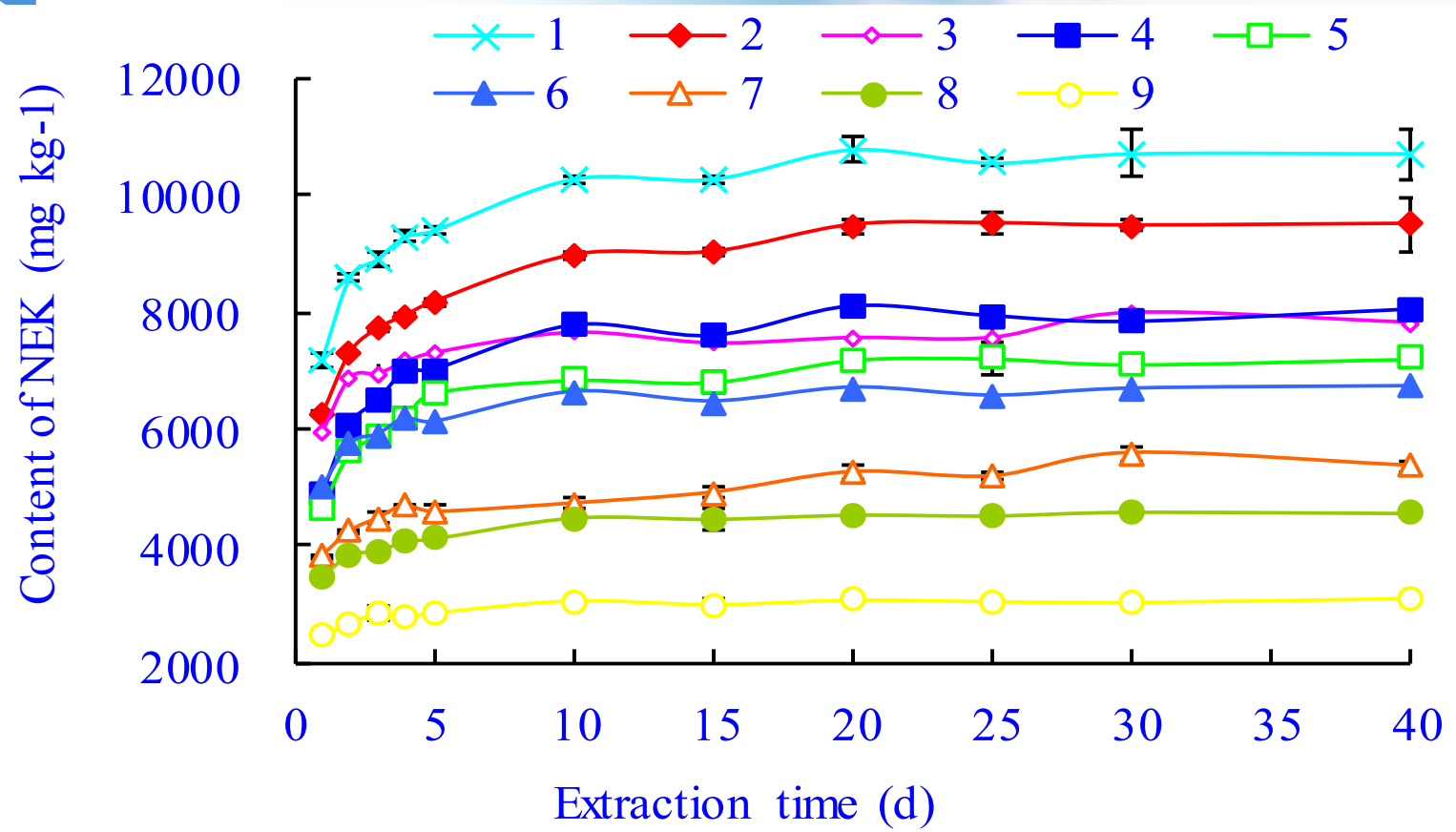
NaTBP method is suitable for NEK extraction

$$K^+ + NaBPh_4 \longrightarrow KBPh_4\downarrow + Na^+ \quad (s = 2.2 \times 10^{-8}\ mol\ L^{-1})$$

- Very low solubility, facilitated the release of fixed K;
- Slight destruction to the original mineral ;
- The easily released K will firstly be extracted ;
- The extracting power could be changed by some factors

Wang et al., 2010, Soil Science

How much is the NEK in soil?



Amount of K extracted by NaTBP from 9 soils at 45°C with time (soils collected from different sites of China with wide range of K)

There are maximum values for soil NEK extracted by the NaTBP method

How much is the NEK in soil?

K values of 9 soils measured with different methods （mg kg^{-1})

Soil name	NH_4Ac extracted K	Hot HNO_3 extracted K	Maximum NEK extracted by NaTBP	Total K
Loessial soil (Yangling, Shanxi)	190	1667	10081	21914
Paddy soil (Changshu, Jiangsu)	162	675	8867	16100
Red earth (Yingtan, Jiangxi)	47	230	7720	13800
paddy soil (Wangcheng, Hunan)	66	497	7632	14070
Fluvo-aquic soil (Fengqiu, Henan)	278	2243	6499	21820
Paddy soil (Wuxi, Jiangsu)	98	518	6469	16020
Fluvo-aquic soil (Laiyang, Shandong)	42	870	5181	16300
Black soil (Hailun, Heilongjiang)	175	1164	4433	21642
Brown-red earth (Qichun, Hubei)	155	606	3074	10715

How much is the NEK in soil?

The linear relationship between soil K values measured with different methods (Correlation Coefficients r and P, n=9)

		NH_4Ac extracted K	Hot HNO_3 extracted K	Maximum NEK released by $NaBPh_4$
Hot HNO_3 extracted K	r	0.83421		
	P	0.0052**		
Maximum NEK released by $NaBPh_4$	r	0.03509	0.12241	
	P	0.9286	0.7537	
Total K	r	0.62914	0.82998	0.29991
	P	0.0695	0.0056**	0.4330

There maximum NEK extracted by the NaTBP method has no correlation to other forms of K, which indicating that NEK could be differentiated from structural K in soils

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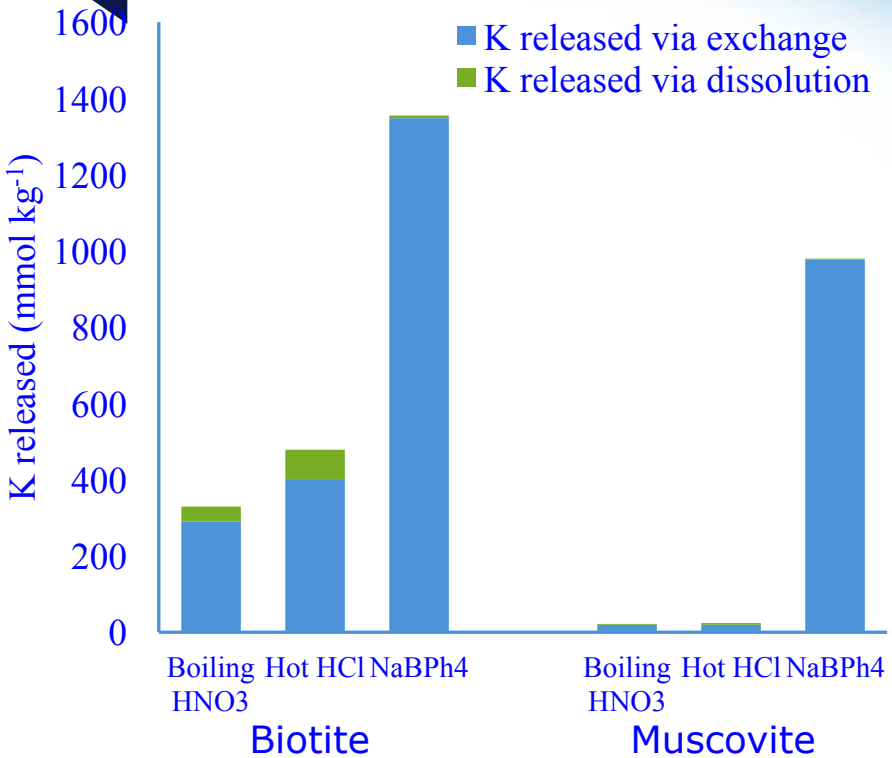
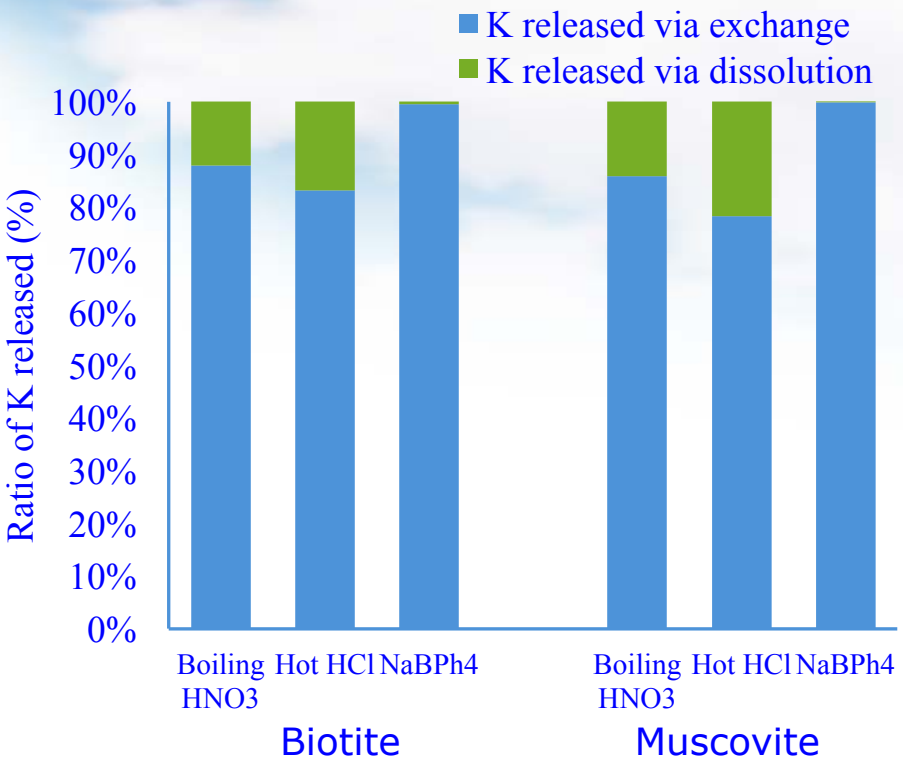
Retaining ability	Couple affinity	Interlayer affinity,	Static affinity	Free ion
Balance relationship	Weathering →	Slow ⇄	Quick ⇄	
Diffusion coefficient	10^{-23}～10^{-15}		～10^{-7}	
New methods	Total K – Total NEK	Total NEK by NaTBP – NH_4Ac-K	NH_4Ac-K	
Relative content	45%–80% (90%–98%)	20%–55% (2%–8%)	0.1%～2%	

Could be differentiated

Wang et al., 2016, Pedosphere

NEK is the main soil K pool available to plants





The amount and ratio of extracted K released through cation-exchange reaction and the dissolution of micas

The K released from the K-bearing minerals are mainly via the cation-exchange reaction but not the dissolution effect.

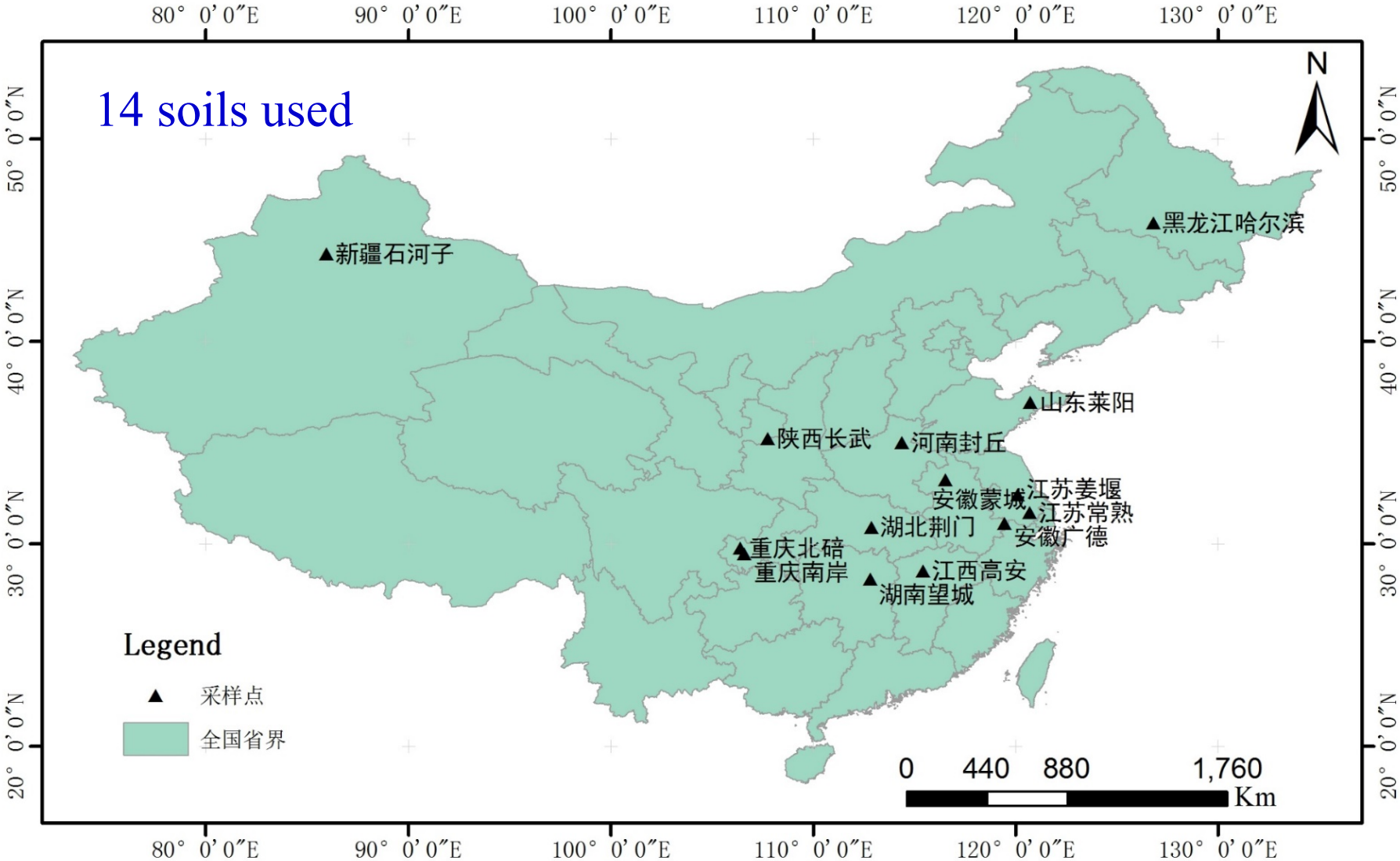
Wang et al., 2011, Plant Soil; Li et al., 2015, Applied Clay Science

How to grade soil NEK according to its availability to plant?

Successive cropping is a reliable method to test soil K availability to plant.

The NaTBP method could mimic plant root to extract K from soil. Can we establish a grading system for plant-available K in soil by this method?

Grading plant-available K in soils



Grading plant-available K in soils

K exhaustion by ryegrass at normal rate:

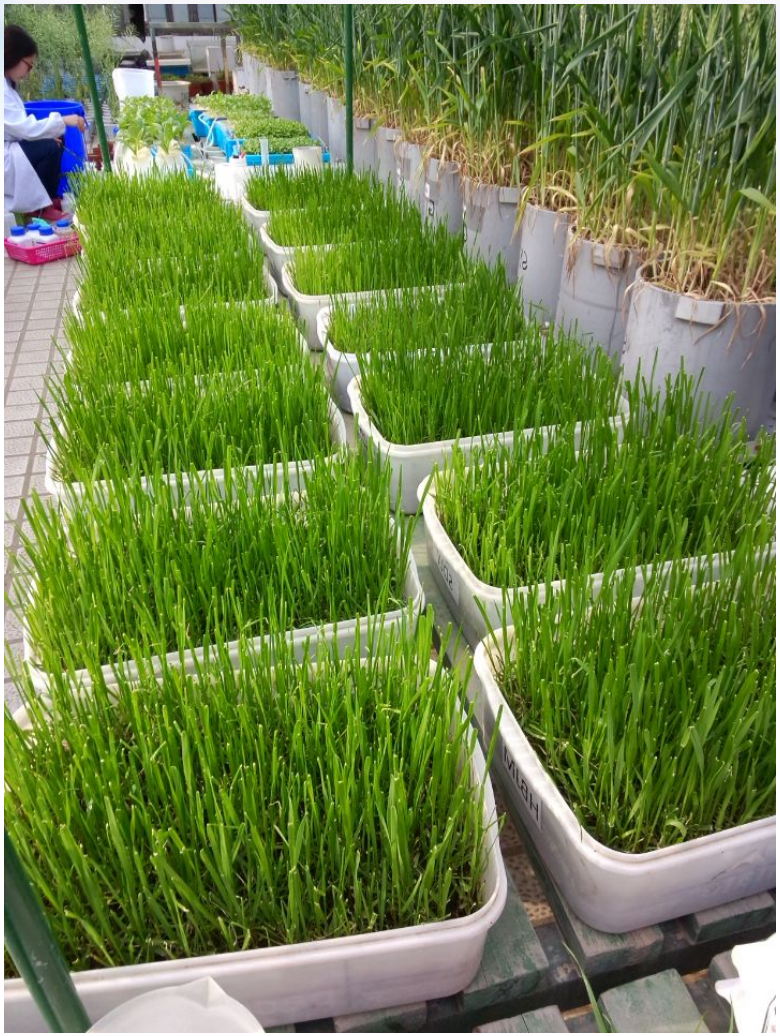
Two treatments: CK +K 5kg soil in pot (18 cm× 20 cm (h × d)). Other nutrients were supplied with nutrient solution omitted K. Soils were dried and reinstalled and the new seeds were sowed after each ryegrass cropping of 30 d. Totally 12 harvest finished.

Grading plant-available K in soils

K exhaustion by ryegrass at intensive rate:

One treatment: without K

5kg soil in pot (40cm×20cm×10cm). Soils were dried and reinstalled and the new seeds were sowed after 5 harvest of ryegrass. Three sowing and 15 harvest of ryegrass finished.



Grading plant-available K in soils

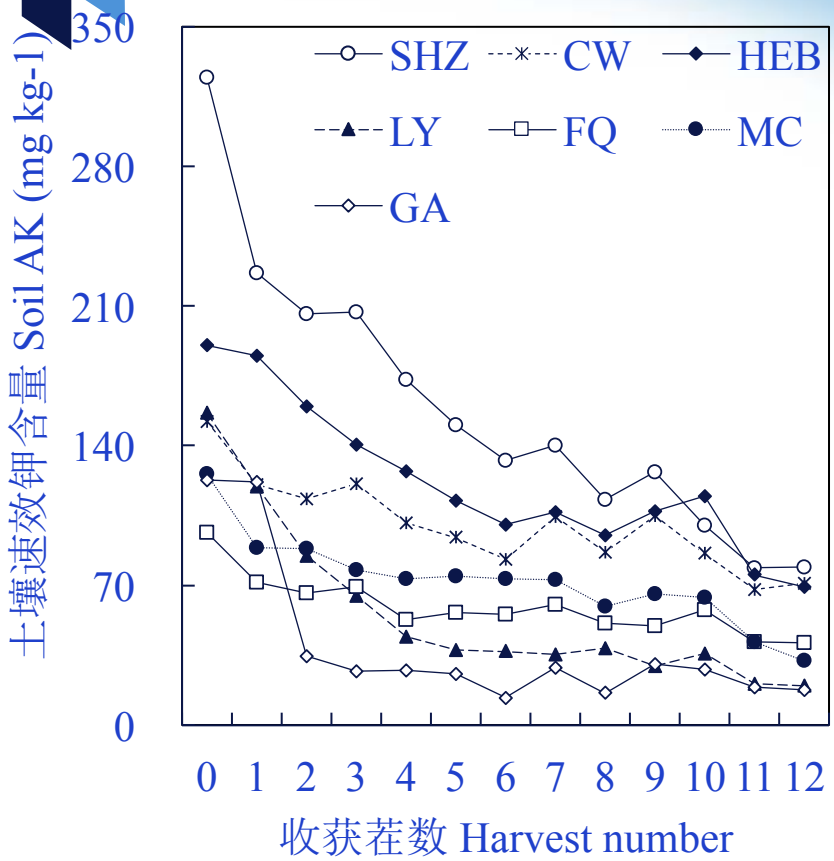
Successive Extraction of soil K with NaTPB method

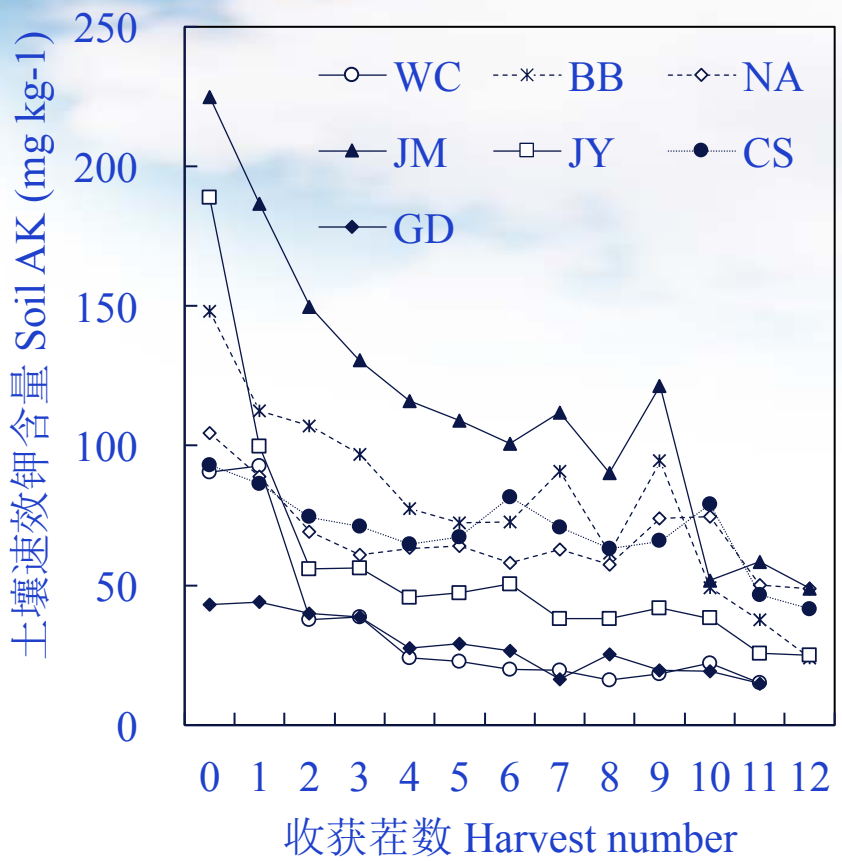
Weak NaTBP method: 0.2 mol L^{-1} NaTPB. Extraction period: 5 s, 10 min 0.5 h, 1 h, 2 h, 4 h, 8 h, 12 h, 24 h, 48 h, 96 h, and 144 h.

Strong NaTBP method: 0.2 mol L^{-1} NaTPB + 1 mol L^{-1} NaCl. Extraction period: 5 s, 2 min, 5 min, 10 min, 20 min, 30 min, 40 min, 60 min, 90min, and 120 min.

Samples of 0.5 g soil were weighed into 50-mL centrifuge tubes. 3.0 mL of NaTPB solution was added and the tubes were shaken at 200 rpm for the extraction period. 25 mL quenching solution (0.5 mol L^{-1} NH_4Cl + 0.14 mol L^{-1} $CuCl_2$) was added to the tubes to stop the extraction. The tubes were then heated in boiling water for 60 min to dissolve the KTPB precipitate. The suspension was vacuum filtered through membrane filters and the K was measured with a flame photometer.

Grading plant-available K in soils

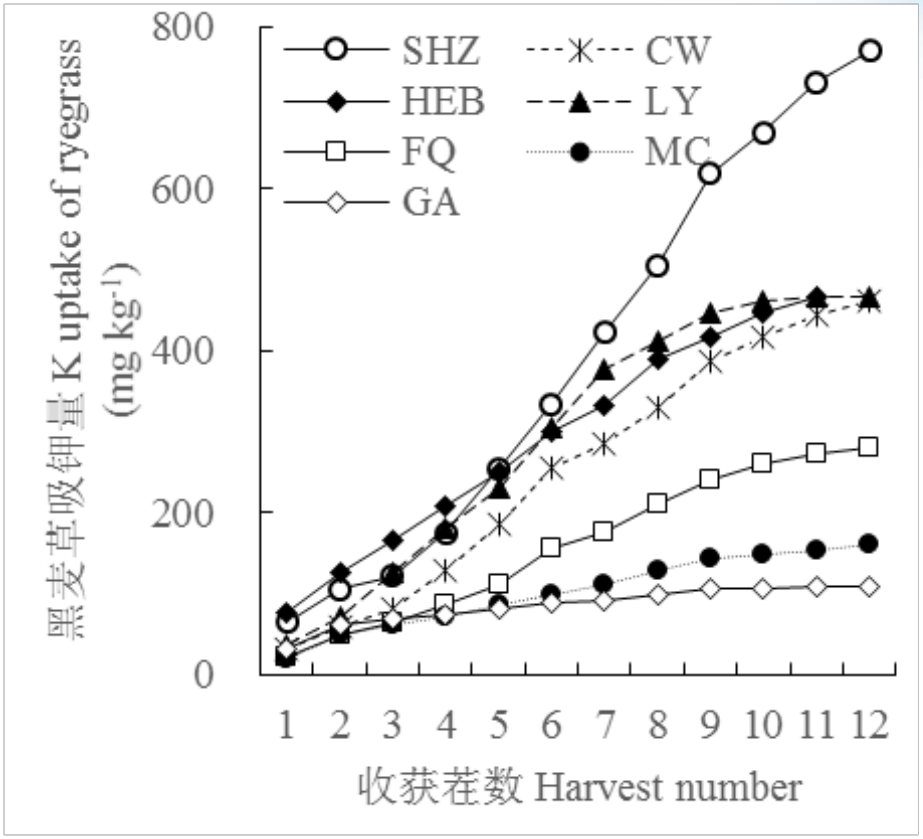


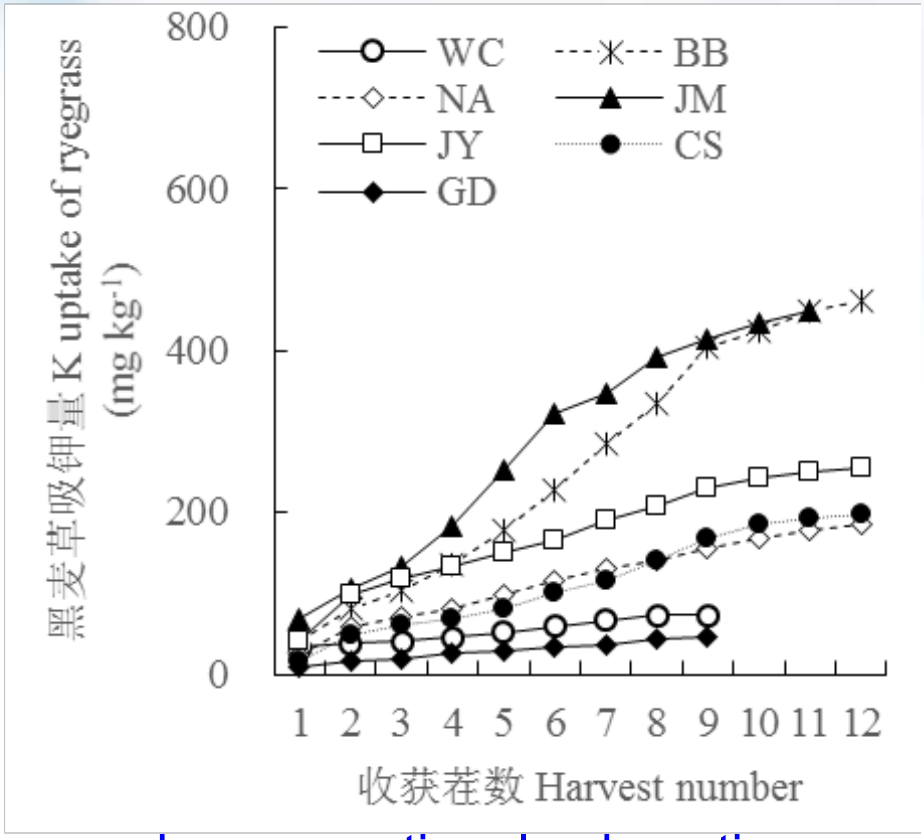


The soil available K as affected by ryegrass uptake under conventional exhaustive experiment

Soil available K declined quickly initially, but declined slowly or remained stable as the K exhaustion extended.

Grading plant-available K in soils

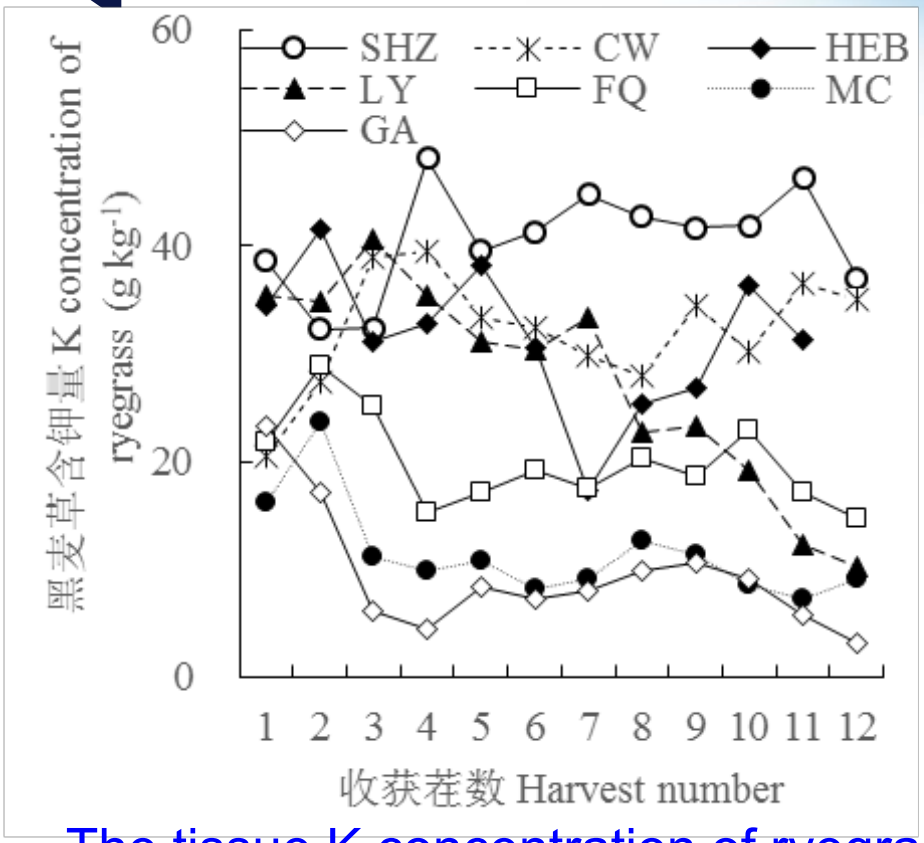


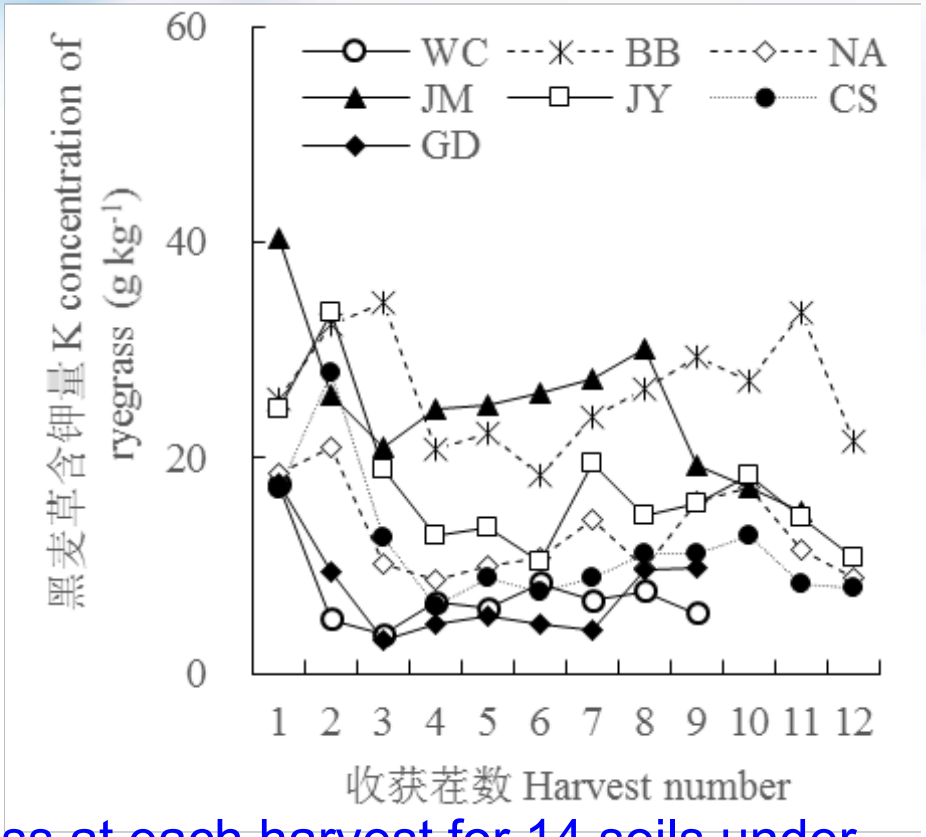


The accumulated K uptake by ryegrass under conventional exhaustive experiment

The K uptake by ryegrass differed greatly among the soils.

Grading plant-available K in soils

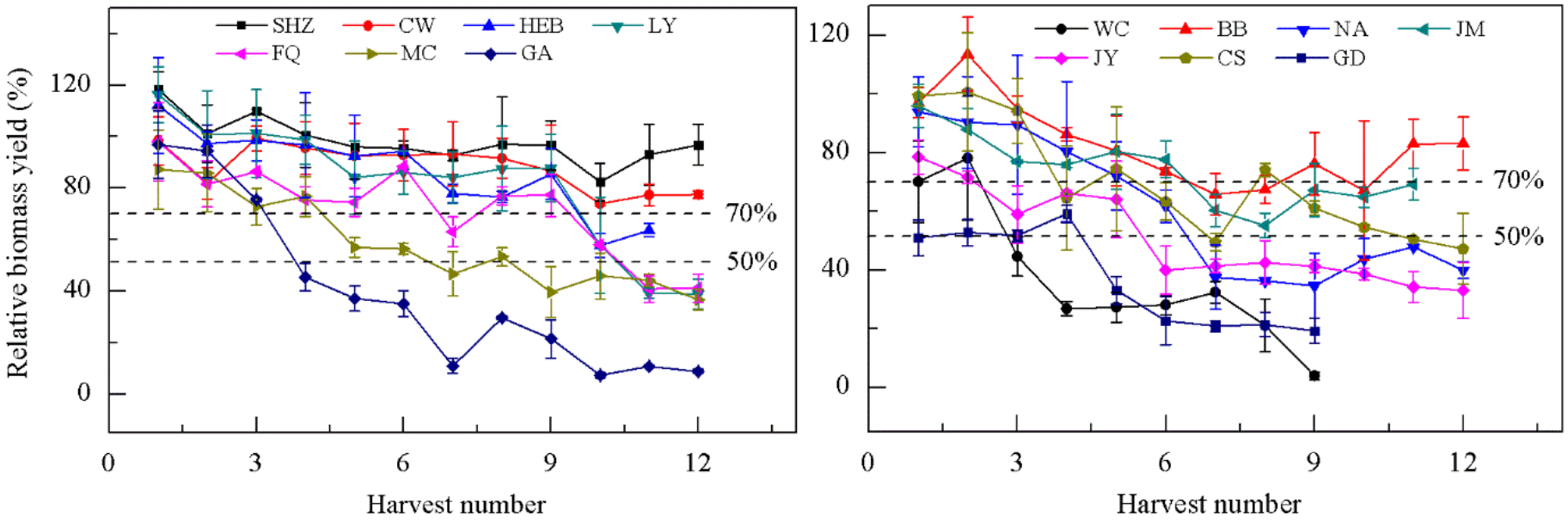




The tissue K concentration of ryegrass at each harvest for 14 soils under conventional exhaustive experiment.

The K concentration of ryegrass is not stable since the concentration could be easily affected by the growth rate which could be easily affected by other factors such as the climate

Grading plant-available K in soils



Relative biomass yield for ryegrass at each harvest for 14 soils under conventional exhaustive experiment. (Dotted lines indicate the critical values)

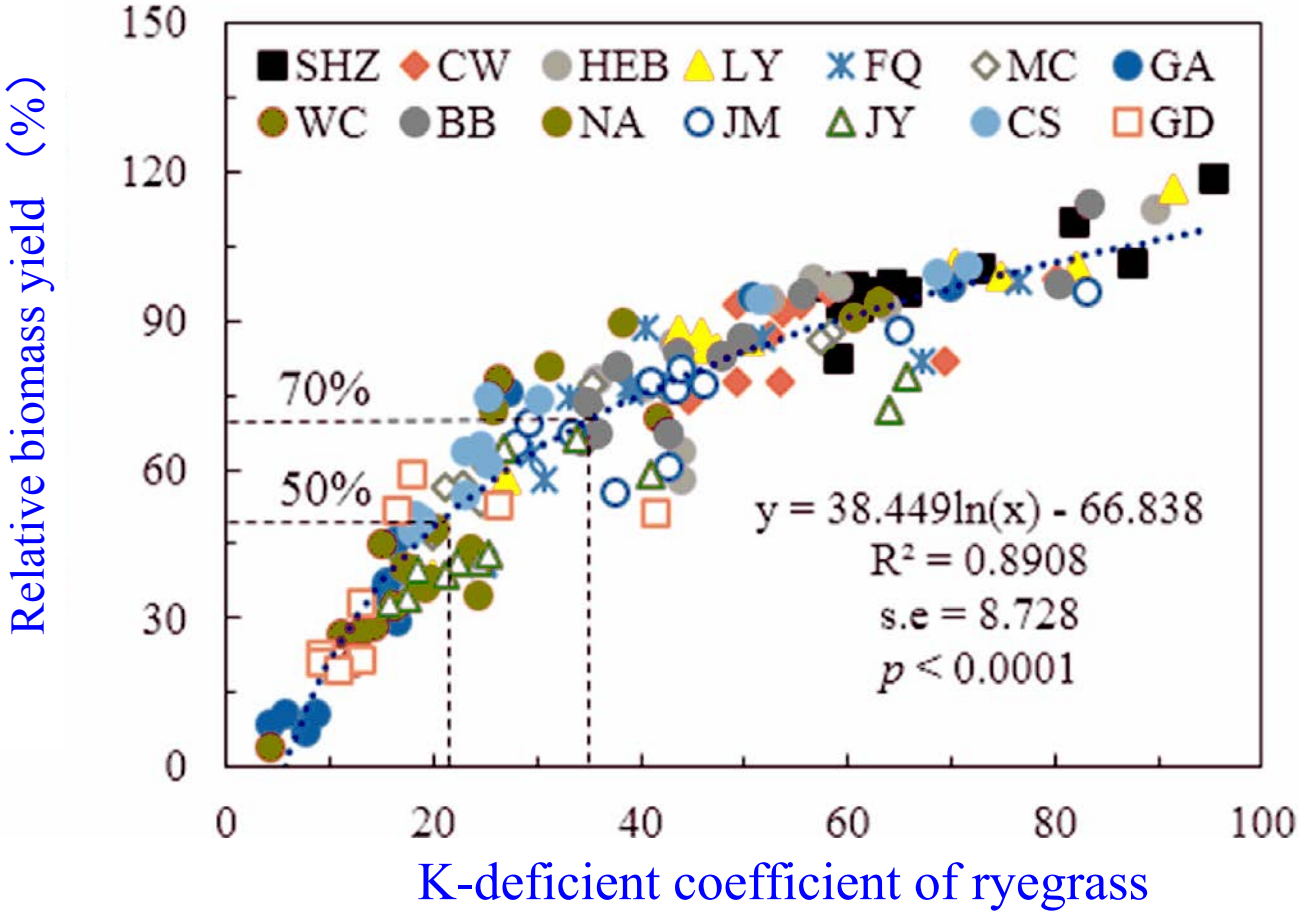
The relative biomass is an important index for soil K availability, while it also sometimes fluctuated as the soil K availability declined.

Grading plant-available K in soils

Values of RBY, tissue K concentration (Kc), relative K concentration (RKc), and relative K uptake (RKu) for ryegrass were occasionally erratic because of differences in the physical characteristics of the soil, which affected the drainage and aeration in the pots

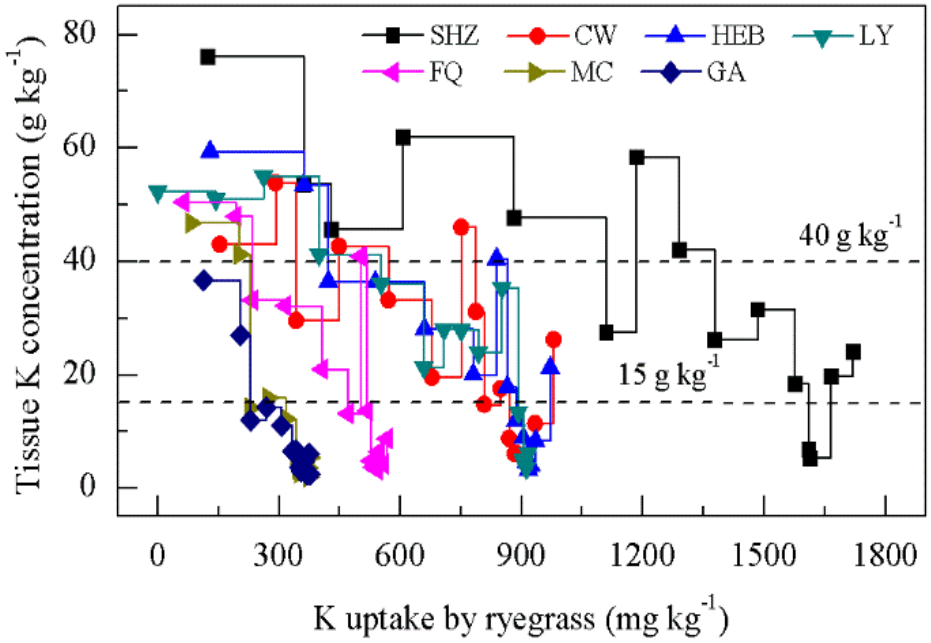
Principal component analysis (PCA) was applied to evaluate the K-deficient coefficient of ryegrass under a conventional exhaustive experiment by considering all the growth indices

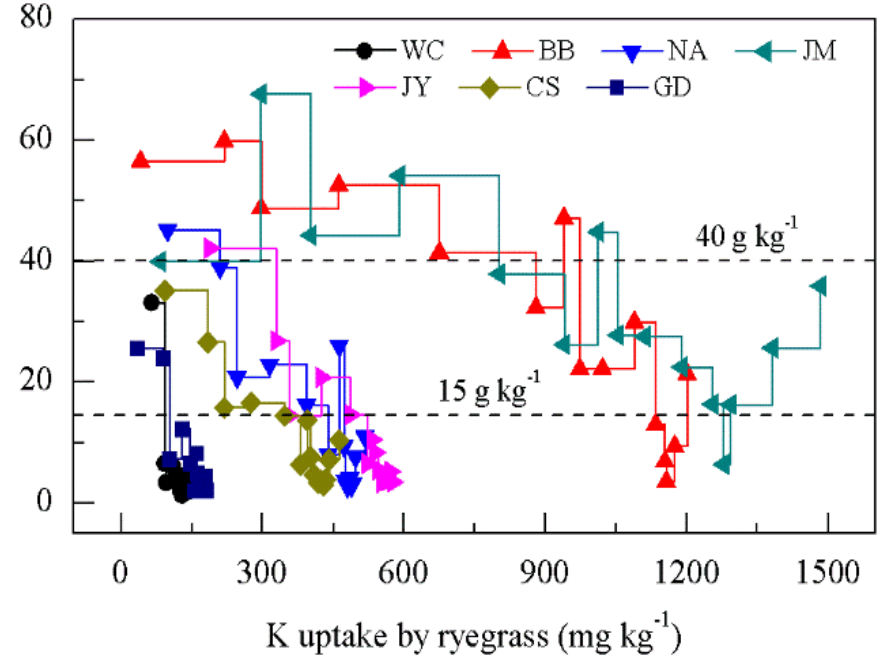
Grading plant-available K in soils



Relation between relative biomass yield and K-deficient coefficient of ryegrass under conventional exhaustion experiment. (The right-angled lines reflect the inflexion points of K-deficient coefficient based on the critical values of relative biomass yield)

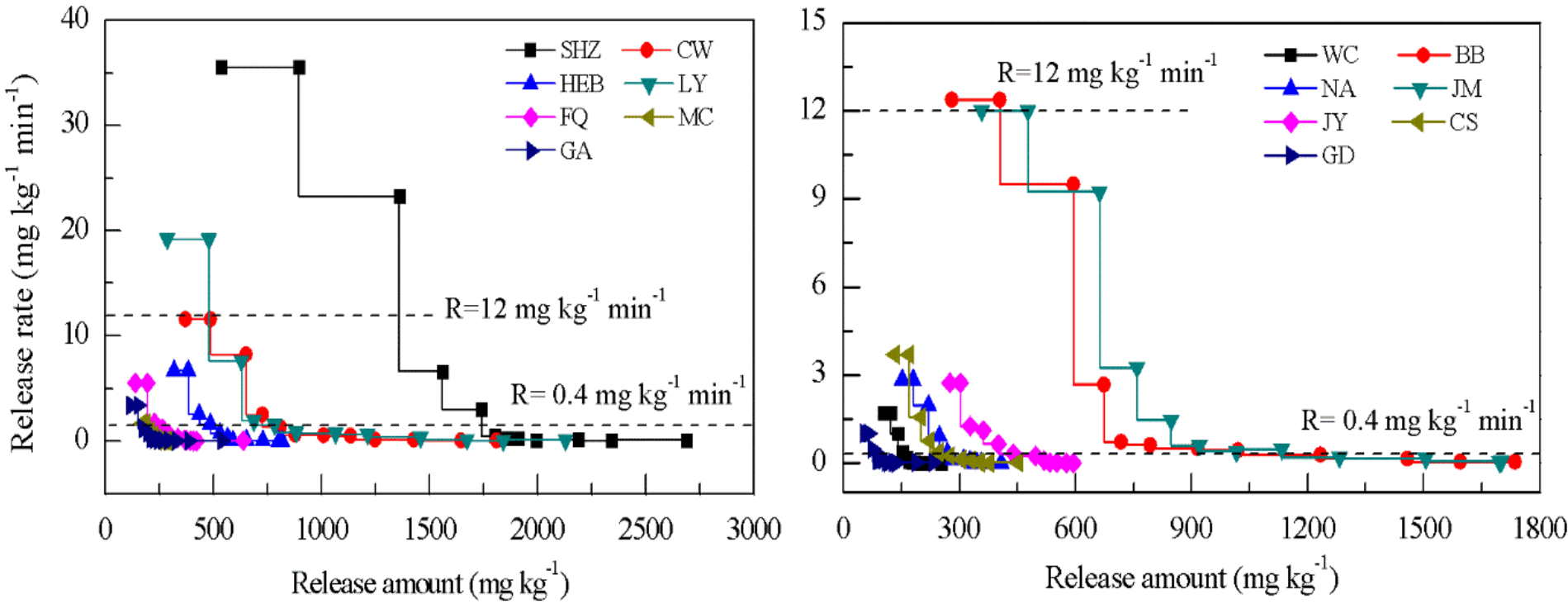
Grading plant-available K in soils





Relation between tissue K concentration and K uptake accumulation of ryegrass under intensive exhaustive experiment (Dotted lines show the turning points of K concentration of ryegrass based on the change trend of tissue K concentration and K uptake accumulation of ryegrass.)

Grading plant-available K in soils



Potassium release amount and rate when extracted by weak extraction method for different soils. (Dotted lines in the figures express the critical values of K release rate based on the change trend of K release amount and rate.)

Grading plant-available K in soils

Grading criterion of soil plant-available K

Plant-available K grading	K release rate by weak extraction method (mg kg^{-1} min^{-1})	RBY of ryegrass (%)	K-deficient coefficient of ryegrass	K concentration of ryegrass under intensive exhaustive experiment (g kg^{-1})
HAK	>12	>70	>38	>40
MAK	0.4-12	50-70	22-38	15-40
LAK	0.1-0.4	10-50	8-22	5-15
NAK	<0.1	<10	<8	<5

*HAK, MAK, LAK and NAK are the high available K, medium available K, low available K and non-available K, respectively.

Comparison of the amounts of the three plant-available levels that extracted by NaTPB and uptake by ryegrass grown in different soils (mg kg^{-1})

Soil Abbr.	HAK			MAK		LAK		Total available K	
	Extraction by NaTPB (x1)	Uptake by ryegrass (y1)	Uptake by ryegrass (y2)	Extraction by NaTPB (x2)	Uptake by ryegrass (y3)	Extraction by NaTPB (x3)	Uptake by ryegrass (y4)	Extraction by NaTPB + NaCl for 1h (x4)	Uptake by ryegrass (y5)
SHZ	1358	>770	1291	442	>428	348		2149	> 1719
CW	486	>462	448	392	400	611	>132	1489	> 980
HEB	317	301	361	212	503	541	107	1070	971
LY	477	448	398	587	454	131	64	1195	916
FQ	138	86	193	159	214	372	160	668	566
MC	169	73	202	53	71	192	103	413	376
GA	118	62	113	80	90	242	173	440	377
WC	104	33	64	37	0	173	76	314	140
BB	403	461	675	511	414	1074	> 112	1988	> 1201
NA	151	70	98	95	296	566	123	812	517
JM	477	392	591	656	664	219	230	1352	1485
JY	275	119	188	125	168	259	220	658	576
CS	132	60	93	91	183	516	187	739	463
GD	54	9	34	20	54	226	91	300	179
Correlation	$y_1 = 1.096x_1 - 81$ ($R^2 = 0.918$)		$y_2 = 0.980x_1 + 13$ ($R^2 = 0.922$)	$y3 = 0.959x2 - 27$ ($R^2 = 0.754$)		$y_4 = 0.061x_3 + 64$ ($R^2 = 0.0279$)		$y_5 = 1.040x_4 - 155$ ($R^2 = 0.898$)	

Values in the row of y_1 are the data under conventional exhaustive experiments, and values in the row of y_2, y_3, y_4 and y_5 are the data under intensive exhaustive experiment

The grading system for plant-available K in soils

Available K grading	Grading method		K content
HAK	A_{10min}-A_{5s}<120 mg kg^{-1}		HAK=A_{5s}
	A_{10min}-A_{5s}>120 mg kg^{-1}	A_{30min}-A_{10min}<240 mg kg^{-1}	HAK=A_{10min}
		A_{30min}-A_{10min}>240 mg kg^{-1}	HAK=A_{30min}
MAK		A_{4h}-A_{HAK}<92 mg kg^{-1}	MAK=A_{4h} - HAK
		A_{4h}-A_{HAK}>92 mg kg^{-1}	MAK=A_{24h} – HAK
LAK			LAK=A_{S-1h} - HAK - MAK
NAK			NAK= TK - A_{S-1h}

A_{5s}, A_{10min}, A_{30min}, A_{4h} and A_{24h} is the amount of K extracted by 0.2 mol L^{-1} NaTPB for period of 5s,10min,30min,4h and 24h, respectively. A_{S-1h} is the amount of K extracted by 0.2 mol L^{-1} NaTPB+1mol L^{-1} for 1 h. TK is the total K of soil.

Li et al., 2016, Scientific Reports

Many Thanks to IPNI!

May the Chinese Rooster New Year bring health, happiness, success and wealth to all of you!