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Balanced Crop Nutrition: Fertilizing for Crop and Food Quality

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Abstract: Globally the ratio of $N:P_2O_5:K_2O$ changed from 2.5:1.3:1 in the 1980s to 3.6:1.4:1 in 2002 as N consumption outstripped that of K. Regardless of their decreased nutrient consumption, developed countries maintained a modest increase in agricultural production. Positive and similar growth rates for agricultural products and nutrient consumption prevail in developing countries, but with the use of a 35% higher nitrogen (N) to potassium (K) ratio than in developed countries. The outcome of a negative K balance is presented here using examples from India, China, Egypt, and Bulgaria. Reasons for a negative K balance stem mostly from farmers' lack of knowledge and socio-economic factors. Maintaining a negative K balance results in decreased soil fertility and stagnating and even decreasing productivity. Balanced and timely application of nutrients needs to be demonstrated through different parameters according to the prevailing agro-climatic conditions. Results from long-term experiments and intensive investment in educational activities play an important role in demonstrating the benefits of balanced fertilization. In contrast, when analyzing nutrient applications in organic agriculture, it appears that often these may not be sufficient to meet a crop's requirement in quantity and time of application and hence creating soil nutrient mining and pollution. Balanced fertilization is significant in reducing pest and disease infestation, which results in higher returns through larger yields and better quality. Finally, the economic benefit from site-specific nutrient management practices is demonstrated for Souteast Asia's farmers.

Key Words: Potassium, nutrient ratio, negative balance, balanced fertilization

How common is unbalanced fertilization?

Globally the ratio of $N:P_2O_2:K_2O$ consumption in 1980 was 2.5:1.3:1, but this has changed dramatically as nitrogen (N) consumption outstripped that of P and K, and now the ratio is 3.6:1.4:1. In fact, since 1980, production of agricultural products has changed little in developed countries, whilst it has increased significantly in developing countries (Figure 1). Such growth is maintained by larger inputs of fertilizers, and indeed, when comparing nutrient consumption in developed and developing countries, there is the same growth pattern (Figure 2).

Comparing growth trends in agricultural production to those of nutrient application shows that over the last 25 years growth rates of the main crop groups and meat production in developed countries ranged from 0.2% to 3.4% per annum, whilst consumption of N, P_2O_5, and K_2O decreased over the same period at 0.8%, 3.0%, and 2.8% per annum, respectively (Table 1). However, in developing countries, crop and meat production and nutrient consumption increased. Production increased by 1.9% to 6% per annum fueled by average annual growth rates of 3.8%, 4.1%, and 5.8% for N, P_2O_5, and K_2O, respectively (Table 1).

These changes led to an improvement in the $N:P_2O_5:K_2O$ ratio in developing countries from 6.2:2.6:1 in 1980 to 4.3:2.5:1 in 2002, reflecting much larger K application rates. However, there is still a wide gap between the developing and developed countries. In developed countries, N consumption is 2.8 times that of K_2O, while in developing countries, relative N consumption is 4.3 times that of K_2O.

Although the nutrient requirement of crops may differ, the amount of N and K removed by many of them tends to be the same, except for many fruits and vegetables, when the amount of K removed exceeds that of N. The supply of N and K in soils also differs and depends on soil organic matter, soil texture, mineralogy, and climate. Policy issues also affect nutrient consumption, and a higher subsidy to a specific nutrient

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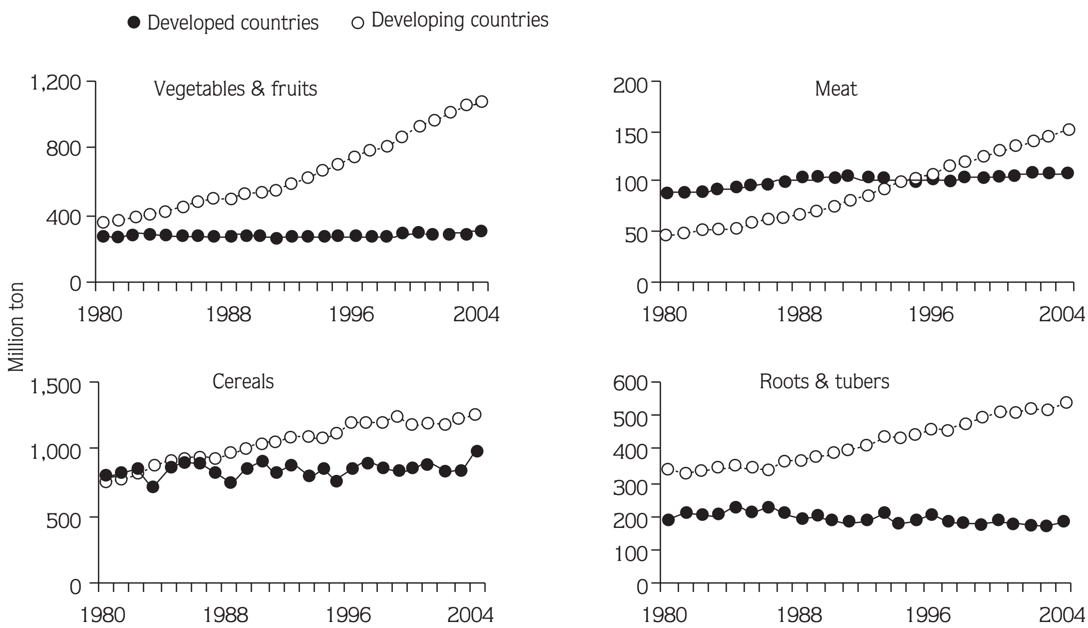

Figure 1. Production of major crop groups and meat in developed countries and developing countries, 1980-2004. (Source: FAO http://faostat.fao.org/faostat/collections, last accessed December 2005).

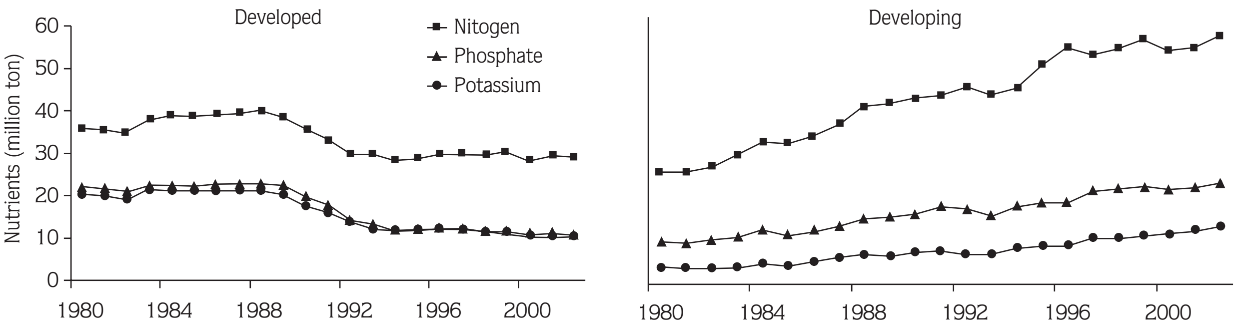

Figure 2. Nutrient consumption in developed and developing countries, 1980-2004. (Source: FAO http://faostat.fao.org/faostat/collections, last accessed December 2005).

will no doubt increase its use. However, the final decision on how much N and K to apply is taken by the farmer, based on his knowledge. Market conditions, yield expectation, and climate will affect the farmer's short-term decisions, whilst his knowledge and education will affect his decisions related to the sustainability and long-term fertility of his soil.

Outcome of unbalanced crop nutrition

This paper presents 4 different country examples of negative K balances. In India, the slow but continuous reduction in the soil's K supply in the Indo-Gangetic plains may lead to stagnating or reduced yields. In China, the demand for K in regions with highly weathered soils and an insufficient K supply, when accompanied by a positive balance for N and P, causes a large negative K balance. In Egypt, on the highly productive irrigated land there is a severe negative K balance, especially on soils of low fertility. In Bulgaria, a recent assessment of farm gate and regional nutrient balances shows a decline in soil fertility.

India

Use of mineral fertilizers in India almost tripled from 5.5 million mt in 1980 to currently (2002) 15.1 million mt of N, P_2O_5, and K_2O of which only ~10% are potash

Table 1. Production and growth rates of major crop groups and averaged nutrient consumption in developed and developing countries (1980-2004). (Source: FAO http://faostat.fao.org/faostat/collections, last accessed December 2005).

Crop / factor	Developed countries			Developing countries		
	1980	2004	Ave. annual growth rate	1980	2004	Ave. annual growth rate
	Million mt		%	Million mt		%
Cereals	783.7	990.7	1.4	766.2	1273.3	2.2
Fruit & Vegetables	271.8	301.2	0.5	355.6	1067.9	4.7
Roots and tubers	184.4	182.7	0.2	337.8	532.7	1.9
Soybean	51.1	91.6	3.4	29.9	112.7	6.0
Meat	89.7	81.6	0.8	47.0	150.6	5.0
Nutrient consumption (%)			N= (0.8) P_2O_5 = (3.0) K_2O = (2.8)			N= 3.8 P_2O_5 = 4.1 K_2O = 5.8

fertilizers. At the same time, production of cereals increased significantly from 140.5 to 233.4 million mt between 1980 and 2004 and that of fruits and vegetables more than doubled from 56.3 to 127.7 million mt in the same period. Do current fertilization rates support such large increases in production and ensure the sustainability of the system?

Yadvinder-Singh et al. (2004) studied the long-term effects of organic inputs on yield and soil fertility in the typical rice–wheat crop rotation practiced in the Indo-Gangetic plains in India. After the dramatic rise in productivity during the 1970s and early 1980s, yields in this region have either remained stagnant or declined (Yadvinder-Singh et al., 2004). Yields of cereals in the Punjab are the largest in India (3953 kg ha^{-1}; FAI, 2005) and they receive the most nutrients (368 kg ha^{-1}), yet with very little K of only about 10 kg ha^{-1} (FAI, 2005). The detailed balance calculation of input/output for K showed that over a 12-year period the negative K balance varied between -932 and -1810 kg K ha^{-1}, depending on the treatment and consequent yield and K input through straw and farmyard manure (FYM) (Figure 3).

The addition of K through organic matter appears to be significant, yet it is not sufficient to supply and replenish the K removed. The balance calculation shows that for a zero net balance an additional ~90 kg K ha^{-1} $year^{-1}$ as fertilizer would have been sufficient for both crops (wheat and rice).

Such a negative balance may lead to a decrease in exchangeable potassium (K_{ex}) in soil. Figure 4 shows the long-term effects of applying no K in the Control + 150N treatment. There has been a decrease of approximately 30% in K_{ex}, as compared to the application of FYM + 150N, which showed only a slight reduction.

The authors comment that “Current K fertilizer recommendations for P and K are inadequate in the long run” and they also rule out the possibility of decline in soil organic matter as the reason for negative yield trends. Finally the authors conclude that the adverse changes in climate along with a decreased soil supply of available K may be the possible reasons associated with yield decline.

China

The spatial and temporal variability of N, P, and K balances for agro-ecosystems in China was described by Shen et al. (2005). Inputs of nutrients in fertilizers and organic matter (from crop residues and human and animal excreta) were calculated and compared with their removal in harvested produce. Balances were calculated at province level, which represent the major agro-ecosystems of China.

Large N and P positive balances were found in almost all regions, as also reported by others (Cui et al., 2005; Peng et al., 2005). In sharp contrast, negative K balances were found in almost all provinces (Figure 5), and they were very serious in Shanghai, Jiangsu, Zhejiang, Beijing,

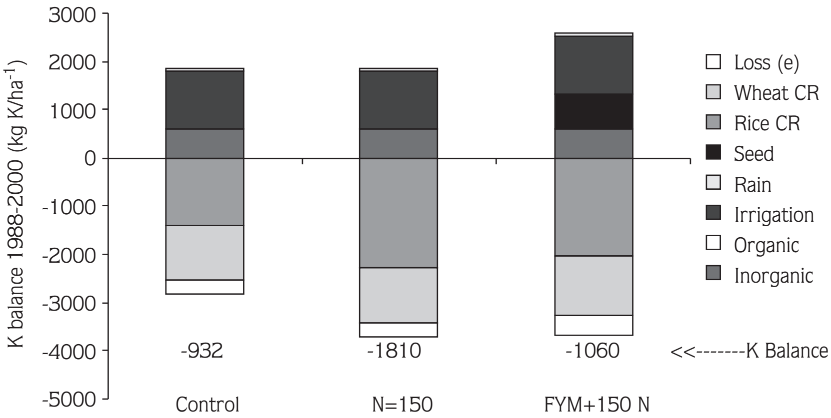

Figure 3. Apparent K balance during 1988-2000 in a long-term rice-wheat experiment, Punjab, PAU. (Adapted from Yadvinder Singh et al., 2004).

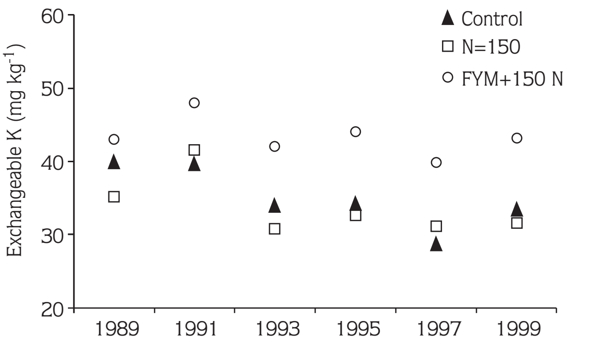

Figure 4. Long-term effects of inorganic and organic inputs on available K content in soil. (Adapted from Yadvinder Singh et al., 2004).

and Xinjiang, where the negative K balance exceeded 72 kg K ha^{-1} $year^{-1}$ (Shen et al., 2005).

Low fertilizer input alone appeared to be the main reason for the K deficit in Xinjiang and Beijing. However, in the Eastern Provinces the negative K balance was due to too small a K input (even though it was quite large) to replenish the large amount of K removed in the harvested crops and losses by leaching. In addition, large areas of East and Southeast China suffer from a negative K balance ranging from 48 to 72 kg K ha^{-1} $year^{-1}$ (Figure 5). Interestingly, these provinces are also associated with large surplus applications of N, which aggravate the negative K balance.

The authors related the nutrient balances to economic and social factors. They pointed to the correlation between GOVA (per capita gross output of value of agriculture), especially in North China and to NIRH (per capita net income of rural households). The lower these socio-economic factors are, the higher is the negative K balance. These findings demonstrate the important role of socio-economic development on nutrient balances.

Egypt

Potassium fertilization in Egyptian irrigated agriculture has become very important since the completion of the High Dam in Aswan, which prevented the continuous deposition on farmers' fields of the Nile silt-rich in K bearing minerals (Abdel Hadi, 2004). In addition, Nile alluvial soils with high clay content can have a high K fixing capacity. Thus, even with a high K_{ex} level there might not be sufficient available K for various crops (El-Fouly and El-Sayed, 1997). In addition, the newly reclaimed soils (approximately 800,000 ha, 25% of the total cultivated land) are sandy and calcareous, and poor in organic matter and macro- and micronutrients (Abd El Hadi, 2004).

Using the average yields in 2002-2004 of rice, wheat, fruit, and vegetables, the amount of K removed was calculated. Approximately 250,000 mt K_2O (conservative calculation, with all straw of rice and wheat returned to the field) and 489,650 mt K_2O (with all straw of rice and wheat removed from the field) are removed annually (Table 2).

During this period, potash consumption (input of K) in Egypt was only 57,000 mt K_2O, (FAO, 2005). This means that the negative balance for potash was between 183,000 and 433,000 mt K_2O, or between 3 and 8 times

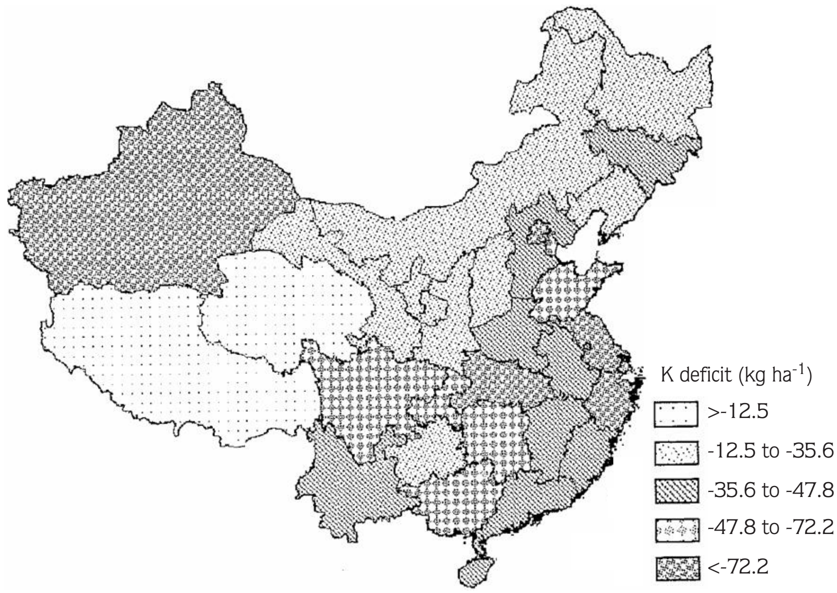

Figure 5. Change of K balance in the agro-ecosystems in China from 1997 to 2001 (Adapted from Shen et al., 2005).

the amount of potash used. This calculation is valid for 75% of the cultivated land in Egypt.

The production of fruit and vegetables is considerable and therefore very significant in K_2O consumption. We estimate that currently these crops are responsible for approximately half of the K_2O removed in Egypt (Table 2). In future, with increased production of fruit and vegetables on the newly reclaimed land, with its poor K-supplying capacity, there should be a need for higher K_2O consumption.

Bulgaria

Nutrient consumption in Bulgaria was at its peak during the mid 1980s, but fell dramatically to about 20%, 0%, and 0% for N, P_2O_5, and K_2O of its peak use during the mid and late 1990s. During this period, fruit production fell by 75%, vegetables by 30%, and cereals by 20%.

Nikolova (2005) calculated K balances at farm gate, regional, and national levels. Only dairy farms showed a positive K balance (145 kg K ha^{-1}). Arable and mixed

Table 2. Mean (2002-2004) area, production, yield, and calculated removal of potassium in various crops in Egypt.
Source: FAO http://faostat.fao.org/faostat/collections , last accessed December 2005
(1) Source: K+S / Nutrient removal; accessed December 2005 http://www.kali-gmbh.com/duengemittel_en/TechService/NutrientsRemoval/graincrops.cfm

Crop	Area	Production	Yield (mt ha^{-1})	K_2O removed (mt)$^{(1)}$	
				Straw removed	Straw left in field
	'000 ha	'000 mt	mt ha^{-1}	mt	
Rice	626	6143	9.8	168,000	25,000
Wheat	1045	6882	6.6	140,000	41,800
Fruit	443	7447	16.8	66,450	66,450
Vegetables & melons	576	14,854	25.8	115,200	115,200
Total				489,650	248,450

farms in 7 regions of Bulgaria, representing all types of soils and regions, all showed a negative K balance due to the very small amounts of K applied. The author concludes that the mean annual K deficiency varies between 43 and 79 kg ha^{-1}, and the national K balance is approximately -200,000 mt K $year^{-1}$, a similar level since the 1990s.

The long-term consequences of a negative K balance on soil fertility are obvious. In 13 years (1989-2002), the frequency of “Low” K status soils doubled and that of “High” K status fell from 71% to 27% (Figure 6).

Balanced and timely nutrient application

The following examples demonstrate various consequences of correcting unbalanced nutrient management. These are related to i) long-term fertilization; ii) organic agriculture; iii) the effect of balanced fertilization on yields, quality, and pest and disease infestation and iv) the economics of balanced fertilization.

Long-term observations

Fertilization is a decision taken by the farmer according to economic parameters. When there is no short-term economic response to applied K, the farmer tends to eliminate this factor from his manuring policy.

In a 3-year experiment in cotton grown on vermicultic soil, an increase in cumulative yield in the order of 13% to 21% was found for applying 120-240 kg K ha^{-1}; however, at 480 kg K ha^{-1}, an increase of 42% was achieved (Dobermann et al., 2005; Figure 7). These data may mislead, because in 1985 there was only a very small increase in yield from the applied K compared to that of

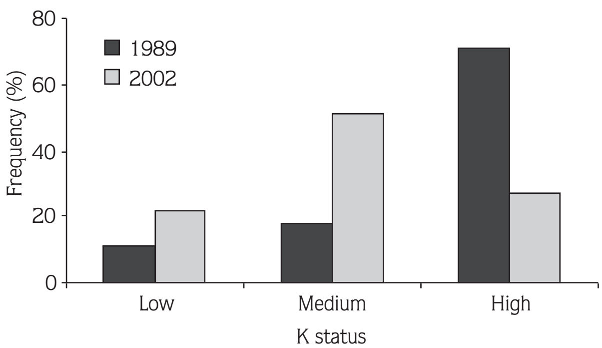

Figure 6. Change in K status in soils, 1998-2002. (Source: Nikolova, 2005).

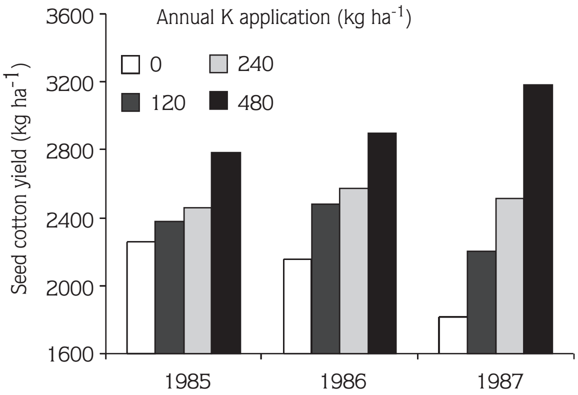

Figure 7. Response of response of annual seed cotton yield to annual K applications on a vertisol (adapted from Dobermann et al., 2005).

1987. In addition, application of 480 kg K ha^{-1} was the only rate in which yields were increasing in all 3 years. In contrast to the large K application, where no K was applied there was a decrease in organic matter and of available soil K that caused K fixation and resulting in a 3-year downward trend in yields. This example illustrates the need to consider the longer-term effect of repeated K fertilization, especially with high K rates in heavy soils with fixation capacity.

Organic agriculture

Organic agriculture is often perceived as a clear-cut solution for better crop production. A mixture of beliefs and scientific data hinders the real questions and consequences from long-term practice of organic agriculture. Can organic farming match today’s large requirements for balanced and timely nutrient application? Soil fertility status after 21 years of organic agriculture shows a greater decline in available K in soil than where fertilizers have been used.

A 21-year long-term experiment at Forschungsinstitut für biologischen Landbau (FiBL) in Frick, Switzerland, compares 4 farming systems differing mainly in the management of fertilization and plant protection (Mäder et al., 2002). Four basic treatments were compared: 2 organic systems (biodynamic and bioorganic) that used farmyard manure and slurry corresponding to a certain amount of livestock per area unit; 1 conventional system using the same amount of farmyard manure as the organic systems but with the addition of mineral fertilizers to reach the plant-specific Swiss standard recommendation; and another conventional system using no fertilizer during the first crop rotation, then mineral fertilizers exclusively, as in regular non-livestock farming. The results show that yields of winter wheat, potatoes, and grass clover were 20% higher with the 2 non-organic treatments by an amount corresponding to lower input costs, including fuel. However, there was a negative K balance with the organic treatment (-36 K_2O ha^{-1}), compared to a positive balance with mineral NPK. There was a negative N balance with all 4 systems but it was larger with the organic systems (-173 kg N ha^{-1}) compared to that (-108 kg N ha^{-1}) with mineral NPK fertilizers (Figure 8).

In contrast, organic dairy farms have reported positive nutrient balances, mainly due to larger inputs of nutrients in animal feed (Öborn et al., 2005).

Timely application of nutrients from organic sources is complicated. Nitrogen supply is highly dependent on mineralization of the organic matter, which can be assessed in terms of total N supply, but for practical reasons is usually insufficient to meet the requirements of a crop at the appropriate time (Johnston and Poulton, 2005). Dahlin et al. (2005) discussed the use of N from organic material. They showed that the expected leaching loss of N from poultry manure is far greater than that from ammonium nitrate (Figure 9) and that N uptake from ammonium nitrate is much higher than that from red clover manure. Clearly, the precise timing and split application of ammonium nitrate can supply N in a much more controllable way than can be achieved with organic materials.

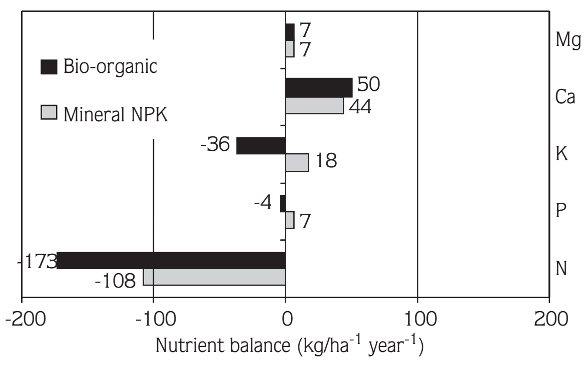

Figure 8. Nutrient balance after 21 years comparing organic and mineral fertilization treatments (adapted from Mäder et al., 2002).

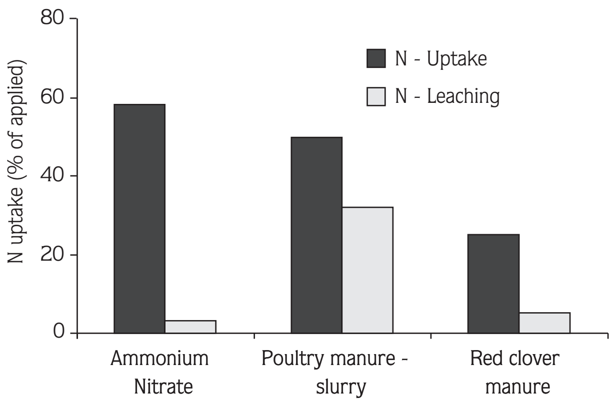

Figure 9. Nitrogen in harvested crops and leaching as affected by various N sources (adapted from Dahlin et al., 2005).

However, efficiency of phosphate use from single superphosphate (SSP) or poultry litter compost was equal (Sikora and Enkiri, 2005). Even greater efficiency of phosphate use is achieved with fertigation systems, when P is added in very frequent applications of water and fertilizer (Silber, 2005). In fact, both P and K efficiency were increased by daily and even more frequent application of water and nutrients.

In summary, organic agriculture may cause soil nutrient mining due to insufficient nutrient application and may lead to large losses, especially of nitrogen and potassium, but not necessarily in dairy farms. In contrast, using mineral fertilizers that can be applied at flexible timing and rates can increase the uptake of nutrients and thus reduce loss to the environment.

Effect on yields, quality, and plant health

Nutrient application is highly unbalanced in Punjab. In 2004/05, the state consumed 1.562 Mt of nutrients, of which 1.2; 0.32 and 0.043 Mt was N, P_2O_5, and K_2O, respectively. The $N:P_2O_5:K_2O$ ratio of 28:5:1 is highly unbalanced, due to the very high N application (282 kg N ha^{-1}) compared to the very small K application (10 kg K_2O ha^{-1}). In order to evaluate the effect of potassium in a typical crop rotation performed in districts of Punjab, IPI has initiated research and extension activities at the KVK Bahowal, Directorate of Extension of Punjab Agriculture University. The effect of K was demonstrated in farmers' fields in 5 districts on a typical pea-sunflower-maize crop rotation, grown on sandy loam soil. This project has a specific extension character and includes demonstration plots, farmers' field days, and literature in the local language (Punjabi). Both scientific and extension activities were possible in these experiments.

Response to K was apparent in all 3 crops, and ranged between 5% (in peas, with little applied K) and 45% (in sunflower, with 90 kg K_2O ha^{-1}) (Figure 10). K application also brought the following benefits:

- increased the seed/grain weight in all crops (Figure 10),
- increased the number of filled grains and seeds in maize and sunflower (+25% and +11%, respectively),
- decreased lodging in maize (-65%)
- increased the 'shininess' of grains.

Nutrient application is highly unbalanced also in Madhya Pradesh: in 2004/05, consumption was about 1 million mt nutrients, of which N, P_2O_5, and K_2O were 617,723; 393,253 and 55,296 t, respectively. The N:P_2O_5:K_2O ratio of 11:7:1 is highly unbalanced, reflecting a very low application of potash (3.7 kg K_2O ha^{-1}).

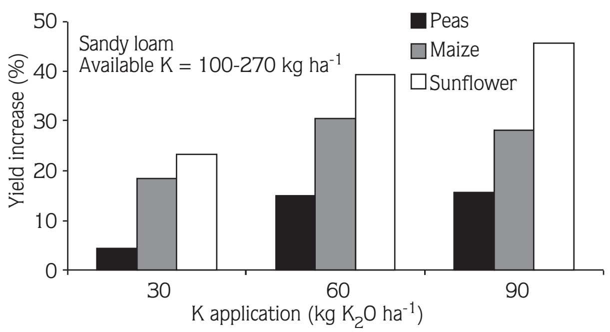

Figure 10. Potassium effect on yield increase in peas, maize, and sunflower. (Source: IPI, 2005).

Soybean is grown on about 4.5 million ha in the State of Madhya Pradesh and production accounts for 59% of India's total. In 2004, the Secretary of Agriculture of the State declared that in 8 districts 100,000 ha of soybean had been completely damaged by pests and insects. Total area affected was almost 1 million ha, about 25% of the total area growing soybean in the State.

Often better plant nutrition decreases the susceptibility of crops to attacks by insects and diseases, and this reduces the need for pesticides and insecticides. Results from various experiments performed by IPI and by IRRI show that applying K reduces the damage caused by insects and disease. The effect of potash application on soybean was demonstrated in an IPI experiment in Indore, Madhya Pradesh through the project "Studies on role of potassium nutrition in balanced fertilization of Soybean-Wheat cropping system" (IPI, 2005). One of the major effects for potash application was consistent reduction of infestation and incidence of various insects and disease (Table 3, Figure 11).

A reduction of 50% to 75% of the damage was observed in farmers' fields, resulting in large savings of pesticides and insecticides. In addition, potash application increased nodule number and dry weight (60% and 100% respectively) and consequently the yield (35%) (IPI, 2005).

Table 3. Effect of potash application on infestation of blue beetle (Cneorane spp.), stem fly (*Melanagromyza sojae* Zehnt., defoliators and girdle beetle (*Oberia brevis*) and of incidence of collar rot (caused by *Sclerotium rolfsii*) and Myrothecium leaf spot. (Source: IPI 2005: IPI-ICAR project, annual report 2004).

	Insect infestation				Disease incidence	
Level of K_2O	Blue beetle (*Cneorane* spp.)	Stem fly- Stem tunnelling (*Melanagromyza sojae* Zehnt.)	Defoliators	Girdle beetle (*Oberia brevis*)	Collar rot (caused by *Sclerotium rolfsii*)	Myrothecium leaf spot
kg ha^{-1}	Mrl(1)	% infestation	mrl	% infestation	% mortality	PDI(2)
0	5.9	13.91	1.3	8.35	9.17	38.57
25	2	3.87	1	2.17	6.07	28.45
50	1.8	2.87	0.8	2.06	4.61	22.58
75	1.3	0	0.7	1.91	2.22	25.41

(1) mrl = meter raw length

(2) PDI = percent disease incidence (1-9 scale)

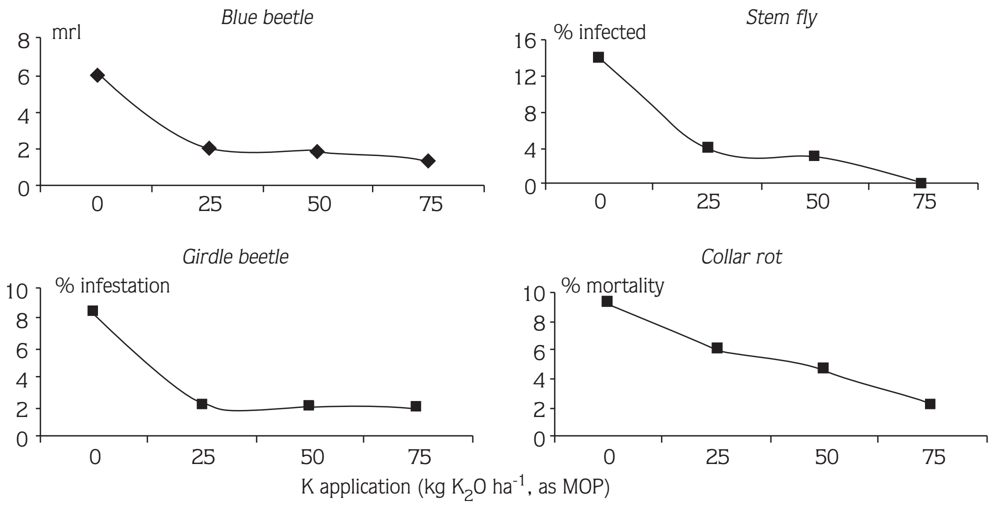

Figure 11. Effect of K on infection of soybean from various insects and disease. (Source: IPI, 2005).

Perrenoud (1990) reviewed almost 2450 literature references on this subject and concluded that the use of K decreased the incidence of fungal diseases in 70% of cases. The corresponding decrease of other pests was bacteria 69%, insects and mites 63%, and viruses 41%. Simultaneously, K increased the yield of plants infested with fungal diseases by 42%, with bacteria by 57%, with insects and mites by 36%, and with viruses by 78%. Kafkafi et al. (2001) recently reviewed the role of both K and chloride on the suppression of diseases and stresses in plants. Potassium may exert its greatest effect on disease through specific metabolic functions that alter the compatibility relationship of the host-parasite environment (Huber and Arny, 1985). A number of possible mechanisms may be involved. These include: (i) enhanced host tolerance due to increased water potential that restricts infection by pathogens and, in consequence, plants are better able to withstand disease; (ii) suppression/inhibition of pathogens through lower tissue NO_3^- (which decreases crop susceptibility), nitrification inhibition and to increased soil NH_4^+ and NH_4^+ uptake, resulting in rhizosphere acidification (Magen and Imas, 2004).

Better nutrient management, which involved reduced and split N application, along with increased P and K application, reduced the intensity of disease by 50% and increased yield by 12.5% (Table 4). These results from the Site Specific Nutrient Management (SSNM) project in the Philippines demonstrate the positive effect of nutrient management on plant health (Buresh et al., 2005).

The economics of balanced fertilization

The "Reaching Towards Optimal Productivity" (RTOP) workgroup of the Irrigated Rice Research Consortium (IRRC) has been instrumental in the development, evaluation, and promotion of site specific nutrient management (SSNM) as an approach for increasing the profit of Asian rice farmers through more efficient use of plant nutrients. It operates through partnerships with the national agricultural research and extension systems (NARES) in Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam. In 2005, RTOP activities were incorporated into the new "Productivity and Sustainability" workgroup of Phase III (2005-2008) of the IRRC (IRRI, 2005). The project demonstrates the importance of N management through the use of the Leaf Color Chart (LCC) in increasing N use efficiency and yields, and consequently larger P and K requirements. Potassium fertilization recommendations are calculated through SSNM plots on farmers' fields, taking into account also the amount of straw recycled back to the field.

Table 4. Effect of real-time N management on sheath blight () intensity and rice yield in the 2001 wet season at IRRI in the Philippines (Source: Buresh et al., 2005).

N management	Disease intensity %	Grain yield $mt\ ha^{-1}$
Fixed time and rate	33 (6)	4.0 (0.8)
SSNM, real time	21 (11)	4.5 (0.2)

Values within parentheses are SD.

The economics of SSNM have been analyzed for recent years. Table 5 shows the increased net profit gained from using the SSNM approach. Farmers in Southern India increased their net profit by 47%, while those in Southern Vietnam by only 4.25%. This calculation does not take into account additional benefits, even though not directly related to the farmers, of smaller N losses to the environment through emissions to the atmosphere and leaching.

The RTOP workgroup is supported also by IFA, IPI, and PPI.

Educational and extension activities are performed both at the scientific level and by meetings at the field level. Recommended K levels (set by the local extension service) match the latest findings of SSNM in the Old Delta in Southern India, reflecting the need to promote these to farmers. However, in the New Delta, the higher K rates recommended by SSNM (Table 6) need to be addressed at research, extension, and farmers levels to be brought into practice to benefit farmers.

Table 5. Annual net benefits for SSNM and farmers' fertilizer practice (FFP) as determined through focus-group discussions (total of 2 rice crops, 2002-2003). (Source: IRRI, 2005).

Site	Annual net benefit		
	SSNM	FFP	Difference
	USD ha^{-1} $year^{-1}$		
Southern India	520	352	168 (+47%)
Central Luzon, Philippines	1218	1078	140 (+13%)
Southern Vietnam	834	800	34 (4.25%)

Table 6. SSNM recommendation for K, as compared to the current recommendation and farmers' practice, in the dry season in the Cauvery Delta of southern India. (Source: Buresh et al., 2005).

Parameter	Fertilizer K	
	Old Delta	New Delta
	kg ha^{-1}	
Current recommendation	42	42
Use by surveyed farmers	21	37
SSNM recommendation	42	65

Conclusions

Long-term negative K balances, mainly caused by insufficient K fertilization and limited use of crop residues required for increased yields, cause deterioration of soil fertility that leads to stagnating and decreased production. Common reasons for inadequate K use are the farmers' lack of knowledge, and frequently of their advisors, as well as socio-economical factors. The constant shift from staple low cost crops to high value horticultural crops is a major driver in correcting unbalanced fertilization.

Long-term experiments with various fertilization treatments reveal valuable processes that cannot be seen in short-term experiments. Even though long-term experiments may lack immediate economic results, they have value for the longer term sustainability of food production and thus require support and advice.

Balanced and timely nutrient application contributes to sustainable growth of yield and quality; influences plant health and reduce the environmental risks. Balanced nutrition with mineral fertilizers can assist in integrated pest management and reduce damage from infestations of pests and diseases and save inputs required to control them.

Balanced fertilization generates higher profits for the farmers, not necessarily through reduced inputs. The role of education and extension in delivering the up-to-date knowledge on nutrient management is crucial, challenging, and continuous.

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