Research Findings

History and Prospects of Potash Application in China

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Introduction

China is a country with a large population and limited farmland. Its population is over 1.34 billion with less than 0.1 ha of arable land per person, one-third of the world average. As a result, China is always under great pressure to guarantee food security. However, the Chinese have made a great effort to maintain a high degree of self-sufficiency, which currently stands at 95 percent. In 2011 the total annual grain yield of the country was 571 billion kilograms, representing over 400 kg of grain for every inhabitant. In relation to the total world population, China feeds as much as 20 percent of the population with only 9 percent of the arable land at its disposal. This great achievement has not only guaranteed food security and sustainable development in China, but has also made a great contribution to the stable supply of grain in the world. Fertilizer has undoubtedly played an essential and irreplaceable role in Chinese food production.

Agricultural development and fertilizer application in China

Before 1949, grain yield was very low because farmers only used manures to maintain the nutrient supply in the fields. Since that time, however, China has been producing and applying more and more fertilizers to ensure a constant, continuing increase in grain production. The present Chinese government attaches great importance to agriculture, the countryside and farmers.

Fertilizer application has continued to increase since the beginning of the 1950s. From the 39,000 mt used in 1950, an enormous rise in fertilizer application occurred, reaching as much as 3.51 Mt by 1970. Over the same period, grain yield also increased rapidly, total grain production reaching 240 Mt as compared with 132 Mt in 1950. This increase continued, with total grain yields in 1980, 1990 and 2010 of 320, 452 and 546 Mt, respectively. In 2011, the total grain yield reached 571 Mt, with a unit yield of 5.166 mt ha^{-1}, an increase of 3.9 percent compared with 2010. The increasing use of better balanced fertilizer application over eight years (from 2003-2011) allowed grain production in China to reach a new high level. These increasing grain yields from 1949 to the present day are closely correlated to the enormous rise in fertilizer consumption over the same period, as reported in Table 1.

Many scientists have questioned the possible over-use of fertilizers in recent years, even though it has resulted in increases in production of both cereal grains and cash crops. Since the 1980s there has been a gradual move towards vegetable and fruit tree planting, which in recent years has increased rapidly. These cash crops have higher economic value, but their nutrient requirements are 2-3 times higher than cereal and other staple food crops. Planting of cash crops

Table 1. Consumption of nutrients in China ('000 mt).

Year	Total*	N	P_2O_5	K_2O	Ratio $N:P_2O_5:K_2O$
	'000 mt nutrient				
1949	13				
1950	39				
1952	78				
1962	630				
1970	3,512	2,497	991	24	1:0.40:0.010
1980	12,694	9,425	2,882	387	1:0.31:0.041
1990	25,903	17,480	6,452	1,971	1:0.37:0.113
1995	35,936	22,347	9,950	3,640	1:0.45:0.163
1999	41,245	24,811	11,004	5,430	1:0.44:0.219
2010	55,617	32,000	14,000	9,500	1:0.44:0.297

*Fertilizer consumption in 1949-1962 was basically nitrogen fertilizer.

N, P_2O_5, and K_2O in compound fertilizer were calculated according to the content of the nutrient and compound amount.

Source: Li *et al.*, 2001; National Bureau of Statistics of China, 2011.

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thus acts as the primary impetus for increased chemical fertilizer input.

The planting area of staple food crops and other field crops decreased by 15.13 million ha from 1980 to 2008, while the planting area of vegetables and fruit trees increased by a total of 23.67 million ha. Over the same period, dramatic increases in the total yields of cash crops occurred, including vegetables (6.2 fold), melons and fruits (5.2 fold), oil crops (2.8 fold) and sugar crops (3.6 fold). These increases both in cash crop yields and planting area accounted for approximately 50 percent of increased fertilizer use (unpublished data). In 2010, cereal and other staple food crops accounted for 60 percent of fertilizer use, while the remaining 40 percent was applied to vegetables, fruit trees and other cash crops (unpublished data).

Input of chemical fertilizer has promoted nutrient cycling in farmland ecosystems, playing an important role in sustaining yield of food crops in China. Various other factors have also made a contribution, including use of suitable varieties, irrigation and field management, but many researchers have concluded that fertilizer input accounts for 40-50 percent of the effect.

On a world scale, since 1993 China has become the world's largest chemical fertilizer consumer, accounting for 1/3 of total use. In reviewing the history of NPK fertilizer application in China, it may be summarized that the use of N began in 1950, P in the 1960s and K in the 1970s. The application rates of chemical fertilizer in the initial stages were very low at 78,000 and 630,000 mt in 1952 and 1962, respectively, and consisted mainly of N (Table 1). Studies on the benefits of P fertilizer to crops in China began in 1960, which promoted P application.

From Table 1, it is evident there was almost no supply of inorganic K fertilizer before the 1970s, with only a small amount of K fertilizer being imported in 1972. From the mid 1970s, the application of N and P significantly increased but there was little increase in K application. From the 1980s, K application gradually increased, with the NPK application ratio of 1:0.31:0.041 in 1980 being improved to 1:0.37:0.113 (including compound fertilizer) by 1990. By 1999, K_2O consumption had risen to 5.43 Mt, and the application ratio of NPK had increased further in favor of K, to 1:0.44:0.219. The figures for 2010 show that K application (as K_2O) had dramatically increased to 9.5 Mt, and the application ratio of NPK was 1:0.44:0.297. Obviously, the NPK ratio in favor of K significantly increased over the years as did the average growth rate in grain yield, which amounted to 11.7 percent during the 30 years from 1980 to 2010.

A historic contribution has been made by Chinese researchers in furthering the application and extensive use of K fertilizer. The study of soil K was already being carried out at the Institute of Soil Science, Chinese Academy of Sciences (ISSAS) in Nanjing in the early 1950s. From then on, numerous other research, education and agricultural establishments were set up, radiating from south to north throughout the country, which supported research teams dealing specifically with potassium. The study of soil K and K fertilizer became one of the most active topics in the discipline of soil-plant nutrition and fertilizer science, which included the following areas of research interest: characterization and distribution of soil K-bearing minerals; fixation and release of soil K; content, form and availability of soil K; evaluation of soil K fertility; cycling of K in farmland; K budgets and management; and the relationship between K and crop quality as well as its effect in increasing biotic and abiotic stress resistance in crops. Together with this research, a large amount of effort was made in extension work to demonstrate the benefits of K fertilizer application to farmers.

Besides the requirement of agricultural development, close cooperation with related international organizations has further stimulated active agronomic research in K. Cooperation between ISSAS and the International Potash Institute (IPI) began at the end of the 1970s, with 12 international K symposia being convened from 1983 to the present time, and numerous field experiments aimed at optimizing K application, in more than 10 provinces, autonomous regions and cities. More recently, cooperation between the Potash and Phosphate Institute (PPI) and some other international organizations has also begun. This international cooperation, conducted by means of international symposia, publishing in international scientific journals, and carrying out field experiments and demonstrations, has benefited international academic communications and research training, as well as playing an important role in soil K research and K application on soils in China.

Contribution of K to agricultural sustainability

General situation of soil K fertility in China

The most important K source in soil is aluminosilicate minerals, which include potassium feldspar and biotite, secondary aluminosilicate minerals (such as hydrous micas or illite), and continuous weathering products such as vermiculite. High temperature and rainfall, as well as obvious wet and dry seasons, characterize southern subtropical and tropical areas in China. Through long-term weathering the parent minerals are strongly weathered. Besides kaolinite, these soils contain relatively abundant amounts of hydrargillite and hematites, and these areas are therefore typical K-deficiency regions in China. The main mineral in the middle subtropical area is kaolinite, but small amounts of hydrous micas and vermiculite are present. In the north of China, because of slow weathering and regardless of parent minerals, the soils contain large amount of hydrous micas and montmorillonite-like minerals, which have a strong exchange capacity for K in clay soil. Brown soil (Alfisols) contains large amounts of hydrous micas and vermiculite, while chernozem and chestnut soils are abundant in hydrous micas as well as montmorillonite-like minerals. The main soil mineral in the desert and semi-desert areas is hydrous micas.

A large variation in total soil K content occurs in China. The K content of the latosols in Guangxi province is the lowest, at 3.6 g kg^{-1}, while an aeolian sandy soil in Jilin province is the highest, at 26.1 g kg^{-1}, a 7.3 fold difference. Generally, the total K content in south China (except the purple soil) is low, whereas it is high in northeast and northwest areas of the country.

According to the second national soil survey of the 1980s, the readily available (exchangeable plus soluble) K distributions were characterized as given in Table 2. As shown, marked differences in K status occur between the various regions of China. Soils in which the readily available K is more than 150 mg kg^{-1} account for more than 37 percent in northeast and northwest, followed by north China at 30 percent, but less than 14 percent in central China and south China. Similarly, soils in which readily available K is less than 50 mg kg^{-1} only account for less than 3.5 percent in northeast and northwest China, but more than 50 percent in south China. With regards to slowly available K, specific ranges occur for particular soil types. In China, soil K-supply potential has been classified into seven levels, depending on the slowly available K content (Map 1 and Table 3). The map of soil K-supply potential is of benefit for a macroscopic understanding of soil K fertility, which provides a basis for K allocation and application. Table 4 shows that K-supply potential in the four provinces of Sichuan, Guizhou, Shanxi and Gansu differ significantly.

Color	K potential supply	Slowly available potassium (mg kg^{-1})	Predominant clay minerals in soil
	Very low	<66	Kaolinite
	Low	66-166	Kaolinite-hydrous micas
	Medium-low	166-330	Vermiculite-kaolinite
	Medium	330-500	Hydrous micas - Vermiculite-kaolinite
	Medium-high	500-750	Hydrous micas - Vermiculite (chlorite)
	High	750-1,160	Hydrous micas - Montmorillonite
	Very high	>1,160	Hydrous micas

Map 1. Predominant K bearing minerals and K potential supply in soils of China.
Source: Xie and Li, 1990.

Soil K fertility is comprehensively determined by parent material, weathering degree, fertilization, plant uptake, soil erosion and soil leaching. Overall, soil K fertility gradually increases from south to north in China, which is consistent with the decrease of kaolinite and increase of hydrous micas.

Evolution of K fertilizer effect 1960-1990

The possible benefits of K mineral fertilization were considered by Lin (1989), in discussing three NPK fertilizer effectiveness experiments carried out on a national scale during 1936-1940, 1958-1962 and 1981-1983. During the first two experimental periods, K fertilizer application was without effect on yield. However, in the third experimental period (1981-1983), potash application significantly increased yield in south China, while still having no effect on most of the food crops in north China. These findings fit well with present knowledge of the soils of south China, in being inherently lower in K than those of the north, as discussed earlier.

Latosol and latosolic red soils are typically K-deficient, and were those used first in experiments to test the beneficial effects of K fertilizer. Rubber trees planted in latosolic red soil in the west of Guangdong province at the end of the 1950s commonly showed the symptom of yellow leaves, the main reason for which was proved by ISSAS to be K deficiency following two years' experiments from 1960 to 1961. In the 1960s, there was no mineral fertilizer K supply, so cement kiln dust was used instead in many experiments carried out in Guangdong, Hunan, Jiangxi and Jiangsu provinces. Data summarized by the Soil and Fertilizer Institute in Guangdong in 1973 showed that from 109 field trials in rice, yields in 90 percent of plots in west Guangdong were increased by 10-35 percent, the best effect being demonstrated in sandy and black mud fields.

Symptoms of K-deficiency in rice occurring in south China at the end of the 1970s, such as Brown Spot Disease, were found to be triggered by K-deficiency through experiments with a calcareous paddy soil in Liuzhou city, Guangxi province. K fertilizer application in south China proved to be very effective, as evident from a series of experiments in the 1970s. Corn yields increased by 21 percent in 6 experiments in 1974, and an increase of 7.9 kg corn per kilogram K_2O (agronomic efficiency of potassium; AEK) was reported by Guangxi Soil and Fertilizer Institute in 1974. Similarly, the project entitled "agricultural use and evaluation of K from Qinghai salt lake", which was organized by the Chinese Ministry of Agriculture and carried out in several provinces in south China from 1981 to 1984, showed that the application of 75 kg K fertilizer (K_2O) per hectare resulted in an AEK of 7 kg rice per kilogram K_2O.

The response of crops to K application was evident not only from the experimental sites but also from demonstration plots, the area of which gradually increased with

Table 2. Distribution of soils according to their readily available K content in the ploughed layer in different regions of China.

Region	Soil group	K content (mg kg^{-1})				
		>200	150-200	100-150	50-100	<50
		%				
Northeast China	Dark burozem, black soils, chernozems	19.8	17.6	39	21.0	1.7
North China	Burozem, cinnamon soils, fluvo-aquic soils	14.2	16.4	32.3	32.2	4.4
Northwest China	Catanozems, brown pedocals, gray desert soils, brown desert soils	27.7	25.1	25.5	18.3	3.5
Southwest China	Purplish soils, yellow earths	14.6	10.3	27.9	41.3	5.8
East China	Paddy soils, yellow brown earths, cinnamon soils	6.2	13.8	27.1	40.1	12.8
Central China	Red earths, yellow earths, paddy soils	1.2	12.8	21.4	56.0	9.2
South China	Latosols, lateritic red earths	2.6	3.8	9.9	33.6	52.2

Source: Xie *et al.*, 2000.

Table 3. K-supplying potential (slowly available K) in major soils of China. See also Map 1.

K-supplying potential	Level of slowly available K (mg kg^{-1})	Soil type
Very low	<66	Latosol, latosolic red soil, calcareous soil and related paddy soil (Guangxi and Guangdong)
Low	60-166	Red soil, yellow soil and related paddy soil (Hunan and Jiangxi)
Medium-low	166-330	Paddy soil around Taihu lake and Zhujiang river, sandy soil around Yangtze river
Medium	330-500	Paddy soil in Dongting lake and Ganjiang river, yellow-brown soil, boggy soil, sandy fluvo-aquic soil (Hubei, Guizhou and Sichuan)
Medium-high	500-750	Purple soil (Sichuan and Hubei), chestnut soil, meadow soil (Heilongjiang and Inner Mongolia)
High	750-1,160	Dark-brown soil, black soil, brown soil, clay fluvo-aquic soil, mountain soil (Heilongjiang, Jilin, Shanxi, Shandong, Hebei and Henan)
Very high	>1,160	Grey desert soil, brown desert soil (Xingjiang and Inner Mongolia)

Source: Xie *et al.*, 2000.

Table 4. Statistical data of slowly available K in four southwestern and northwestern provinces.

Province	Number of samples	Slowly available K (mg kg^{-1})						
		<66	66-166	166-330	330-500	500-750	750-1,160	>1,160
		%						
Sichuan	940	0.85	11.91	26.28	26.28	25.85	6.70	1.60
Guizhou	758	5.41	36.62	38.65	14.12	4.75	0.79	0.66
Shanxi	497	-	-	1.41	1.61	13.88	52.31	30.78
Gansu	210	-	-	-	0.95	18.10	44.76	36.19

Source: Xie *et al.*, 2000.

the support of IPI and PPI (IPNI). These demonstration areas included 1,400 ha of K fertilizer application in the Liujiazhan Plantation of Jiangxi province during 1978 to 1979 in collaboration with ISSAS, which also supported a rice demonstration in Jinhua county of Zhejiang province in 1979. Further demonstrations were carried out in Liujiang county of Guangxi in 1981 as well as a demonstration on 70,000 ha in Taihe, Jiangxi province, during 1983 to 1984. Yields increased in all the K fertilizer demonstrations and the effects were further verified by demonstration of K-based balance fertilization in Guangxi by Canpotex in 1986.

The well-established research on K in the southern part of the country has been complemented by continuing research work in northern parts of China on soil K depletion. The application of K to the K-deficient soils of north China has resulted in yield increases since the 1980s passing through three stages: no effect, minor effect and significant effect, each stage lasting around 10 years. Experiments were set up on soils with low K content in Shandong, Henan and Hebei provinces by the Soil and Fertilizer Institute of the Chinese Agricultural Academy of Sciences in collaboration with PPI in 1986, in which responses to different levels of K application were observed. As time went on, the effect of K application became more and more pronounced, the K input rate gradually increasing from the 1990s, as higher inputs of N and P raised the potential for crop yield responses to K application. 1,350 field experiments and demonstrations were designed in northeast and north China, and the results showed that yields of the main crops were significantly increased by K application when NP input was adequate. Yields of crops with high K requirement, such as cotton and sugar beet, were even increased by K application on soils rich in K. 107 experiments were conducted in northwest China (Shanxi, Qinghai, Ningxia and Xinjiang) in the 1990s, and the yields in 78.5 percent of experiments were significantly increased, by more than 5 percent, after K application. Current findings are also confirming the need for K fertilization in new varieties. The cultivation of Bt-cotton is now extending quickly in China, and it is evident that inadequate supply of K leads to premature senility and reduces yield significantly. For the long staple (fiber) cotton in Xingjiang, an adequate supply of K is very important for high quality. Thus for cotton, even in soils showing comparatively high levels of K availability, K fertilizer is needed.

The benefits of potash application to maize, the main crop grown on the cambisols of Shandong and the alfisols of Hebei in the North China Plains (NCP) were shown recently by Niu *et al.* (2011). Potash applied in various locations increased yields by 10 to 21 percent, with the strongest response in high yielding practices (HP) over conventional practice (CP; Table 5). Agronomic efficiency of K applied (AEK) to maize varied between 2 and 12 kg yield per kg K_2O applied, with the higher AEK being very profitable for the farmer (value-cost-ratio; VCR; data not shown). Higher AEK values were obtained in fields where K application was only one of the measures taken to improve productivity (high yielding systems; HP); other measures included increased plant density and optimized P fertilizer levels. K application also improved partial productivity of N (PFPN) by approx. 20 percent. In almost all locations, the partial factor productivity of K (PFPK) was higher in the HP plots. Finally, apparent recovery of K applied (REK) was higher at high K levels and in HP management systems, and increased to approx. 30 percent. This data shows that efficient use of potassium in the NCP, an area considered a few years ago as non-responsive to K, increases nitrogen use efficiency, productivity and brings economic value to the farmer.

The effects of NPK application on soil fertility and sustainable productivity through long-term experiments have also been studied in depth. The results from three long-term experiments in central China, north China and west China are shown as examples in Table 6, the soil K-supply potential differing in the three experiments. On soils with the lowest K supply potential, in Hunan province, the effects of K application remained significant for 27 years. At an upper-middle level of soil K supply potential in Henan, the effect of K application continued to be observed after 12 years' K input. The soil K supply potential in Shanxi was highest and no effect was observed after 20 years' K input.

Some other long-term experiments have shown the enormously beneficial effect of K application in seriously K deficient soils, and that the effect becomes more significant with time. For the calcareous paddy soil in Liujiang county in Guangxi province, in which total K, readily available K and slowly released K were 1.9 g kg^{-1}, 44 mg kg^{-1} and 114 mg kg^{-1}, respectively, indicative of a very low K

Table 5. Average effect of K application on maize in seven locations in the North China Plains (NCP) and efficiency indicators (adapted from Niu *et al.*, 2011). CP: conventional practice; HP: high yielding practice. The locations were in Shandong (Shuitun, Laiyang and Dajin) and Hebei (Qingyuan (3 locations) and Zhengding). K1 and K2 levels were different between locations (120 and 240; 75 and 150; and 90 and 180 kg K_2O ha^{-1}, respectively).

K treatment	Yield				PFPN		PFPK		AEK		REK	
	CP	Increase	HP	Increase	CP	HP	CP	HP	CP	HP	CP	HP
	mt ha⁻¹	*%*	*mt ha⁻¹*	*%*	-------------------kg kg⁻¹-------------------						------%-----	
K0	6.46	-	6.58	-	37.7	28.4	-	-	-	-	-	-
K1	7.10	9.9	7.62	15.7	41.4	32.9	81.1	87.2	7.1	11.8	0.18	0.30
K2	7.42	14.9	7.96	21.0	43.7	34.4	42.9	46.1	6.2	8.4	0.21	0.25

Table 6. Long-term effect of K fertilizer input in three different soil types.

Location	Period of experiment	Soil type	Soil K content			Rotation		Fertilizer rate			K effect (Comparison between NP and NPK treatment)
			Total	Readily available	Slowly available			N	P_2O_5	K_2O	
			g kg⁻¹	----------*mg kg⁻¹*----------				-----------*kg ha⁻¹*-----------			
Changsha city, Hunan	1981-2007	Red paddy soil	14.1	62.3	173.9	Double rice	Early rice	150	90	120	Effective immediately; the average annual yields of early rice and late rice increased by 15.2% and 17.2%, respectively, during each of the 27 years
							Late rice	180	90	120	
Fengqiu county Henan	1990-2009	Fluvo-aquic soil	18.6	82.9	797.5	Wheat-corn	Wheat	150	75	150	Effective after 12 years; the average annual yields of wheat and corn increased by 12% and 17%, respectively, from 2002 onwards
							Corn	150	60	150	
Yangling county Shanxi	1991-2010	Loess soil	21.6	200	1,500	Wheat-corn	Wheat	165	57.6	68.5	No effect in 20 years
							Corn	187.5	24.6	77.8	

Source: Data from ISSAS field experiments and other sources.

supply potential, the yield in the NPK treatment was greater by 60 percent than that of the NP treatment after 15 years (Du *et al.*, 2001). There is other evidence of the benefit of K fertilization from four year, long-term field experiments with double rice conducted in Shanggao County in Jiangxi province from 2005-2008 (Tang *et al.*, 2011). For the early and late rice, the N, P, K rates were 150, 75 and 180 kg ha^{-1}, and 180, 45 and 180 kg ha^{-1} respectively. In 2005, the early rice yield in the NPK treatment increased by 12.1 percent, and late rice yield increased by 32.3 percent, and these values were raised further in 2008, to 18.3 percent and 37.2 percent, respectively (Tang *et al.*, 2011). The results of 666 field experiments also showed that application of K fertilizer increased rice yield by 11.7 percent in 6 provinces in southeast China, the rice yield increasing by 7.5 kg per kg K_2O applied (Xie, 2000). The recent results of the IPNI China project have also shown that the agronomic efficiency of K of the main cereal crops has greatly improved, as compared with those in the 1980s (Table 7). With the extended use of hybrid rice and super rice in China, higher rice yields have been obtained requiring higher amounts of K fertilizer as well as suitable amounts of N and P fertilizer. Thus, K-deficiency has become a potentially more serious problem during cultivation while the effect of K fertilizer has become more significant.

Table 7. Agronomic efficiency of K in main cereal crops in China.

Crop	Agronomic efficiency of K			
	1980-1983	2002-2007		
	Whole country	North	South	Whole country
	----------------------*kg kg⁻¹*----------------------			
Rice	4.9	7.5	7.8	7.7
Wheat	2.1	7.0	8.3	7.3
Corn	1.6	9.4	7.5	9.2

Source: IPNI unpublished data.

In recent work by Zhang *et al.* (2011), the authors analyzed K balance in wheat and maize over a 15 (1990-2005) or 18 year (1990-2008) period at five distinctive agro-ecological zones across China, with exchangeable K values from 74 to 288 and non-exchangeable from 487 to 1,764 mg kg^{-1}. Results for K balance (partial K balance; total K uptake – total K input) were negative (between -22 to -226 kg K ha^{-1} $year^{-1}$) in all regions except in Qiyang (Hunan), where K application was similar to removal, with additional organic manure (OM) resulting in a positive K balance. In all regions, application of only NP caused a much higher K negative balance as compared to the control, and the application of OM was mostly beneficial from the point of view of K balance. This work shows that typically used K application rates often do not offset the high K removal by the crop, and hence, K balance remains negative and affected by exchangeable and non-exchangeable K levels in the soil.

Recycling of nutrients and using alternative sources of K

As population and food production have grown in China, so too has the total amount of K removed from farmland through the harvesting of plant materials, such as grains, fruits or foliage. In order to maintain the fertility and productive capacity of the soil, this K has to be replaced, and in general, the beneficial effects of K on crop growth have been recognized in China, causing a steady increase in K consumption. However, the increase in the price of K fertilizer from the end of the first decade of the 21^{st} century has stimulated much interest in recycling of straw and crop residues in the soil. Despite the agronomic difficulty of this practice, K levels in both are significant and can assist farmers in supplying at least part of the K requirement.

The value of K in crop residues has long been known; of the plant nutrients, K, like N, is a very easily recycled nutrient and both elements are important constituents in organic fertilizer, which has historically played an important role in Chinese agriculture. While returning straw to the field requires agronomic skills and labor, the increased cost of K fertilizer has created a real incentive for farmers and the Government to make more efficient use of this K source. Hence measures have recently been taken by the Government to promote straw recycling, thereby reducing the cost of K fertilization and protecting the environment by avoiding its burning.

A negative K balance prevails in many agro-ecological regions in China and varies from -10 to -158 kg K_2O per year (Jianmin *et al.*, 2004). The authors have drawn attention to two important sources of K that can be used: crop residues and irrigation water. A 15 year experiment near Shanghai, investigating nutrient balance using crop residues (data from Wang, cited by Jianmin *et al.*, 2004) showed that while K balance when only K fertilizer was added was at -528 kg ha^{-1} (over 15 years), the addition of straw considerably decreased the negative balance to -166 kg ha^{-1}, implying that straw alone cannot suffice crop needs and both sources (fertilizer and straw) should be used. One of the explanations for this is that adding straw, a well-documented agronomic practice, also increases the yields and hence the uptake of crops.

Jianmin *et al.* (2004; data cited from Xu *et al.*, 1998) also show that irrigation water and rain contribute K (approx. 20-35 and 5 kg K_2O per annum, respectively), but losses due to runoff and leaching are also significant. Nevertheless the total K balance taking into account all these factors is positive (net contribution) at approximately 10-17 kg K_2O ha^{-1} per year.

Clearly, Chinese agriculture is entering a period when efficient use of all resources is essential. Innovative agronomic practices and meticulous calculations of nutrient balance, taking into account gains (e.g. crop residues) and losses (e.g. leaching), are needed, in order to ensure that the productivity levels required will not cause soil depletion and reduction of soil fertility.

Prospects

The population in China is set to increase and to guarantee national food security, there is a need for chemical fertilizer application to further increase crop yields. To support rational K fertilizer application, more research should be carried out to establish a clear understanding of soil K status and cycling in crop fields. Experimental findings need to be demonstrated and passed on by extension workers and advisers to farmers, so that they become conversant with available knowledge to increase efficient K use in crop production. At the same time, mined sources of K fertilizer need to be maintained to meet the K fertilizer supply.

Improving understanding of soil K and K cycling in crop fields

A better understanding of soil K status and K cycling in crop fields is fundamental for rational K fertilizer recommendation. A number of questions may be posed in this respect. How much K in soils is available to crops? What practical methods for testing soil K are suitable for various soils and for different crops? How should K fertilizer be applied to maintain both high crop yield and soil K balance? All these issues need to be further investigated. Results from the ISSAS K research group have shown that total non-exchangeable K (NEK) values in soils are very high, averaging 40 percent of the total K in soils, with availability being determined by the release rate (Zhou and Wang, 2008). New methods are needed to classify and quantify NEK, to enable a better understanding of K status in soils. In China, NH_4OAc extracted K is the main index for both soil K availability and K fertilizer recommendation. However, the NH_4OAc method does not include soil NEK, and is thus not suitable for evaluation of K availability in soils in which NEK contributes, to a varying extent, to plant K uptake. A new method to evaluate plant available K in different soils has been established (Wang *et al.*, 2010) and its potential for general use on soils in China in relation to crop production needs to be further investigated. K fertilizer recommendations should not only aim to obtain the highest crop yield, but should also consider maintenance of soil K fertility. To achieve this target, more research in the future needs to be directed to the study of K cycling and balance, involving crops growing in the field.

Extension of soil test based fertilization for high K use efficiency

Soil test based fertilization refers to a technology of nutrient application which takes into account indigenous supplies of nutrients in soils, crop nutrient requirements and nutrient balance. This can increase nutrient use efficiency, decrease fertilizer input, and at the same time, increase yield and farmers' income.

160 million farmers from all over China benefited from a national project of soil test based fertilization, which took place from 2005 to 2010. Results from 3,000 field experiments on various crops, including rice, corn and wheat, were statistically analyzed in 2009. Yields of soil test based fertilizer treatments, compared with conventional fertilization treatments, were shown on average to be 450 kg ha^{-1} higher. Nitrogen input was lowered by 15-30 kg ha^{-1} and N, P_2O_5 and K_2O use efficiencies were increased by 10 percent, 7-10 percent, and 7 percent, respectively. According to this investigation, in the core production area in Jiangsu province,

the N, P_2O_5 and K_2O input ratio was 1:0.3:0.32 for soil test based fertilization in wheat, whereas it was 1:0.28:0.22 in conventional fertilization. The K input ratio was obviously increased through the soil test based fertilization program.

Sustaining K fertilizer supply by various means

The consumption (imports plus potash produced in China) of K fertilizer gradually increased from 1972, reaching 9.41 Mt K_2O in 2007. China ranks first in the world in K fertilizer imports, consuming 20 percent of total world production. The price of K has increased dramatically in recent years, which has not only suppressed K supply and limited agricultural application, but has also threatened national food security. Efforts have therefore been made to lessen dependence on imported K. Potash is mined in China in salt lakes, but in relatively small amounts. K production in 1980 was only 20,000 mt, but has increased rapidly and by 2005 was supplying 2.54 Mt, constituting 37 percent of the country's use. However, K is very limited in supply in China, accounting for only 2 percent of the total global resource. K production of 3 Mt K_2O per year can only be sustained for about 50 years, and there will always be a dependence on imported K.

Resources of soluble K in China are poor, but non-soluble K resources (K-rich silicon minerals) are very abundant, including feldspars and micas with K (K_2O) content of greater than 10 percent. This potential K resource includes deposits that may be more than 200×10^8 mt (K_2O). In recent years some companies have been exploring possibilities of developing K fertilizer from these non-soluble minerals. Additionally, efforts have been made to mine K resources abroad, in collaboration with foreign countries, in order to compensate for the deficiency of soluble K as a natural resource in China.

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