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Bioavailability of soil potassium and its distribution in China cropland

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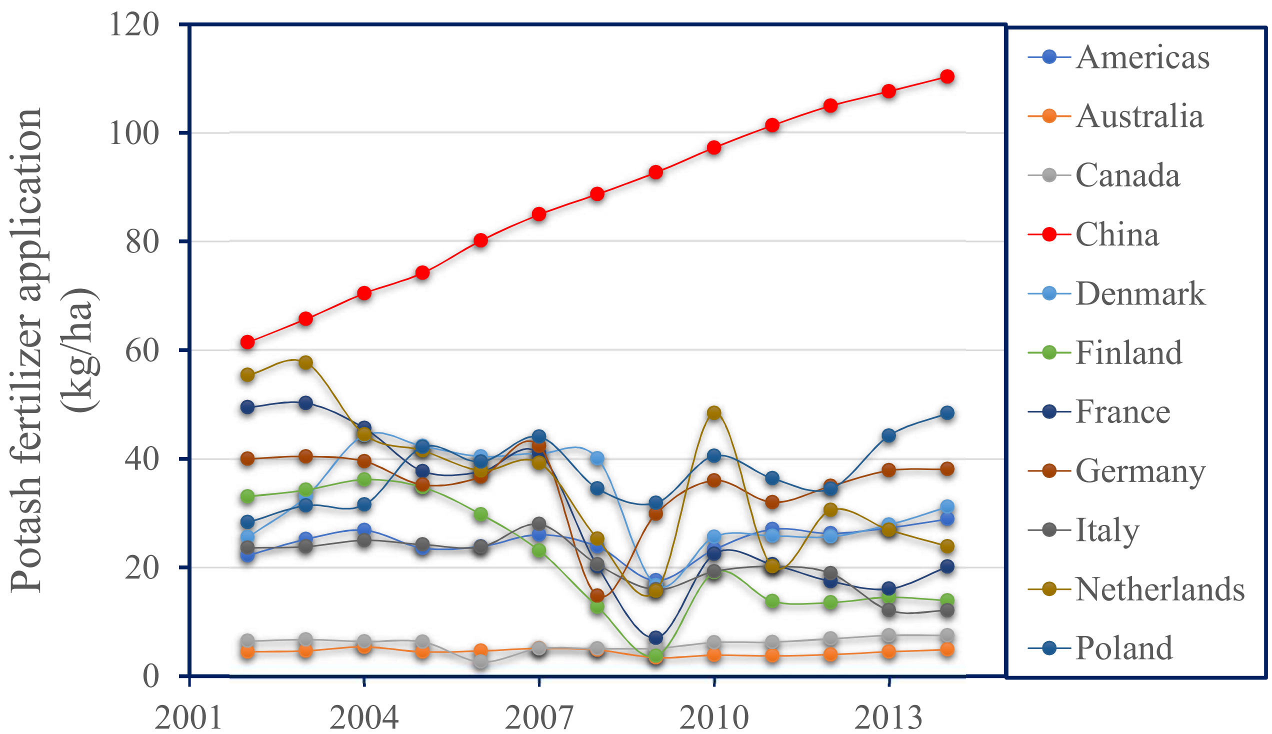
Outline

- Background
- Bioavailability of soil potassium
- Soil available potassium distribution in China
- Conclusion

Background



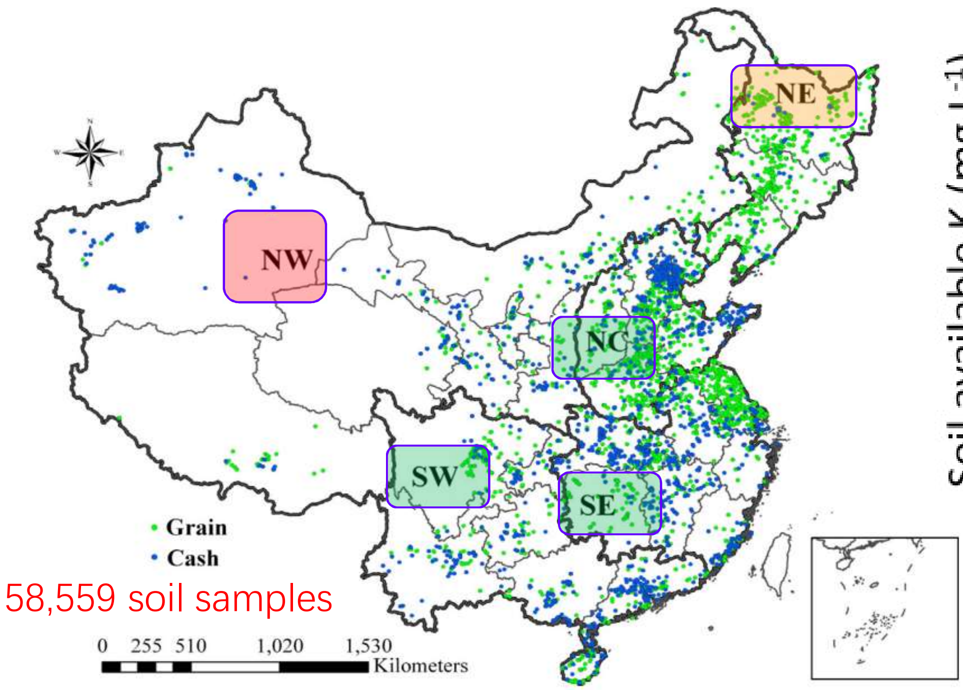
Potash fertilizer application per hectare of cropland

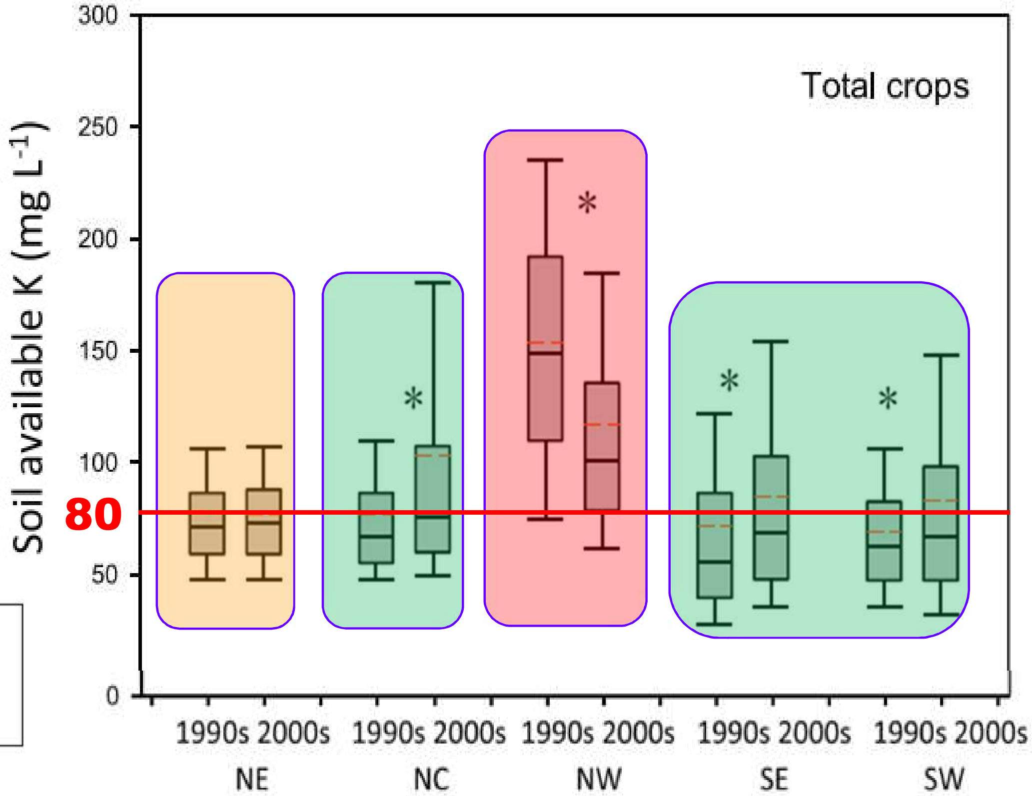
Average potash fertilizer application rate, measured in kilograms of total nutrient per hectare of cropland.

- Potassium (K) has a crucial role in crop growth, yield, quality, and stress resistance.
- K fertilizer application rate was increased in China, and the application rate was higher in China than in lots of the other contires.

Data from the FAO Fertilizer Database.

Background

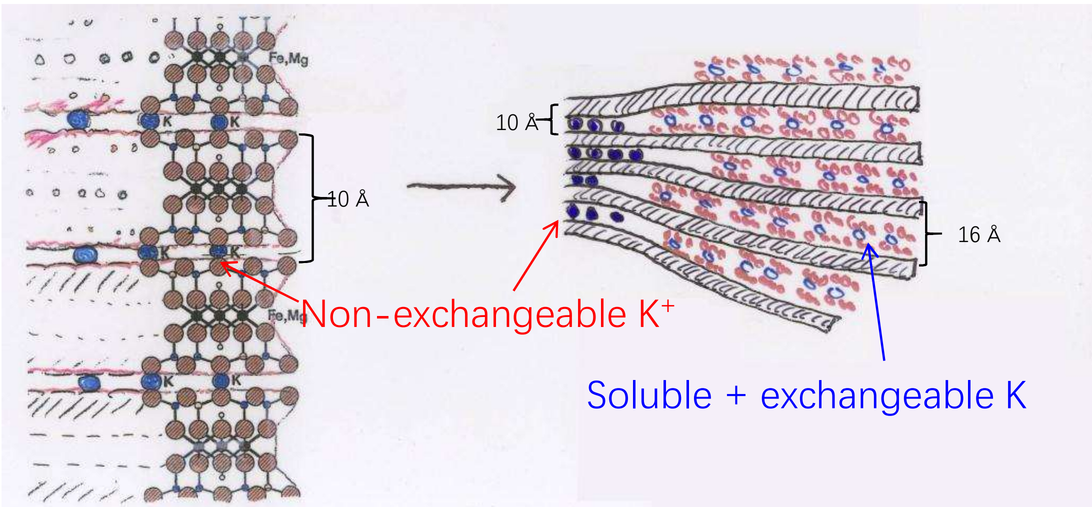




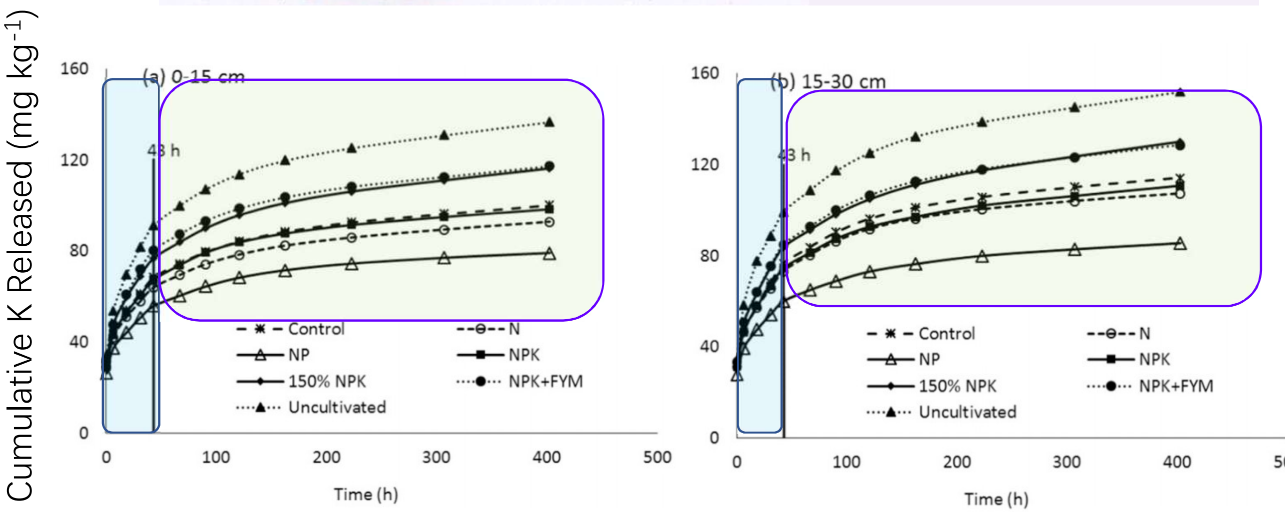
The values of soil available K were lower than the 80 mg L^{-1} (the critical value for K deficiency), with the only exception in the NW region.

He P et al., 2015, *Field Crops Research 173, 49-56.*

Background



The available K are replenished by non-exchangeable K (NEK) when they are depleted.



The plant availability of NEK depends primarily on the rate at which it can be released as more labile forms (i.e., both exchangeable and soluble).

NEK bioavailability grading ?

Das et al., 2019, *Geoderma 341, 76-92.*

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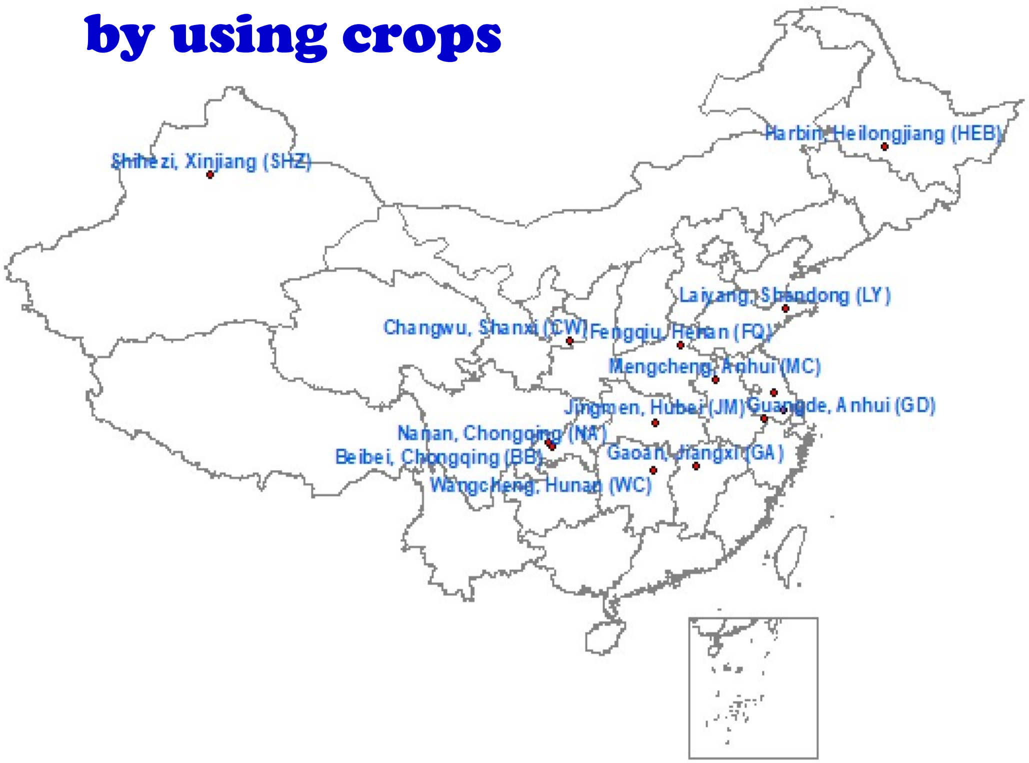
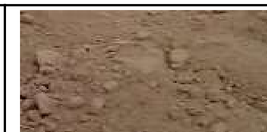
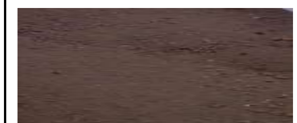
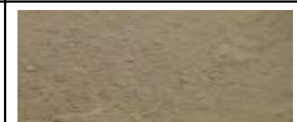
- Soil available potassium distribution and influence factors
- Conclusion

Bioavailability of soil potassium

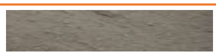
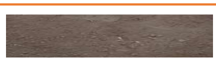
- **Acquisition of soil potassium by using crops**



Sites for the 14 experimental soils

SHZ		CW	
HEB		LY	
FQ		MC	
GA		WC	
BB		NA	
JM		JY	
CS		GD	

Site characteristics of the 14 agricultural sites in the study

Code	Soil photo	NH_4OAc-K (mg kg^{-1})	HNO_3-K (mg kg^{-1})	TK (g kg^{-1})	Elevation (m)	Mean annual precipitation (mm)	Mean annual temerature (mm)
SHZ		**324.6**	**1310.8**	**27.4**	433	225	7.8
CW		**152.4**	**1431.0**	**25.2**	1213	588	9.4
HEB		**190.4**	**1175.1**	**27.2**	116	523	4.9
LY		**156.5**	**972.0**	**23.3**	41	800	12.0
FQ		**96.6**	**681.8**	**23.1**	70	615	14.3
MC		**125.8**	**542.5**	**17.5**	27	812	15.4
GA		**122.9**	**829.7**	**26.2**	41	1560	18.1
WC		**90.7**	**310.6**	**16.8**	66	1411	17.7
BB		**148.3**	**655.7**	**28.1**	327	1105	18.2
NA		**104.6**	**357.9**	**18.6**	538	1089	18.0
JM		**224.9**	**1067.6**	**27.6**	46	1179	16.4
JY		**188.8**	**604.6**	**20.2**	5	992	15.2
CS		**93.2**	**474.2**	**22.6**	4	1054	16.2
GD		**43.1**	**351.2**	**16.3**	34	1150	15.7

➢ Acquisition of soil potassium by using crops

- **Conventional exhaustive experiment**

Culture medium: 5kg soil were put in plastic pots of 20 cm in diameter and 20 cm deep

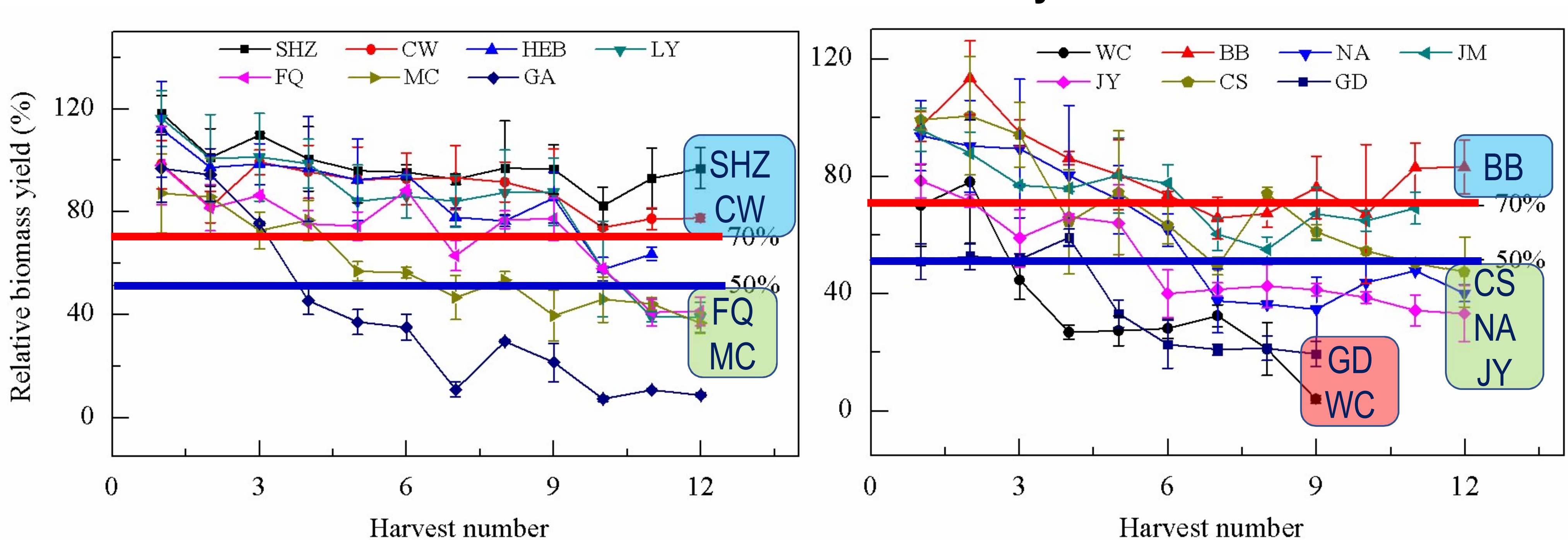
Two treatments: no K fertilizer and K fertilizer with potassium sulfate (200 mg K kg^{-1} soil)

The aboveground parts of the plants were harvested after they had grown for 30 d, 12 cuts were collected.

➢ Acquisition of soil potassium by using crops

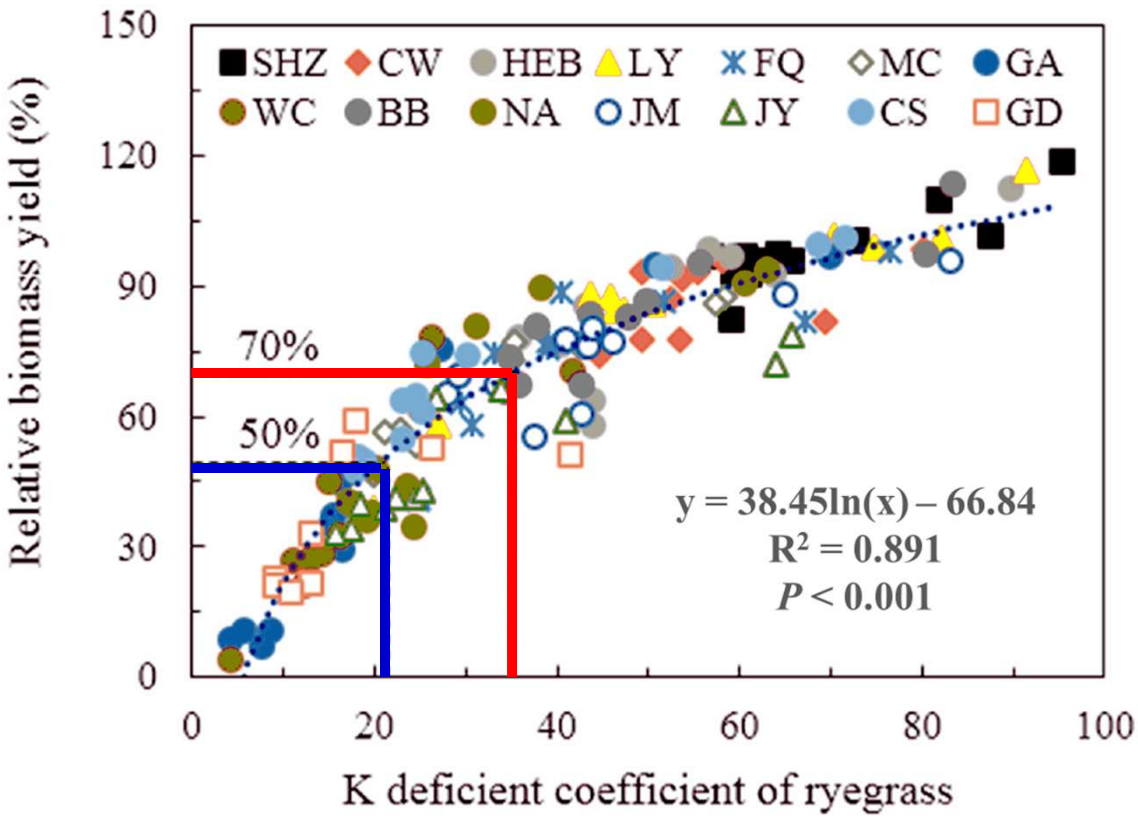
- **Conventional exhaustive experiment**

The RBY during the growth period decreased slightly if its values were > 70%, but decreased substantially when its values varied from 50% to 70%. However, when the values of RBY were < 50%, the curves began to flatten. Thus, RBYs of 70% and 50% were determined to be critical values in the current study.



Relative biomass yield for ryegrass at each harvest for 14 soils under conventional exhaustive experiment.

- **Conventional exhaustive experiment**



Relation between relative biomass yield and K-deficient coefficient of ryegrass under conventional exhaustive experiment.

K deficient coefficient = 0.245 (RBY) + 0.236 (Kc) + 0.258 (RKc) + 0.261 (RKu)

The critical values of the RBY (70% and 50%) were used to grade the K status in soils to judge available K supplication to plant growth.

According to these parameters, the ryegrass K-deficient coefficients of 35 and 22 were obtained as inflexion points in the current study.

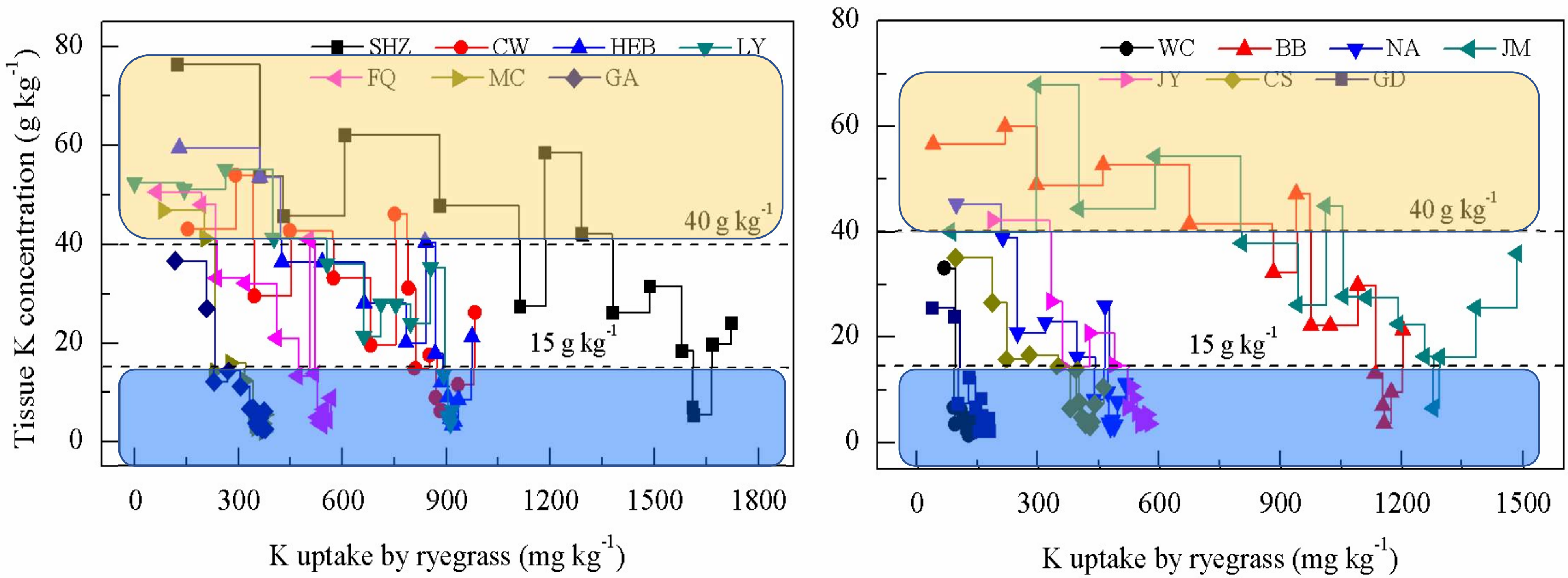
➢ Acquisition of soil potassium by using crops

- **Intensive exhaustive experiment**

- ✓ **The soils (5.0 kg) were put in plastic pots measuring 40 cm × 20 cm × 10 cm (length × width × height).**
- ✓ **Management measures were the same as conventional exhaustive experiment but with no K fertilizer.**
- ✓ **The aboveground part of the ryegrass (> 5 cm in height) was harvested after its length exceeded 20 cm, then harvested again when the length exceeded 20 cm again until the ryegrass could no longer grow in the pot. The experiment was repeated, sowed anew. 15 crops were cut.**

➢ Acquisition of soil potassium by using crops

- **Intensive exhaustive experiment**



Relationship between tissue K concentration and K uptake by ryegrass under intensive exhaustive experiment.

The tissue Kc of 15 g kg^{-1} and 40 g kg^{-1} were as turning points in the intensive exhaustive experiments.

➢ Extraction of soil potassium with NaTPB

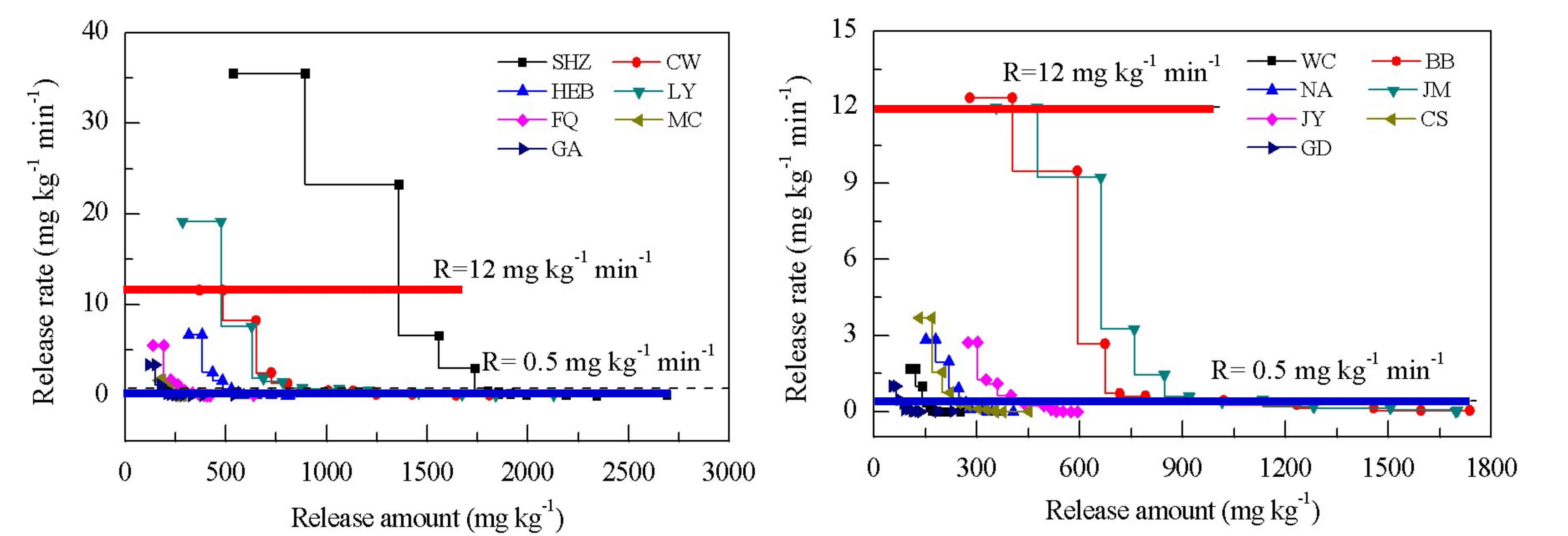
- **The weak extraction method**

3 mL 0.2 mol L^{-1} NaTPB was added and then the tubes were shaken at 200 rpm for each incubation 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).

- **The strong extraction method**

3 mL 0.2 mol L^{-1} NaTPB + 1.0 mol L^{-1} NaCl were added to the tubes, which were then shaken at 200 rpm for incubation periods of 1 h.

➢ Extraction of soil potassium with NaTPB



Potassium release amount and rate when extracted by weak extraction method.

Release trend	Quickly released K	Medially released K	Slowly released K
Release rate (mg kg^{-1} min^{-1})	> 12	0.5-12	<0.5

Bioavailability of soil potassium

Three categories are detailed in the table: highly available K (HAK), medially available K (MeAK), and lowly available K (LAK).

Grading criterion of soil plant-available K

Plant-available K grading	RBY of crops (%)	K-deficient coefficient of ryegrass	K concentration of ryegrass under intensive exhaustive experiment （$g\ kg^{-1}$）	K release rate in soils by weak extraction method ($mg\ kg^{-1}\ min^{-1}$)
HAK	> 70	> 35	> 40	> 12
MeAK	50-70	22-35	15-40	0.4-12
LAK	< 50	< 22	< 15	< 0.4

HAK, MeAK and LAK are the highly available K, medially available K and lowly available K, respectively.

Bioavailability of soil potassium

Soil abbreviation	HAK		MeAK		LAK		MaAK	
	Extraction by NaTPB (y_1)	Uptake by ryegrass (x_2)	Extraction by NaTPB (y_2)	Uptake by ryegrass (x_2)	Extraction by NaTPB (y_3)	Uptake by ryegrass (x_3)	Extraction by NaTPB + NaCl over a 1-h period (y_4)	Uptake by ryegrass (x_4)
SHZ	1358	1291	442	428	348		2149	1719
CW	486	448	392	400	611	>132	1489	980
HEB	317	361	212	503	541	>107	1070	971
LY	477	398	587	454	131	>64	1195	916
FQ	138	193	159	214	372	>160	668	566
MC	169	202	53	71	192	103	413	376
GA	118	113	80	90	242	173	440	377
WC	104	64	37		173	76	314	140
BB	403	675	511	414	1074	>112	1988	> 1201
NA	151	98	95	296	566	>123	812	517
JM	477	591	656	664	219	230	1352	1485
JY	275	188	125	168	259	220	658	576
CS	132	93	91	183	516	>187	739	463
GD	54	34	20	54	226	91	300	179

Bioavailability of soil potassium

Soil abbreviation	HAK		MeAK		LAK		MaAK	
	Extraction by NaTPB (y_1)	Uptake by ryegrass (x_2)	Extraction by NaTPB (y_2)	Uptake by ryegrass (x_2)	Extraction by NaTPB (y_3)	Uptake by ryegrass (x_3)	Extraction by NaTPB + NaCl over a 1-h period (y_4)	Uptake by ryegrass (x_4)
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FQ	138	193	159	214	372	>160	668	566
MC	169	202	53	71	192	103	413	376
GA	[illegible]	[illegible]	80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WC	104	[illegible]	37	[illegible]	173	76	314	140
BB	403	675	511	414	1074	>112	[illegible]	> 1201
NA	151	98	95	296	566	>123	812	517
JM	477	591	656	664	219	230	1352	1485
JY	275	188	125	168	259	220	658	576
CS	132	93	91	183	516	>187	739	463
GD	54	34	20	54	226	91	300	179

Correlation

$R^2 = 0.922$
$p < 0.01$

$R^2 = 0.754$
$p < 0.01$

$R^2 = 0.494$
$p = 0.119$

$R^2 = 0.864$
$p < 0.01$

Bioavailability of soil potassium

A new serial method to measure HAK, MeAK, LAK, and MaAK in soil.

Grading system of the bioavailability of soil potassium

Bioavailability	Grading criteria		Concentration of K
Highly available	A_{10min}-A_{5s}<120 mg kg^{-1}		A_{5s}
	A_{10min}-A_{5s}>120 mg kg^{-1}	A_{30min}-A_{10min}<240 mg kg^{-1}	A_{10min}
		A_{30min}-A_{10min}>240 mg kg^{-1}	A_{30min}
Medially available		A_{4h}-A_{HAK}<92 mg kg^{-1}	A_{4h} - A_{HAK}
		A_{4h}-A_{HAK}>92 mg kg^{-1}	A_{24h} - A_{HAK}
Lowly available			A_{S-1h} - A_{HAK} - A_{MeAK}
Maximally available			A_{S-1h}

Note: A_{5s}, A_{10min}, $A_{30\ min}$, A_{4h} and A_{24h} is the amount of K extracted by 0.2 mol L^{-1} NaTPB for the 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 + 1 mol L^{-1} NaCl for 1h.

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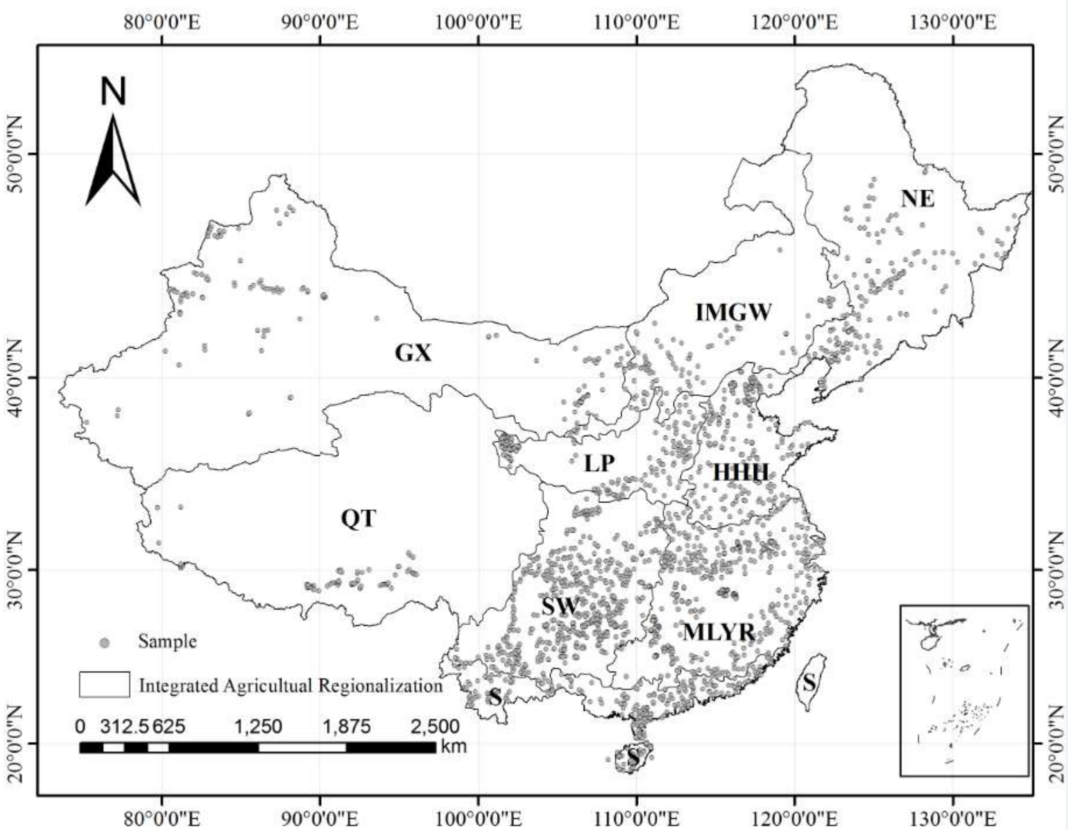
- Soil available potassium distribution in China
- Conclusion

Soil available potassium distribution in China

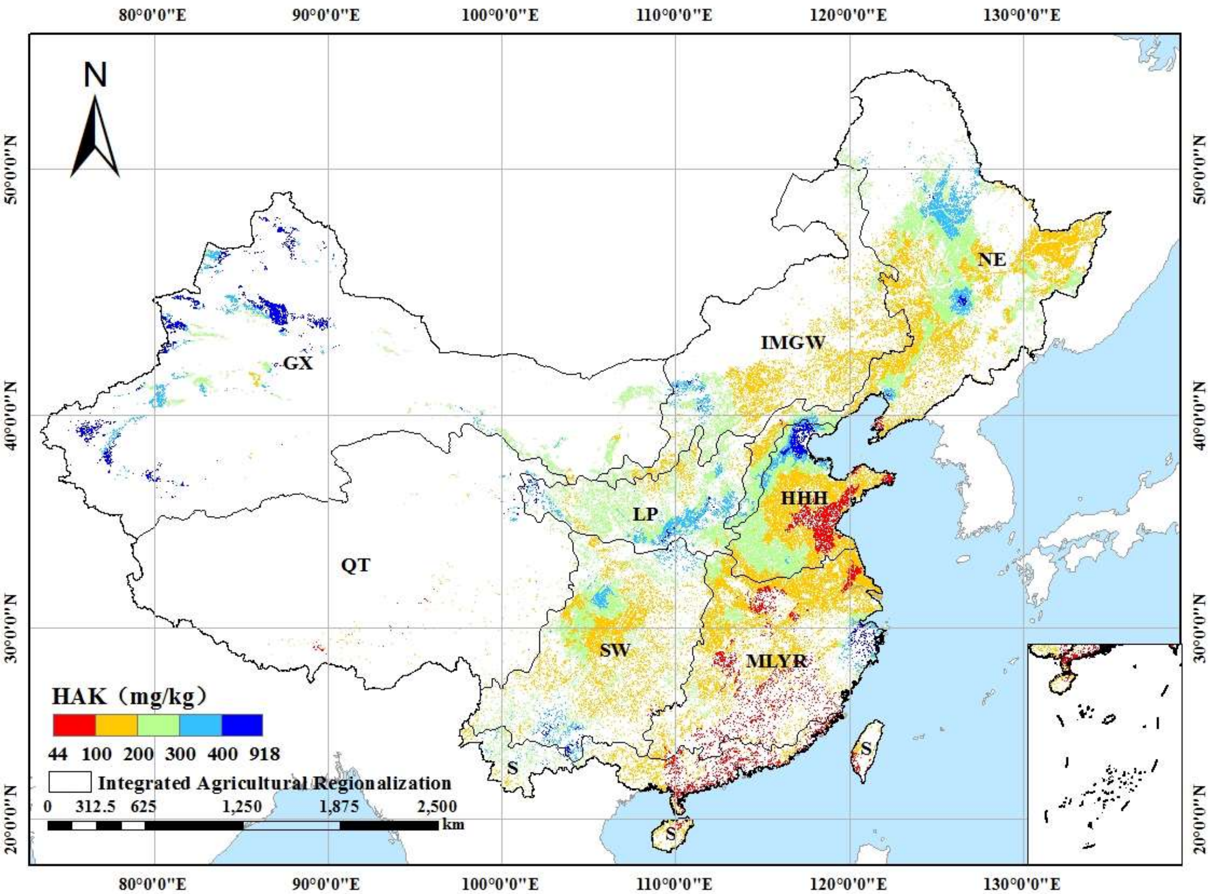


The location of the sample sites across nine agricultural regions in China.

- **2,428 soil samples**
- **Multiple climate zones**
- **Diverse topographic conditions**
- **Varied soil key properties**

NE, the northeast region; IMGW, inner Mongolia and the area along the Great Wall; HHH, the Huang–Huai–Hai region; LP, the Loess Plateau, MLYR, the middle and lower reaches of the Yangtze River; SW, southwestern China; S, southern China, GX, Gansu and Xinjiang; and QT, Qinghai and Tibet

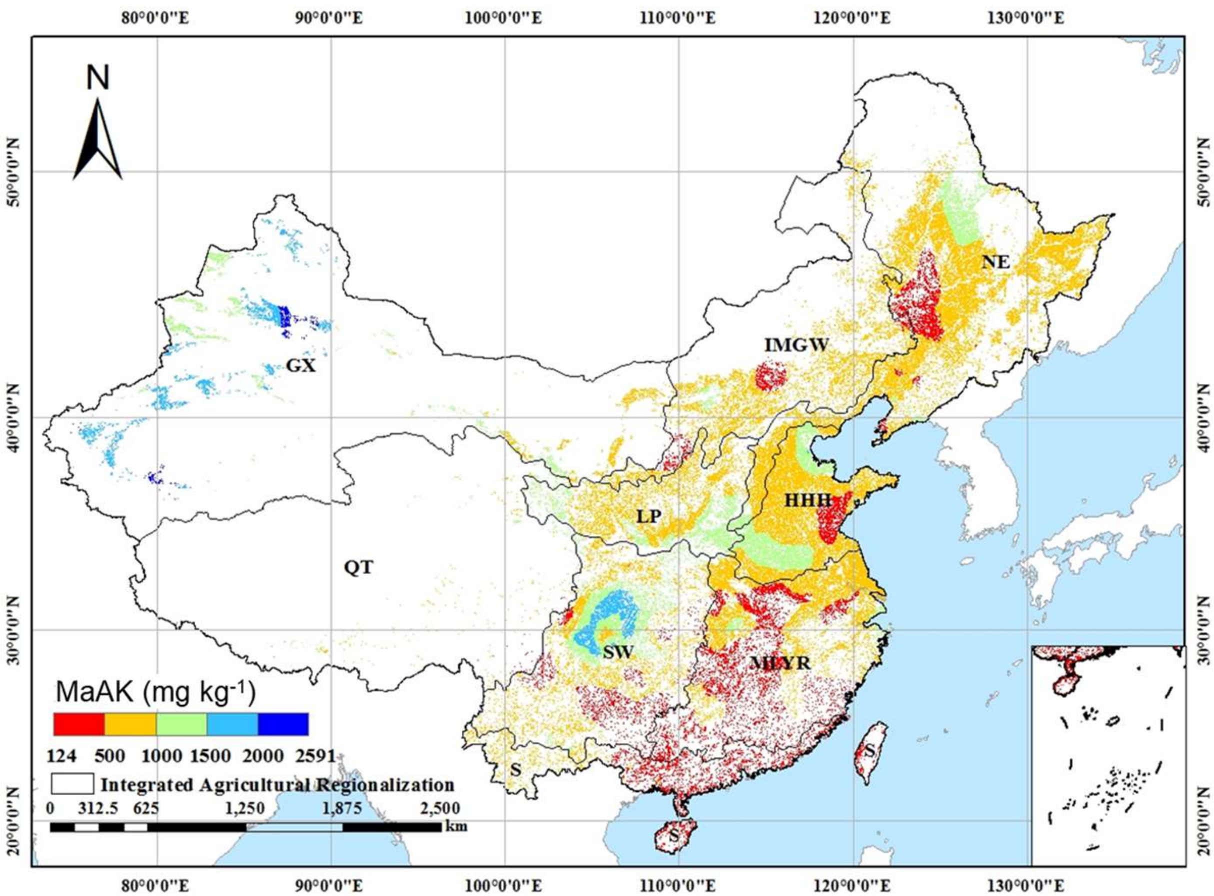
Soil available potassium distribution in China



Spatial distribution of highly available K (HAK) content in soil from the nine agricultural regions of China

- **HAK > 400 mg kg^{-1} (deep blue)** were mainly distributed as small patches in GX, northeastern and north-northeastern HHH.
- **HAK in the range 300–400 mg kg^{-1} (light blue)** was mainly distributed in parts of GX, NE, and HHH, and slightly less in IMGW, LP, and SW.
- Most cropland soils had **HAK in the range 100–300 mg kg^{-1}**.
- The regions of S, MLYR, and HHH generally had soil **HAK < 100 mg kg^{-1} (red).**

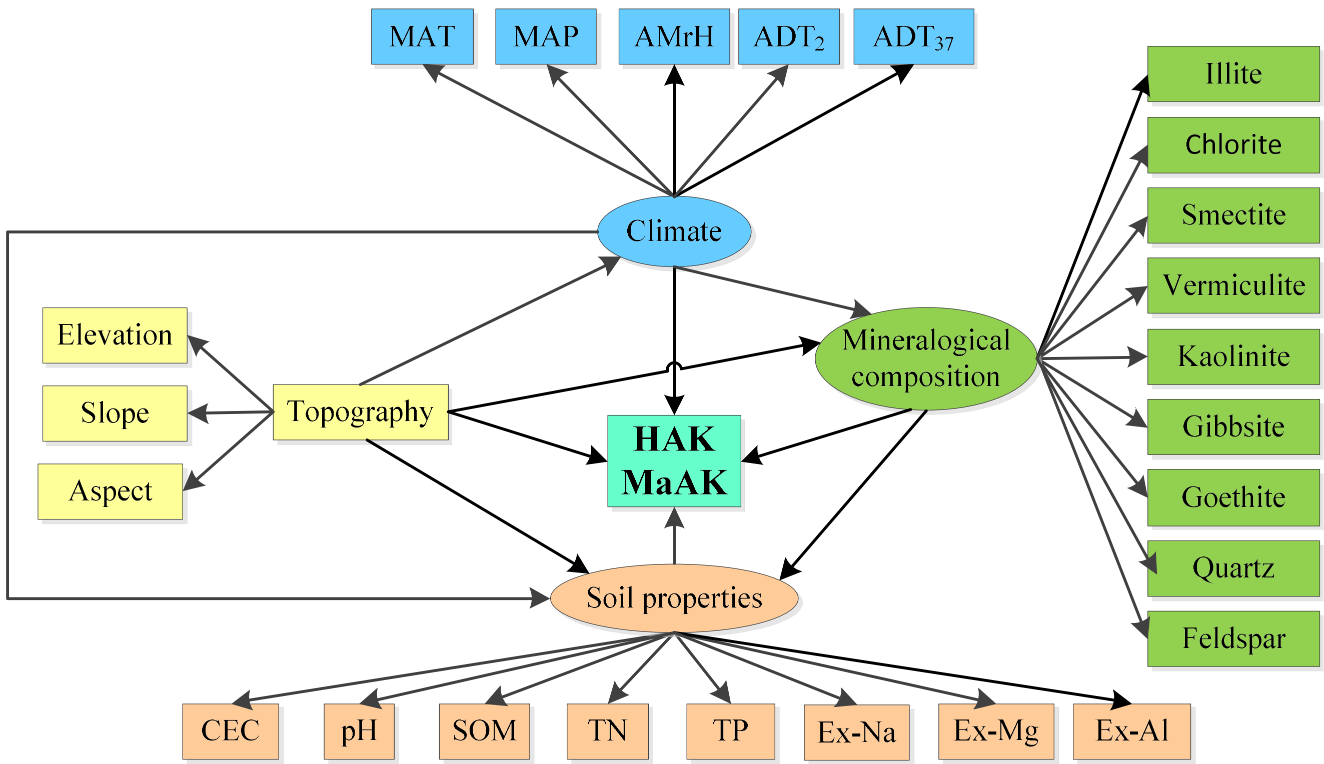
Soil available potassium distribution in China



Spatial distribution maximally available K (MaAK) content in soil from the nine agricultural regions of China

- **MaAK > 1,500 mg kg^{-1} (deep and light blue)** were distributed as small patches in northwestern regions of GX and SW.
- Most cropland soils had **MaAK in the range 500–1,500 mg kg^{-1} (orange and green)**.
- The central to eastern parts of the country generally had soil **MaAK < 500 mg kg^{-1} (red).**

Influence factors of soil available potassium distribution

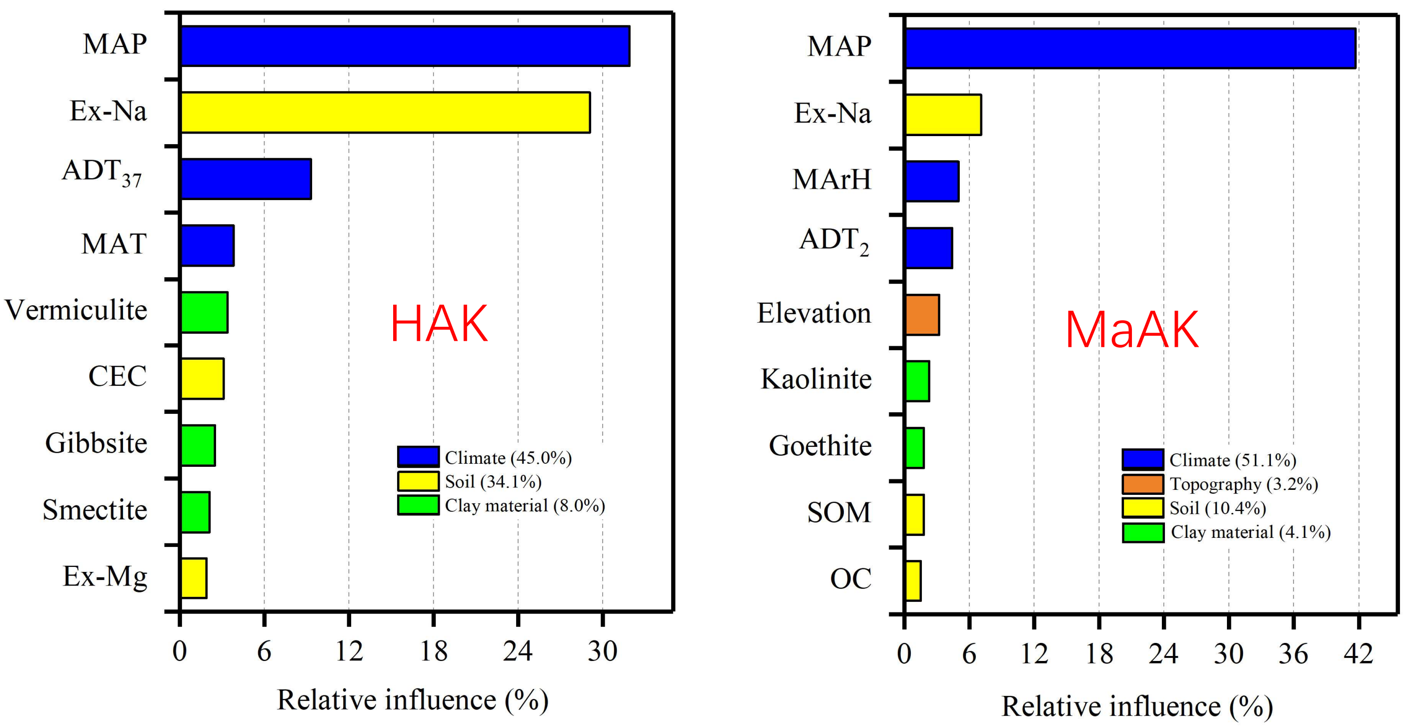


An a-priori structural equation model of the direct and indirect effects of climate, topography, key soil properties and clay mineralogical composition on HAK and MaAK.

MAP, mean annual precipitation; MAT, mean annual temperature; MArH, mean annual relative humidity; ADT37, annual days of minimum temperature more than 37°C; ADT2, annual days of maximum temperature less than 2°C

pH, soil pH; CEC, cation exchange capacity; SOM, soil organic matter; TN and TP, soil total nitrogen and total phosphorus; Ex-Na, Ex-Mg and Ex-Al, exchangeable sodium, exchangeable magnesium and exchangeable aluminium.

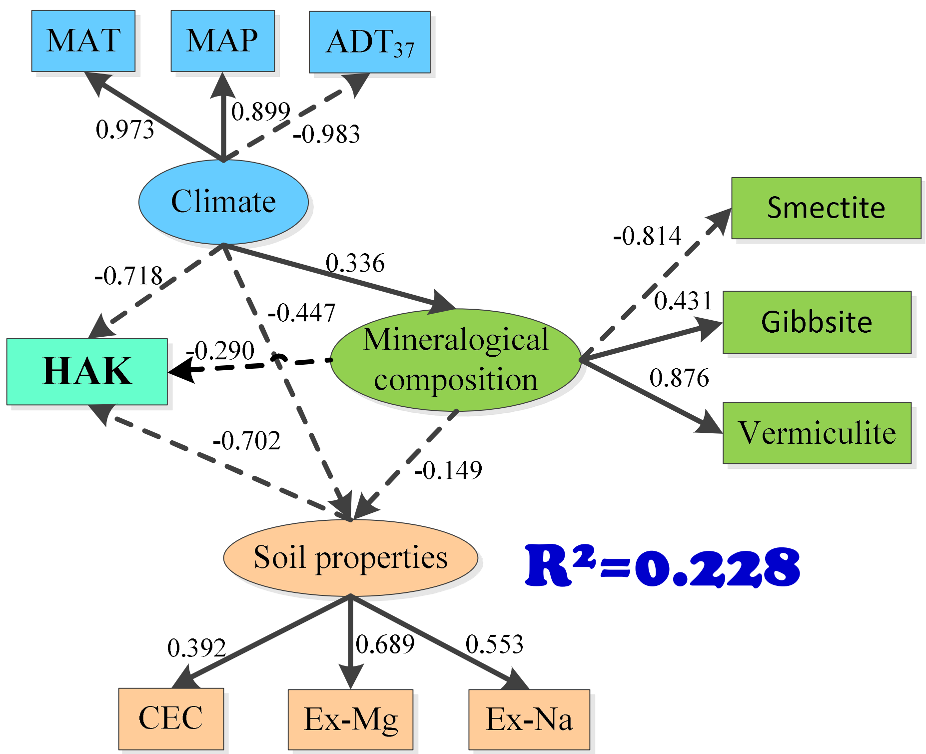
Influence factors of soil available potassium distribution



The relative importance (%) of influence variables identified by the best-subsets selection for soil HAK and TAK.

Best-subsets selection method: to identify the significantly influential factors controlling of soil HAK and MaAK.

Influence factors of soil available potassium distribution

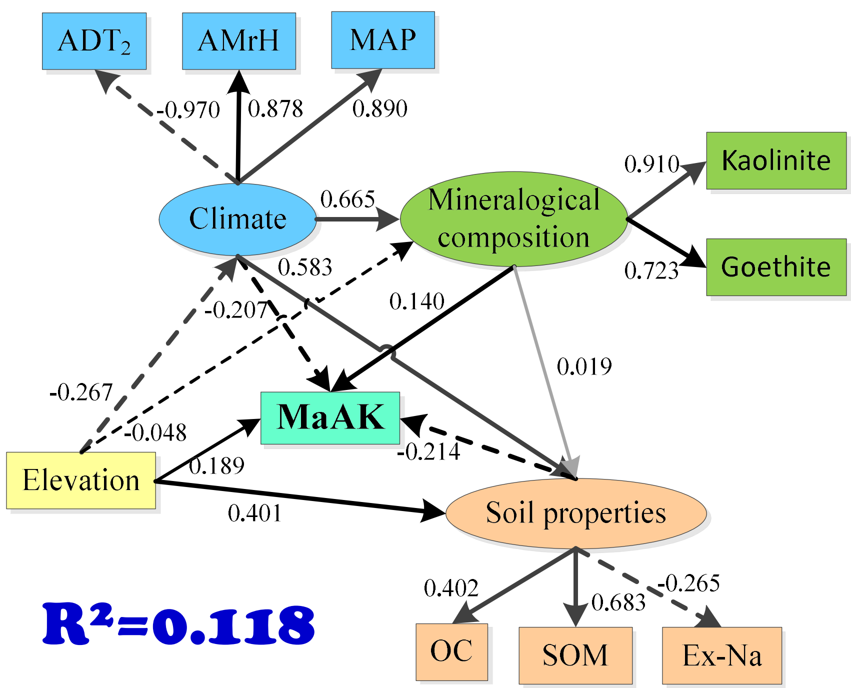


χ^2/df = 1.294; GFI = 0.998; NFI = 0.999;
RMSEA = 0.014; R^2 = 0.228

Structural equation modeling the direct and indirect effects of climate, key soil properties and clay mineralogical composition on soil HAK.

Effects	Items	Climate	Mineral	Soil
Direct	Mineral	0.336	0	0
	Soil	-0.447	-0.149	0
	HAK	-0.718	-0.290	-0.702
Indirect	Mineral	0	0	0
	Soil	-0.050	0	0
	HAK	0.251	0.105	0
Total	Mineral	0.336	0	0
	Soil	-0.497	-0.149	0
	HAK	-0.467	-0.185	-0.702

Influence factors of soil available potassium distribution



χ^2/df = 1.838; GFI = 0.997; NFI = 0.997; RMSEA = 0.023; R^2 = 0.118

Structural equation modeling the direct and indirect effects of climate, topography, key soil properties and clay mineralogical composition on soil MaAK.

Effects	Items	Elevation	Climate	Mineral	Soil
Direct	Climate	-0.267	0	0	0
	Mineral	-0.048	0.665	0	0
	Soil	0.401	0.583	0.019	0
	MaAK	0.189	-0.207	0.140	-0.214
Indirect	Climate	0	0	0	0
	Mineral	-0.178	0	0	0
	Soil	-0.16	0.012	0	0
	MaAK	-0.028	-0.034	-0.004	0
Total	Climate	-0.267	0	0	0
	Mineral	-0.226	0.665	0	0
	Soil	0.241	0.595	0.019	0
	MaAK	0.161	-0.240	0.136	-0.214

Conclusions

- A new grading criterion of plant-available K in soils based on the K release rate from soils and plant growth indices was established.
- The contents of HAK and MaAK was mainly distributed higher in western and northern China, but lower in the east and south.
- Climate, topography, soil key properties and clay mineralogical composition explained 22.8% and 11.8% of the variations in soil HAK and MaAK at the national scale.
- What about the effects of anthropogenic factors on soil plant-available K at local scale?

Thank you for your attention!

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