Research Findings

Yield Response of Winter Rapeseed to Potassium Fertilization, Use Efficiency and Soil's Potassium Critical Level in the Yangtze River Valley

Zou, J., and J.W. Lu[(1)].

Abstract

A study on the response of winter rapeseed (*Brassica napus* L.) to potassium (K) application was carried out on soils in the region of the Yangtze River Valley (YRV). Effects of K treatment on K use efficiency by the crop in relation to soil available K levels were also reported. A total of 132 field experiments were conducted in farmers' fields in the major winter rapeseed-growing areas in YRV of China. Results of these field experiments showed that, the average field increment resulting from 100 kg K ha^{-1} application was 358 kg ha^{-1}, an increase over the control CK (no K) of 18.0 percent in 2005/2006 and 2006/2007. The average internal use efficiency (IE) of K was higher in the CK treatment (21.9 kg grain, kg^{-1} K uptake) than in the +K (100 kg K ha^{-1}) treatment (17.7 kg grain, kg^{-1} K uptake). Oilseed rape required 68.1 kg of K to produce 1,000 kg seed. The recovery efficiency of K fertilizer in rapeseed production ranged from 0 to 100 percent, with an average of 39.3 percent. The K balance at most experimental sites was negative, with an average net removal of 117.6 kg K ha^{-1} in the CK treatment, and 56.8 kg K ha^{-1} in the +K treatment. The results indicate that there was a significant negative relationship between yield increments by K application and soil available K content. Based on the relative yield of CK/+K at 90 percent level, the soil available K (NH_4OAc-extractable K) critical level was 135 mg kg^{-1}.

Keywords: Rapeseed (*Brassica napus* L.); Potassium fertilizer; Potassium use efficiency; yield; Soil available K critical level.

Abbreviations: K, potassium; YRV, the Yangtze River Valley; PFP_K, K partial factor productivity; AE_K, K agronomic efficiency; IE_K, K internal efficiency; RIE_K, reciprocal internal efficiency; RE_K, apparent K recovery efficiency; KHI, K harvest index; DM, above-ground plant dry matter.

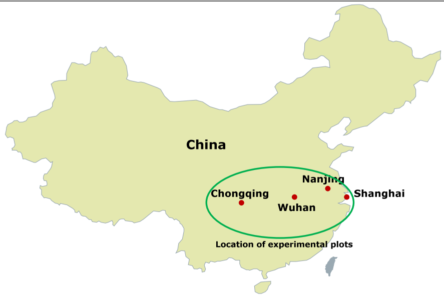
[(1)]*College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China. Correspondence author. E-mail address: lujianwei@mail.hzau.edu.cn*

Introduction

Winter rapeseed (*Brassica napus* L.) is the dominant oilseed crop in China. The Yangtze River Valley (YRV) is one of the three major rapeseed growing areas in the world and also offers considerable potential of increased production. The planted area of rapeseed in YRV is generally around 6.0×10^6 ha which is equivalent to 80 percent of the total cultivated rapeseed in China and 20 percent of that of the world (NBSC, 2007; Fu *et al.*, 2003). In addition, Hubei Province has the largest rapeseed production in China both in terms of area cultivated and yield.

Since the 1960s, potassium deficiency has increased over a wide area of China (Lu, 1989; Zhang *et al.*, 2008) and crop demands can no longer be met by the application of manures. Increased crop production from a rise in nitrogen and phosphorus fertilizer use has led to higher depletion of soil potassium. Significant responses to K fertilizer have been demonstrated on a variety of crops (Zhang *et al.*, 2008). Soil potassium deficiency is more serious in southern China, the areas of potassium shortage in the south of the Yangtze River accounting for about 80 percent of that across the entire country (Chen *et al.*, 2008). Soil potassium deficiency is recognized as one of the limiting factors for crop production (including rapeseed) in YRV.

Rapeseed has a high potassium demand to produce a healthy high-yielding crop containing between 150 to 300 kg of K ha^{-1} at maximum, excluding roots (Holmes, 1980). Considerable rapeseed yield increases, due to potassium fertilization, have been reported in various countries including Germany (Orlovius, 2000), south-western Australia (Brennan *et al.*, 2007), and Pakistan (Khan, 2004). In China similar increases have been reported by Liu and Tu (1989) and Lu *et al.* (2003). Measurements of extractable soil K have been related to yield responses and K fertilization as observed by Soper (1971). In the USA, 150 mg kg^{-1} soil of NH_4OAc-extractable K has been recommended as an adequate status (Gerwing *et al.*, 2001) which is similar to that in the UK (MAFF, 2000). These recommendations are in accord with the report of Govahi (2006) stating that rapeseed yield did not respond to applied K fertilizer when 209 mg kg^{-1} of NH_4OAc-extractable K was present in the soil. Likewise in south-western Australia, rapeseed yields were increased by application of K fertilizer to soils with less than 60 mg kg^{-1} Colwell-K (Brennan and Bolland, 2006). In China, according to field experiments in the 1980s, a K supply in the soil of 110 mg kg^{-1} NH_4OAc-extractable K was necessary to obtain maximum yields (Liu and Tu, 1989). However, because of the variance of soil testing methods, soil texture, climate, rapeseed varieties, yield levels, and other cultural management practices, the critical level for soil available K differed between regions.



Location of the experiments in the Yangtze River Valley, Southeast China.

Research Findings

With the development of crop breeding technology and improvement in farming practices, the main commercial rapeseed cultivars have changed greatly and grain yield levels have increased significantly from the 1980s (Fu *et al.*, 2003). It is widely recognized that information about crop response to fertilization, as well as nutrient use efficiency, soil nutrient balance and soil test requires updating and revaluation (Peck and Soltanpour, 1990; Chen and Zhang, 2006). Unfortunately, there has been little current national or regional emphasis on the effect of K fertilization, soil K balance or K critical level in winter rapeseed-growing in China.

In this paper, we present the results of some recent research on the effect of K fertilizer application on rapeseed in 10 provinces along YRV. The objectives of this work were to assess rapeseed yield response to K fertilizer in this region and to evaluate potassium use efficiency and the K balance of rapeseed systems. Other objectives were to examine the relationship between soil available potassium concentration and yield response to K fertilization, and to revise and update the critical soil available K level for current winter rapeseed production.

Table 1. Experimental sites.

Year	Number of trials	Sites
2000/2001	68	Qichun, county in Hubei province
2004/2005	7	Qichun, county in Hubei province
2005/2006	30	Qichun, Ezhou, Huangmei, Jingmen, Jingzhou, Tianmen, Wuxue, Zhijiang, Xiantao and Honghu counties in Hubei province
2006/2007	27	Pengzhou county in Sichuan, Tongzhou county in Jiangsu, Shanggao county in Jiangxi, Shaoxing county in Zhejiang, Tongnan county in Chongqing, Guangde county in Anhui, Zhijin county in Guizhou, Xinyang county in Henan and Lilin county in Hunan province

Materials and methods

Description of experimental sites

132 field experiments were conducted in farmers' fields in the major winter rapeseed-growing areas of China in 2000/2001 and 2004/2005-2006/2007. The experimental sites were located in 10 provinces of YRV: Hubei, Sichuan, Jiangsu, Jiangxi, Zhejiang, Chongqing, Anhui, Guizhou, Henan and Hunan.

The experimental year, the number of sites and their various locations are listed in Table 1. There were 68 experiments sites in 2000/2001, 7 sites in 2004/2005, 30 sites in 2005/2006, and 27 sites in 2006/2007. In 2005/2006 and 2006/2007, 3 experiments were conducted at each site, each experiment lasting for one year only. The recommended double-low rapeseed (*Brassica napus* L. with low glucosinolate and erucic acid content) cultivar for each region was used (as listed in the Ministry of Agriculture of the People's Republic of China from 2000 to 2006). The variety of winter rapeseed grown differed between sites. Rice or cotton was grown as a preceding crop.

Soil samples were taken prior to transplanting. The various soil chemical parameters and their ranges, with average values shown in parentheses, were as follows: initial soil pH of all experimental sites ranged from 4.6 to 8.0 (6.5), organic matter from 10.7 to 40.8 g kg^{-1} (25.3 g kg^{-1}), total N from 0.4 to 2.7 g kg^{-1} (1.4 g kg^{-1}), available P from 2.1 to 39.3 mg kg^{-1} (15.5 mg kg^{-1}), available B from 0.15 to 1.36 mg kg^{-1} (0.34 mg kg^{-1}), and available K from 28.5 to 289.0 mg kg^{-1} (96.8 mg kg^{-1}).

Experimental plot of K fertilization in rape seed crop. Photo by Lu Jian-wei.

Experimental design and treatments

Each experiment had two fertilizer treatments (1) CK, 0 kg K ha^{-1}; (2) +K, 100 kg K ha^{-1} as potassium chloride (60% K_2O) replicated three times using a plot area of 20 m^2 (4 m×5 m). To ensure that K was the only nutrient element limiting rapeseed production in the control treatment, the following fertilizers were applied to the soil in both treatments: 180 kg N ha^{-1} as urea (46% N); 39 kg P ha^{-1} as superphosphate (12% P_2O_5); 7.5 kg borax (11% B) ha^{-1}. Of the nutrients supplied, 60% N, 100% P, 62.5% K and 100% B were applied as basal fertilizers before transplanting. 20% N and 20% K were applied to the soil surface 50-60

Research Findings

days after transplanting, and the remainders (20% N and 17.5% K) were applied at stem elongation. Other than fertilizer application and grain harvest, each experimental field was managed using the individual farmer's current management practices.

Plant and soil sampling and analysis

Standard methods of soil analysis were used on sieved air-dried topsoil (0-20 cm) collected before transplanting: soil pH (glass electrode, soil/water ratio of 1:2.5); organic matter (dichromate wet combustion); total N (Kjeldahl digestion with H_2SO_4-K_2SO_4-$CuSO_4$-Se); available P, spectrophotometrically following Olsen extraction with 0.5 M $NaHCO_3$ at pH 8.5; available K, flame photometry following extraction with 1 M NH_4OAc; available B was determined by the hot water extraction method (Bao, 2000).

At final harvest (usually in early May), six plants were taken at random from each plot including all above-ground biomass (phytomass). After air-drying for two weeks, all plant samples were separated into seed, pod and stem. Dry weights of each component were determined after oven-drying at 70°C for 48 h. and samples were digested in a double-acid mixture of H_2SO_4 and $HClO_4$ in the ratio of 95:5. K concentration in the digest was measured by a flame photometer (Bao, 2000). Seed yield was determined from the total plot area (20 m^2) at maturity and adjusted to a moisture content of 8.5 percent fresh weight. Pod yield was calculated by the ratio of pod : seed of sampled plant. The same calculation using stem : seed ratio was made to determine stem yield.

Data analysis

Potassium use efficiencies were calculated based on the concepts and terminology of Witt *et al.* (1999), Peng *et al.* (2006) and Dobermann *et al.* (1996) from their work on irrigated rice. This terminology is as follows:

- **Partial factor productivity** (PFP_K, kg kg^{-1}) = seed yield/K supply.
- **Agronomic K efficiency** (AE_K, kg kg^{-1}) = (seed yield $_{+K}$ – seed yield $_{CK}$)/K supply. This is the incremental efficiency from applied potassium over the control.
- **Internal K efficiency** (IE_K, kg kg^{-1}) = seed yield/K uptake in above-ground plant DM. IE_K is thus defined as the amount of seed yield in kg ha^{-1} produced per kg plant K accumulation in above-ground plant dry matter (DM).
- **Reciprocal internal K efficiency** (RIE_K, kg 1,000 kg^{-1}) = (K uptake in above-ground plant DM/seed yield) ×1000.
- **Apparent K recovery efficiency** (RE_K, %) = (K uptake in above-ground plant DM $_{+K}$ – K uptake in above-ground plant DM $_{CK}$)/K supply×100.
- **K harvest index** (KHI, kg kg^{-1}) = K uptake in seed/K uptake in above-ground plant DM.

The critical level of soil available K was determined from the relationship between relative yield and the concentration of soil available K (Soper, 1971). Relative yield was determined by dividing the yield observed in the control by the yield of the fertilized treatment. In this research, relative yield was set at 90 percent, and then the critical level of soil available K was determined by the graphic method (Cate and Nelson, 1971) and logarithmic function method (Chen and Zhang, 2006).

Statistical analysis was performed using the data processing system (DPS) software (Tang and Feng, 2002) and SPSS 17.0. The difference between different treatments was determined using the least significant difference (LSD) test at the 0.05 probability level.

Land of rape seed. The experiment setup in one of the regions. Photo by Lu Jian-wei.

Results

Yield response to applied K

The results of field experiments in 2005/2006 and 2006/2007 were used to describe grain yield response to applied K. Grain yield ranged from 956 kg ha^{-1} to 4,087 kg ha^{-1} (mean value 2,206 kg ha^{-1}) for the CK treatments, compared with 1,222 kg ha^{-1} to 4732 kg ha^{-1} (mean value 2,564 kg ha^{-1}) when 100 kg K ha^{-1} was applied (Table 2). K fertilizer application was thus shown to have a positive effect on grain yield in most trials, with increases from 3 kg ha^{-1} to 1,005 kg ha^{-1} (mean value 358 kg ha^{-1}), and an average increased rate of 18 percent.

Fig. 1 describes the relationship between soil K available content (x) and yield response (y_1) in the experimental plots. The equation was y_1 = -374.67ln (x) + 1,933.1 (r=0.6653**; n=57). The high variability of grain yield in response to applied K between experimental sites probably relates to site differences in soil K status at transplanting and differences in environmental conditions during growth. For example, the available K was only 42.3 mg kg^{-1} at Hubei Ezhou, and the +K treatment increased yield by about 42.5 percent compared with the CK treatment. By contrast, at Hubei Honghu, Jiangxi Shanggao and Zhejiang Shaoxing, where the soil available K was much higher, the increasing rate raised yields by only less than 10 percent.

Differences in grain yield between the various sites were apparent. Jiangsu

Research Findings

Table 2. Soil available K content, rapeseed yield to K fertilizer application, K partial factor productivity (PFP_K) and agronomic efficiency (AE_K) in 2005/2006 and 2006/2007 growing seasons.

	Soil avail. K	Seed Yield		Response to K		AE_K	PFP_K	PFP_N	
		CK	+K					CK	+K
	mg kg^{-1}	------*kg ha^{-1}*------		*kg ha^{-1}*	*%*	*kg kg^{-1}*	*kg kg^{-1}*	*kg kg^{-1} N*	
Range	32.3-289.0	956-4,087	1,222-4,732	184-1,005	-8.2-68.5	0-10.1	12.2-47.3	5.3-22.7	6.8-26.3
Aver.±Std.	115.4±63.8	2,206±603 b	2,564±633 a	358±274	18.0±15.3	3.6±2.7	25.6±.3	12.3±3.4 b	14.2±3.5 a

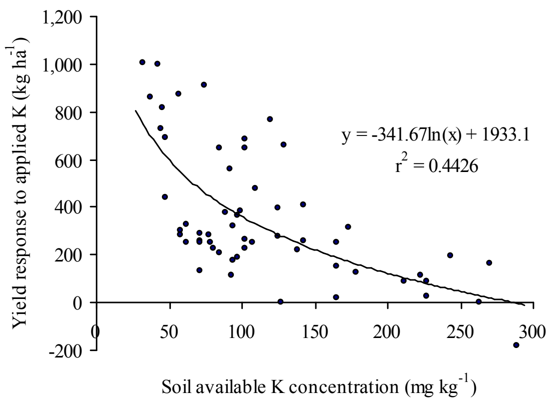


Fig. 1. Relationship between grain yield to applied K and soil available K level.

Tongzhou had a higher grain yield (3,310 kg ha^{-1} in the CK treatment and 3,825 kg ha^{-1} in the +K treatment) than the other sites in both CK and +K treatments. The greater yield in Jiangsu was probably due to the higher climatic yield potential caused by lower air temperature and/or higher solar radiation compared with the other sites (Peng *et al.*, 2006). Our data support the results of the National Bureau of Statistics of China (NBSC, 2006) that indicate the unit yield of Jiangsu province was the highest in China. K partial factor productivity (PFP_K) ranged from 12.2 kg to 47.3 kg (mean value 25.6 kg) grain per kg K applied. Agronomic K efficiency (AE_K) ranged from 0 kg to 10.1 kg (mean value 3.6 kg) grain per kg K applied. Of the 19 sites, Jiangsu Tongzhou and Hubei Ezhou were the highest in PFP_K and AE_K respectively.

Besides PFP_K, Table 2 also gives PFP_N in the CK and +K treatments. PFP_N ranged from 5.3 to 22.7 kg kg^{-1} N (mean value 12.3 kg kg^{-1} N) for the CK treatments, compared with 6.8 to 26.3 kg kg^{-1} N (mean value 14.2 kg kg^{-1} N) for the +K treatments, findings which indicate that K fertilizer application increased N use efficiency.

Potassium concentration, uptake and nutrient use efficiency

Potassium concentration and accumulation in rapeseed plants for 2005/2006 and 2006/2007 growing seasons are presented in Fig. 2 and 3. Differences in K nutrition status, as expressed in the average values, were clearly reflected by the K concentrations in the stem and pod, which were much higher in the +K treatment (Fig. 1). By contrast, however, K concentrations in the grain were similar in both fertilizer treatments (0.81% in the CK and 0.82% in the +K). This is in agreement with the work of Holmes and Brennan (1980 and 2006), who reported that applications of K fertilizer had a negligible effect on the K concentration in rapeseed grain. The lack of uniformity of K concentration in rapeseed at different experimental sites may be due to the difference in rapeseed varieties.

The total above-ground K accumulation for the CK treatment averaged 117.6 kg K ha^{-1}, while for plants grown in the +K treatment, the average was 156.8 kg K ha^{-1} (Fig. 2). The result showed that application of K fertilizer could enhance plant uptake by 33.2 percent for K, mostly in the stem.

The nutrient harvest index, i.e. nutrient accumulation in grain as a proportion of nutrient accumulation in above-ground plant DM, was calculated to analyze nutrient distribution in the crop. It is an indicator of the

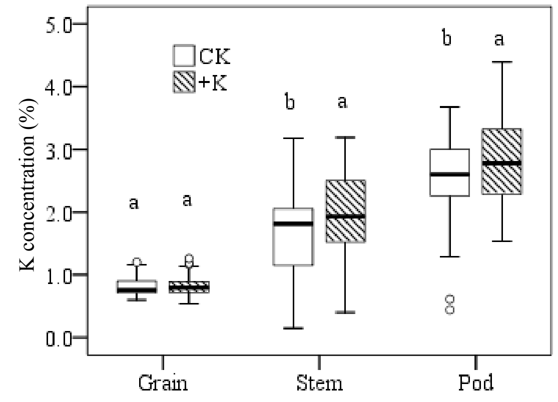


Fig. 2. K concentrations in grain stem and pod.

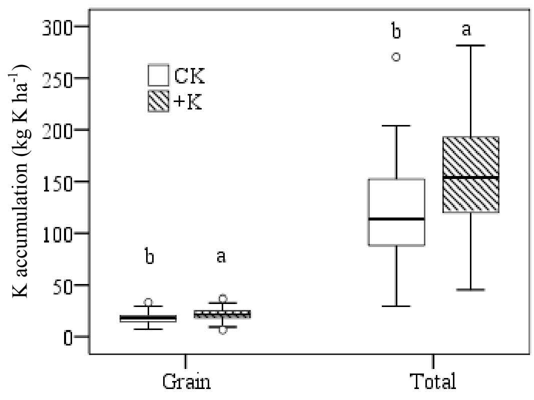


Fig. 3. K accumulations in grain and above-ground plant DM.

Note: The upper and lower limits of each box represent the 25th and 75th percentiles for rapeseed yield. The horizontal line in the center of the box indicates the median. Different lowercase letters (a, b) indicate significant difference (P <0.05).

Research Findings

efficiency with which the plant utilizes mineral nutrients in terms of grain yield production. Potassium harvest index (KHI) in the +K treatment averaged 0.14 kg kg^{-1}, compared to 0.17 kg kg^{-1} in the CK treatment (Table 3). K application caused a decline in KHI except at Jiangsu site. At Anhui Guangde, for example, ample K supply decreased KHI by about 71.6 percent compared to CK plots. These results showed that potassium deficiency may increase the ratio of K accumulation in grain, and a higher ratio of K accumulation occurred in stem and pod when K fertilizer was applied. The findings are in accord with the conclusions of Zou *et al.* (2008) that high yield in rapeseed is closely associated with adequate translocation of potassium to stem and pod.

Internal K efficiency (IE) is the grain yield produced per unit plant nutrient. Nutrient interactions seem to be major determinants of IE. With a limited K supply, there is maximum dilution of K in the plant, and uptake is not restricted by other growth factors such as N or P (Dobermann *et al.*, 1996). Taking all the trials into account, the average IE_K for CK plots was 21.9 kg grain per kg plant K; this was equivalent to 45.7 kg K per 1,000 kg grain. However, when the supply of K is ample and growth is not limited by uptake, maximum K accumulation occurs in the plant (Janssen *et al.*, 1990). The average IE_K was thus much lower in the +K treatment (17.7 kg grain per kg plant K) than in the CK treatment which was equivalent to 56.5 kg K per 1,000 kg grain.

Apparent potassium recovery efficiency and K balance

Apparent K recovery efficiency (RE_K) is also presented in Table 3. The recovery of K fertilizer was influenced by the soil available K. This agrees with results from Xie (2000), who reported that RE_K for rice was negatively related to the supply of soil potassium at the same rate of K fertilizer application. Where the soil available K was much lower, for instance, at Hubei Ezhou, Hubei Qichun and Hunan Lilin, RE_K was more than 50 percent.

Table 3. K harvest index (KHI), K internal efficiency (IE_K), reciprocal IE (RIE_K, kg K in above-ground plant DM per 1,000 kg rapeseed), apparent K balance (the rate of K supply - K uptake in above-ground plant DM) and apparent K recovery efficiency (RE_K) in 2005/2006 and 2006/2007 growing seasons.

Treatment		KHI	IE_K	RIE_K	K balance	RE_K
		kg kg⁻¹	*kg kg⁻¹*	*kg 1,000 kg⁻¹*	*kg K ha⁻¹*	*%*
CK	Range	0.07-0.51	9.1-70.0	14.3-110.2	-270.5 - -29.3	—
	Aver.±Std.	0.17±0.07 a	21.9±10.4 a	45.7	-117.6±51.0 b	—
+K	Range	0.06-0.24	9.8-33.1	30.2-102.2	-181.4-54.9	0-100.0
	Aver.±Std.	0.14±0.04 b	17.7±5.5 b	56.5	-56.8±53.5 a	39.3±27.1

RE_K was highest (73.6 percent) at Hubei Ezhou and lowest (10.7 percent) at Jiangsu Tongzhou, the average for all sites being 39.3 percent. This result was within the current level of RE_K in China (35-50 percent) (Xie *et al.*, 2000; Yan *et al.*, 2008).

Apparent K balance was measured as the difference between total K added and that removed by the crop (Singh *et al.*, 2002). Although K inputs from rainfall and seepage or sedimentation were not measured at the experimental sites, we suspect that these factors had only negligible effects on the K balance (Dobermann *et al.*, 1996). In addition, straw is generally completely removed in most winter rapeseed-growing regions of China. We therefore calculated the apparent K balance based on fertilizer input and above-ground uptake (Table 3). The soil potassium exhaustion was stronger in the CK treatment which ranged from 29.3 to 270.5 kg K ha^{-1} (mean value 117.6 kg K ha^{-1}) than that in the +K treatment (mean value 56.8 kg K ha^{-1}).

Relationship between soil available K and response of rapeseed to K application

Relative rapeseed yields of CK/+K for all the samples were positively correlated with soil available K as determined by soil extraction with ammonium acetate. As shown in Fig. 4, the soil available K data conformed to an asymptotic relationship with relative yield as interpreted using the logarithmic equation and Cate-Nelson model. The equation for describing the relationship between relative rapeseed yield (y_2) and soil available K content (x) was $y_2 = 18.176\ln(x) + 0.7444$ (r=0.6583**; n=132). It was concluded that the ability of soils to supply K to plants and response of rapeseed yield to K fertilizer application was reflected by soil available K content.

Based on the relative yield of CK/+K at 90 percent level, the soil available K critical level was obtained by the graphical method and logarithmic function method (Cate and Nelson, 1971; Chen and Zhang, 2006). The results showed that the soil K critical level for rapeseed in YRV was 135 mg K kg^{-1} which was identical for the two methods. Using the soil test level of 135 mg K kg^{-1}, 106 experimental fields were below the borderline. In other words, about 80 percent of rapeseed-planting fields in YRV were deficient in potassium.

Discussion

Changes in winter rapeseed response to K fertilization

Rapeseed yield responses to applied K fertilizer in early 1980s were reported by Liu and Tu (1989) in Hubei province. By measuring grain yield responses to K fertilizer applied at 40 experimental sites in 1980s, they observed that rapeseed yield increased significantly by K application, the average increment being 258 kg ha^{-1}, an increasing rate of 14.2 percent and AE_K of 2.0 kg grain per kg K. Our study confirmed this significant

Research Findings

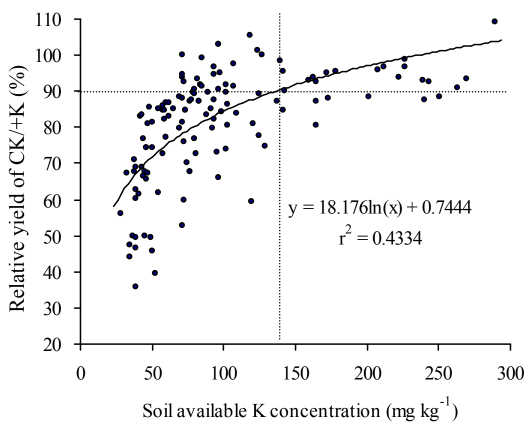


Fig. 4. Determination of soil available K critical level. Relationship between relative rapeseed yield and soil available K level.

increase of rapeseed yield with K fertilization in the other 9 provinces besides Hubei. In 2005/2006 and 2006/2007 growing seasons, the average increment, the percentage increase and AE_K were 358 kg ha^{-1}, 18.0 percent and 3.6 kg grain kg^{-1} K, respectively. Compared with grain yield responses to K in the early 1980s, current responses may also be explained by two reasons:

1. The first is that the commercial cultivars of rapeseed grown in YRV have changed from those of the 1980s. The double high (high erucic acid and high glucosinolates) cultivars of the 1980s have been replaced by double low (low erucic acid and low glucosinolates) cultivars (Fu *et al.*, 2003) which according to the findings of Zou *et al.* (2008) have a much higher requirement for K at the current yield level.

2. The second reason is the lower soil potassium status of the rapeseed-planting region of YRV since the 1980s (Xie *et al.*, 2000; Zhang *et al.*, 2008). In China, winter rapeseed is usually cultivated in a crop rotation which includes rice or cotton as a previous crop. Rapeseed in rotation with rice accounts for about 70 percent of Chinese rapeseed acreage (Liu, 1990). At present, although potassium fertilizers are applied extensively in areas of YRV (Xie *et al.*, 2000), the potassium balance is negative in most of the rice growing areas because of low rates of K fertilizer applied by rice farmers in comparison to the high amounts of K removed in the grain and straw (Dobermann *et al.*, 1996 and Zhang *et al.*, 2008). As a result, soil K status decreases annually in most of the rapeseed growing areas.

Low apparent K recovery versus high soil K exhaustion

China's consumption of K fertilizers has increased steadily from 3.90×10^5 t K_2O in 1980 to 6.32×10^6 t in 2004. The $N:K_2O$ ratio in mineral fertilizers consumption is currently 1:0.24 (Jin *et al.*, 2006). Although a recent survey on fertilizer use by 100 rapeseed farmers in Hubei province showed a somewhat higher ratio of $N:K_2O$ was 1:0.31 (Zou *et al.*, 2008), this is well below the recommended ratio of $N:K_2O$ of 1:0.4-0.7 for current rapeseed production (Zhang *et al.*, 2006 and Zou *et al.*, 2008). Imbalanced use of fertilizers not only limits rapeseed yield but also depletes soil nutrients.

The results of our research showed that fertilizer K application at the rate of 100 kg ha^{-1} in the +K treatment was insufficient to match the K removal (Table 3). The K balance on most experimental sites was negative, with an average net removal of 56.8 kg K ha^{-1} in the +K treatment and 117.6 kg K ha^{-1} in the CK treatment. The average apparent K recovery efficiency was 39.3 percent which was much lower compared with that in the developed countries. Reducing the rate of potassium application could improve apparent K recovery efficiency (Xie, 2000) but by decreasing K application, soil K exhaustion may be exacerbated.

Management practices that not only improve apparent K recovery efficiency but also maintain soil potassium fertility include: returning the straw to field and using organic manure and fertilizer as nutrient sources for crop production. Data from the northern part of the Central Lithuanian Lowland (Kristaponyte, 2005) showed that the potassium balance in the mineral-organic fertilization systems was positive, and potassium fertilizer compensated 106.7 percent of the uptake by plants, whereas in the solely mineral or organic fertilization systems its balance was negative. Dobermann (1996) also reported that where mineral fertilizers are used and straw is incorporated, reserves of soil K are maintained and may even be increased. Results from the soil and fertilizer professional statistical data in 2000 collected by the National Agro-Technical Extension and Service Center showed that on a national basis, there was 3.99×10^6 t K_2O in rice straw (Gao *et al.*, 2002). If pre-rice straw could be effectively used, even reducing the amount of potassium fertilizer would not only satisfy the relatively high K demand of rapeseed but also maintain the soil K fertility.

The new soil K critical level and further studies on K management in rapeseed systems

The purpose of soil test critical levels is to describe soil test results in easily understandable terminology and to simplify the process of making fertilizer recommendations by placing soils in response categories (Dahnke and Olson, 1990). These critical levels can provide and estimate the probability of response to fertilization (Heckman *et al.*, 2006). The new soil available K critical level produced at 90 percent relative yield is 135 mg K kg^{-1} for rapeseed in YRV. Previous research in Hubei province of China (Liu and Tu, 1991) has shown that rapeseed yield does not respond to applied K fertilizer when soil NH_4OAc-extractable K values are more than 110 mg kg^{-1}. Thus, some sites (depending on the past critical level) that would be predicted not to respond, do in fact

Research Findings

show responses to K fertilizer when the new soil test critical level is employed.

The new soil test K critical level can be used to predict yield response to K fertilization in current production levels of rapeseed in YRV. The figures in this study, however, cannot be used for K fertilizer recommendations in winter rapeseed. However, in the near future, ongoing research that includes new field trials with different rates of K fertilizer application are likely to provide useful information so that fertilizer recommendations can be made depending on different K soil test levels and yield goals.

Conclusions

Field experiments in 10 provinces of YRV showed that winter rapeseed yield responded positively to fertilizer K application. The yield increment by K application was negatively related to soil NH_4OAc-extractable K concentration and relative yield of CK/+K was positively correlated with soil K. Based on the relative yield at 90 percent level, the soil available K critical level was 135 mg kg^{-1}. This finding indicates that about 80 percent of rapeseed-growing fields in YRV were deficient in potassium. Results also showed that when 100 kg K ha^{-1} was applied, IE_K was 17.7 kg grain per plant K, which is equivalent to a requirement of 56.5 kg K to produce 1,000 kg grain. Moreover, soil K exhaustion was severe compared to the low apparent K recovery in winter rapeseed system.

Acknowledgements

This study was fund by the National Key Technologies R&D Program in the 11th Five Year Plan of China (2008BADA4B08), Program for New Century Excellent Talents in University of Ministry of Education (NCET-07-0345), and Earmarked Fund for Modern Agro-industry Technology Research System of Ministry of Agriculture (nycytx-005), cooperation project between China and the International Plant Nutrition Institute (IPNI), and cooperation project between China and the International Potash Institute (IPI).

References

Bao, S.D. 2000. Soil and Agricultural Chemistry Analysis. China Agricultural Press, Beijing, China (in Chinese).

Brennan, R.F., and M.D.A. Bolland. 2006. Soil and tissue tests to predict the potassium requirements of canola in south-western Australia. Aust. J. Exp. Agric. 46:675-679.

Brennan, R.F., and M.D.A. Bolland. 2007. Influence of potassium and nitrogen fertilizer on yield, oil and protein concentration of canola (*Brassica napus* L.) grain harvested in south-western Australia. Aust. J. Exp. Agric. 47:976-983.

Cate, R.B., and L.A. Nelson. 1971. A simple statistical procedure for partitioning soil test correlation data into two classes. Soil Sci. Soc. Am. J. 35:658-660.

Chen, F., K.Y. Wan, S.S. Chen, G.S. Zhang, and S.Y. Sha. 2008. Progress in study on soil potassium and application of potassium fertilizer in Southern China. *In*: Zhou, J.M., Magen, H., (eds.), Soil potassium dynamic and K fertilizer management. Proceedings of 11th K nutrient symposium of Nanjing Inst. of Soil Sci., CAS, IPI. Hohai University Press, Nanjing, China, p. 99-104 (in Chinese).

Chen, X.P., and F.S. Zhang. 2006. Building up index system of soil testing and fertilizer recommendation by 3414 fertilizer experiments. China Agric. Technology Extension 22:36-39 (in Chinese).

Dahnke, W.C., and R.A. Olson. 1990. Soil test correlation, calibration, and recommendation. *In*: Westerman, R.L., (ed.), Soil testing and plant analysis. ASA, CSSA, and SSSA, Madison, WI, p. 45-71.

Dobermann, A., P.C. Sta Cruz, and K.G. Cassman. 1996. Fertilizer inputs, nutrient balance, and soil nutrient-supplying power in intensive, irrigated rice systems. I. Potassium uptake and K balance. Nutr. Cycl. Agroecosyst. 46:1-10.

Fu, T.D., G.S. Yang, J.X. Tu, and C.Z. Ma. 2003. The present and future of rapeseed production in China. Chin. Oil. 28(1):11-13.

Gao, X.Z., W.Q. Ma, C.B. Ma, F.S. Zhang, and Y.H. Wang. 2002. Analysis on the current status of utilization of crop straw in China. J. Huazhong Agric. Univ. 21(3):242-247 (in Chinese).

Gerwing, J., R.H. Gelderman, and A. Bly. 2001. Investigating potassium deficiencies in corn. Better Crops. 85:12-13.

Govahi, M., and M. Saffari. 2006. Effect of potassium and sulphur fertilizers on yield, yield components and seed quality of spring canola (*Brassica napus* L.) seed. Agron. J. 5:577-582.

Heckman, J.R., W. Jokela, T. Morris, D.B. Beegle, J.T. Sims, F.J. Coale, S. Herbert, T. Griffin, B. Hoskins, J. Jemison, W.M. Sullivan, D. Bhumbla, G. Estes, and W.S. Reid. 2006. Soil test calibration for predicting corn response to phosphorus in the northeast USA. Agron. J. 98:280-288.

Hergert, G.W., W.L. Pan, J.H. Huggins, Grove, and T.R. Peck. 1997. Adequacy of current fertilizer recommendations for site-specific management. *In*: Pierce, F.J., Sadler, E.J., (eds.), The state of site-specific management for agriculture. ASA., Madison, WI, p. 293-300.

Holmes, M.R.J. 1980. Nutrition of the oilseed rape crop. Applied science publishers LTD London.

Research Findings

Janssen, B.H., F.C.T. Guiking, D. van der Eijk, E.M.A. Smaling, J. Wolf, H. van Reuler. 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). Geoderma 46:299-318.

Jin, J.Y., J.K. Li, S.T. Li. 2006. Chemical fertilizer and food security-the demand of chemical fertilizer for cereal crops. Phos. Comp. Fert. 21(3):1-6 (in Chinese).

Khan, H.Z., M.A. Malik, M.F. Saleem, and I. Aziz. 2004. Effect of different potassium fertilization levels on growth, seed yield and oil contents of canola (*Brassica napus* L.). Int. J. Agric. Biol. 6:557-559.

Kristaponyte, I. 2005. Effect of fertilization systems on the balance of plant nutrients and soil agrochemical properties. Agron. J. 3(1):45-54.

Liu, C.Z., and Y.C. Tu. 1989. Study on combined application of nitrogen, phosphorus and potassium to rapeseed. *In*: Soil and Fertilizer Institute of Chinese Academy of Agriculture Science, (ed.), Symposium of National Colloquium of Balanced Fertilizer. Agricultural Press, Beijing, China, p. 215-220 (in Chinese).

Liu, H.L. 1987. Practical cultivation of rapeseed. Scientific Technique Press, Shanghai, China, p. 67-69 (in Chinese).

Lu, J.W., F. Chen, C.B. Yu, J.F. Li, Z.Q. Zhang, D.B. Liu, and T. Xiong. 2003. Response of rapeseed yield to K application and primary study of soil critical available K content for rapeseed. Chin. J. Oil Crop Sci. 25(4):107-112 (in Chinese).

Lu, R.K. 1989. General status of nutrients (N, P, K) in soils of China. Acta Pedol. Sin. 26(3):280-286 (in Chinese).

MAFF (UK-Ministry of Agriculture, Fisheries and Food). 2000. Fertiliser Recommendations for agricultural and horticultural crops (RB 209), 7th ed. The Stationery Office, Norwich.

NBSC (The National Bureau of Statistics of China). 2007. Chinese Statistical Yearbook. http://www.stats.gov.cn/tjsj/ndsj/2007/indexch.htm (in Chinese).

Orlovius, K. 2000. Results of potash, magnesium and sulphur fertilizing experiments on oil crops in Germany. *In*: Zbilansowane nawozenie rzepaku. Aktnalne problemy, p. 229-239, IPI/IMPHOS, Poznan.

Peck, T.R., and R.N. Soltanpour. 1990. The principles of soil testing. *In*: Westerman, R.L., (ed.), Soil testing and plant analysis. ASA, CSSA, and SSSA, Madison, WI, p. 1-9.

Peng, S., R.J. Buresh, J. Huang, J. Yang, Y. Zou, X. Zhong, G. Wang, and F. Zhang. 2006. Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. Field Crops Res. 96:37-47.

Singh, M., V.P. Singh, and D.D. Reddy. 2002. Potassium balance and release kinetics under continuous rice-wheat cropping system in Vertisol. Field Crops Res. 77:81-91.

Soper, R.J. 1971. Soil tests as a means of predicting response of rape to added N, P and K. Agron. J. 63:564-566.

Tang, Q.Y., and M.G. Feng. 2002. DPS Data Processing System for Practical Statistics. Science Press, Beijing, China, p. 648, http://www.chinadps.net (in Chinese).

Witt, C., A. Dobermann, S. Abdulrachman, H.C. Gines, G.H. Wang, R. Nagarajan, S. Satawathananont, T.T. Son, P.S. Tan, L.V. Tiem, G.C. Simbahan, and D.C. Olk. 1999. Internal nutrient efficiencies of irrigated lowland rice in tropical and subtropical Asia. Field Crops Res. 63:113-138.

Xie, J.C., and J.M. Zhou. 1999. Progress in study on soil potassium and application of potassium in China. Soils. 31(5):244-254 (in Chinese).

Xie, J.C., J.M. Zhou, and R. Härdter. 2000. Potassium in Chinese agriculture. Hohai University Press, Nanjing, China (in Chinese).

Yan, X., J.Y. Jin, P. He, and M.Z. Liang. 2008. Recent advances in Technology of increasing fertilizer use efficiency. Sci. Agric. Sin., 41(2):450-459 (in Chinese).

Zhang, F.S., X.P. Chen, L.L. Cheng, and W.F. Zhang. 2008. Soil potassium balance and K fertilizer requirement in China. *In*: Zhou, J.M., Magen, H., (eds.), Soil potassium dynamic and K fertilizer management. Proceedings of 11th K nutrient symposium of Nanjing Inst. of Soil Sci., CAS, IPI. Hohai University Press, Nanjing, China, p. 251-257 (in Chinese).

Zou, J., J.W. Lu, F. Chen, and M.X. Lu. 2008. Effect of potassium fertilization on rapeseed and potassium application technique in China. *In*: Zhou, J.M., Magen, H., (eds.), Soil potassium dynamic and K fertilizer management. Proceedings of 11th K nutrient symposium of Nanjing Inst. of Soil Sci., CAS, IPI. Hohai University Press, Nanjing, China, p. 289-297 (in Chinese).

Zou, J., J.W. Lu, R.L. Liu, Z.Y. Zheng, W.X. Li, and Z.P. Jiang. 2008. Dynamics of dry mass accumulation and nutrients uptake in 4 double-low rapeseed (*Brassica napus* L.) varieties. J. Huazhong Agric. Univ. 27(2):229-234 (in Chinese). ■

The paper "Yield Response of Winter Rapeseed to Potassium Fertilization, Use Efficiency and Soil's Potassium Critical Level in the Yangtze River Valley" appears also at:

Regional Activities/China