Role of Potassium Nutrition in Balanced Fertilization for Soybean Yield and Quality - Global Perspective

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Abstract

Soybean is a major crop for oil and protein consumption by human, animal and fuel. The increased demand for oil and protein stimulated soybean production mainly by land expansion, with very modest growth in its productivity. With mounting pressure for environmental conservation and requirements for biofuels, there is a strong need for research and better crop management to increase its productivity. Soybean is part of many cropping systems with the advantage of supplying residual nitrogen to the following crop. Potassium not only improves yields but also benefits various aspects of quality (oil and protein content, larger seed size). Potassium increases nodulation in soybean's roots and also provides resistance against pest and diseases.

At present, average yield of soybean in India is 0.9 t/ha, which is much below the crop potential productivity. Low use of fertilizers and serious imbalances in the N: P: K application ratio are partially responsible for this low yield. Current fertilization rates are insufficient to sustain high yields and to replenish nutrient removal by the crop. During the last eight years, results from the joint IPI activities with Oilfed, Amlaha, RAK College, Sehore and NRCS, Indore in Madhya Pradesh clearly provide ample of data for improving potash recommendations. The results showed that yields of up to 2.5 t/ha can be achieved and sustained with adequate K application. Increase in soybean oil and protein was also observed with optimum K nutrition, indicating improvement in crop quality. Field demonstrations also indicated that adequate K fertilization was highly profitable for farmers, 50 kg K_2O/ha applied in split doses recorded the maximum net returns.

Introduction

Soybeans were first cultivated in China perhaps 6,000 years ago. During the Zhou and Qin Dynasty (11th Century to 256 B.C. and 221 to 206 B.C., respectively), soybean became a major food crop in the Yellow River Valley in China (Clay, 2004). Seven hundreds year ago, soybean was already grown throughout China; soybean is cultivated in the US since the beginning of the 19th Century, but the very fast growing phase of global soybean cultivation started after World War 2. The origin of soybean's introduction into India is not fully known, but it is believed to have originated from China through the Himalayan Mountains centuries ago.

Soybean is the world's most grown oilseed. Of approximately 400 million Mt a year of oilseeds, 60% is from soybean. Soybean is grown on 90 million ha and is also an important source of protein for human and animal feed. Soybean typically contains 18-20% of oil and 38% of protein, the latter twice as much as pork and 12 times more than milk, and its inclusion in animal feed increases the efficiency with which grain is converted into animal protein.

In early days, soybean was used as a source of protein; however, in modern agriculture, soybean has dual importance: it is used as a source of oil for human consumption and as a protein source for animal feed. In future, soybean may be an important source of biofuels production.

Production

Soybean is grown on over 90 million ha, of which 90% area concentrated in the US, Brazil, Argentina, China and India (32, 24, 16, 10 and 8%, respectively; Table 1). World production is over 220 million Mt per year, and average productivity is 2.38 Mt/ha. Among the five big producers, India suffers from the lowest productivity (only 0.9 Mt/ha), while that of the US is approximately three times higher (Table 1).

Table 1. Area, production and productivity of major soybean producers (2005-06)

Country	Area *million ha*	Production *million Mt*	Productivity Mt/ha
US	28.83	83.38	2.91
Brazil	22.23	57.00	2.56
Argentina	15.20	40.50	2.66
China	9.59	16.35	1.70
India	7.80	7.00	0.90
World	92.54	220.55	2.38

Source: USDA data for 2005-06

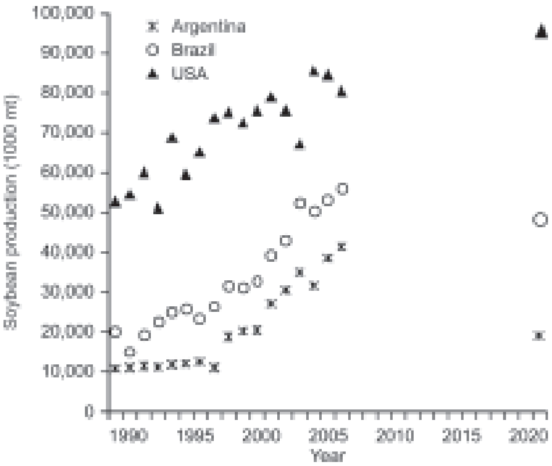


Fig 1. Soybean production in the US, Brazil and Argentina, 1990-2006 and IFPRI forecast for 2020 (Source: FAOSTAT and IFPRI, 2001)

The fastest growing areas and production in recent years is based mostly on land expansion, and thus most of it occurs in Latin America, on the expense of Savanna land. During 1990-2004 soybean land use increased by 60% worldwide and most of this growth took place in Argentina and Brazil. Consequently world soybean production increased by an average of 4.85%, yet the productivity of the crop improved by only 1.55% per annum since 1990. In 2005, Brazil and Argentina together produced approximately 80 million Mt of beans, a similar output to that of the US. The IFPRI calculated future production of soybean in 2020 at 26.8, 48.1 and 94.9 m Mt in Argentina, Brazil and the USA, respectively (IFPRI, 2001). However, whereas this 2001 publication compared 1997 figures with predicted 2020 data, the actual production figures of 2001 and 2004 in Argentina and Brazil respectively, (FAOSTAT, 2006) had already reached the IFPRI forecast for 2020, indicating a much faster growth in these two countries (Fig. 1). No doubt, the increased production of soybean crop surpassed all expectations.

The annual yield of 223 million Mt soybean is used split between a rather small quantity for tofu and meat substitutes products (~15 million Mt) and the rest majority is extracted to yield oil (33 million Mt), mostly for human consumption but also for a growing share of biofuels; and 140 million Mt meal used for cattle, pigs, chicken and fish feed. Soybean is world's major oilseed crop, in 2006-07, soybean production was more than 230 million Mt, followed by rapeseed and cottonseed (each 47 million Mt; Table 2). But in terms of oil produced, soybean and palm oil equally have 30% of the world's vegetable market each, with also similar growth rates in recent years (Fig. 2). Indeed, these two crops are the main oil suppliers for the fast growing market of oil, fueled mainly by large exports to China.

Table 2. World production of major oilseeds (million Mt)

Crop	2004-05	2005-06 (est.)	2006-07 (forcst.)
Soybean	216.6	221.4	232.9
Cottonseed	44.7	48.9	47.0
Rapeseed	45.9	48.9	47.0
Groundnuts (unshelled)	34.8	35.7	34.0
Sunflower	25.4	29.9	29.3
Palm kernels	8.9	9.5	9.6
Copra	5.2	5.1	5.8
Total	381.5	392.8	401.6

Source: FAO Food Outlook (4/2007)

In terms of protein produced, soybean represents the majority of plant based protein: in 2005-06, global meal produced from soybean was 145 million Mt or 67% of world's total production of meal protein. Nevertheless, as animal feed, soybean protein can be easily converted with other meals, and thus offer flexible solutions for animal feed.

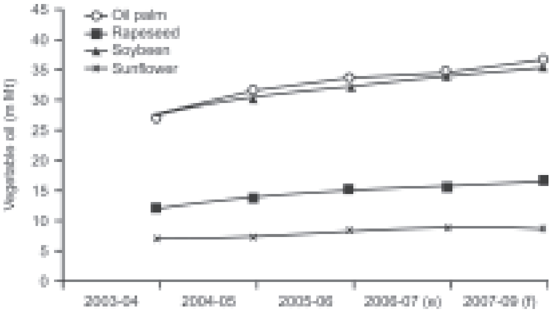


Fig. 2. **World vegetable oil production, 2003-04-2007-08 (Source: USDA)**

Soybean production in India grew significantly since 1990 (Table 3). During the last 17 years, area under soybean tripled, and accordingly the yield. Nevertheless, productivity remained stagnant at approximately 1 Mt/ha, even though farmers saw doubling of income through this period, from Rs 6,300 to more than Rs 12,000 in 2005 (Table 3). Current prices for soybean and global production trends suggest that there is much scope in increasing the productivity of soybean cropping systems in India.

Table 3. Soybean area, production, productivity and producer price in India, 1990-2005

Year	Area ('000 ha)	Production ('000 Mt)	Productivity (kg/ha)	Producer Price (Rs/ha)
1990	2,564	2,601	1,014	-
1991	3,185	2,492	1,025	6,364
1992	3,789	3,390	895	8,522
1993	4,371	4,745	1,086	6,855
1994	4,318	3,932	910.6	8,001
1995	5,035	5,096	1,012	8,993
1996	5,233	5,400	1,032	8,999
1997	5,990	6,463	1,079	10,684
1998	6,493	7,143	1,100	10,062
1999	6,222	7,081	1,138	9,390
2000	6,417	5,276	822	8,783
2001	6,343	5,963	940	10,111
2002	5,660	4,558	777	10,696
2003	6,105	4,655	762	11,174
2004	6,555	7,819	1,193	11,881
2005	7,571	6,876	908	12,215

Source: FAOSTAT (8-2007)

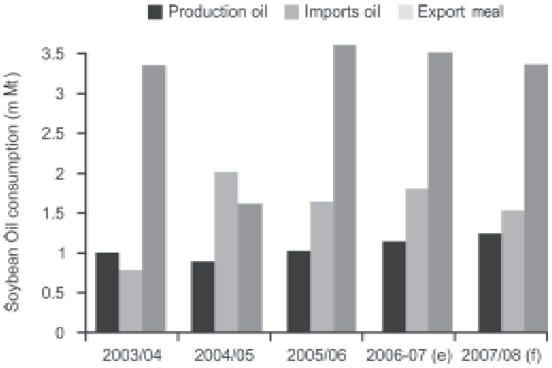


Fig. 3. India's soybean oil production, import and meal export 2003/04 – 2007/08 (Source: USDA)

Even though India is one of the major soybean producers, the country imports a large quantity of soybean oil. In recent years, these imports even exceeded the local production. Among the five big soybean producers, China and India are the only countries, which are not net exporter: both countries import soybean oil, yet India manages to export soybean meal (Fig. 3), possessing a rather limited share of global exports (~6%). This reflects the large need for oil in both countries and to protein meal in China.

Soybean, Wheat and Corn Production Systems

In general, soybean can be produced as an early-season or double crop with winter wheat in cropping systems, representing multiple cropping and increasing the number of crops harvested per unit area of land for a given time period. Including soybean crop in the rotation benefits the crops due to better management of disease, insect, nematode problems, better weeds control and better nutrition management of the cropping system. Being a legume crop, the inclusion of soybean in crop rotations reduces the need for nitrogen fertilizer. Soybean crop fixes nitrogen from the air, which is returned to the soil to be used over successive crops. For example, corn following soybean crop requires less N than a corn-corn rotation because of the residual nitrogen from the soybean crop. Optimum nitrogen fertilizer rates for corn following corn are higher than for corn following soybean and range from 35 to 55 kg additional N required per hectare (Vitosh *et al.*, 1995). A recent review of crop rotation research literature indicated an average yield loss of 9% for continuous corn, with yield losses ranging from 2 to 23% (Erickson and Lowenberg-DeBoer, 2005). Of 26 studies reviewed, only two cited yield advantages to continuous corn. The lower yield potential of continuous versus rotation corn coupled with the higher required optimum nitrogen rates for continuous corn shows a double negative impact on the profitability of the cropping system, even when relative commodity prices point to a preference for corn over soybean. Growing more corn after corn in response to bio-ethanol industry needs is becoming common in USA and soybean acreage is being reduced accordingly.

Corn crop removes more soil phosphorus and less soil potassium per hectare than soybean crop (Vitosh *et al.*, 1995). Per ton of grain, corn removes 6.6 and 4.8 kg of P_2O_5 and K_2O while soybean removes 14 and 23 kg of P_2O_5 and K_2O. A 10 ton/ha corn crop therefore removes 66 kg P_2O_5/ha and 48 kg K_2O/ha, while a 3 ton/ha soybean crop removes a total of 42 and 69 kg of P_2O_5 and K_2O. A one-time move to second-year corn will have negligible effects on P and K soil fertility levels. Over a number of years of corn following corn, however, growers should obviously monitor soil phosphorus and potassium levels and adjust fertilizer rates accordingly.

Nutrient Management in Soybean

Nutrient demand - uptake and removal

Nutrient requirement by soybean crop varies according to soil and climatic conditions, cultivar, yield level, cropping system and management practices. The approximate amount of nutrients taken up by soybean crop are presented in Table 4. Nutrients in the grain are removed from the field, yet the stubble is recycled and the nutrients in it are made available to the next crop. Nitrogen is taken up to the greatest extent, followed by K, then P. A soybean crop yielding 3000 kg/ha is able to extract 240 kg of nitrogen, 45 kg of P_2O_5 and 100 kg of K_2O/ha.

Table 4. Nutrient demand/uptake/removal by soybean crop

Nutrient	Grain only	Total
	kg/mt grain	
N	65	81
P_2O_5	14	14
K_2O	23	33
MgO	5	18
CaO	4	24
S	2	3
	g/mt grain	
Fe	n.a.	366
Mn	20	90
Zn	17	61
Cu	16	25
B	n.a.	39
Mo	n.a.	7

Source: IFA (1992)

Table 5. Sufficiency range for upper fully developed leaf at initial flowering stage

% of dry matter				
N	**P**	**K**	**Mg**	**Ca**
4.62-5.50	0.26-0.50	1.71-2.50	0.26-1.00	0.36-2.00

Source: IFA (1992)

The plant analysis data have been presented in Table 5. Concentrations of essential elements found in indicator tissue reflect the nutritional status of plants. Nutrient concentration data obtained through plant tissue analysis can be an important tool in nutrient management as it can be used in the diagnosis of nutrient deficiency or sufficiency.

Nitrogen

Soybean can fix atmospheric N in the proper strain of *Rhizobium* bacteria which is present in the soil or if the seed is properly inoculated. The plant starts to fix substantial amounts of N approximately 4 weeks after germination. Most estimates show that soybean derives between 25 and 75% of its N by fixation. Fixation is inhibited by high levels of mineral N in the soil, by drought stress and by poor soil aeration (Fageria *et al.*, 1997). Potassium is very important to N fixation because it stimulates early root growth, thus ensuring early nodulation. In addition, K provides the root with the necessary carbohydrates for best nodule functioning.

Soybeans, being a legume, fix adequate atmospheric N to produce yields as high of 3,000-4,000 kg/ha, if well nodulated. Adding N to well nodulated soybeans produced no yield increase and N fertilizer added at planting can delay nodulation. Adding N is recommended only when adequate nodulation is not expected (IFA, 1992).

In a recent study in USA (Ray *et al.*, 2006), soybean yield was increased with the addition of fertilizer N by 8-15% across a wide range of management practices, thus proving that N supplied by N_2 fixation to soybean may not be sufficient to maximize yield. Nonetheless, using fertilizer N at the rate used in this study (approx. 300 kg N/ha) was not economical as N fertilizer costs far exceeded the return from the increased yield. Nitrogen deficiency results in reduced chlorophyll development, pale-green leaf color and reduced growth, development and yield (IFA, 1992).

Phosphorus

This nutrient is taken up throughout the growing season. The period of greatest demand starts just before the pods begin to form and continues until about 10 days before the seeds are fully developed. Much P used in seed development is taken up early, stored temporarily in leaves, stems and petioles, and then translocated into the seed (IFA, 1992).

Phosphorus deficiency is widespread in acid soils for soybean production. An adequate level of P is applied on the basis of critical soil P level (Fageria *et al.*, 1997). Stunted growth is usually the only symptom of P deficiency, though some leaf cupping and discoloration are possible (IFA, 1992).

Potassium

The relatively large amounts of K are required for high yielding soybean. Hanway and Weber (1971) reported that the uptake rate of K is highest during rapid vegetative growth and slows as seed formation begins. Uptake continues until two to three weeks before the seed is mature; it can be depressed by poor soil condition including compaction, excess moisture and poor aeration.

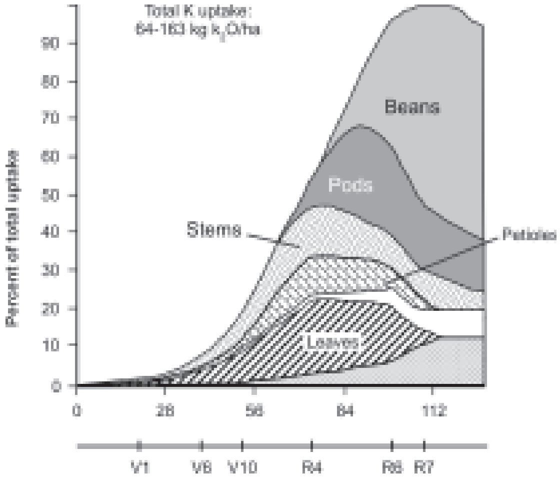


Fig. 4. Relative amount of K in different parts of soybean at different growth stages (Hanway and Weber, 1971), adopted from Snyder and Murrell, PPI-PPIC

Figure 4 shows how K is partitioned among various soybean plant organs (above ground only) throughout the season. Total K accumulation followed a pattern very similar to that of dry matter, with slow accumulation at early vegetative growth stages, and an almost constant, more rapid K accumulation at later vegetative and early to mid reproductive stages. After about growth stage R5 (beginning seed), K was rapidly lost from the leaves, petioles, and stems and repartitioned into the developing beans. Approximately half of the K in mature seeds came from these other plant fractions. At harvest, approximately 56% of the total K in the plant was in the mature seed. The K that had been rapidly taken up between growth stages V10 and R6 accounted for about 75 to 80% of the total K taken up in the above ground soybean tissue (Hanway and Weber, 1971).

In Ontario, Canada, studies looked at the response of soybeans to potassium fertilizer as related to K leaf tissue levels (Reid and Bohner, 2007). The data collected during that study formed the basis for updated critical and normal values for potassium in soybeans. Relative yield (Fig. 5), is the yield without added fertilizer as a percent of the fertilized yield in each of the plots, of 100% indicates that there is no response to added fertilizer. Below a leaf K concentration of 20 g/kg (2.0%), most of the plots showed a response to added K fertilizer. Above this level, most of the plots were unresponsive. Based on the results of these experiments and other similar studies, the critical concentration for K in soybean tissue was established at 2.0% and the maximum normal concentration from 2.5 to 3.0%.

Most K taken up moves to the roots by diffusion through moisture films around soil particles. As the water content of a soil decreases, moisture films around the soil particles become thinner and the path length of ion movement increases and the movement of K to roots decreases (IFA, 1992). Cold soils reduce the rate and extent of root growth and this can limit K uptake. When farmers plant earlier or adopt tillage practices that result in lower soil temperatures early in the growing season, such as no-till, higher levels of available K in the soil are likely to be needed for optimum growth (IFA, 1992).

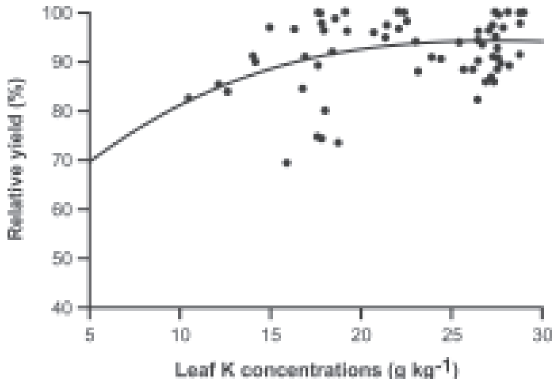


Fig. 5. Relative soybean yield at various leaf K concentrations (10 g kg^{-1} = 1%) (Source: Reid and Bohner, 2007)

K fertilization and application

Crop response to K fertilization is often correlated with exchangeable K in soil and usually fertilization recommendations are based in calibration of a K soil test against soybean grain yield (Fageria *et al.*, 1997). Potassium fertilizer may be split into two or more applications on highly leachable soils or soils which fix large amounts of K. Most non-sandy soils are soils in which fixation is low; usually one application of fertilizer is satisfactory (IFA, 1992). Several sources of K fertilizer can be used, all equally effective.

Potassium fertilizer can be applied broadcast and incorporated into the soil before planting or applied as a starter at planting time. If K is applied in a band at planting time, special care should be taken to locate the band at 5 cm to the side and 5 cm below the seed to avoid fertilizer injury. It is not recommended to apply in "pop-up" (a small amount of fertilizer placed in contact with the seed) should not be used on soybean. Soybean is very susceptible to fertilizer salt injury (Dahnke *et al.*, 1992). The increasing amount of conservation tillage limits the methods of application to essentially surface broadcasting, particularly with no-tillage. As a result, producers often worry whether enough K available, particularly when the fertilizer has not been incorporated.

Studies show that long-term no-till management has resulted in significant vertical soil K stratification. Soil K concentrations in the surface 0 to 5 cm layer are significantly higher than K levels at the 10 to 20 cm depth in no-till fields. This K stratification is mainly attributed to the lack of soil mixing, surface broadcasting of K fertilizer, deposit of crop residue at the soil surface and limited mobility of K in soil. This may reduce plant K uptake, and thus increase the likelihood of K deficiency in crop tissues as well as yield loss in growing seasons when drought occurs, since soil K availability and root growth and activity in the surface layer are more vulnerable to drought stress than those in deeper layers. In addition, presence of crop residue at the soil surface in no-till usually results in higher soil moisture and lower soil temperature in the surface layer, which may reduce soil K availability and restrict root growth early in the season. The risks of reduction in plant K uptake by drought or low temperature in no-till fields become severe when soil K concentrations in deeper layers are too low to optimize plant K uptake. Subsurface placement of K fertilizer, therefore, may improve applied K availability and reduce soil K stratification in no-till systems (Yin and Vyn, 2003).

Foliar fertilization of soybeans is not recommended as a means of supplying K. The large K requirements mean applying K to the soil is the only practical way. Numerous foliar fertilization studies in yield reductions in some cases due to foliar burning.

K deficiency symptoms

The K deficiency is easily recognized as chlorosis starts along the outside edges of leaves, especially the older leaves. This is followed by necrosis (browning) of the leaf margins (IFA, 1992). There is no way to supply enough K during the growing season to improve yields once symptoms occur.

K and nodulation

Soybeans perform nitrogen fixation by establishing a symbiotic relationship with the bacteria, *Rhizobium japonicum*, in root nodules. These bacteria convert nitrogen from the air and convert it to metabolized ammonium N, thus reducing soybean's need for a nitrogen fertilizer.

The influence of potassium supply on nodulation was studied on soybean grown in nutrient solution. The dry matter yield, nodule parameters (nodule number and fresh weight of nodule per plant, average weight of nodule) and total nitrogen accumulation in the plant increased with increasing K supply (Premaratne and Oertli, 1994). In another study on beans, nitrogenase activity increased in proportion to K fertilization especially during the early stages of growth. Potassium had a significant effect on nodule number and nodule dry weight (Parthipan and Kulasooriya, 1989).

The benefit of K on N_2-fixation process stems from the multiple role of K in the plant metabolism:

- Potassium activates more than 60 enzyme systems, including the nitrogenase enzyme which is essential for N_2 -fixation.
- Potassium is essential for photosynthesis. Carbohydrates generated by photosynthesis provide the energy needed by bacteria in nodules to fix atmospheric N.
- Potassium enhances the synthesis of the carbohydrates in leaves and their further translocation to the roots. Once in the root system, the carbohydrates stimulate growth of new root hairs as well as nodule development and function.
- Potassium contributes to good root growth providing a proper "home" for the nodules in which N is fixed.

Studies on the effect of K on the N_2-fixation by root nodules of another leguminous crop (*Vicia faba*) show that the better carbohydrate supply of nodules, by plants well supplied with potassium, results in a higher carbohydrate turnover in the nodules and thus the provision of ATP and reducing electrons required by the nitrogenase is enhanced (Mengel *et al.*, 1974). Plants growing at higher K level have better development of nodules and consequently higher N_2-fixation. Potassium application has shown to increase the number of nodules formed, fresh weight of nodules, and amount of N_2- fixed per nodule, thus promoting the nodule activity of soybean.

K and protein content

The effect of potassium supply of *Vicia faba* on N metabolism was studied by using ^{15}N-labeled molecular nitrogen. Plants well supplied with potassium showed higher contents of ^{15}N in the soluble amino fraction and in the protein fraction of various plant organs as compared with plants of a lower potassium status. This effect was evident particularly in the root nodules (Mengel *et al.*, 1974).

Assimilation experiments, carried out with $^{14}CO_2$, revealed that the content of radioactivity in the sugars and amino acids of the root nodules was increased by the potassium supply of the host plants. In particular, the content of ^{14}C amino acids in the root nodules was influenced beneficially by potassium, which means that potassium favored the provision of reduced nitrogen NH_3 (Mengel *et al.*, 1974). At field level, the effect of K fertilization on soybean grain oil and protein was measured in a few experiments. The responses in oil and protein concentrations are small and inconsistent. However, because of the grain yield response to K, both oil and protein yield are often higher with fertilization (Haq and Mallarino, 2005).

K and soybean quality

Consumers today are seeking benefits from foods that contain naturally compounds beneficial to health (functional foods). For example, phytochemicals with medicinal value are defined as bio-active ingredients in food and are thought to support health and fitness. Isoflavones in soybean belong to this group. They are associated with prevention or treatment of cancer, diabetes, hypertension, and heart disease.

A field study by Wyn *et al.* (2002) confirmed a positive link between K fertilization of soybeans and their isoflavone content. The work showed that, particularly in low fertility soils, K fertilizer increased the major isoflavones - genistein, daidzein and glycitein - by up to 16%. Other beneficial effects of K on soybean quality include improved seed size, fewer damaged and discolored seed and enhanced plant health (better tolerance to pests and improved resistance to disease).

K and reduced susceptibility to pests and disease

In many studies, it has been evidenced that potassium amendments can substantially reduce the severity of several soybean diseases such as purple seed stain (*Cercospora kikuchii*), seed rot (*Phomopsis sp.*), stem and crown blight (*Rhizoctonia solani*) and pod and stem blight (*Diaporthe phaseolorum, Daiphorte sojae*) (Basseto *et al.*, 2007; Perrenoud, 1990).The control of pod and stem blight in soybeans by K use is also related to an escape mechanism, because the fungus can attack soybean only at a particular phenological stage. Earliness due to balanced fertilization provides the possibility to escape (Ito *et al.*, 2001).

During a long-term IPI experiment in India with soybean, the attacks of insects like blue beetle, grey semilooper, girdle beetle and stem fly were clearly reduced with K applications, and this increased yield (Bansal *et al.*, 2001; Fig. 6 and 7).

The reason for the higher incidence of damage by insects and plant pathogens in plants poorly supplied with K is still a matter of discussion. It may in part relate to the function of K in the development of thicker outer walls in the epidermal cells, thus providing protection against plant and animal attack. Additionally, K deficiency is known to impair the synthesis of high molecular weight compounds in the cell (proteins, starch and cellulose) which gives rise to the accumulation of low molecular weight compounds, such as sugars and amino acids, which can provide a ready source of nutrition to animals and plant pathogens.

Other possible mechanisms which may be involved 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); (iv) nitrification inhibition and to increased soil NH_4^+ and NH_4^+ uptake, resulting in rhizosphere acidification (Magen and Imas, 2004).

Fig. 6. **Effect of K application on soybean leaf damage by insects. Sehore, Madhya Pradesh (India). IPI-PRII-RAK. 1999. Control treatment (top) with insect attack, smaller and pale leaves; and 100 kg K_2O/ha treatment (bottom) with less insect attack, bigger and greener leaves**

Results from IPI Experiments – A Short Review

Farmers in Madhya Pradesh grow soybean crop during the monsoon season, and then grow wheat crop during the dry season using moisture stored in the deep vertisol soil, supplemented with some irrigation from groundwater.

While the farmers do use fertilizer, this is restricted to modest rates of nitrogen and phosphorus application supplemented with farmyard manure (FYM). Application rates of nitrogen and phosphorus are less than the rate of removal, and there has been little consideration given to other nutrients. The farmers obtain good wheat yields (though lower than the national average), but typical soybean yields are less than expected in this environment. Yields are low partly due to continuous imbalanced and inadequate plant nutrition.

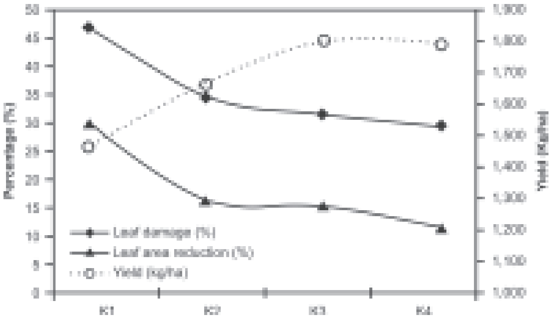


Fig. 7. Effect of K application on soybean yield and leaf damage by blue beetle. Sehore, Madhya Pradesh (India). IPI-PRII-RAK. 2001. K1=0, K2=25, K3=50 and K4=100 kg K_2O/ha

Oilfed Project

Experiments were conducted by IPI in collaboration with Madhya Pradesh (M.P.) Oilfed (Amlaha) on 10 farmers' fields of Sehore district from 1993 to 1996 to study the effect of K application on yield and quality of soybean and wheat crops grown in the system. These field trials were followed by field demonstrations of selected treatments on 15 fields each year for the next 3 years from 1996 to 1999 (Bansal *et al.*, 2001).

The results indicated that grain yield

of 2.5 and 5.5 t/ha in soybean and wheat respectively, can be achieved and sustained with adequate balanced NPK application. Fertilizer doses of $N_{30}P_{80}K_{50+50}$ and $N_{100}P_{50}K_{50+50}$ resulted in highest yield of soybean and wheat, respectively. Application of K in two splits was found to have extra advantage over basal application. About 10% increase in soybean oil and wheat protein content was also observed with optimum K nutrition, indicating improvement in crop quality.

Field demonstrations also showed a strong response to K application. Average soybean yields of 14 farmers in 1998 season were: 1.8, 2.31 and 2.43 t/ha for 0, 50 and 100 kg K_2O/ha, respectively (in split dose). Yield was increased in average by 29% (500 kg/ha) and 35% (624 kg/ha) with application of 50 and 100 kg K_2O/ha respectively. Most of the farmers achieved between 500 to 700 kg/ha more than the control, and for 10 of them, the addition of 500 kg/ha and more was achieved (Fig.8). The field demonstrations indicated that adequate K fertilization was highly profitable. Value-cost ratios (VCR) of 3.2-3.6 in wheat and 11-18 in soybean were obtained.

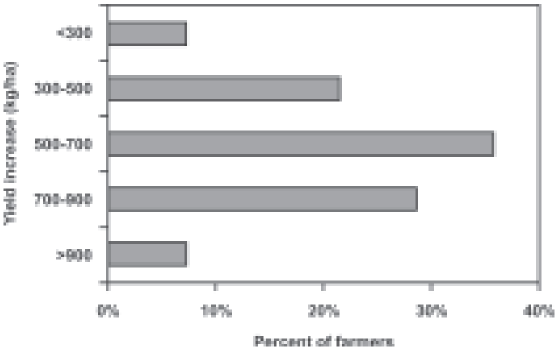
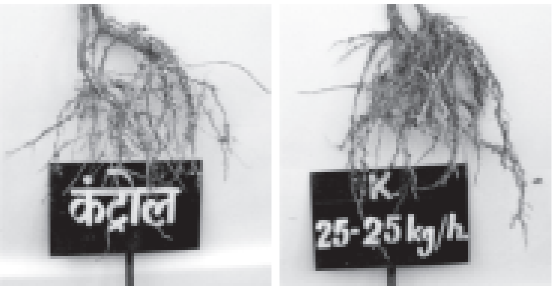


Fig. 8. Frequency distribution of yield increment attained by application of 100 kg K_2O/ha in soybean (*Kharif*, 1998), at farmers' demonstration plots



Control treatment: less developed root system, less nodules

50 kg K_2O/ha (split) treatment: more developed root system, more nodules

Fig. 9. Effect of potash application (50 kg K_2O/ha, split) on soybean roots. Plants taken from Shri Baldev Singh plot, Bedakhedi Village, MP (*Kharif* 1999). IPI-OilFed project in Amlaha

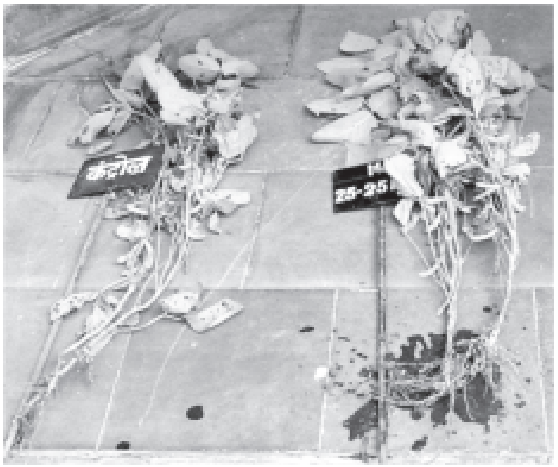


Fig. 10. Effect of 50 kg K_2O/ha (split) applied to soybean crop. Plants taken from Shri Narain Verma plot, Bhilkhedi Village, M.P. (*Kharif* 1999). IPI-OilFed project in Amlaha, MP. Photo by P. Imas.

Left: control treatment K=0 treatment; 50 pods/2 plants; right: 50 kg K_2O/ha (split) treatment; 108 pods/2 plants

RAK College Project

Another IPI project was initiated in Madhya Pradesh at the Research Farm of RAK College of Agriculture, Sehore on "Evaluation of potassium requirement in soybean-wheat cropping sequence in

Vertisols of Sehore region" (IPI, 2002). In the 2001 season, the results showed that nodule number and nodule dry weight increased significantly with K application. Maximum biological nitrogen fixation was recorded at 100 kg K_2O/ha as split. Plant growth parameters as root dry weight and shoot dry weight per plant increased significantly with increasing K doses. Yield attributing characters such as plant height, number of trifoliate leaves, number of branches/ plant, number of pods, seed weight and pod weight per plant were significantly increased with all the treatments of potassium application over control.

Yield of soybean was significantly increased due to all the treatments of potassium application over no K. The increase in grain yield was to the tune of 12.2 to 26.4% and the maximum being at 100 kg K_2O/ha applied in split dose, followed by 50 kg K_2O/ha in split (Table 6). Crude protein content in soybean seed also increased significantly with all the doses of K application both as basal as well as split application.

The leaf damage and leaf area reduction caused by blue beetle and girdle beetle was lowest in 50 kg K_2O/ha as basal. Stem tunnelling caused by stem fly was highest with no K application. From the economical point of view, application of potassium at 50 kg K_2O/ha applied in split doses recorded the maximum net return of Rs.2893/ha (Table 6).

Table 6. Economics of potassium application on soybean grown on Vertisols (Sehore, M.P., 2001)

Treatment kg K_2O/ha	Grain yield kg/ha	Response over control kg/ha	Cost of fertilizer + application Rs/ha	Net returns Rs/ha	B:C ratio
0	1,466	-	-	-	-
25 (basal)	1,645	179	186	1,425	7.66
50 (basal)	1,781	315	372	2,463	6.62
100 (basal)	1,770	304	744	1,992	2.67
25 (split)	1,680	214	296	1,630	5.50
50 (split)	1,841	375	482	2,893	6.00
100 (split)	1,853	387	854	2,629	3.07

Cost of MOP= 446 Rs/q ; soybean seed= 9 Rs/kg ; labour charges for split application of MOP= 110 Rs/ha

As a continuation to the RAK College project, five demonstration plots conducted at different farmers' fields, with three (unreplicated) treatments showed that soybean yield increased by 21.0 and 24.7% over control due to the application of 50 and 100 kg K_2O/ha, respectively.

Fig. 11. Effect of 25 kg K_2O/ha applied to soybean crop. Experiment at Research Farm of RAK College (2003)IPI-RAK project in Sehore, M.P.

NRCS Project

These results were further confirmed by a later IPI project with the National Research Centre for Soybean (NRCS), Indore on “Studies on role of potassium nutrition in balanced fertilization of Soybean-Wheat cropping system” (IPI, 2005).

In the 2004-05 experiment, for both soybean and wheat the split application of potassium gave a slightly higher response than the basal application. The highest grain yield for soybean of 2,259 kg/ha was obtained from the split 50 kg K_2O/ha treatment which also produced the highest wheat grain yield of 5,499 kg/ha. The highest additional yields over the respective controls were thus 749 kg/ha for soybean and 1,920 kg/ha for wheat. Repeating the experiment in 2005-06 season, confirmed the findings reported here (Table 7). The increase is yield is highly correlated to the nodules dry weight (R^2=0.9506; Fig 12). Both parameters were averaged for the single and split applications. Clearly, potash application doubled nodule DW from 300 (K=0) to 600 mg/plant (K=75) and significantly increased the number of nodules per plant. The very high linear correlation (R^2=0.9506) between nodule DW and yield provides an explanation for the effect of potash on seed yield of soybean (Fig. 12).

The benefits of potassium* nutrition in providing resistance to both insect infestations and plant disease on soybean were shown at Indore experiments. Applying K markedly depressed insect infestation in the case of blue beetle (*Cneorane spp.*) and the defoliators expressed by the number of insects per meter row length (mrl). This was also the case for the percentage disease incidence of stem fly *Melanagromyza sojae* (*Zehnt*) and the Girdle beetle (*Oberia brevis*). Similarly increased K application depressed the percentage mortality by collar rot, caused by the fungus *Sclerotium rolfsii* and leaf spot and petiole rot resulting from the pathogen *Myrothecium roridum*.

The GRF (gross return above

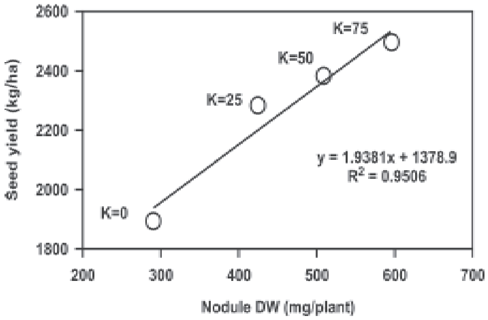


Fig. 12. Relation between nodules DW (mg/plant) and the yield of soybean at four levels of K fertilization (K=0, 25, 50 and 75 kg K_2O/ha). Yield and nodule DW are averaged for the same K level as basal and split. (Sehore, M.P., 2005)

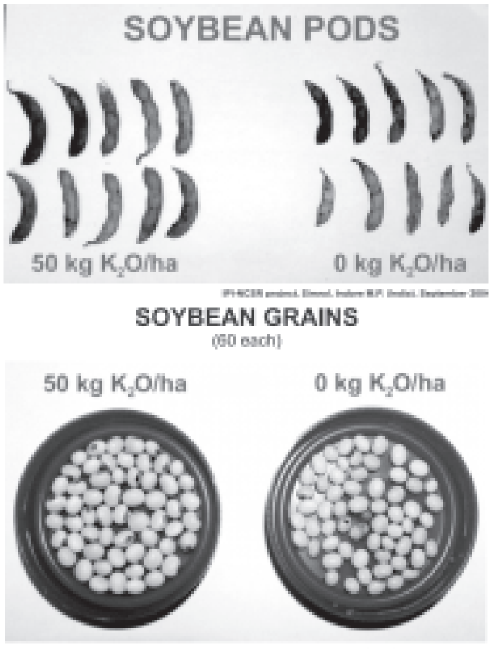


Fig. 13. Effect of 50 kg K_2O/ha applied to soybean crop. IPI-NRCS project in Indore, M.P.

Table 7. Effect of potassium nutrition on growth, yield attributes, yield, protein and oil content in soybean (Sehore, M.P., 2005)

K_2O Level (kg/ha)	0	25	50	75	12.5 (basal) + 12.5 (flowering)	25 (basal) + 25 (flowering)	37.5 (basal) + 37.5 (flow ering)	CD (P=0.05)
Nodules/plant at flowering	113.7	137.0	200.0	142.3	160.0	120.0	131.0	25.75
Branches/plant	2.2	2.7	3.1	2.7	2.5	3.3	2.9	NS
Pods/plant	16.4	23.5	25.9	18.9	20.8	27.9	23.2	NS
Nodule dry weight (mg/plant)	290.0	450.0	680.0	540.0	400.0	510.0	480.0	85.14
Plant height (dm)	54.8	52.6	54.3	56.4	52.8	56.1	54.7	NS
Seed index (g/100 seed)	13.50	14.53	14.59	14.06	14.71	14.88	14.83	0.93
Seed yield (kg/ha)	1895	2320	2425	2356	2237	2553	2405	330.36
Straw yield (kg/ha)	2434	2841	2955	2874	2824	3091	2872	403.90
Harvest index	43.77	44.95	45.07	45.04	44.20	45.23	45.05	NS
Protein %	39.71	39.33	38.71	38.85	39.35	39.22	38.85	NS
Oil %	13.97	14.74	14.50	14.83	14.50	14.76	14.53	NS

fertilizer costs in Rs/ha) - the most important figure and "bottom line" for the farmer - calculated by the additional returns less the additional costs in potash application, increased from 5,266 to 12,670 to 13,358 for the three K treatments respectively (25 kg K_2O/ha as basal, 50 kg K_2O/ha as basal, and 25 kg K_2O/ha as basal and 25 kg K_2O/ha at flowering). This remarkable return demonstrates at first hand to the farmer the benefits, which can accrue by applying potash to these soils and to the soybean/wheat cropping system in particular.

What Next?

Meat demand

Growth in demand for livestock products indicates that there will be a consequent rise in demand for animal feed, not only of cereals but of other feeds and particularly proteins. FAO reports on a 'livestock revolution' that is taking place, as a result of the rapidly growing world population, income growth, increasing urbanization, changes in lifestyles and food preferences (Speedy, 2004).

Predictions from the International Food Policy Research Institute (IFPRI) show that global demand for meat products will increase by 58% between 1995 and 2020. Consumption of meat will rise from 233 million mt in 2000 to a possible 300 million mt by 2020; milk consumption will increase from 568 to 700 million mt by 2020, and there will be an estimated 30% increase in egg production (Speedy, 2004).

At the same time, between 1995 and 2020, about 97.5% of the global population increase will be in developing countries, by which time 84% of the world's people (an estimated 6.3 billion) will be living in developing nations. Consumption of meat products grows and will grow much faster in developing countries than in the developed world. Consumption in the developing world is determined by purchasing power, and greater consumption of meat and milk will be stimulated by economic growth and more disposable income in the growing, more prosperous middle class (Speedy, 2003).

Nevertheless, the differences in consumption between countries are still very large. In Western developed countries, the daily per capita protein consumption can be as high as 80 g/day, whereas in poor developing countries it is as low as few g/day; optimum for human is 40 g/day from animal source (Gilland, 2002).

Protein availability and supply is a particular concern, especially in the light of meat and bone meal restrictions, the adoption of genetically modified crops, dioxin residues in fishmeal and increasing pressures on fisheries policy. Due to the bovine spongiform encephalopathy (BSE) or mad cow disease crisis, associated with the feeding of meat and bone meal, there is much concern caused on the sources of feed protein and their suitability, quality and safety. Fear regarding safety of foods of animal origin has shifted the preference of plants as source of protein for the animal feed industry (Chadd *et al.*, 2004). In this respect, soybean remains the most important and preferred source of high quality vegetable protein for animal feed manufacture. Soybean meal, which is the by-product of oil extraction, has a high crude protein content of 44 to 50% and a balanced amino acid composition, complementary to maize meal for feed formulation. Soybeans provide a high quality and highly digestible protein source that is also high in lysine, making it well suited to feed compounders (Bajjalieh, 2004).

A measure of success of this crop is the increase in production of 70% between 1996 and 2006, with most grown in the United States, Brazil and Argentina (FAOSTAT, 2007). In the European Union soybean dominates the protein supply for animal feed and the ban on meat and bone meal has resulted in further imports.

Biofuels

The fast development of biofuels has brought fresh opportunities for many agricultural production systems. As subsidies in the US and legislation and tax benefits in Europe were implemented in order to encourage the use and production of biofuels, a shift in crop land use occurred in the US (maize replacing soybean) and in Europe (using the set aside land for rapeseed crop). The expansion of maize for biofuels production is very significant, the annual quantity of corn grain that can be absorbed by the biofuels industry is similar to the annual US maize exports. This created pressure on prices of maize, soybean, wheat and other commodities.

Biodiesel accounts for about 2% of US diesel consumption, with 70 operational plants and 50 under construction, soybean being the main feedstock (IFA, 2007). There is a large difference between yields, oil content and thus oil yield between the various oil crops from which biodiesel can be produced. Cassman (2007) shows that 1 hectare of oil palm crop in Indonesia or Malaysia yields almost ten times more energy than soybean crop grown in Brazil or the US (Fig. 14).

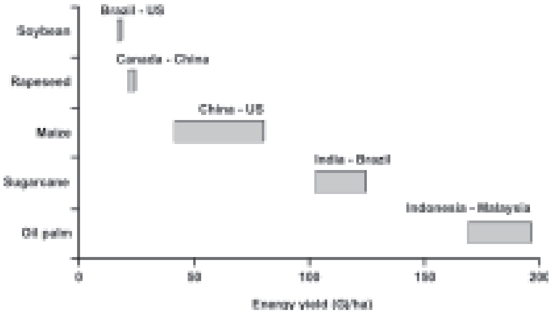


Fig. 14. Gross energy yield of various biofuels crops (Source: Cassman, 2007)

The energy calculations for biofuels are quite complicated and still debated. These are involving the energy calculations of inputs to the crops and to the biorefineries that produces ethanol or biodiesel. A detailed example of these calculations is described in details for maize, switchgrass and wood ethanol and soybean and sunflower biodiesel (Pimentel and Patzek, 2005). Table 8 describes the energy inputs of two crops, maize and soybean, demonstrating the high energy inputs maize requires. The energy input for applying nutrients is clearly very different as soybean does not require the addition of nitrogen, which consumes approximately ~30% of the total energy input of maize. Yet the final calculations for efficiency and profitability have to take in account also the energy net balance for the manufacturing process, or the 'life-cycle energy' of a specific crop.

Johnston and Holloway (2006) showed that soybean-biodiesel produces a 93% energy gain vs. 25% for corn-ethanol. However, others (Liska *et al.*, 2007) show that even though previous analyses of net energy yield from maize grain were of relatively low efficiency of 1:1.3 (energy input:output, net energy yield of 30 Gj/ha), improvements in the biorefineries, progressive management and higher maize crops and the integration with livestock systems to reach a 'close-loop' systems can remarkably improve the net life-cycle energy ratio to 1:2.7.

Table 8. Energy inputs of corn and soybean production per hectare in the US

Item	**Maize**	**Soybean**
	Kcal X 1000	
Labor	462	284
Machinery	1018	360
Diesel	1003	442
Gasoline	405	270
Nitrogen	2448	59
Phosphorous	270	156
Potassium	251	48
Lime	315	1349
Seeds	520	554
Irrigation	320	
Herbicides	620	130
Insecticides	280	
Electricity	34	29
Transport	169	40
Total energy input	8,115	3,746
Energy output from yield (8,655 & 2,668 kg/ha respectively)	31,158	9,605
Input:output ratio	1:3.84	1:2.56

Source: Adapted from Pimentel and Patzek (2005)

Johnston and Holloway (2006) also grade biodiesel future potential. Among the top five are the leading oil palm growers (Malaysia and Indonesia) and the large soybean growers (Argentina, US and Brazil). The estimated production costs vary from 0.49-0.53 $/L of biodiesel in using palm oil to 0.62-0.7 $/L in soybean oil. Clearly, the potential for biofuels is large. As the development of this sector is heavily dependent on government's policies, life-cycle energy calculations for each crop and agro-climatic region has to be carried, also in view of substantial concerns over food security.

Conclusion

Soybean is a major and vital crop for oil and protein consumption by human, animal and fuel. The increased demand for oil and protein fueled soybean production mainly by land expansion, with very modest growth in its productivity. In future, with mounting pressure for environmental conservation and requirements for biodiesel, there is a strong need for research and better crop management to increase its productivity.

Soybean is part of many cropping systems with the advantage of supplying residual nitrogen to the following crop. Adequate potassium supply in soybean is necessary throughout the growing period, till the latest stages of maturity. Potassium increases nodulation in soybean's roots and the formation of protein in the grain. The positive effect of potassium on yields is through larger seed size and as demonstrated at IPI experiments, more filled pods per plant.

During the last eight years, results from the joint IPI activities with M.P. Oilfed, Amlaha, RAK College and NRCS clearly provide ample of data for improving potash recommendations. These suggest that the application of 50 to 100 kg K_2O ha to soybean crop brings an additional direct income of Rs. 2,500-3,000, plus large savings in usage of pesticides. Split application of potash may be superior to a split application in terms of yield gained, and possibly leads to higher use efficiency of the applied potash. Further research to better understand the nutrient management requirements in the soybean-wheat cropping system of Madhya Pradesh will help in meeting future demand for soybean. This higher yield of approximately 2 mt/ha achieved in our experiments should be targeted also in other soybean growing areas in India. More research work should be also carried to better understand the relation between potash application and the reduced vulnerability of the crop to pests, insects and diseases.

References

Bajjalieh, N. 2004. Proteins from oilseeds. In: *Protein Sources for the Animal Feed Industry*. Proceedings of the FAO Expert Consultation and Workshop Bangkok, Food and Agriculture Organization of the United Nations, Rome. 29 April – 3 May 2002. pp. 141-159.

Bansal, S.K., Dixit, A.K., Imas, P. and Magen, H. 2001. The effect of potassium application on yield and quality of soybean and wheat in Madhya Pradesh. *Fertiliser News* 46: 45-52.

Basseto, M.A, Ceresini, P.C. and Valério Filho, W.V. 2007. Severidade da mela da soja causada por Rhizoctonia solani AG-1 IA em função de doses de potássio. *Summa Phytopathologica* 33: 56-62.

Chadd, S.A., Davies, W.P. and Koivisto, J.M. 2004. Practical production of protein for food animals. In: *Protein Sources for the Animal Feed Industry*. Proceedings of the FAO Expert Consultation and Workshop Bangkok, Food and Agriculture Organization of the United Nations, Rome. 29 April – 3 May 2002. pp. 77-123.

Clay, J. 2004. World Agriculture and the Environment. Island Press, Washington, Covelo, London. pp.173-202.

Dahnke, W.C., Fanning, C. and Cattanach, A.1992. Fertilizing Soybean, SF-719, North Dakota State University of Agriculture and Applied Science.

Erickson, B. and Lowenberg-DeBoer, J. 2005. Crop Rotation Literature Review. Dept of Agricultural Economics, Purdue Univ, W. Lafayette. http://www.agecon.purdue.edu/pdf/Crop_Rotation_Lit_Review.pdf.

Fageria, N.K., Baligar, V.C. and Jones, C.A. 1997. Growth and mineral nutrition of field crops. 2nd ed. M. Dekker, New York. pp.624.

FAOSTAT. 2007. FAO Statistics Division. http://faostat.fao.org.

Gilland, B. 2002. World population and food supply Can food production keep pace with population growth in the next half-century? Food Policy 27, pp. 47-63.

Hanway, J.J. and Weber, C.R. 1971. Accumulation of N, P and K by soybeans (*Glycine max L.*) Merrill) plants. *Agronomy Journal* 63:406-408.

Haq, M.U. and Mallarino, A.P. 2005. Response of Soybean Grain Oil and Protein Concentrations to Foliar and Soil Fertilization. *Agronomy Journal* 97:910–918.

IFA. 1992. World Fertilizer Use Manual. International Fertilizer Industry Association. Paris. pp.632.

IPI. 2002. Annual report (internal). International Potash Institute, Horgen, Switzerland.

IPI. 2005. Annual report (internal). International Potash Institute, Horgen, Switzerland.

IFA. 2007. A Survey of the Anticipated Impact of Biofuel Development on Short-, Medium- and Long-Term Fertilizer Demand. International Fertilizer Association (IFA), Paris, France.

Ito, M.F., Mascayrenhas, H.A.A., Tanaka, R.T., Martins, A.L.M., Otsuk, I.P., Carmello, Q.A.C. and Muraoka, T. 2001. Control of stem canker in soybeans by liming and potassium fertilizer. *Rev. de Agricultura*, Piracicaba 76: 307-316.

Johnston, M. and Holloway, T. 2006. A global comparison of national biodiesel production potentials. A report submitted to Environmental Science & Technology. http://www.sage.wisc.edu:16080/energy.

Liska, A. J., Cassman, K., Yang, H. and Walters, D. 2007. Life-Cycle Performance of Biofuels: GHG Mitigation and Net Energy. In: *Expert Consultation on Biofuels*—IRRI, Los Baños, Philippines, 27-29 August.

Magen, H. and Imas, P. 2004. Potassium chloride and suppression of disease. Poster presented at the XVTH International Plant Protection Congress, Beijing, China, May 11-16.

Mengel, K., Haghparast, M. and Koch, K. 1974. The Effect of Potassium on the Fixation of Molecular Nitrogen by Root Nodules of Vicia faba. *Plant Physiology* 54: 535–538.

Parthipan, S. and Kulasooriya, S.A. 1989. Effect of nitrogen- and potassium-based fertilizers on nitrogen fixation in the winged bean. *World Journal of Microbiology and Biotechnology* 5: 335-341.

Perrenoud, S. 1990, Potassium and plant health. IPI Research Topics No. 3, 2nd rev. edition. International Potash Institute, Switzerland.

Pimentel, D. and Patzek,T.W. 2005. Ethanol Production Using Corn, Switchgrass, and

Wood; Biodiesel Production Using Soybean and Sunflower. *Natural Resources Research* 14:1 65-76.

Premaratne, K. P. and Oertli, J. J. 1994 .The influence of potassium supply on nodulation, nitrogenase activity and nitrogen accumulation of soybean (*Glycine max L. Merrill*) grown in nutrient solution. *Nutrient Cycling in Agroecosystems* 38, 95-99.

Ray, J.D., Heatherly, L.G. and Fritschi, F.B. 2006. Influence of Large Amounts of Nitrogen on Nonirrigated and Irrigated Soybean. *Crop Science* 46:52–60.

Reid, K. and Bohner, H. 2007. Interpretation of Plant Analysis for Soybeans. http://www.omafra.gov.on.ca/english/crops/facts/soybean_analysis.htm.

Speedy, A.W. 2003. Global Production and Consumption of Animal Source Foods. *Journal of Nutrition* 133, pp. 4048-4053.

Speedy, A.W. 2004. Overview of world feed protein needs and supply. In: *Protein Sources for the Animal Feed Industry*. Proceedings of the FAO Expert Consultation and Workshop Bangkok, Food and Agriculture Organization of the United Nations, Rome. 29 April – 3 May 2002. pp. 9-27.

Vitosh, M.L., Johnson, J.W. and Mengel, D.B. 1995. Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa. Extension Bulletin E-2567. Michigan State Univ., The Ohio State Univ., and Purdue Univ. http://www.ces.purdue.edu/extmedia/AY/AY-9-32.pdf.e

Wyn, T.J., Yin, X., Brunlsema, T.W., Jackson, C.C., Rajcan, I. and Brouder, S.M. 2002. Potassium fertilization effects on isoflavone concentrations in soybean. *Journal of Agricultural Food Chemistry* 50: 3501-3506.

Yin, X. and Vyn, T. J. 2003. Potassium Placement Effects on Yield and Seed Composition of No-Till Soybean Seeded in Alternate Row Widths. *Agronomy Journal* 95:126-132.

Role of Potassium Nutrition in Post-harvest Processing Quality of Soybean

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Abstract

The quality of raw material for producing food products plays a vital role to manufacture products of desirable quality. Therefore, the quality of soybean to be used to manufacture soybean based food products will determine the quality of products. The application of balanced fertilization for producing soybean is one of the main factors that affect the quality of soybean grains. After nitrogen and phosphorus, potash is the third most important and essential nutrient for optimal growth and vigour of plants and microorganisms. Since potassium is directly or indirectly involved in most plant processes, it will certainly affect the development of soybean grain and its constituents. The indicators such as grain size, grain protein and oil content, grain lust, grain health, etc. reflecting the post-harvest processing quality of soybean, will be affected by potash nutrition. This paper will present some of the related aspects such as food quality, soybean post-harvest processing and quality indicators, potash nutrition and indirect link of potash nutrition to post-harvest processing quality of soybean as no research has been carried out on the direct effects of potash nutrition on the quality of soybean food products.

Definition and Need of Food quality

In general term, quality is defined as fitness for use whereas food quality refers to the value for each quality parameter that is subjectively and objectively attached to food and constitutes the following:

- Nutritional quality
- Functional quality
- Hygienic quality
- Sensory quality
- Environmental compatibility
- Safe food

The tailoring of food quality has become a need of time in the era of WTO and globalization not only in developed countries but in developing countries also because of the following factors:

- Increasing urbanization
- Increasing economic status
- Increasing health consciousness
- Increasing demands for functional foods
- Lowering transportation and processing cost
- Demographic changes
- To keep the pace with accelerated technological development

Soybean Post-harvest Processing and Quality Indicators

After harvesting soybeans are passed through various processing operations including cleaning, grading and drying and then converted into different food products as given below:

Table 1. Potential food products from soybean and its derivatives/ingredients

Soybean and its products/ingredients	Potential food applications
Whole soybean	Soy-based dairy analogs, full fat soyflour, snack foods, sprouted bean, tempeh, miso, natto, sauce and soycandy
Soybean oil	Cooking/shortening oil, salad oil, margarine, bread spread and soy-lecithin
Soy-proteins (Edible soybean meal)	Defatted soyflour, texturised soy-protein, soy-protein concentrate, soy-protein isolates and dietary fibre
Soybean by-products (hull and okara)	Single cell protein (SCP) and dietary fibre
Soybean crop residue (leaf, branches and stems)	Animal feed, fuel and manure

Soybean products such as tofu, soymilk, miso, edamame and soynuts of desirable quality are generally made from large seeded soybeans as these are moderately high in protein content with improved ratio of 7S/11S protein or lack of lipoxygenase (Chen, 1998). The beans suitable for making tofu also have a high NSI, high water uptake, low calcium and high germination rate (Helms *et al.,* 1998). The yield, texture and quality of tofu and soymilk are affected by protein and oil content. A high protein/oil ratio provides a higher tofu yield and firmer texture. The taste of tofu and soymilk is associated with the content of soluble carbohydrates in general and sucrose in particular.

For obtaining the higher yield of oil from the extraction, the varieties with high oil content would be preferred due to economic reasons. Similarly soybeans for making natto are characterized by small seed size with clear hilum and thin seed coat having higher content of carbohydrates and proteins. Soybeans with medium seed size having higher germination rate are preferred for sprouted beans. High protein, high isoflavone, high sugar and lipoxygenase free soybeans are most suitable for sprouted beans. High protein soybeans offer an improved nutritional advantage and can be used in several products form to combat the problem of malnutrition. High isoflavone soybeans are required to harness the health benefits including anti-cancer, blood pressure lowering and estrogenic and anti-estrogenic properties in post-menopausal problems from soybeans.

The indicators for functionality of soybean can therefore be summarized as physical (seed size, seed colour, seed health, seed lust, uniformity, seed shape, hilum colour, seed coat strength, water absorption capacity, seed hardness), and compositional (protein, oil, carbohydrates, calcium, fibre, ash and fatty acids content). Other unique grain quality components include lipoygenase, isoflavone, protein sub-units, allergenic proteins, trypsin inhibitors water soluble proteins texture and flavour.

Potash Nutrition

After nitrogen and phosphorus, potash is the third most important and essential nutrient for optimal growth and vigour of plants and microorganisms. Potassium is a 'work horse' plant nutrient and perhaps this is why it is not bound into any specific plant compound. Since potassium is directly or indirectly involved in most plant processes, it should not be surprising that potassium nutrition is closely associated with each of the following important functions:

- Essential for photosynthesis
- Transport of photosynthate to storage organs
- Efficiency of nitrogen fixation by rhizobium in crops like soybean etc.
- Ability to withstand stresses
- Activation of enzymes
- Development of root system
- Production of oil and protein
- Water absorption by roots and water economy

Because of the above functions, any shortage of potassium can result into low crop yield, quality and profitability. It is the vital nutrient for quality. Therefore, the continous potash deficiency in soil may affect the following:

- Sustainability of soil fertility
- Yield and income
- Quality and competitiveness
- Stress tolerance
- Compatibility with the environment

Potassium regulates many metabolic processes required for growth, fruits and seed development ((Nelsen *et al.*, 1984). Many vegetables and fruits crops are high in potassium, which is vital for animal and human nutrition (Tucker, 1999). The concentration of sugar in beet and sugarcane responded positively to potash applications due to the stimulation of assimilation and translocation of sugar from the leaves into the beet and cane. The energy consumption in transporting beet and cane with high sugar will be less as compared to lower sugar. Potash adequate plants are more tolerant to drought than that of potash deficient. Potash deficiency results into wilting plant that have a lower gas exchange and thus less assimilation (Krauss, 2004).

Linkages between Potash Nutrition and Post-harvest Processing Quality

No research work has been carried on the direct effects of potash nutrition on the quality of soybean products. The potassium nutrition is associated to quality of the seed through the following regulatory mechanisms:

- Nitrogen metabolism
- Sugar transport
- Water utilization
- Stress resistance

The above functions of the potash in plant processes define the role of potassium in altering the quality of soybean indirectly and indicate that :

- Potash alters the functional properties
- K correlates with sensory qualities
- K entails hygienic properties
- K increases the content of functional constituents
- K improves the physical appearance and shelf-life of different crops
- Potash application matches environmental requirements

From the above information it can be interpreted that potash nutrition will certainly affect the physical as well as chemical composition of soybean and hence of the soybean products.The balanced fertilization with potash increases oil and protein content and at the same time improves seed development. The inclusion of appropriate amount of potash in soybean fertilization has also enhanced isoflavone content of soybean. This shows that potash is very important to produce identity preserved soybean also. There is immediate need to include the research work on direct effects of potassium on the quality of soybean based food products and their functionality.

References

Chen, P. 1998. Developing High Quality Identity Preserved Soybeans for the Speciality Soyfood Market. In: *Identity Preserved Soybeans*. USSEC.pp22-33 (http://ussoyexports.org/buying_u.s._soy/IPbook/chap-3-IP_Process.pdf).

Helms, T.C., Cai, T.D., Chang K.C. and Enz, J.W. 1998. Tofu Characteristics Influenced by Soybean Crop Year and Location. North Dakota Agriculture Research (An online Research Journal of North Dakota Agriculture University), Fall.

Krauss, A. 2004. K effects on yield quality. Paper presented at Potafos IPI – PPI – PPIC Symposium on K in Brazilian Agriculture, September 22-24, 2004 at Sao Pedro, SP, Brazil.

Nelsen, D.R., Bellville, R.J. and Porter, C.A. 1984. Role of Nitrogen Assimilation in Seed Development of Soybean. *Plant Physiology* 74: 128–133.

Tucker, M.R. 1999. Essential Plant Nutrients: their presence in North Carolina soils and role in plant nutrition. In: Agronomic Reports, North Carolina, Department of Agriculture and Consumer Services, pp. 1-9 (www.agr.state.nc.us/agronomi/pdfiles/essnutr.pdf).

Role of Potassium in Abiotic and Biotic Stress Management

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Abstract

Abiotic and biotic stresses negatively influence survival, biomass production and finally the crop yield. It is a challenge to understand the basis of abiotic and biotic stress tolerance and to manipulate them. This review intends to focus on the role of potassium in abiotic and biotic stress management in crop production. Moisture deficit created by drought or withholding irrigation results in a significant reduction in plant water potential, osmotic potential, relative water content, photosynthetic rate, respiration, etc. Moreover, a marked reduction in various growth characters like leaf area, weight or yield has been reported under abiotic and biotic stresses incidence of insect-pest and diseases. The application of potassium in general, mitigates the adverse effect of such stresses, which facilitate the conditions, that favours more or higher growth and yield levels of crop.

Introduction

Potassium is an alkali metal that occurs naturally in most of the soils. The total K content of the earth crust is about 2.3 to 2.5 per cent, but only a very small proportion of it becomes available to plants (Leigh and Jones, 1984). It is one of 18 elements that are essential for both plant and animal life (Brady and Weil, 2002). Plants require K proportionately in large quantities, hence, it is regarded as one of the three major plant food elements (Golakiya and Patel, 1988; Leigh and Jones, 1994; Dev, 1995). Higher yields of better quality depend greatly on the capacity and capability of the crop to resist or tolerate moisture and temperature abnormalities, diseases and other stresses during growing periods (Amtmann *et al.*, 2004; Dev, 1995). Potassium is involved in many physiological processes such as photosynthesis (Vyas *et al.*, 2001), photosynthetic translocation (Umar, 1997; Tiwari *et al.*, 1998), protein and starch synthesis, water and energy relations (Rao and Rao, 2004), translocation of assimilates (Tomar, 1998) and activation of number of enzymes (Vyas *et al.*, 2001; Sharma and Agrawal, 2002). Potassium also improves the water use efficiency (Singh *et al.*, 1997 ; 1998) through its influence on maintenance of turgor potential (William, 1999). As most of the *kharif* and *rabi* crops are grown under rainfed conditions, crops experience water and temperature stresses of varying degrees and duration at various growth stages, thus, relevance of K nutrition under such stress conditions may assume great importance.

Potassium in Plant System

Potassium, an important macronutrient for plants, carries out vital functions in metabolism, growth and stress adaptations (Krauss, 2001; Krauss and Johnston, 2002).

These functions can be classified into those that rely on high and relatively stable concentrations of K^+ in certain cellular compartments and those that rely on K^+ movement between different compartments, cells or tissues (Vyas *et al*., 2001). The first class of functions includes enzyme activation, stabilization of protein synthesis and neutralization of negative charges on proteins (Marschner, 1996). The second class, linked to its high mobility, is particularly evident where K^+ movement is the driving force for osmotic changes as, for example, in stomatal movement, light-driven and seismonastic movements of organs, or phloem transport (Amtmann *et al*., 2004). In other cases, K^+ movement provides a charge-balancing counter-flux i.e. essential for sustaining the movement of other ions (Singh and Singh, 1999). Thus, energy production through H^+ ATPases relies on overall H^+/K^+ exchange (Tester and Blatt, 1989). Accumulation of K^+ (together with an anion) in plant vacuoles creates the necessary osmotic potential for rapid cell extension (Singh and Singh, 1999; Warwick and Halloran, 1991).

Potassium deficiency leads to (i) growth arrest due to the lack of the major osmoticum (Singh *et al*., 1997 ; Warwick and Halloran, 1991) , (ii) impaired nitrogen and sugar balance due to inhibition of protein synthesis, photosynthesis (William,1999) and long-distance transport (Bhaskar *et al*., 2001) and (iii) increased susceptibility to pathogen probably due to increased levels of low molecular weight nitrogen and sugar compounds (Tiwari *et al*., 2001). In a natural environment, low-K conditions are often transient therefore, plants have developed mechanisms to adapt to short-term shortage of K supply.

Potassium is involved in numerous functions in the plant, such as in enzyme activation, cation/anion balance, stomatal movement, phloem loading, assimilate translocation and turgor regulation, etc. (Golakiya and Patel, 1988; Singh *et al*., 1999; Umar, 1997). Stomatal resistance decreases and photosynthesis increases with increasing K content of leaves (Peoples and Koch, 1979). In tobacco plants well supplied with K, 32% of the total N^{15} taken up within 5 hrs was incorporated into protein whereas, by 11% in K deficient plants (Koch and Mengel, 1974). Potassium deficient leaf cells accumulate substantial quantities of low molecular weight organic compounds (Noguchi and Sagawara, 1966; Baruah and Saikia, 1989) because they act as an osmoticum in the absence of sufficient potassium.

Potassium and Stress Tolerance

Abiotic and biotic stresses negatively influence survival (Agrawal *et al*., 2006) biomass production and crop yield (Amtmann *et al*., 2004; Dev, 1995; Tomar, 1998). Climatic extremes and unfavorable soil conditions are two major determinants affecting crop production (Singh *et al*., 2004). Potassium supply up to certain extent, can lessen their adverse effects on crop growth. The word abiotic means non-living and the components are those that do not have life, such as soil and climate / weather parameters. The biotic means living and components are those that have life, for example, plants, animals, microorganisms as well as some decomposers.

Abiotic Stresses

Soil moisture

The transport of K ion in soil medium towards plant roots takes place by mass flow and diffusion. On an average 10 per cent of total K^+ requirement of crops is transported by mass flow. In general diffusion is the main process of K^+ transport. According to Nye (1979) the diffusion of K^+ in the soil solution increases with soil moisture. Tortuousity i.e. the soil impedance increases with drying of soil. The diffusion coefficient for K^+ of about $1x10^{-7}$ cm^{-2} sec^{-1} at a soil water content of 23% decreases to $5x10^{-8}$ cm^{-2} sec^{-1} at 10% moisture content which is about $1.5x10^{-5}$ cm^{2} sec^{-1} in pure water (Mengel and Kirkby, 1980). As water stress develops, K^+ helps in reducing the extent of crop growth loss through maintaining higher activity of enzyme nitrate reductase, which normally decreases under stress condition (Saxena, 1985). Potassium is also involved in the biosynthesis of proline and crop varieties with higher proline content are reported to have high yield stability as well as high productivity under moisture stress (Krishnasastry, 1985).

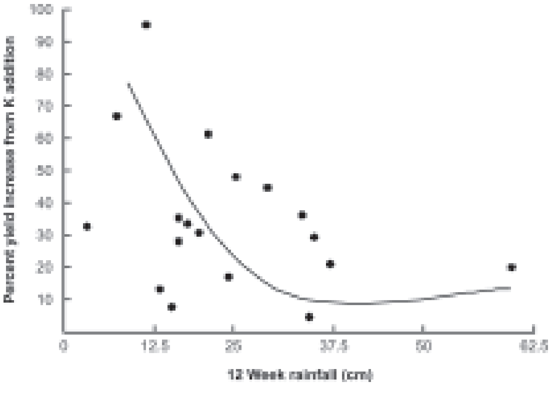

Fig.1. Soybean response to K is greater with low rainfall (Source: Barber, 1963)

With variations in wet and dry conditions, the added K fertilizer may yield large responses in K responsive soils. Barber (1963; 1971) reported that lesser the rainfall for 12 weeks after planting, the greater the per cent yield increase of soybean from K additions (Fig.1). However, with low rainfall the roots tend to function more in the sub-soils and much lower in low K status (Nelson, 1978).

To provide 5 kg K/ha to the roots, the required K concentration in the soil solution in moist and dry soils varied. The drier the soil, the higher is the needed K concentration (Johnston *et al.*, 1998). The K flux improves with the soil moisture (Fig.2). On the other hand, a generous K supply can, to certain extend, compensate less diffusive K flux in drier soils.

With high rainfall and/or in waterlogged conditions the pore spaces in the soil get filled with water and oxygen content declines. This lowers respiration in plant roots and thus decline in nutrient absorption. However, by adding high amounts of K, the K need of the plant can be met even when root respiration is restricted (Skogley, 1976). Working on barley crop the adequate K had a reduced transpiration rate during stress (rate relative to 1.0 under non-stress) 5 minute after exposure to hot windy conditions. On the other hand, under severe K deficiency, the transpiration rate greatly increased. Greater water loss, thus, could limit the crop yield. Hot and dry winds are common occurrence in the plains and may be disastrous to crops.

Potassium fertilization can partially overcome the adverse conditions of poor aeration caused by waterlogging or compaction (Nye, 1979). The uptake of K is a process that requires energy provided by root respiration. If oxygen is lacking, root respiration is impaired and so is K uptake. As early as in 1963, Brown reported that poorly drained soils with low K resulted in poor yield as compared to the well drained soils. However, when K was increased to 150 kg/ha the yield increased even in poorly drained fields (Table 1)

Table 1. Yield of lucerne (ton/ha) under varying pH and drainage conditions

Soil drainage	pH 5.8		pH 6.5	
	37 kg K/ ha	150 kg K/ha	37 kg K/ha	150 kg K/ha
Poorly drained	7.4	10.7	8.10	12.3
Well drained	9.2	10.7	9.8	11.9

Source: Brown (1963)

A number of physiological disorders are related to K levels in poorly aerated paddy soils. In such soils excessive ferrous (Fe^{2}+) or the presence of respiration inhibitors like hydrogen sulphide may inhibit K uptake and cause Fe toxicity, a disorder commonly known as "bronzing" (Dev, 1995 ; Hardter, 1997).

Soil salinity

Plant adaptations to saline conditions can depend on an increase in specific inorganic and organic solutes within the cell, which may contribute osmoregulation or to the ability to prevent the accumulation of salts within the cytoplasm (Warwick and Halloran, 1991; Singh and Singh, 1999) . The operation of either mechanism is important for tolerance and adaptations to salinity. Analysis of plant tissues for Na and K contents under salt stress condition has been suggested as one of the useful parameter to measure the varietal salt tolerance (Warwick and Halloran, 1991; Singh and Tiwari, 2006). In this regard, Singh and Singh (1999) tested four chickpea varieties including tolerant and susceptible for Na and K contents with increasing salt stress (Singh *et al.*, 2004). It was observed that the values of K content in tolerant genotypes were significantly higher than those of susceptible genotypes (Singh *et al.*, 2006).

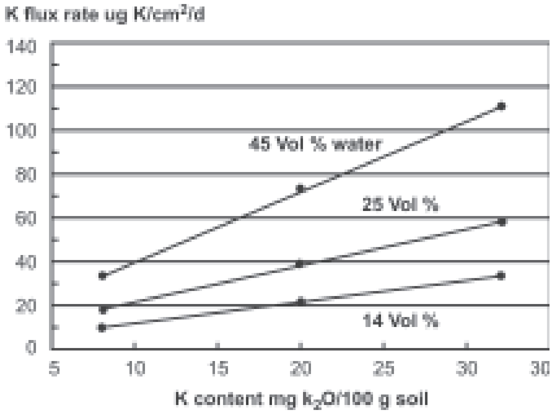

Fig. 2. K diffusive fluxes as affected by soil water content and K status of the soil (Source: Gath, 1992)

Temperature

Potassium can help plants to tolerate to both very high and very low temperatures (Grewal and Singh, 1980)). The relationship between K nutrition and temperature is complicated by the interaction of soil and plant factor (Johnston *et al.*, 1998). Frost damage has been reduced by maintaining of good level of K in the tissues of both annual and perennial crops (Grewal and Singh, 1980; Shrinivasa Rao and Khera, 1995). The results from the findings of Grewal and Singh (1980) demonstrated that frost damage of the foliage of potato is inversely related to the K content of leaves.

Similarly, the pattern of K uptake increases with increasing temperature up to a maximum and very high temperature can be detrimental if the loss of energy through respiration becomes excessive. Alterations in the amount of shade influences the effect of factors, such as temperature and moisture condition on growth and yield and thereby, K requirements (Nelson, 1978 ; Dev, 1995; Rao, 2004)

Biophysical properties

The biophysical role of potassium, in turgor maintenance and expansive growth, particularly its role in stomatal regulation and its effects on water use and carbon dioxide assimilation processes are affected by K deficiency (Rao, 1999). However, moisture stress undoubtedly is known to reduce the turgidity of cells (Umar, 1997) and thereby, decreases stomatal conductance and photosynthesis (Singh *et al*., 1998). Potassium application helps in drought tolerance and enhanced maturity as well as juice quality in sugarcane. The application of potash @ 80 kg K_2O/ha resulted in an increase in leaf area, diffusion resistance of stomata and thereby, reduced transpiration rate over without application (Tiwari *et al*., 1998). This could be due to adequate supply of the potassium. However, the stomata close rapidly under drought and minimize the transpiration rate (Umar, 1997). Role of K in stomatal regulation in *Brassica* under moisture stress had also been reported (Sharma *et al*., 1992).

It has also been observed that most of the tropical legumes experience frequent droughts of varying degree and durations during their growth periods. Potassium influences the water economy and crop growth through its effect on water utilization, by root growth reflecting maintenance of turgor, transpiration and stomatal behavior (Nelson, 1978) and consequently influencing dry matter production to greater extent (Cadisch *et al*., 1993). Singh *et al*. (1997) also observed relatively lower values of leaf osmotic potential under water stress. While, these increased upon watering, indicating the change in osmoregulation. Under stress condition, the decline in osmotic potential is mainly due to the accumulation of solute like K^+, proline and soluble carbohydrates. Moreover, the osmotic adjustment enables plants to deplete the soil water to a lower soil water potential level. Thus, facilitates a greater exploration of available soil moisture by roots (Singh *et al*., 1997; Tiwari *et al*., 1998; Willium, 1999).

Golakiya and Patel (1988) studied the effect of cyclic dry spells and potassium treatments on the yield and leaf diffusive resistance of groundnut. The repeated occurrence of stress conditions caused considerable reduction (up to 75%) in pod yield and the shortfall in production was still higher in the case of consecutive dry spells. Potassium application of 60 kg K_2O/ha enhanced the level of production over control (no water stress) and could also restore the loss in pod yield to a noticeable extent. A marked increase in the diffusive resistance of leaves with K fertilization supports the contention that potassium plays an important physiological role in counteracting adverse conditions caused by drought.

Photosynthesis is the process through which the energy of solar radiation is directly converted into sugar, starch and other organic components (William, 1999). Though, K is not an integral part of chlorophyll molecule, but it influences photosynthesis to a greater extent. Photosynthesis rate drastically decreases under water deficit because of both stomatal and non-stomatal factors (Umar, 1997; Singh *et al*., 2004). The reduction in photosynthetic rate is also due to decreased leaf water potential and RWC under water stress, which leads to decrease in stomatal conductance. The rate of photosynthesis is enhanced with supply of K in rooting medium because K helps in maintaining the rate by improving RWC and leaf water potential through osmotic adjustment under stress (Singh *et al*., 1997). It has also been reported that accumulation of optimum K in guard cells provides the adequate amounts of solute necessary in developing proper leaf water potential gradient required for movement into guard cells for stomatal opening necessary for photosynthesis. The amount of solar energy transformed into dry matter production, thus will be greater even in moisture stress condition under adequate K supply (Cadisch *et al*., 1993).

Effect of K levels (25, 50,100 and 200 ppm) on water relations, CO_2 assimilation, enzyme activation and plant performance under soil moisture deficit in cluster bean (Vyas *et al*., 2001) have shown that the plant water potential and RWC declined due to water stress at all K levels . However, the decline was less in plants growth at 200 ppm K level as compared to plants grown at low K levels. Wyrwa *et al*. (1998) observed that in K depleted soils under drought condition, the triticale yield got decreased by more than 50% whereas, application of 100 kg K_2O/ha increased the yield to a level which was only about 17% less than the yield of plants well supplied with water (Fig. 3).

The yield improvement due to K application in number of crops suggests that under low moisture K application may result in yield improvement only when K availability is limiting. The evidences indicate that application of K mitigates the adverse effect of water stress by favorably influencing internal tissue moisture, photosynthetic rates and nitrogen metabolism.

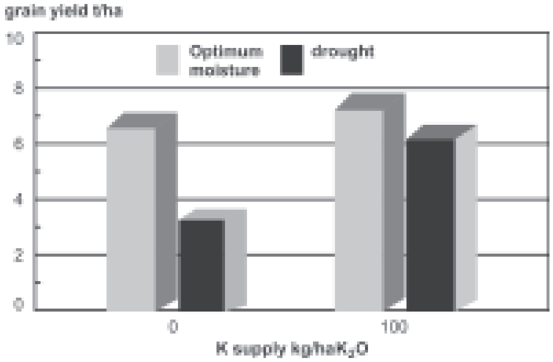

Fig. 3. Effect of potassium supply on yield of triticale as affected by drought (Source: Wyrwa *et al*., 1998)

Biotic Stresses

Insect-pest and disease incidence

Crops are constantly subjected to several fungal, bacterial and viral deceases. It has been observed that disease incidence, in general increases with the increase in Nitrogen level (susceptibility) that results in an increase in reducing and non-reducing sugar contents, but invariably decreases with potassium applications (Velazhahan and Ramabadran, 1992). Amongst fungal diseases especially the sheath rot caused by *Sarocladium oryzae* in rice has assumed much importance in recent years by causing heavy yield losses (Bhaskar *et al*., 2001). They reported that the sheath rot disease incident in rice increases with increase in N levels from 0 to 300 kg N/ha while, the phenol content in leaf sheath was found to increase with K application as compare to N levels.

Further, it was observed that higher the phenol content, lower was the sheath rot incident probably due to growth of inhibiting pathogens.

Potassium has been shown to reduce the severity of several plant diseases. For example, Baruah and Saikia, (1989) reported that at low levels of potash the stem rot disease infestation in rice was relatively much greater ranging from 38.5 to 42.5 per cent, in comparison to optimum K levels. Potassium inhibits the accumulation of soluble carbohydrates as well as nitrogenous compounds in the tissues, thus helping to counteract a situation that favours fungal growth when K level is deficient. Similarly, lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals (Jayraman and Balasubramanian,1988). Potassium, more than any other element, is known to reduce plant susceptibility to diseases by influencing biochemical processes and tissue structures. Due to the interaction of factors, such as environmental conditions, susceptibility of the plant or variety to disease, disease incidence and level of other nutrients, the effects of K can be variable. In a recent review it has been reported that high levels of K nutrition reduced the severity of more than 20 bacterial diseases, more than 100 fungal diseases and 10 diseases caused by viruses and nematodes (Marschner, 1995; Marschner *et al*., 1996). Potassium deficiency usually results in the accumulation of soluble N compounds and sugars in plants, which are a suitable food source for parasites. Whereas adequate K results in stronger tissue and thicker cell walls which are more resistant to disease penetration, while N has the opposite effect.

The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens especially for obligate parasites such as mildew or rust. This group of pathogens requires living plant cells to complete their life cycle. Thus, the host cell must survive the invasion by the parasite if the latter is to survive. Ample N supply helps in longevity of cells, high turnover of assimilates and high content of low molecular weight compounds. Facultative parasites, in contrast, require weak plants to be infested and killed to survive. Vigorous plant growth stimulated by ample N would suppress infestation by this group of pathogens. This may explain differences in the expression of plant diseases in relation to the nutrition of the host (Krauss, 2000) summarizes (Fig. 4) the effects of N and K on the severity of the infestation by both obligate and facultative parasites.

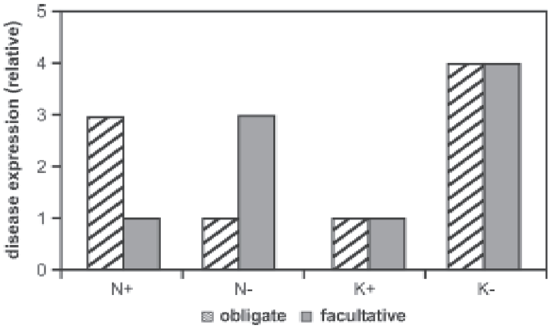

Fig. 4. Effect of N and K on expression of diseases caused by obligate and facultative parasites (Source: Marschner, 1995)

As a general observation, plants excessively supplied with N have soft tissue with little resistance to penetration by fungal hyphae or sucking and chewing insects (Krauss, 2000). On-farm trials in India with soybean showed considerable less incidences with girdle beetle, semilooper and aphids when supplied with adequate potash (Fig. 5). Similarly, excessive growth due to an unbalanced N supply can also create microclimatic conditions favorable for fungal diseases. Lodging of cereals as commonly observed at over supply with nitrogen and inadequate potash is a good example, humidity remains longer in lodged crops giving ideal conditions for germination of fungi spores.

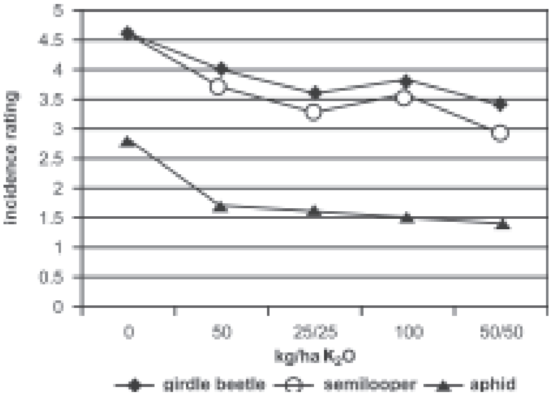

Fig. 5. Pest incidence in soybean as affected by potash supply (Source: Krauss, 2000)

Insufficient K also causes a pale leaf colour that is particularly attractive to aphids, which not only compete for assimilate but transmit viruses at the same time. Wilting, commonly observed with K deficiency, is another attraction to insects. Cracks, fissures and lesions that develop at K deficiency on the surface of leaves and fruits provide easy access, especially for facultative parasites.

The ratio between nitrogen and potassium plays obviously a particular role in the host/pathogen relationship. Perrenoud (1990) reviewed almost 2450 literature references on this subject and concluded that the use of potassium (K) decreased the incidence of fungal diseases in 70% of the 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% (Fig. 6).

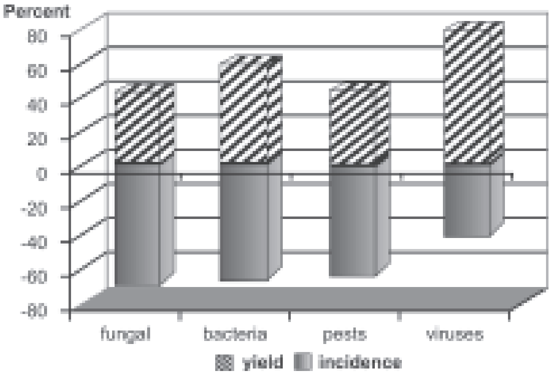

Fig. 6. Effect of potassium on yield increase and pest incidences (Source: Perrenoud, 1990)

The effect of K on crop specific host/pathogen relationships for rice in Asia has recently been summarized by Hardter (1997). For example, stem rot, *Helminthosporium sigmoideum*, generally occurs at high nitrogen supply in soils poor in K. With improved K supply, the incidence decreases and yields increase. A similar inverse relationship between disease incidence and plant nutrition with K has been reported for brown leaf spot in rice (*Helminthosporium oryzae*), rice blast (*Piricularia oryzae*) or sheath blight of rice (*Thanatephorus cucumeris*). A curative effect from applying K is also seen for bacterial diseases in rice like bacterial leaf blight, *Xanthomonas oryzae*, although highly susceptible varieties hardly responded to K in contrast to varieties with a moderate degree of resistance. The number of whitebacked plant hopper, *Sogatella furcifera,* could be substantially reduced with K in the resistant rice variety IR 2035 but K had almost no effect with the susceptible variety TN-1.

The enhanced rates of K application can induce or improve insect resistance by the following mechanisms. Accumulation of defensive phenolic compounds and their derivatives found to be toxic to insects. Thus, making the plants less palatable to insects and thereby causing non-preference (Perrenoud, 1990; Hardter, 1997).

Probable explanations for the beneficial effect of K on the host pathogen relationship focus on the following mechanisms. At insufficient K and/or excessive nitrogen, low molecular soluble assimilates like amino acids, amide and sugars accumulate in the plant cells. Correspondingly, Noguchi and Sugawara (1966) found in leaf sheaths of rice that the content of soluble N increased from 0.18 at adequate K to 0.45% at NP only. Similarly, soluble sugar increased from 1.52% to 2.43% at NP. The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens such as obligate parasites to complete their life cycle.

Conclusion

In India, moisture and temperature stresses are the most important abiotic stresses for crop productivity and yield potentials. Soil moisture alters physiological processes; root elongation, turgidity and rate of regeneration; stomatal conductance; photosynthesis and rate of crop development and maturity. It has been observed that crop responses to fertilizer K additions are often the greatest when water is either deficient or excessive. Potassium stimulates the degree and extent of root proliferation, root branching, etc. The greater root proliferation usually gives plants better access to sub soil moisture. Adequate K decreases the rate of transpiration through affecting the stomatal conductance.

Potassium usually speeds the rate of development and maturity, altering the deleterious effects of stress at critical growth stages. Under conditions where rainfall patterns are highly cyclical, drought effects can be reduced by advancing the date of pollination when most crops are highly sensitive to moisture stress.

Pulses especially chickpea experiences temperature stress under rainfed condition as this crop is taken after *kharif* crops. The crop experiences low temperature at initial stage of growth, results in poor and slow vegetative growth while, high temperature at the end of cropping sequence leads to forced maturity resulting low crop production. Potassium application helps plants to tolerate both the high and low temperatures.

Amongst abiotic stresses, soil salinity is a major constraint that affects plant growth and yield. Extra expenditure of energy for osmotic adjustments or in repair mechanism under salinity stress causes growth reduction. Potassium content in salt tolerant genotypes has been reported to be significantly higher than those of susceptible genotypes. Addition of K in salt-affected soils improves crop yields including vegetable crops.

Potassium application inhibits the accumulation pf soluble carbohydrates as well as nitrogenous compounds in the tissues. This helps to counteract a situation that favours fungal growth when K levels are deficient. Similarly lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals. Insufficient K also causes pale yellow colour to leaves that attracts aphids, wilting in crops, commonly observed in K deficient soils. Cracks, fissures and lesions that develop under K deficiency on surface of leaves and fruits provide easy access for facultative parasites.

Available literature on K shows that K application decreases incidence of fungal diseases by 70 % of the cases, bacteria by 69%, insect and mites 63% and viruses 41%. Simultaneously, increase the yield of plants infested with fungal diseases by 42% with bacteria 57% with insect and mites by 36%and with viruses by 78%.

It has established that phenol content in leaves increases with increase in K application resulting in low disease incidence (leaf sheath rot and stem rot in rice). Potassium content in shoots of tolerant genotypes of various crops has been reported to be significantly higher than those of susceptible genotypes. Plants under moisture stress have low photosynthetic rate. The decrease in solar energy harvest efficiency due to moisture could be enhanced with K application.

References

Agrawal, P., Agrawal, P., Reddy, M. and Sopory, S. 2006. Role of DREB transcription factors in abiotic and biotic stress tolerance in plants. *Plant Cell Reports* 25 (12): 1263-1274.

Amtmann, A., Armengaud, P. and Volkov, V. 2004. Potassium nutrition and salt stress. In M.R. Blatt, ed, *Membrane Transport in Plants.* Blackwell Publishing, Oxford.

Barber, S.A. 1963. Rainfall and responses. *Better Crops with Plant Food* 47 (1): 6-9.

Barber, S.A. 1971. Soybean responds to fertilizer and rotation. *Better Crops with Plant Food* 55(2): 9.

Baruah, B.P. and Saikia, L. 1989. Potassium nutrition in relation to stem rot incidence in rice. *Journal of Potassium Research* 5: 121-124.

Bhasker, C.V., Ramarao, G. and Reddi, K.B. 2001. Effect of nitrogen and potassium nutrition on sheath rot incidence and phenol content in rice. *Indian Journal of Plant Physiology* 6: 254 – 257.

Brady, N.C. and Weil, R.R. 2002. The Nature and Properties of Soils. Pearson Education, inc. pp.6.

Brown, C.S. 1963. Alfalfa adoption with fertilizers. *Better Crops with Plant Food* 47 (7): 4 - 13.

Cadisch, G., Bradley, R.S., Boller, B.C. and Nosberger, J. 1993. Effect of P and K on N_2 fixation of field grown *Centrosema acutifolium* and *C. macrocarpum. Field Crop Research* 31:329-340.

Dev, G. 1995. Potassium – An essential element. In: *Proc. Use of potassium in Punjab agriculture.* PAU, Ludhiana, July 5, 1994. pp.17-23.

Gath, S. 1992. Dynamik der Kaliumanlieferung im Boden. Report of the Institut für Landeskultur, Justus-Liebig-University Giessen, Germany.

Golakiya, B.A. and Patel, M.S. 1988. Role of potassium in counteracting the effect of cyclic drought on groundnut. *Journal of Potassium Research* 4: 163-167.

Grewal, J.S. and Singh, S.N. 1980. Effect of potassium nutrition on frost damage and yield of potato plants on alluvial soils of the Punjab (India). *Plant Soil* 57: 105-110.

Hardter, R. 1997. Crop nutrition and plant health of rice based cropping systems in Asia. *Agro-Chemicals News in Brief* 20(4): 29-39.

Jayraman, S. and Balasubramniam, R. 1988. Role of potassium on yield and incidence of pest and diseases in chilli. *Journal of Potassium Research* 4(2): 67-70.

Johnston, A.E., Barraclough, P.B., Poulton, P.R. and Dawson, C.J. 1998. Assessment of some spatially variable soil factors limiting crop yield. Proc. The International Fertilizer Society, York, UK: 419.

Koch, K. and Mengel, K. 1974. The influence of the level of potassium supply to young tobacco plants (*Nicotiana tabacum* L.) on short term uptake and utilization of nitrate nitrogen. *Journal of Science and Food Agriculture* 25: 465-471.

Krauss, A. 2001. Potassium and biotic stress. Ist FAUBA – Fertilizer –IPI Workshop Potassium in Argentina Agricultural Systems Nov. 20 – 21, 2001 Buenos Aires Argentina.

Krauss, A. and Johnston, A.E. 2002. Assessing soil potassium, can we do better? Proc. 9th Int. Cong. Soil Sci. Faisalabad, Pakistan.

Krauss, A. 2000. Potassium, integral part for sustained soil fertility In: *Proc Regional IPI Workshop on Potassium and Phosphorus Fertilization effect on soil and crops,* 23-24 October, 2000 Dotnuva - Akademija, Lithuania.

Krishnasastry, K.S. 1985. Influence of potassium on proline accumulation under stress *PRII Res. Review Series* 2: 39-45.

Leigh, R.A., Jones, R.G.W. 1984. A hypothesis relating critical potassium concentrations for growth, distribution and functions of this ion in the plant-cell. *New Phytol.* 97: 12-13.

Marschner, H. 1995. Mineral nutrition of Higher Plants. 2nd ed., Academic Press, pp. 436-460.

Marschner, H., Kirkby, E.A. and Cakmak, I. 1996. Effect of mineral nutritional status on shoot-root partitioning of photo assimilates and cycling of mineral nutrients. *Journal Exp. Botany* 47: 1255-1263.

Mengel, K. and Kirkby, E.A. 1980. Potassium in crop production. *Advances in Agronomy* 33: 59-110.

Nelson, W.L. 1978. Influence of K on tolerance to stress. Potassium in Soil and Crops Potash Research Institute of India, New Delhi pub. pp. 203-221.

Noguchi, Y. and Sugawara, T. 1966. Potassium and japonica rice. Intern. Potash Inst., Basel, Switzerland: 102.

Nye, P.H. 1979. Diffusion coefficient and uncharged solute in soil and soil clays. *Advances in Agronomy* 31:225-272 .

Peoples, T.R. and Koch, D.W. 1979. Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. *Plant Physiology* 63: 878-881.

Perrenoud, S. 1990. Potassium and plant health. IPI Res. Topic 3, Intern. Potash Institute, Basel, Switzerland.

Rao, N.K. and Kameshwarrao, B.V. 2004. Effect of potash levels and topping on leaf potassium , yield and quality in flue cured tobacco. *Indian Journal of Plant Physiology* 9: 288-293.

Saxena, N.P. 1985. The role of potassium in drought tolerance. *Potash Review* 16: 102.

Sharma, G.L. and Agrawal, R.M. 2002. Potassium induced changes in nitrate reductive activity in *Cicer arietinum* L. *Indian Journal of Plant Physiology* 7 (3): 221-226.

Sharma, K.D., Kuhad, M.S. and Sandwal, A.S. 1992. Possible role of potassium on drought tolerance in Brassica. *Journal of Potassium Research* 8: 320-327.

Singh, A.K. and Singh, R.A. 1999. Effect of salinity on sodium and potassium and proline content of chickpea genotypes. *Indian Journal of Plant Physiology* 4:111-113.

Singh, N., Chhonkar, V., Sharma, K.D. and Kuhad, M.S. 1997. Effect of potassium on water relations, CO_2 exchange and plant growth under quantified water stress in chickpea. *Indian Journal of Plant Physiology* 2 : 202-206.

Singh, R.A., Roy, N.K. and Haque, M.S. 2004. Effect of nitrogen and potassium on sheath rot incidence and nutrient content in rice. *Indian Journal of Plant Physiology* 9 : 90-93.

Singh, S.N. and Tiwari, U.S. 2006. Sodium and potassium ratio as an index to sodicity tolerance of tomato. *Indian Journal of Plant Physiology* 11: 329–332.

Singh, S., Tiwari, T.N. Shrivastava, R.P. and Singh, G.P. 1998. Effect of Potassium on stomatal behavior, yield and juice quality of sugarcane under moisture stress conditions *Indian Journal of Plant Physiology* 3: 303–305.

Singh, T., Deshmukh, P.S. and Kushwaha, S.R. 2004. Physiological studies on temperature tolerance in chickpea (*Cicer arietinum* L) genotypes. *Indian Journal of Plant Physiology* 9: 294-301.

Skogley, E.O. 1976. Potassium in Montana soils and crop requirements. *Montana Agr.Ext. Stn. Res. Report 18.*

Shrinivasa Rao, Ch. and Khera, M.S. 1995. Consequences of potassium depletion under intensive cropping. *Better crops* 79: 24 -27.

Tester, M. and Blatt, M.R. 1989. Direct measurement of K channels in thylakoid membranes by incorporation of vesicles into planar lipid bilayers. *Plant Physiology* 91: 249-252.

Tiwari, H.S., Agrawal, R.M. and Bhatt, R.K. 1998. Photosynthesis, stomatal resistance, and related characteristics as influenced by potassium under normal water supply and water stress conditions in rice (*Oryza sativa L*). *Indian Journal of Plant Physiology* 3: 314 -316.

Tomar, V.S. 1998. Role of potassium in water stress management in soybean . *Farmer and Parliament* **33**: 15-26.

Umar, S. 1997. Influence of potassium on solar energy harvesting efficiency of groundnut under different soil moisture stress. *Indian Journal of Plant Physiology* 2 : 315-317.

Velazhahan, R. and Ramabadran, R. 1992. Influence of potassium fertilization on sheath rot and phenol content of rice. *Madras Agricutural Journal* 70:294-298.

Vyas, S.P., Garg, B. K., Kathju, S. and Lahiri, A.N. 2001. Influence of potassium on water relations, photosynthesis, nitrogen metabolism and yield of Cluster bean under soil moisture stress. *Indian Journal of Plant Physiology* 6: 30 – 37.

Warwick, W.N. and Halloran, G.M. 1991 Variation in salinity tolerance and ion uptake in accessions of beetle grass (*Diplachne fusca* L). *New Phytol.* 119: 161-168.

William, T.P. 1999. Potassium deficiency increases specific leaf weights and leaf glucose levels in field grown cotton. *Agronomy Journal* 91: 962-968.

Wyrwa, P., Diatta, J.B. and Grzebisz, W. 1998. Spring triticale reaction to simulated drought and potassium fertilization. In: *Proc. 11th Int. Symposium on Codes of good fertilizer practice and balanced fertilization,* September, 27-29, 1998, Pulawy, Poland. pp. 255-259.

Potassium Dynamics of Vertisols and Associated Soils and Its Use Efficiency

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Abstract

Balanced nutrition with all the essential plant nutrients supply is pivotal for sustainable and higher crop production. In India soil reserve potassium (K) is getting depleted continuously and crop responses to potassium are increasing in time and space. In several long term studies including soybean-wheat on Vertisols (Typic chromustert) at Jabalpur and finger-millet-maize on Vertic ustopept at Coimbatore, the sustainability of crop yields was threatened in the absence of K application. In several well managed long term fertilizer experiments in black soils, the potassium balances have been negative, the magnitude of which depended on the extent of crop K removal and the additions through fertilizers and manures. In many production systems, the non-exchangeable K reserves are in fact supporting the level of production. The black soils of India though rich in available K have generally poor reserves of non-exchangeable K. This is also reflected in poor mica content in these soils which is often present only in traces. Higher productivity cannot be achieved/ maintained by solely relying on exchangeable K reserve of soils. It was also revealed that a soil test, based on non-exchangeable K, might better reveal the K status of soil rather than simple estimate of exchangeable K, which is currently being used. Potassium negative balances can be curtailed or lowered by applying an adequate rate of K on the basis of soil test, addition of rural and non-toxic urban composts and also by efficiently recycling the crop residues in the different production systems.

Introduction

Balanced nutrition considers having all 17 essential nutrients available to the crop plants (as per their need at different physiological growth stages) in adequate but not in toxic amounts. The proportional supply is quintessential for improving nutrient use efficiency since any one nutrient in sub-optimal supply can limit the crop yields. Although the entire range of essential nutrients is involved in balanced nutrition, the focus is on a proper balance among nitrogen (N), phosphorus (P) and potassium (K) use. At present in India, NPK use is perilously imbalanced with respect to K. In the year 2020 the deficit of K in Indian agriculture has been projected to be around 8.1 million tonnes/ annum (Katyal, 2001) while the estimates of N and P balances are positive. There are many examples from long term fertilizer experiments (LTFE) conducted in India where a decline in the yields of crops occurred as a result of K deficiency (Ladha *et al.*, 2003; Rupa *et al.*, 2003). Addition of fertilizer K with adequate amount of N and P increased crop yields in different production systems (Rupa *et al.*, 2003; Wanjari *et al.*, 2004).

Sustainability of Crops / Cropping Systems

From numerous experiments, it is evident that imbalanced application of nutrients does not maintain a sustainable production system in Vertisols and associated soils. This was analysed by the Sustainability Yield Index (SYI) in different cropping systems of LTFE (Table 1). Higher SYI indicates better sustainability of the system. The highest SYI value was observed in 100% NPK+FYM treatment followed by 150% NPK, 100% NPK, 100% NP, 100% N and control. The data in Table 1 indicates the importance of K in maintaining the sustainability of the system. In soybean-wheat system on Vertisols at Jabalpur also there was marked improvement in SYI with the additions of K.

Table 1. Sustainable Yield Index (SYI) for various treatments at different long-term experiments in India

Location	Crop	Control	N	NP	100 % NPK	150 % NPK	100 % NPK+FYM	Ym (t ha^{-1})
Coimbatore	Fingermillet	0.05	0.12	0.48	0.47	0.51	0.55	4.85
	Maize	0.05	0.07	0.40	0.43	0.45	0.50	5.60
Jabalpur	Soybean	0.18	0.20	0.38	0.44	0.38	0.47	3.72
	Wheat	0.13	0.13	0.49	0.53	0.54	0.57	6.20.

Ym= Maximum observed yield in t ha^{-1}

Source: Wanjari *et al.* (2004)

Influence of soil available potassium on SYI

The regression analysis was done using SYI as dependent variable and soil available K status as independent variable at different locations and cropping systems. Maximum R^2 value between SYI and available K was observed by soybean-wheat system (0.92 and 0.89) in Chromustert (Jabalpur) (Fig.1). Thus, it implies that available K status of soil had great influence on SYI. Potassium addition is, therefore, essential to meet the demand of soybean-wheat system in Chromustert (Jabalpur) compared to associated soil at Coimabatore.

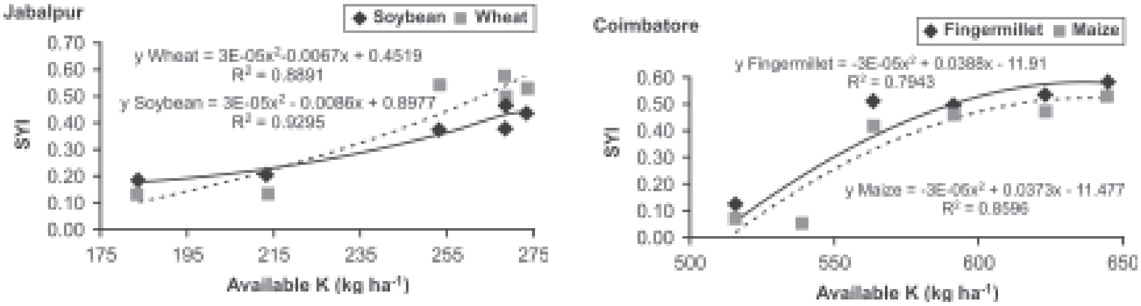

Fig. 1. Regression equations between SYI and available K status of soils of Vertisol (Jabalpur) and associated soil (Coimabatore)

Potassium Balances in Different Cropping Systems in India

In most of the cropping systems being practiced in India, potassium balance is negative since K application seldom matches K removal, resulting in greater dependence on soil K. Under such conditions there is greater demand on soil reserve K to meet the crop K requirement. In other cropping systems also such as rice-rice on Inceptisols and soybean-wheat-cowpea on Vertisols, the total uptake of potassium by the crops far exceeded the amount of K applied (Table 2). The plots which did not receive K fertilizer (control, N and NP) under continuous cropping with soybean-wheat-maize fodder exhibited more contribution of soil reserve K to crops. The results of long-term experiments clearly demonstrate that mining of soil K occurred with NP and even with NPK application (Rupa *et al.*, 2003).

Table 2. Removal and addition of potassium during 21 crop cycles of rice-rice and 27 crop cycles of soybean-wheat, maize fodder rotations

Treatment	**Fertilizer K added during 21 and 27 crop rotation**		**1 M NH_4OAc K (kg ha^{-1})**		**Total K uptake crops (kg ha^{-1})**		**Contribution of nonexch. K (kg ha^{-1})**	
	AH	**TH**	**AH**	**TH**	**AH**	**TH**	**AH**	**TH**
			After cropping (1994)	**After cropping (1999)**				
Control	0	0	32	252	1176	3247	1183	3129
N	0	0	20	263	1743	4418	1738	4311
NP	0	0	26	235	1890	10067	1891	9932
NPK	2100	2117	40	308	2877	11826	792	9647
NPK+ FYM	3150	4142	67	324	3507	14094	399	9906

AH = Aeric Haplaquept; TH = Typic Haplustert; 1 *M* NH_4OAc K (kg ha^{-1}) was 25 and 370 in AH and TH, respectively. AKUE (Apparent K use efficiency)= [(kg K uptake in K treated plot - kg K uptake in NP treated plot)/kg K applied] x 100

Source: Rupa *et al.* (2003)

Changes in Soil Potassium Status

In India, potassium fertilizer recommendations for various crops are generally advocated based on 1M ammonium acetate (NH_4OAc) extractable K in soil. Though, this method successfully predicts the fertilizer K requirements of crop plants in many instances, but recent evidences show that 1M NH_4OAc K is not sensitive to the changes in soil K that takes place during intensive cropping.

In rice-rice and soybean-wheat systems, irrespective of the treatments, potassium was depleted significantly in all the plots under intensive cropping, thereby indicating a state of continuous stress on the soil system to meet the K requirements of the crops (Rupa *et al.*, 2003,Table 2). Even in plots supplied with K fertilizer, the total uptake of potassium by the crops has exceeded the amount of K applied thus drawing much of the K need from non-exchangeable reserves. The contribution of non-exchangeable K to total K uptake of crops was worked out using the following relationship:

K uptake from non-exchangeable form = Total K uptake by plants + available K after cropping – Fertilizer K added – available K before cropping

In the above equation K losses due to leaching could not be accounted for and assumed zero leaching. Fertilizer K application considerably reduced the contribution of non-exchangeable K to total uptake. It was observed that in plots receiving fertilizer K (NPK and NPK+FYM) the contribution of non-exchangeable K to plant uptake was lower as compared to NP and N which could be due to external supply of 2100 kg K/ha (NPK) and 3150 kg K/ha (NPK+FYM) in case of Aeric Haplaquept and 2117 kg K/ha (NPK) and 4142 kg/K ha (NPK+FYM) in case of Typic Haplustert (Table 2). The total potassium uptake by the crops was appreciably increased due to the application of N, NP, NPK and NPK+FYM. The effect of N and P in enhancing K uptake was largely because of N nitrification which caused K to leave the non-exchangeable K sites to the solution.

Reduction in nonexchangeable K under long term cropping of finger millet-maize-cowpea sequence was observed in Vertic Inceptisol at Coimbatore (Santhi *et al*., 1998) and under soybean-wheat-cowpea system at Jabalpur (Bansal and Jain, 1988).

Forms of Potassium

Available K

Available K is an index of soil K availability to crops and it is also used in soil testing services in India. The nonexchangeable K is an index of releasable reserve of K in soils. The total soil K, which in addition to the available and non-exchangeable K also includes the fixed K and the K present in the mineral lattice of certain primary minerals like feldspars. The distribution of available K with depth in different soil series is given in Fig. 2. Black soils were generally richer in available K with 200 to 300 mg K/kg soil. Shendwada, because of its high clay and CEC, was exceptionally rich in available K.

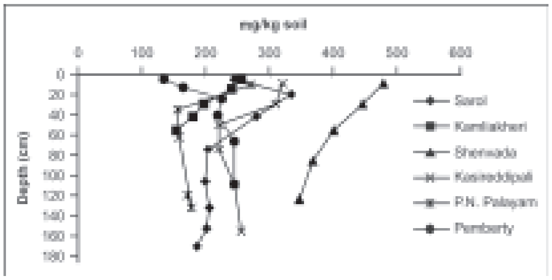

Fig. 2. Distribution of available K in some black soil (Vertisols/ Inceptisols)

Boiling nitric acid extractable K

Boiling nitric acid extractable K ranged between 600 to 1100 mg K/kg soil (Fig. 3). The soils Sarol, Kamliakheri and Kasireddipalli have low values whereas PN Palayam, Shendwada and Pemberty have high values. Shendwada had exceptionally high content of boiling nitric acid extractable K in surface soil which may be due to high amount of clay content and K bearing minerals.

Total K

The total K in black soils was less than 1.5% with an exception of Pemberty series, which had exceptionally high content of total K (Fig. 4). This may be due to K-feldspars present in the sand and silt fractions of this soil. The total K in the surface layer of the black soils was in the order Pemberty>Shendwada>Sarol>PN Palayam >Kasireddipalli>Kamliakheri.

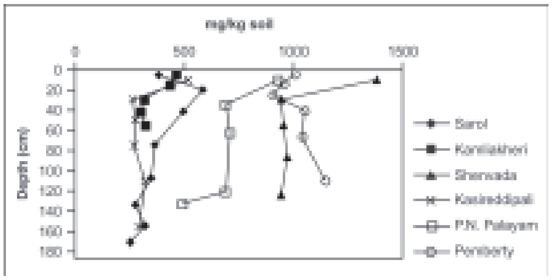

Fig. 3. Distribution of 1 N boiling nitric acid K in some black soils

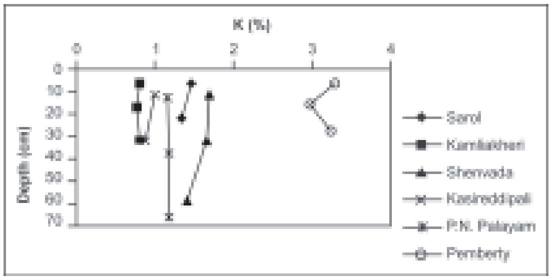

Fig. 4. Depth-wise distribution of total potassium in some benchmark black soils

Potassium fractions (water soluble, exchangeable and non-exchangeable) were highly influenced by continuous use of fertilizer and manure in both Alfisol and Inceptisol (Table 3). In both the soils, balanced application of nutrients maintained the larger amount of K in all the fractions compared to imbalanced use of nutrients. The rate of renewal and equilibrium among K fractions is faster in Inceptisol of Coimbatore compared to Alfisol of Bangalore. Thus, maintaining the larger fraction of exchangeable-K suggests that Inceptisol soils will continue to maintain the supply of K and the crop will not suffer for the want of K. However, Alfisol may not maintain the K supply in the future, therefore, to sustain the crop productivity potassium addition is very essential.

Table 3. Effect of continuous cropping and manuring on K fractions in soil (mg kg^{-1}) in LTFE in Inceptisol (Coimbatore) and Alfisol (Bangalore) in India

Treatment	Inceptisol				Alfisol			
	Water soluble	Exchang-eable	Non-Exchan-geable	Total	Water soluble	Exchan-geable	Non-Exchan-geable	Total
Control	12	183	813	3665	4.9	35.6	38.2	4708
N	10	126	707	3485	3.6	27.1	30.8	4662
NP	7	108	514	3275	3.5	26.3	29.3	4691
NPK	20	231	899	3788	9.9	51.5	47.3	4436
150% NPK	24	244	1036	3939	10.3	56.2	54.2	4368
100% NPK+ FYM	23	254	971	2890	10.5	61.5	60.2	4519
100% NPK+ Lime	-	-	-	-	10.0	53.8	50.1	4452
LSD (0.05)	1.0	13	80	89	0.83	3.1	3.5	114.1

Initial distributions of water soluble, exchangeable and HNO_3 + $HClO_4$ extractable K fractions were 3.1, 19.5 and 302.5 mg 100 g^{-1} in the surface layer (0-15 cm) (Table 4). Continuous growing of rice-wheat for 8 years without organic manure caused a decline in the exchangeable K from 19.5 mg K 100 g^{-1} soil (initial) to 16.0 and 13.8 mg K 100 g^{-1} soil in the control and 90 kg N ha^{-1} + organic manure favored a build up of solution and exchangeable K. The incorporation of FYM and GM alone did not have a significant effect on exchangeable K. Growing crops either in the presence or absence of organic manure led to a significant depletion of HNO_3 + $HClO_4$ extractable K (non-exchangeable). The magnitude of depletion was larger at 180 kg N ha^{-1}. Similar effects on distribution patterns of different forms of K were also noted in the other two lower soil layers. The decline in all forms of K in the absence of organic manure was due to the removal of K by crops in excess of the K input from external sources. The increase in the exchangeable K in the presence of organic manures could be due to an increase in the exchange sites (CEC) as a result of addition of manure. Continuous incorporation of manure over a period of 25 years resulted in an increase in CEC by 4-6 cmol kg^{-1} (Sharma *et al.*, 1998).

Table 4. Distribution of different forms of K as influenced by the use of manure and fertilizer after 8 years of a rice-wheat system grown on Vertisols of India

Treatment	WSK (mg 100 g^{-1} soil)	NH_4OAc-K (mg 100 g^{-1} soil)	$HNO_3O+HClO_4$-K (mg 100 g^{-1} soil)	Depletion of K (mg 100 g^{-1} soil)
Initial (1991)	3.1±0.2	19.5±3.1	303±8.2	-
Control	2.5	16.0	293	10.0
90 kg N ha^{-1}	3.2	13.8	289	13.5
180 kg N ha^{-1}	3.2	12.5	285	17.5
90 kg N + 5 t FYM	4.0	23.0	288	15.0
90 kg N + 3 t GM	4.1	24.0	288	14.1
5 t FYM	3.0	21.0	296	6.5
6 t GM	2.8	20.5	298	4.5
CD (P=0.05)	0.4	1.1	9.7	-

Source: Singh *et al.* (2002)

The Vertisols and vertic type of soils had high amounts of available but low amounts of reserve K (Table 5). These soils could raise crops without fertilizer K for sometime but may soon get depleted. Shallow Vertisols (particularly from Madhya Pradesh and Gujarat states) are not self-fertilizing, hence may need fertilizer K application soon enough.

Table 5. Potassium fertility of Vertisol and vertic type Benchmark soil series of India

Soil series	NH_4OAc-K	HNO_3-K	Fertility rating	
	(mg/kg±SD)	(mg/kg ±SD)	Available-K	Reserve-K
Sarol (M.P.)	348 ±88	769 ±252	High	Low
Kamaliakheri (M.P.)	279±75	603 ±182	High	Low
Pithvajal (Gujarat)	407±89	776± 173	High	High
Shendvada (Maharashtra)	482±81	1024±187	High	Low
Pemberty (A.P.)	216±50	711±133	High	High
Noyyal (T.N.)	688±132	2339±276	High	Low
Kalathur (T.N.)	193±38	893±102	High	Low

Source: Sekhon *et al.* (1992)

Non-exchangeable K release rate

Change in non-exchangeable K of soils under cropping has been observed in many cases irrespective of the available K status and dominant minerals of soils (Subba Rao *et al*., 1993). Effect of long term rice-rice cropping, fertilization and manuring on K release pattern in 0.01 M $CaCl_2$ and by EUF fraction (Srinivasa Rao *et al*., 2000) indicated a substantial reduction in K release from soils due to continuous cropping. Application of 100% NPK+15 t FYM maintained higher K release whereas 100% NP showed the lowest K release. Non-exchangeable K released during 30-35 minutes in EUF extraction also indicated a similar change. It can be observed from the pattern of EUF desorption that K desorbed during the first 30 minutes (which indicates exchangeable form of K) did not vary much among treatments whereas the differences were much clear in EUF after 30- 35 minute. EUF quotient, that indicates greater long term supply power of soil showed a definite reduction due to 20 years of cropping in rice-rice system on an Inceptisol (Table 6). Treatment 100% N and 100% NP showed a lower EUF quotient due to larger depletion of nonexchangeable K.

Table 6. Potassium supplying parameters derived from EUF desorption in a Tropaquept soil

Treatment	**EUF K quotient***	
	1980	1994
Control	0.39	0.28
100% N	0.37	0.24
100% NP	0.34	0.21
100% NPK	0.46	0.38
100% NPK+FYM	0.51	0.41

* The ratio of K desorbed during 30-35 minute to that of the K desorbed during 0-30 minutes

The contribution of nonexchangeable K to plant K uptake was worked out in both green house studies as well as in field experiments. Mengel (1985) indicated that the crops particularly the cereals with well branched root system draw K from soil, majorly from nonexchangeable source .

Soil Test Based Fertilizer K Recommendation

General fertilizer recommendations results in application of excess amounts of fertilizer in such area where it is not needed and insufficient amounts in others where it is needed. Soil test based fertilizer recommendations are essential to economize fertilizer use and to optimize production on sustainable basis without polluting the environment. Fertilizer K recommendations increase with higher yield goals and decrease with increase in soil test values. (Table 7).

Relationship of K Forms with Different Soil Properties

The available K and 1 N boiling nitric acid K in Vertisols are correlated (Table 8). This is possible since in these soils a significant portion of 1 N boiling nitric acid K is comprised of available K. These soils are dominated by expanding minerals like smectites and vermiculites where the interlayer K is generally very less. Most of the non-exchangeable K in these soils is present in the edge or wedge zones of these minerals. The available K is also related to organic C and CEC in these soils. No relationship, however, is obtained between available K and EC, showing that in these soils exchangeable K forms the major part of available K.

Table 7. Soil test based fertilizer potassium (K_2O) requirement for different crops and soils of India

Soil	Site	Target (q/ha)	Soil test values (kg/ha)							
			100	150	200	250	300	350	400	500
Rice										
Black	MP	50	*	*	69	60	51	42	33	-
Black	Guntur (AP)	50	*	52	42	33	23	14	-	-
Black soil	Nandyal	60	*	*	50	44	38	32	26	-
Black (Adanur series)	Parts of TN	70	*	*	91	71	51	31	11	-
Wheat										
T. Chromusterts	Maharashtra	40	*	*	56	45	34	23	12	-
Black Vertisols	MP	35	*	*	56	49	41	33	25	-
Maize										
Shallow black & medium black soils	Parts of MP	40	*	*	67	63	59	55	51	43
Mixed black	Coimbatore (TN)	50	209	185	160	136	111	86	62	13
Gram										
T. Chromusterts	Rahuri (MS)	25	*	26	24	22	20	18	14	12
Medium black soils	Parts of MP	20	*	51	42	34	25	17	8	-
Groundnut										
Vertic Ustochrepts, clay loam	Rahuri (MS)	20	47	39	31	23	15	7	-	-

Source: Subba Rao and Srivastava (2001)

Table 8. Correlation coefficient between the important soil properties among the black soils of Indian SAT (N=20)

Soil Properties	Coefficients	pH	EC	OC	CC	CEC	AVK	NEK
pH	Pearson Correlation	1.000	0.154	0.165	-0.047	-0.161	0.023	0.178
	Sig. (2-tailed)	-	0.516	0.488	0.843	0.498	0.925	0.452
EC	Pearson Correlation	0.154	1.000	-0.147	0.832	-0.739	-0.294	0.198
	Sig. (2-tailed)	0.516	-	0.536	0.000	0.000	0.209	0.403
OC	Pearson Correlation	0.165	-0.147	1.000	-0.367	0.324	0.532	0.276
	Sig. (2-tailed)	0.488	0.536	-	0.111	0.163	0.016	0.238
CC	Pearson Correlation	-0.047	0.832	-0.367	1.000	-0.611	-0.480	-0.007
	Sig. (2-tailed)	0.843	0.000	0.111	-	0.004	0.032	0.976
CEC	Pearson Correlation	-0.161	-0.739	0.324	-0.611	1.000	0.564	-0.184
	Sig. (2-tailed)	0.498	0.000	0.163	0.004	-	0.010	0.436
AVK	Pearson Correlation	0.023	-0.294	0.532	-0.480	0.564	1.000	0.545
	Sig. (2-tailed)	0.925	0.209	0.016	0.032	0.010	-	0.013
NEK	Pearson Correlation	0.178	0.198	0.276	-0.007	-0.184	0.545	1.000

EC= Electrical conductivity; OC= Organic Carbon; CC= Calcium carbonate; CEC= Cation Exchange Capacity; AVK= Available potassium; NEK= Non-exchangeable K

Cumulative K Release

Among the black soils, the minimum cumulative K release was observed in Kamliakheri (around 150 mg/kg) and the maximum was observed in Shendvada (310 mg/kg). Sarol series was intermediate. It is also observed that initially there was rapid rate of K release followed by a slower rate of release after around 10 to 12 extractions (Fig. 5.).

Mineralogical Investigations

Micas are the key minerals that supply potassium to crops. Biotite mica supplies K to growing plants and therefore its abundance in different soils of Indian Semi-arid tropics (SAT) will provide information regarding the probable response to added K and also guide us about the total releasable K stocks in different soils (Table 9).

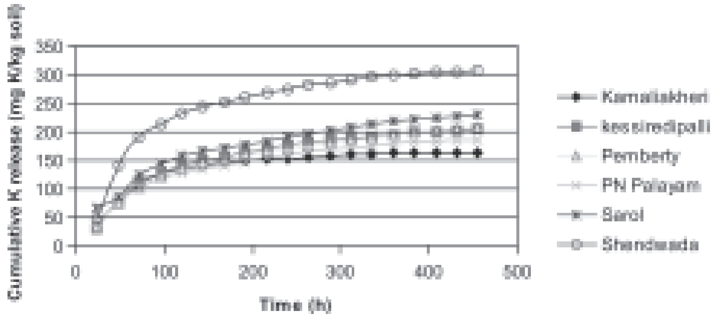

Fig. 5. Cumulative K-release from clay fraction in some benchmark black soils

Table 9. Minerals present in the clay fraction of Indian SAT Vertisols

Soil Series	Minerals Identified
Kamliakheri	Smectite (90%), Mica (3%), Kaolinite (6%), Quartz (4%)
Kesireddipalli	Smectite (91%), Mica (2%), Kaolinite ((3%), Quartz (4%)
Pemberty	Smectite (57%), Mica (34%), Calcite (4%), Kaolinite (3%), Quartz (2%)
PN Palayam	Smectite (90%), Vermiculite (3%), Mica (4%), Kaolinite (2%), Quartz (1%)
Sarol	Smectite (87%), Chlorite (9%), Mica (13%), Kaolinite (14%), Vermiculite (5%), Quartz (11%)
Shendwada	Smectite (67%), Mica (13%), Kaolinite (15%), Quartz (5%)

Mica minerals are the constituents in the clay and silt fractions. The actual clay sized biotite and muscovite mica content in the different soil series is shown in figure 6. The soils of Hisar contained the highest amount of biotite mica i.e. anound 8% followed by the soils of middle IGP (Pura and Rarha). These soils are very rich in K stock and so they have a very long term K supplying power among all the soils studied. The soils Kakra, Nabha, Lukhi and Khatki (upper IGP) also contained high amount of biotite mica that was generally more than 4%. Palathurai soil contained exceptionally high amount of biotite mica that was around 5%. The other two soil series (PN Palayam and Irugur) in Coimbatore region contained little amount of biotite mica. The two red soils in the Bangalore region differ considerably in their biotite content. It was higher in Tymagondalu soils than in Vijaypura.

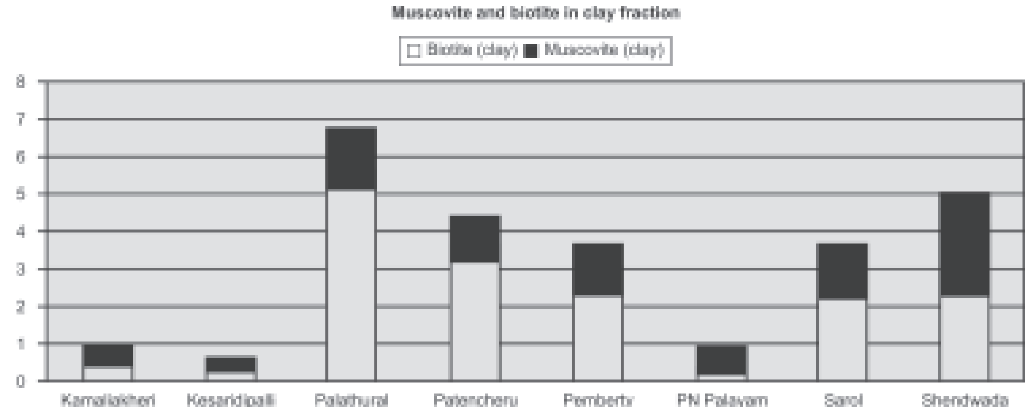

Fig. 6. Muscovite and biotite mica in clay fraction of Indian SAT Vertisols

This explains the striking K response obtained in Vijaypura soil series in many experiments including the Long Term Fertilizer Experiment of ICAR. The biotite mica content was also measured in silt fraction. In the soils of Irugur, Kamliakheri, Kasireddipalli and Khatki, the biotite mica is mainly concentrated in the silt fraction indicating that silt size biotite and in these soils, crop requirement of K may be met from the K supply from the silt fraction. In addition to measurement of K in clay fraction, efforts should be made to measure K in silt fraction to get comprehensive knowledge of K supply from a particular soil.

Use Efficiency of Applied K

Apparent use efficiency of applied K in Typic Haplustert in NPK treated plot was about 83%, which increased to 97% with the use of FYM (Table 10). In Aeric Haplaquept the K use efficiency was relatively low in NPK (47%) and NPK+FYM treated plots (51%) as compared to Typic Haplustert. This might be ascribed to greater crop removal of soil potassium and its content in available form in all the treatments in the Typic Haplustert soil.

Table 10. Apparent potassium use efficiency (%) under different nutrient management

Treatment	Apparent Potassium Use Efficiency (%)	
	Typic Haplustert	Aeric Haplaquept
Control	-	-
100% N	-	-
100% NP	-	-
100% NPK	83	47
NPK+ FYM	97	51

The nutrient use efficiency of K is higher in sorghum compared to wheat in Vertisol at Akola (Table 11). The highest values were recorded in NPK+FYM in wheat. However, FYM alone could not sustain K use efficiency compared to integrated use of NPK+FYM. The K use efficiency decreased in super optimal dose i.e. 150% NPK compared to 100% NPK. The K use efficiency in sorghum was higher probably due to excessive uptake of K by the crops.

Table 11. Long term effect of fertilizer application on potassium use efficiency in sorghum-wheat sequence in Vertisols of Akola, India

Treatment	Potassium Use Efficiency (%)	
	Sorghum	Wheat
Control	-	-
100% N	-	-
100% NP	-	-
100% NPK	286	103
150% NPK	251	96
NPK+FYM	164	146
FYM 10 t ha^{-1}	52	-

Conclusion

Soil test based potassium fertilizer application is must in Vertisols and associated soils. The negative K balance indicates that it will be impossible to maintain the present production levels of the cropping systems. Long term studies suggest that application of farmyard manure and recycling of crop residues can help to improve the K balance in different cropping systems. There is, however, a need to work out long term K balance in different cropping systems based on precise data on K removal from a field or region through straw, K inputs from irrigation or rainwater besides the well defined inputs and outputs such as fertilizers, manures and grains. Straw management can strongly influence K budgets and can help in efficient management of K for a sustainable cropping system in different agro-ecoregions.

References

Bansal, K.N. and Jain, S.C. 1988. Forms of potassium in a Vertisol as influenced by long-term intensive cropping and fertilizer use. J*ournal of Potassium Research* 4: 104-109.

Katyal, J.C. 2001. Fertilizer use situation in India. *Journal of Indian Society Soil Science* 49: 570-592.

Ladha, J.K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R.L., Bijay Singh, Yadvinder Singh, Singh, Y., Kundu, A.L., Sakal, R., Ram, N., Regmi, A.P., Gami, S.K., Bhandari, A.L., Amin, R., Yadav, C.R., Bhattarai, E.M., Das, S., Aggarwal, H.P., Gupta, R.K. and Hobbs, R.R. 2003. How extensive are yield declines in long-term rice-wheat experiments in Asia*? Field Crops Research* 81: 159-180.

Mengel, K. 1985. Dynamics and availability of major nutrients in soil. *Advances in Soil Science* 2: 65-133.

Mukhopadhyay, S.S., Sidhu, P.S., Bishnoi, S.R. and Brar, S.P.S. 1992. Changes of quantity-intensity parameters on cropping. J*ournal of Potassium Research* 8: 21-34.

Rupa, T.R., Srivastava, S., Swaruup, A., Sahoo, D. and Tembhare, B.R. 2003. The availability of potassium in Aeric Haplaquept and Typic Haplustert as affected by long-term cropping, fertilization and manuring. *Nutrient Cycling in Agroecosystem*s 65: 1-11.

Santhi, P., Sankar, S.J., Muthuvel, P. and Selvi, D. 1998. Long-term fertilizer experiments-status of N, P and K fractions in soil. *Journal of Indian Society of Soil Science* 46 (3): 395-398).

Sekhon, G.S. 1999. Potassium in Indian soils and crops.In: *Proceedings of Indian National Science Acad*emy B65: 83-108.

Sekhon, G.S., Brar, M.S., and Subba Rao, A. 1992. Potassium in some benchmark soils of India. Potash Research Institute of India, Gurgaon, Haryana, India. pp. 1-82.

Sharma, N., Srivastava, B., Mishra, B., Srivastava, N.C. 1998. Change in some physico-chemical properties of an acid soil as affected by long term use of fertilizer and amendments. *Journal of Indian Society of Soil Science* 36:688-692.

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

Srinivasa Rao, Ch., Subba Rao, A., Swarup, A., Bansal, S.K. and Rajagopal, V. 2000. Monitoring the changes in soil potassium by extraction procedure electroultrafiltration (EUF) in a Tropaquept under twenty years of rice-rice cropping. *Nutrient Cycling in Agroecosystems* 56: 277-282.

Subba Rao, A. and Srivastava, S. 2001. Soil Test based Fertilizer Recommendations for Targeted Yields of Crops. Indian Institute of Soil Science, Bhopal, India. pp. 1-326.

Subba Rao, A., Sesha Sai, M.V.R.and Pal, S.K. 1993. Nonexchangeable potassium reserves and their characterization in some soils of India. *Journal of Indian Society of Soil Science* 41 (4); 667-673.

Tiwari, K.N. 1985. Changes in potassium status of alluvial soils under intensive cropping. *Fertilizer News* 30 (9): 17-24.

Wanjari, R.H., Singh, M.V. and Ghosh, P.K. 2004. Sustainable Yield Index: an approach to evaluate the sustainability of long-term intensive cropping systems in India. *Journal of Sustainable Agriculture* 24 (4): 39-56.