Role of Potassium in Balanced Fertilization of Soybean-Wheat Cropping System

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Abstract

The experiments on research farm and farmers' field were conducted at NRC for Soybean, Indore and in nearby villages during 2003-04 to 2005-06 to assess the impact of balanced fertilization particularly of potassium nutrition on productivity of soybean as well as soybean-wheat cropping system under NRCS-IPI Project. Potassium application had significant positive effect on growth and nodulation in soybean. It favourably influenced the quality parameters of soybean as well. There was significant reduction in insect-pests infestation and disease incidence in soybean receiving potassium dressings. Application of 25 kg basal + 25 kg K_2O/ha at flowering (R_2 stage) gave maximum productivity of soybean-wheat cropping system while application of 25 kg K_2O/ha as basal was most economical in terms of IBCR indicating the utility of K applications for resource poor farmers. The negative balance of K in all the treatments, except with the application of 75 kg K_2O/ha as basal to both the crops of the system, brought out the need for reorienting the present recommended levels of K to meet the system need and enhance system efficiency in sustainable way.

Introduction

Soybean is the premier oilseed crop in India. Although the crop has history of only three and a half decade's of commercial cultivation, but it has exhibited phenomenal growth and provided resilience to oilseed and edible oil production in the country. The productivity of soybean crop has shown gradual build up from the time of its initiation of commercial cultivation, but it is hovering around 1 t/ha for more or less last one decade, mainly in view of deficit and erratic distribution of rainfall and uncertainity in onset of monsoon being experienced on account of global climatic change. Being rainfed, the productivity of oilseeds in general and soybean in particular has been far below the potential yield achievable. Constraint analyses have indicated that unbalanced nutrition is one of the important reasons for restricted growth in productivity (Sharma *et al.*, 1996 and Tiwari, 2001).

It is a general practice among farmers of major soybean growing regions to apply some N and/or P mostly through di-ammonium phosphate or single superphosphate (SSP) and that too in sub-optimal levels. By and large, K applications are dispensed with in view of conceived high status of the element in the soil, particularly in Vertisols. As a matter of fact, even the level of K, which is under recommendation, is insufficient to meet the requirement of the soybean crop as well as that of soybean based cropping system (Joshi, 2004). Though, sulphur is also not included in the fertilizer schedule, gets incidentally included wherever the SSP is applied (Bhatnagar and Joshi, 1999). In spite of the fact that the uptake of K by an average soybean crop is about 101-120 kg /ha (Nambiar and Ghosh, 1984 and Aulakh *et al.,* 1985), hardly any attention has been paid to meet the crop requirement. Vedprakash *et al.* (2001) found that values of net depletion of K (sum total of available and non-exchangeable K) from soil profile after 27 cropping cycles of soybean-wheat were quantitatively much higher than the expected K depletion values suggesting considerable depletion of K from soil. There has been a wide gap between recommendations of K application vis-à-vis its uptake. This status of nutrition management in soybean make it unbalanced.

Now, it has become imperative to optimize K nutrition for soybean-wheat cropping system so as to optimize the productivity from the system by way of making the fertilization balanced. Besides, K being a quality element, has been found to play an important role in providing drought tolerance to crop plants by regulation of stomatal opening and building up resistance against insect-pests and diseases. In view of this, the NRCS-IPI Project "Role of Potassium Nutrition in Balanced Fertilization of Soybean-wheat Cropping System" was initiated in 2003-04 and concluded in 2005-06 with the twin objectives:

- To assess the impact of balanced fertilization particularly potassium nutrition on productivity of soybean-wheat cropping system.
- To study the role of potassium nutrition in providing resistance against insect-pests and diseases of soybean.

Material and Methods

A field experiment was laid out at the Research Farm of National Research Centre for Soybean during 2003-04 to 2005-06 with nine treatments (Table 2) replicated thrice under Randomized Block Design. Soybean (*cv.* JS 93-05)–wheat (*cv.* Sujata) sequence was taken on fixed plot (3.6m x 6.0m) basis. Concurrently, trials on the farmers' field were also undertaken under real farm conditions at three locations with four treatments, namely 0, 25, 50 and 25 (basal) + 25 (at flowering) kg K_2O/ha. Soybean and wheat varieties grown were JS 335 and Sujata, respectively.

The physico-chemical characteristics of soils of the experimental sites are presented Table 1. Soybean received the recommended levels of N and P (20 kg N and 60 kg P_2O_5/ha) as basal. Subsequent wheat crop was supplemented with 120 kg N and 60 kg P_2O_5/ha. The potassium was applied as per treatments to both the crops through basal placement and side dressing in standing crop at flowering (R_2 stage). The foliar sprays of 0.5% KCl solution @ 800 litres/ha were applied at flowering and at one week interval subsequently as per treatment. The carriers used for supplementing N and P were urea and single super phosphate, respectively. The recommended package of practices was followed for both the crops. The data accumulated over three years were pooled and results were concluded.

Table 1. Soil characteristics of experimental sites

Characteristics	Research farm	Village		
		Umrikheda	Gokanya	Simrol
pH	7.8	7.8	7.7	7.9
EC (dS/m)	0.20	0.20	0.14	0.29
Organic Carbon (%)	0.47	0.61	0.85	0.74
Available N (kg/ha)	178	191	263	245
Available P (kg/ha)	8.30	8.60	11.50	9.30
Available K (kg/ha)	296	316	377	293

Salient Results

Soybean

Significant positive effect of potassium application on growth and nodulation of soybean was noticed. Dry weight (g/plant) of plants at flowering and plant height at harvest were significantly highest with split applications of K, either 25 kg (basal) + 25 kg K_2O/ha (at flowering) or 37.5 kg (basal) + 37.5 kg K_2O/ha (at flowering), respectively over control and foliarly sprayed K treatments. Nodule number and their dry weight were maximum with 50 kg K_2O/ha. All the treatments involving basal and split applications of K significantly enhanced branches/plant, pods/plant and seed index over control. The maximum branches/plant were observed with 50 kg K_2O/ha (basal), while pods/plant and seed index were maximum with split application of 25 kg (basal) + 25 kg K_2O/ha (at flowering).

Potassium application significantly improved the seed yield of soybean (Table 2 and Fig. 1). The split application of potassium had an edge over basal application and maximum seed yield was recorded with 25 kg (basal) + 25 kg K_2O/ha (at flowering), which was significantly superior over control, two and four foliar sprays of 0.5% KCl. Potassium nutrition had significant positive influence on harvest index of soybean and varied in proportion to K applied to the crop (Fig. 1).

Table 2. Effect of potassium nutrition on soybean seed and wheat grain yield and SEY of soybean-wheat cropping system (pooled 3 years data)

Level of K_2O (kg/ha)	Soybean seed yield (kg/ha)	Wheat grain yield (kg/ha)	SEY (kg/ha)
0	1746	3714	4064
25 (basal)	2109	4560	4962
50 (basal)	2295	4764	5278
75 (basal)	2250	4689	4182
12.5 (basal) + 12.5 (at flowering)	2108	4836	5136
25 (basal) + 25 (at flowering)	2447	5107	5647
37.5 (basal) + 37.5 (at flowering)	2274	4796	5266
2 spray @ 0.5 % KCl at flowering and 1 week after flowering	1910	4051	4441
4 spray @ 0.5 % KCl at flowering and 1 week interval after flowering	1992	4179	4604
CD 5%	116.1	364.6	1037.0

Protein content was significantly higher with split application of 37.5 Kg (basal) + 37.5 kg K_2O/ha (at flowering) over control while maximum oil content was recorded with the application of 25 Kg K_2O/ha as basal, which was significantly higher than control.

Soybean crop responded significantly to K application in terms of kg seed/kg K_2O applied. The maximum response was observed with foliar application followed by 25 kg K_2O/ha as basal and 25 kg (basal) + 25 kg K_2O/ha (at flowering). However, the Incremental Benefit Cost Ratio (IBCR) was highest with 25 kg K_2O/ha as basal.

Basal and split application of all the levels of K significantly reduced the infestation of blue beetle at 20 DAS while, all the levels and methods of K application i.e. basal, split and foliar, significantly reduced the infestation of defoliators, girdle beetle and stem fly in soybean. Similarly, application of K in any form brought significant reduction in collar rot mortality and Myrothecium leaf spot.

At farmers' field, there was considerable effect of K application on seed yield and yield increase with K application was up to 40% at 25 kg (basal) + 25 kg K_2O/ha (at flowering). The response per kg K_2O applied and IBCR were maximum with the application of 25 and 50 kg K_2O/ha as basal, respectively.

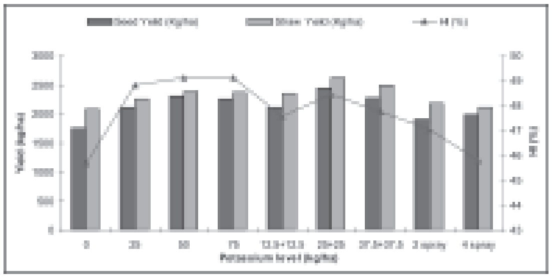

Fig. 1. Effect of potassium nutrition on seed and straw yield of soybean and harvest index (pooled 3 years data)

Wheat

The inclusion of potassium in the fertilizer schedule irrespective of mode of application in general, enhanced the yield of wheat to the extent of 38% (Table 2) with 25 kg (basal) +25 kg K_2O/ha (at flowering) over control. The basal applications of potassium were found superior over foliar sprays. Application of K in equal splits (basal and at flowering) had an edge over basal applications. The maximum response was observed with foliar application followed by 25 kg K_2O/ha as basal and 12.5 kg (basal) + 12.5 kg K_2O/ha (at flowering). However, the IBCR was highest with 25 kg K_2O/ha as basal. In general, the IBCR decreased with the increasing levels of potassium.

At farmers' field, there was considerable effect of K application on grain yield of wheat and yield increase with K application was up to 19% at 25 kg (basal) + 25 kg K_2O/ha (at flowering). The response per kg K_2O applied and IBCR were maximum with the application of 25 and 50 kg K_2O/ha as basal, respectively.

Soybean-Wheat Cropping System

The system efficiency was evaluated in terms of soybean equivalent yield (SEY). The inclusion of potassium in the fertilizer schedule irrespective of mode of application in general, enhanced the productivity of the system to the extent of 9.3 to 39.0 per cent (Table 2). The basal applications of potassium were found superior over foliar sprays. The maximum soybean equivalent yield was recorded with the split application of 50 kg K_2O/ha (25 kg basal + 25 kg at flowering), which was significantly superior over two and four foliar sprays of 0.5% KCl and control.

The maximum response was observed with foliar application followed by 12.5 kg (basal) + 12.5 kg K_2O/ha (at flowering) and 25 kg K_2O/ha as basal. However, the IBCR was highest with 25 kg K_2O/ha as basal. In general, the IBCR decreased with the increasing levels of potassium.

There was definite effect of K nutrition on productivity of soybean-wheat cropping system in terms of soybean equivalent yield at farmers' field. At farmers' field, there was considerable effect of K application on grain yield of wheat and yield increase with K application was up to 29% at 25 kg (basal) + 25 kg K_2O/ha (at flowering). The response per kg K_2O applied and IBCR were maximum with the application of 25 and 50 kg K_2O/ha as basal, respectively.

K uptake by plant

Maximum total K uptake by soybean, wheat and the system were observed with 37.5 kg basal + 37.5 kg K_2O/ha at flowering followed by 25.0 kg basal +25.0 kg K_2O/ha at flowering (Fig.2).

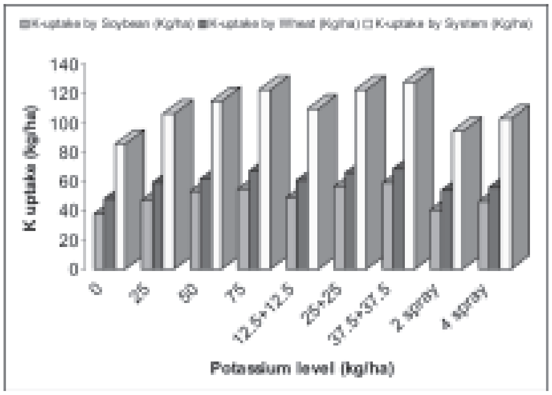

Fig.2. Effect of potassium nutrition on K uptake by soybean, wheat and cropping system (pooled 3 years data)

K status and balance in soil

The maximum Ammonium Acetate-K, $CaCl_2$-K and HNO_3-K content after wheat harvest i.e. at the completion of the cropping system was observed with the application of 37.5 Kg (basal) + 37.5 K_2O/ha (at flowering) followed by 75 kg K_2O/ha as basal. Except application of 75 kg K_2O/ha as basal to both the crops of the system, there was negative balance of K in the soil after completion of the cropping system at all the levels.

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Management of Potassium Nutrition in Soybean Based Cropping Systems in the State of Madhya Pradesh

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Abstract

Madhya Pradesh, before the commercial introduction of soybean in *kharif*, has been largely following traditional fallow-chickpea/wheat cropping pattern. The increasing adoption of soybean in past four decades has given a sustainable cropping system in the region. As on today, a sizable area is covered by soybean-chickpea (rainfed regime) and soybean-wheat (irrigated regime) cropping systems as the soybean crop covers nearly 4.8 million hectares. The national as well as state average productivity of soybean hovers around 1 tonne per hectare, which is much lower than the potentials of available varieties. Similarly for *rabi* crops also, the yield levels do not commensurate with the productivity potentials. Nutrient imbalances in soil on account of skewed and inadequate applications keeping aside the integrated approach is considered to be one of the major constraints. The essential element potassium has completely been ignored in the nutrient management programmes of the state, particularly for *kharif* crops. The information presented in this paper brings out the need for creating awareness on this aspect and suggests the reconsideration of the recommended levels of K for sustaining the crop yields at respectable level. In addition, the role of potassium in mitigating some of the biotic and abiotic stresses (particularly water stress), which is common in the region on account of global climatic changes) and in improving quality of economic produce of crops is highlighted.

Introduction

It is well understood from the time the landmark theory of mineral nutrition of plants and the Sprengel- Liebig "Law of minimum" proposed in the beginning of 19th Century (Ploeg *et al.,* 1999) that the crop performance is dependent on the balanced and adequate nutrition of plants. The documentations in the past also bring out that for the lower productivity of crops in India, the unbalanced and under nutrition is one of the major reasons. Among various crops grown in India, the pulses and oilseeds, which conserve the energy most, are unfortunately grown under most energy deficient management. Although, there has been consistent growth in usage of fertilizers in India in the past (Fig. 1), the fertilizer applications are highly sub-optimal and skewed (Table 1) leaving a deficit of almost 10 million tonnes NPK per annum. For dryland agriculture, it has been reported that the NPK removed by the crops were to the tune of 7.4 million tonnes and possibly replenished to the extent of 1.4 million tonnes leaving a negative balance of 6 million tonnes (Katyal and Reddy, 1997; Katyal *et al.*, 1999). Of this deficit between exhaustion by the crop and replenishment, nearly half is estimated to be on account of potassium. It has been contemplated that on account of the removal of potassium from the soil in harvested crops, continuous cropping without the use of potassium fertilizer causes a decline in available K content in soils. The larger the crops, the greater the removal so the decline can be more serious at high levels of fertility (Biswas *et al.*, 1977; Singh and Brar, 1977). Under multiple cropping system (2 or three crops a year) annual K loss is high and ranges from 205 to 330 kg/ha in India (Anon., 1983). Sekhon (1980) and Subba Rao and Ghosh (1982) have commented on the effects of N and NP fertilizers increasing the K loss. Reddy *et al.* (2005) have brought forth that cropping in Madhya Pradesh, Central India, experiences an overall nutrient deficit of about 1 million tonnes nitrogen (N), phosphorus (P) and potassium (K) annually. The status of nutrient management for crops, particularly soybean in Madhya Pradesh, is quite unsatisfactory and warrants corrective measures to ensure optimised for this crop as well as soybean based cropping systems.

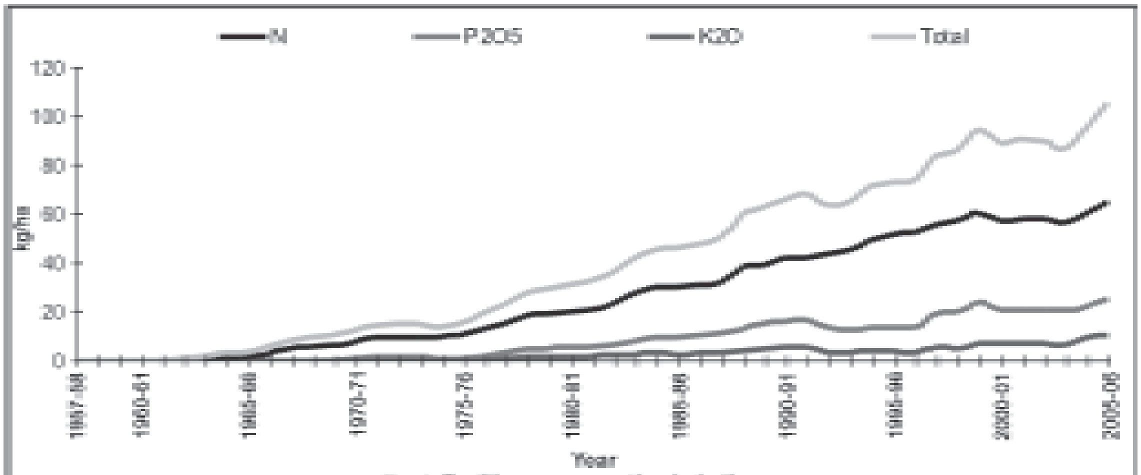

Fig. 1. Fertilizer consumption in India

Table 1. N: P_2O_5: K_2O consumption ratio in major soybean growing states of India

State	N: P_2O_5: K_2O Consumption Ratio					
	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
M P	10.2:7.2:1	13.5:9.6:1	11.9:8.8:1	12.1:7.2:1	11.2:7.1:1	9.5:5.5:1
Maharashtra	4.1:1.9:1	4.2:1.9:1	4.2:2.0:1	4.9:2.4:1	3.7:2.0:1	3.2:1.8:1
Rajasthan	92.0:30.5:1	85.1:29.2:1	57.4:20.2:1	48.8:17.7:1	33.2:12.4:1	31.2:12.2:1
Karnataka	3.1:1.6:1	1.2:0.6:1	1.1:0.5:1	2.6:1.3:1	2.4:1.3:1	2.3:1.3:1
A P	6.5:2.9:1	5.2:2.4:1	5.2:2.1:1	4.8:2.0:1	4.0:1.8:1	4.3:1.9:1
India	7.0:2.7:1	6.8:2.6:1	6.5:2.5:1	6.9:2.6:1	5.7:2.2:1	5.3:2.2:1

Source: Worked out using the data from Fertilizer Statistics, The FAI, New Delhi

Potassium "The Quality Element"

Potassium is one of the three major essential nutrient elements required by plants. Unlike nitrogen and phosphorus, potassium does not form bonds with carbon or oxygen, so it never becomes a part of protein and other organic compounds (Hoeft *et al.*, 2000). Although K is not a constituent of any plant structures or compounds, it is involved in nearly all processes needed to sustain the plant life. Potassium in cell sap is involved in enzyme activation, photosynthesis, transport of sugars, protein and starch synthesis. It is known to help crop to perform better under water stress through the regulation of the rate at which plant stomata open and close. It is also known for its role to provide lodging resistance and insect/disease resistance to plants. Since potassium is involved in many metabolic pathways that affect crop quality, it is often called as "the quality element" (Dev, 1995).

The Soybean and Soybean Based Cropping Systems in Madhya Pradesh

Soybean is one of the nine major oilseed crops of India and occupies premier position. It shares nearly 28 per cent of area and 30 per cent production in oilseeds (2005-06). Since the commercial exploitation, the crop has been increasingly off setting the import bill of the nation. The contribution as on date is 18-20 per cent to the national oil production and Rs 40, 000 million of foreign earnings through the export of soy-meal. At present it covers an area of about 8.7 million hectares, which is likely to produce more than 9.0 million tonnes of soybean during the year. Madhya Pradesh (4.8 m ha), Maharashtra (2.5 m ha) and Rajasthan (0.7 m ha), in that order, constitute the major niche for the cultivation of this crop. There are bright prospects of further continuing the trends of accrued benefits in future as there exists a wide gap between the national productivity (1 t/ha) and the production potentials of varieties bred in India (3 to 4 t/ha) and the yield levels achieved in front line demonstrations under real farm conditions have been around 2 t/ha i.e. almost double of the national average yield (Tiwari *et al.,* 2001). Constraint analyses have indicated that unbalanced nutrition is one of the important reasons of low productivity (Sharma *et al*., 1996; Tiwari, 2001; Joshi and Bhatia, 2003).

Although a number of cropping systems are adopted by the farmers of Madhya Pradesh (Table 2), the major cropping sequences followed are soybean-wheat and soybean-chickpea and pigeon pea/corn as intercrops in soybean (Bhatnagar and Joshi, 1999). However, limited area with good irrigation facility is utilized for early soybean-early potato-wheat and early soybean–garlic/onion-wheat. Yadav and Subba Rao (2001) reported that soybean-wheat (1979 thousand ha), soybean-chickpea (918 thousand ha) and soybean-fallow (813 thousand ha) are with sizable area in the state. The cropping intensity in the state is about 135 per cent.

Table 2. Soy-based cropping systems in Madhya Pradesh

	Cropping sequence	Inter-/mixed-/companion cropping
Major	Soybean-chickpea (rainfed)	Soybean + pigeon pea
	Soybean-wheat (irrigated)	Soybean + corn
Others	Soybean-potato (I)	Soybean + sorghum
	Early soybean-garlic (I)	Soybean + cotton
	Early soybean-safflower (R)	Soybean + groundnut
	Early soybean-rapeseed/mustard	Soybean in fruit (mango/guava) orchards

Source: Modified from Bhatnagar and Joshi (1999)

As has been stated, the nutrient management in soybean in the cropping systems is not satisfactory at all. It is a general practice among farmers of major soybean growing region to apply some nitrogen and/or phosphorus mostly through DAP or single superphosphate. By and large, no potassium is applied and sulphur is also not included in the fertilizer schedule but gets incidentally included wherever the super phosphate is applied (Bhatnagar and Joshi, 1999). Even unwarranted top dressing with either urea or DAP is also not uncommon. Still some farmers resort to planting of delicate soybean seed mixed with DAP/single super phosphate.

The soils sustaining soybean in Madhya Pradesh

In Madhya Pradesh, soybean is mainly grown on *Malwa* plateau, part of Deccan plateau and Central Highland in the state (Tamgadge *et al.*, 1996). The state grows soybean largely on Vertisols and associated soils. Madhya Pradesh soils fall within the three agro-ecological regions (AER) as established by The National Bureau of Soil Survey and Land Use Planning based on physiography, soil type, agro-climatic conditions and length of growing period and land use. These regions are AER-4, -5, and -10 which are briefly described in Table 3.

Table 3. The predominant soybean-growing agro-ecological regions

Agro-ecological region/sub-region	Description	Districts of Madhya Pradesh
4	**Northern Plain (and Central Highlands) including Aravallis, hot semi-arid ecoregion**	
4.3	Ganga Yamuna doab, Rohilkhand and Avadh plain, hot moist semi-arid ESR, loamy alluvium-derived soils (sodic phase inclusion), medium to high AWC and LPG 120-150 days	Bhind
4.4	Madhya Bharat plateau and Budelkhand uplands, hot moist semi-arid ESR, with deep loamy and clayey mixed Red and Black soils, medium to high AWC and LPG 120-150 days. The dominant soils are Ustochrept-gullied land and Ustochrept-Chromusterts. These are very deep soils, mildly alkaline in reaction and low in organic carbon.	Shivpuri, Gwalior, Morena, Datia, and northern tips of Guna and Sagar

5	**Central Highlands (Malwa), Gujarat Plain and Kathiwar Penunsula, semi-arid ecoregion**	
5.2	Madhya Bharat plateau, Western Malwa plateau, Eastern Gugarat plain, Vindyan and Satpura range and Narmada valley, hot moist semi-arid ESR with medium and deep clayey black soils (shallow black soils as inclusion), medium to high AWC and LGP 120 to 150 days. These swell-shrink soils are the dominant group in the region with loamy to clayey Vertic Ustochrepts and clayey Chromusterts. These soils are predominantly high in available K, but medium/medium to high in exchangeable K. Although high in available K, but K saturation is quite low. These are slightly to moderately alkaline, calcareous as well as non-calcareous and low to medium in organic matter.	Jhabua, Ratlam, Mandsaur, Ujjain, Indore, Dewas, East Nimar, West Nimar and Dhar, parts of Rajgarh and Shajapur
10	**Central Highlands (Malwa and Bundelkhand), hot sub-humid (dry) ecoregion**	
10.1	Malwa plateau, Vindyayan scrapland and Narmada Valley, hot dry sub-humid ESR with medium and deep clayey black soils (shallow loamy black as inclusion), high AWC and LPG 150-180 days. Medium to deep black soils are interspersed to patches of red soils. The dominant groups are Ustoorthants, Ustochrepts, Chromusterts and Haplustalfs. These soils are predominantly high in available K, but medium/ medium to high in exchangeable K. Black soils are calcareous, slightly to moderately alkaline and low to high in organic matter.	Guna, Rajgarh, Raisen, Sagar, Bhopal, Sehore, Shajapur, Hoshangabad, Jabalpur, Narsimhapur, Vidisha, and Damoh (south and Central) Dewas east
10.2	Satpura and Eastern Maharashtra plateau, hot dry sub humid ESR with shallow and medium loamy to clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LPGn150-180 days. Soils are moderately alkaline with low organic carbon content.	Betul
10.3	Vindyan scrapland and Baghelkhand plateau hot dry sub-humid ESR with deep loamy to clayey mixed Red and Black soils, medium to high AWC and LPG 150-180 days. Soils are slightly alkaline with low organic carbon content.	Tikamgarh, Chhtarpur, Panna, Satana, Rewa, Sidhi and Shahdol Chhindwara, Seoni, Mandla, Balaghat, south eastern parts of Jabalpur
10.4	Satpura Range and Wainganga Valley, hot moist subhumid ESR with shallow to deep loamy to clayey mixed Red and Black soils, low to medium AWC and LPG 180-210 days. Soils are acidic in reaction with low to medium organic carbon content	

Source: Velayutham *et al.* (1999)

Uptake, Recommendation and Application of Potassium for Soybean

Potassium enters in plant as K^+ and remains in plant in ionic form. A small fraction of it is found absorbed by protein in active leaves to cater to many enzymatic reactions and this form is not extractable by water. It is essential for reactions in using high-energy phosphates (adenosine phosphates), in first reaction in photosynthesis in using the captured light energy to convert adenosine di-phosphate (ADP) and phosphate into adenosine tri-phosphate (ATP) in the synthesis of amino acids.

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 to name only few. Stomatal resistance decreases and photosynthesis increases with increasing K content of leaves (Peoples and Koch, 1979).

Potassium in soil solution is in equilibrium with exchangeable potassium on clay minerals and humus. Potassium moves in soil by diffusion process and hence is not as easily available to plants as nitrogen. It does not get lost from the soil as nitrogen does. It moves from older leaves to younger leaves. Therefore, the older leaves are the first to show deficiency symptoms.

Potassium uptake by soybean

Hanway and Weber (1971) reported that soybean takes up and accumulates K throughout the growing season. However, young seedlings of soybean do not use much potassium, but the rate of uptake climbs to a peak during the period of rapid vegetative growth. The potassium in vegetative parts is transferred to seed during pod fill process. The mature soybean seed contains nearly 60 per cent of the total K in plant (Hoeft *et al.,* 2000). Deficiency symptoms, if those are going to appear in soybean, will be seen during the period from late flowering to early seed fill. The potassium concentration in soybean plants decreases near maturity. Any deficit of K during the late vegetative and during the reproductive stage is going to reflect on yield of soybean.

Potassium uptake in soybean has been estimated as about 101-120 kg/ha K (Nambiar and Ghosh, 1984; Aulakh, 1985). Similar removal of 101 kg/ha of K has been reported in case of soybean in Madhya Pradesh state by Swarup *et al.* (2001). Subsequent work on vertisols reveal K uptake by soybean to be 33 to 100 kg/ha (Khan, 2006; Bundela, 2005) and between 56 to 198 kg/ha by soybean-wheat systems (Bundela, 2005) at Indore depending on the yield levels achieved in the experimentation on combined use of nutrients. As a thumb rule it is understood that the soils high in K may not pose any problem but those low in available K shall need building up of K during the period when it is needed most. It has been reported elsewhere that soybean responds well over a wide range of soil tests (Johnson, 1980). While working with South African soils having high-K fixing capacity of, Kovacevic and Vukadinovic (1992) reported dramatic yield responses. In general, the soybean is grown in semi-arid regions, particularly Vertisols and associated soils, which are rich in potassium, but have shown yield response. This is true with respect of other crops as well as while analysing the data accumulated from long term experiments (1971-1983) in India, Nambiar and Ghosh (1984) reported a negative K balance in 10 out of 11 sites. In 5 out of 11 sites, the K deficit was higher than 120 kg K_2O/ha. They stated that the optimum potassium requirements calculated on the basis of soil analysis were therefore not sufficient to compensate the larger K amounts taken up by the crops i.e. 52 to 503 kg K_2O/ha. The data also showed that K response has generally been increasing with time even in soils rich in K. Under Vertisols of Jabalpur, in soybean-wheat-fodder maize system, the yield response to applied K between 1973-77 recorded was 2.9 kg/kg seed for soybean increased to 13.7 between 1992 and 96 (Rao *et al.*, 2001). Crop uptake of K far exceeded the quantity applied and K balance was generally negative even with the use of 150 % of the optimum K doses (with N and P) and the highest negative balance was noted when only N and P were applied and K was omitted.

K as related to leaf drop and residues

Unlike forage legumes (alfalfa and clover), soybean does not absorb much more K than needed for best yield. Leaf drop in soybean also accounts for a significant amount of the decrease in total potassium in the plant. All of the potassium in crop residues is available during the first season because the potassium remains in water soluble form within the plant. The crop helps to recycle available potassium and return a portion of what it took from the soil.

It is to be noted that in potassium balance, the dominant factor has been off take in the crop, more particularly in that part which is not marketed or eaten (Pieri, 1983). The return of as large a part as possible of crop residues is needed. At the NRC for Soybean, Indore, it was observed that the leaf-litter in soybean was to the tune of about 1 t/ha with a range of 0.5 t/ha in case of the variety 'MACS 101' and up to 2.5 t/ha in the variety 'T-49'. The K content in leaf was found to be around 4.0 %. This will amount to a recycling of about 40 kg K/ha through leaf drop (O.P. Joshi, unpublished).

The need of the cropping system/ rotation is also to be kept in mind. Potassium should be preferably applied to the non-cereal crop of the rotation (Pieri, 1983) on account of the tendency of the *Gramineae* to take up K in excess of their requirements (luxury consumption). That precisely is the reason that potassium nutrition in soybean becomes important not only for the crop itself but also for other components of the soybean-based cropping system.

Recommendation vs. uptake in case of soybean

Based on the agronomic experimentation in different agro-climatic regions, the All India Coordinated Research Project on Soybean has recommended application of nitrogen, phosphorus, potassium and sulphur at the levels of 20 kg N/ha, 26.0-34.6 kg P/ha, 16.6–33.2 kg K/ha and 20 kg S/ha, keeping in view the adjustment based on soil test values. The reported crop uptake of these nutrients was 125-190 kg/ha of N, 19-43 kg/ha of P, 101-120 kg/ha of K and 9-22 kg/ha of S (Nambiar and Ghosh, 1984; Aulakh, 1985; Tandon and Sekhon, 1988; Pasricha and Tandon, 1993, Nambiar, 1994). A similar report for K removal in Madhya Pradesh was made by Swarup *et al.* (2001). Ved Prakash *et al.*

(2001) found that values of net depletion of K (sum total of available and non-exchangeable K) from soil profile after 27 cropping cycles of soybean-wheat were quantitatively much higher than the expected K depletion values (based on K input-output balance sheet) suggesting considerable loss of K from soil profiles. Changes in available nutrient status of soil as a consequence of nutrient management treatment after 2 cropping seasons with soybean-wheat rotation at NRC for Soybean, Indore (Bundela, 2005) revealed negative balance of soil K (56 to 152 kg/ha). Consistently higher rainfall during the rainy season could be attributed to cause K loss through leaching. Recommendation of 20 kg N/ha as starter dose is well justified. It is capable of meeting the nitrogen requirement as the soybean crop has been reported to fix atmospheric nitrogen to the extent of 50 to 300 kg/ha (Keyser and Li, 1992), which is further supplemented by biomass recycling and non-symbiotic fixation. Recommendation of phosphorus and sulphur also matches the respective nutrient uptake.

There appears to be a wide gap between the recommendations of potassium application *vis-à-vis* its uptake. This fact was probably uncared for on account of richness of Vertisols and associated soils in K. By and large, farmers in the major soybean growing areas apply no potassium. Swarup *et al*. (2001) have reported an overall negative balance of potassium in Madhya Pradesh state, which was highest in *Malwa* plateau, the home of soybean. With the introduction of improved high yielding varieties and intensive agriculture, it is imperative to standardize and readjust the recommendation for potassium for sustainable soybean-based cropping systems. The revision of K levels are further needed in view of lower fertilizer use efficiency of K (20-40%) than that of N (above 40%) for soybean and corn (Carpenter, 1975) and major movement of the element in soil to plant roots by diffusion and lesser contribution of root hairs in K uptake as compared to phosphorus (Mengel and Barber, 1974).

Analysis of data available on supplementation (Directorate of Agriculture, Madhya Pradesh), uptake, recommendation and need for optimum performance of soybean in Madhya Pradesh presents an interesting outcome (Fig. 2 and 3). The total N: P_2O_5: K_2O per ha application in the state varies from 33 to 48 kg/ha, whereas application in *kharif* is from 23 to 38 kg/ha. This supplementation does not meet the recommendation of even soybean (100 kg/ha) and leaves a wide gap. Moreover, the situation of potassium nutrition is still grave. The per hectare potassium application in *kharif* is less than 1.5 kg per hectare as against 20 kg/ha recommendation. Figure 3 shows that if we have to sustain the present level of national productivity (1 t/ha), the amount of P_2O_5 + K_2O required will be about 88 kg/ha. Taking clue from the observation made by Cassman (1999), the possible stabilization of yield under Indian conditions can be 1.6 t/ha and to replenish these two nutrients removed by soybean crop alone, we may need about 140 kg/ha. As has been said earlier, in general, the soybean crop receives either sub-optimal quantities of NP or P through DAP or single super phosphate, the need for potassium is not attended to. This justifies rethinking of recommendations, particularly for potassium.

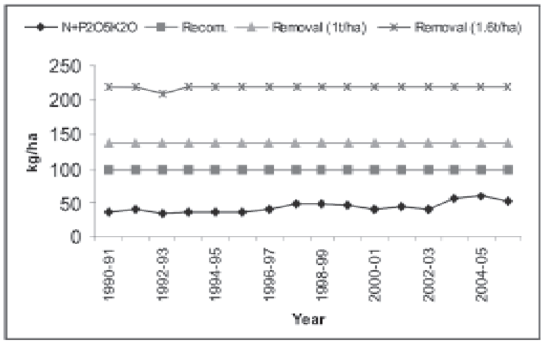

Fig. 2. $N+P_2O_5+K_20$ application vs need-Madha Pradesh

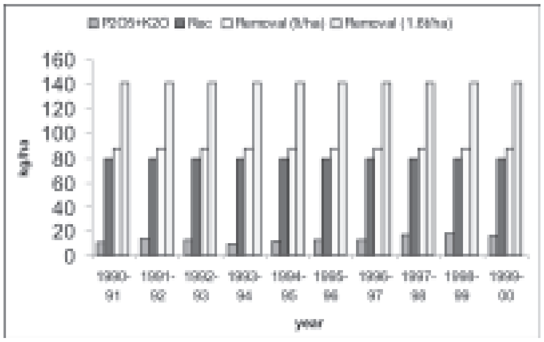

Fig. 3. $P_2O_5+K_2O$ (*kharif*) application vs need-Madhya Pradesh

Response of Soybean to Potassium

The fact that the K nutrition of soybean has not been paid due attention in the past is further substantiated as follows.

Response realized in the vertisols-region of Madhya Pradesh

The long-term experimentation conducted on Vertisols of Jabalpur in soybean-wheat-maize fodder revealed not only the yield of soybean was increased by 6 per cent, but application of potassium at recommended levels also enhanced the uptake of major, secondary and some of the micronutrients (Table 4). Similar was the effect of application of K on the other crops under rotation.

Table 4. Yield response and uptake of nutrients by soybean (JS 72-44) in crop rotation with wheat and maize fodder in medium black soils of Jabalpur (1971-1989)

Treatment*	Yield	Uptake (kg/ha)						Uptake (g/ha)			
	(kg/ha)	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu
Control	1079	71	5.0	45	20	7	1	71	287	89	26
Rec. N	1362	114	8.1	63	24	8	2	80	374	111	29
Rec NP	2158	178	17.8	103	47	14	8	114	687	218	67
Rec. NPK	2287	196	19.6	112	55	18	11	132	717	241	64

*Taken from 10 treatments

Source: Annual Report 1987-88 and 1988-89. AICRP on Long Term Fertilizer Experiments, ICAR

Soybean is not especially sensitive to magnesium deficiency. Research has not supported the claim that high potassium will reduce yield by inducing a shortage of magnesium (Hoeft *et al.*, 2000). However, Dixit and Sharma (1993) reported increasing yield responses for soybean with increasing K levels up to 25 kg K/ha applied to wheat in wheat-soybean-linseed sequence on silty clay loam of Palampur, but also recorded reduction of Ca and Mg uptake.

The Vertisols supporting soybean cultivation often experiences lime induced Fe stress. Hughes *et al.* (1992) reported that in the absence of adequate K, the Fe deficiency chlorosis associated with lower leaf concentration is experienced. In Fe-stressed soybean and tomato, H^+ ion release and reduction of Fe^{3+} to Fe^{2+} declined in K-deficient versus K-sufficient plants.

More conclusive results on yield responses of soybean were obtained in experimentation organized by International Potash Institute at Sehore from 2001-03 (Gupta, 2003), Amlaha from 1993-97 (Magen, 1997), and Indore (Vyas, 2007) from 2003-06 in Vertisols Madhya Pradesh, both at research farm and farmers fields. At all the three places more or less similar results have been achieved with respect to significant positive response to potassium towards growth parameters, nodulation characteristics, nutrient uptake, reaction towards insect-pests and diseases, seed quality and yield in spite of medium to high initial levels of available potassium (225 to 378 kg/ha). Subba Rao and Srinivasa Rao (1996) also reported that the Vertisols and associated soils of this region have relatively high exchangeable K, but per cent K saturation is quite low. That is the reason for instances wherein swell shrink soils having high exchangeable K responded to K application. The above results have been reconfirmed subsequently (Khan, 2006; Bundela, 2005). In general, of the districts covered under Madhya Pradesh and Chhattishgarh, only three fall under low K category whereas 10 under medium and 31 under high category (Hasan, 2002)

There has been response of applied potassium in soybean-wheat cropping system up to 50 kg K_2O per hectare as basal and split (25 kg as basal and 25 kg as top dressed at 35-40 days after sowing) along with recommended NP, with an edge for split application over basal. At Sehore, Amlah and Indore, the increase in soybean yield over control recorded was reaching up to 30 per cent, 22 per cent and 62 per cent, respectively. In general, there has been about 28 per cent increase in soybean equivalent yield from soybean-wheat system on split application of K @ 50 kg K_2O/ha during the experimental period at Indore. The data for all the three locations were evaluated for economic benefit and the results followed the yield response. While working on Vertisols of Indore, Khan (2006) could record 35 per cent yield increase by basal application of 60 kg K_2O/ha in soybean.

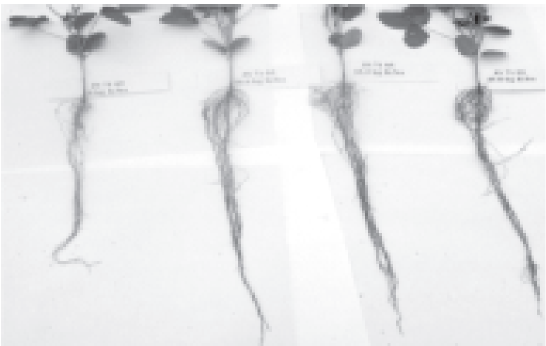

Fig. 4. The response of potassium application on rootting pattern in soybean (Billore, 2007)

Potassium in Stress Management

Soybean being a rainfed crop and normally cultivated in *kharif* in India, gets affected by various biotic and abiotic factors. Similarly, the crops that follow soybean are also exposed to these factors reducing the performance of crops in a cropping system. Potassium is capable of minimising these effects of stresses by forming *organometallo* complex, which in turn save tissues and plant organs by regulating hydration, synergistic and antagonistic reactions and endergonic processes in plant cells. The physiological and biochemical disorders created under abiotic stresses are obviated by the accumulation of organometallo-osmoticums like potassium-malate, potassium-citrate and potassium-oxalate, etc. in plants. Application of K augment the synthesis of natural organic osmoticum like sugars, C_3 and C_4 acids, betaine, etc. and favours the accumulation of proline and abscisic acid involved in withstanding protein denaturation under stress conditions. Application of K helps to regulate stomatal movement and control water loss through osmoregulation. However, under saline and alkaline conditions adequate K competes with Na, maintains low Na/K ratio and induces tolerance through stabilizing chemiosmotic potential in plants. Potassium application reduces allelopathic interaction between sugarcane and groundnut under drought conditions (Dwivedi, 1998). Thus, the essentiality of K has been found to be indispensible in biophysical processes, activation of biochemical reaction, chemi-osmotic energy regulation, osmoticum synthesis and organometallo-osmoticum formation (Dwivedi *et al.,* 1992), especially to obviate the injuries of stress environment. Cakmak (2005) also stated that it seems reasonable to suggest that the improvement of K-nutritional status of plants might be of great importance for the survival of crop plants under environmental stress conditions, such as drought, chilling and high light intensity. Several examples are presented here emphasizing the roles of K in alleviating adverse effects of different abiotic stress factors on crop production.

Potassium in mitigating drought effect

In spite of the fact that the soybean is the most resilient crop, which can stand water stress to a great extent, the reduction in yield on account of drought experienced at different stages of crop growth can further be minimized if adequate potassium application is restored to. It shall be worth mentioning here that soybean is, by and large, cultivated under rainfed conditions and the climate, particularly quantum and distribution of rainfall, in the major soybean growing regions has been aberrant in past few years on account of global climatic changes. The inherent strength of the crop made it possible to have yield fluctuations during these years of the order of plus/minus 20 per cent over years; 20 per cent reduction in drought years and 20 per cent increase in sufficiency years over national average yield of 1 t/ha. The evidences suggest that K fertilization can further help in curtailing the yield loss on account of drought (Table 5) A study (Anuradha and Sarma, 1995a, b) on Vertisols could observe the drought mitigating effect up to the level of application of K up to 50 kg/ha.

Table 5. Effect of K_2O on soybean yields and profits in a year of good rainfall and in a dry year

K_2O (kg/ha)	Yield (t/ha)			Soil test fall 1980
	Good year 1980	Stress Year 1981	Yield loss	(kg K/ha)
0	3.8	2.0	1.8	144
6	4.0	2.8	1.2	170
112	4.0	3.2	0.8	220
224	3.9	3.2	0.7	264
Response to K_2O	0.3 t/ha	1.2 t/ha		
Profit from K_2O	44$/ha	259$/ha		

Source: Johnson (1984)

Potassium ensuring better performance against biotic stresses

Potassium is known to play an important role in protecting the plants against biotic stresses. Potassium affects metabolism and in K deficiency, soluble compounds of low molecular weight accumulate, especially soluble N compounds and sugars because of increased of decomposing enzymes and reduced phosphorylation. This is frequently accompanied by better parasite development probably because such compounds constitute a particularly suitable diet for them. Adequate K nutrition increases the content of phenols, which can also play beneficial role in plant resistance. Potassium affects plant morphology, hardening the tissues with resulting improvement in resistance to disease penetration and insect feeding. Stomata are open for longer than necessary in potassium deficiency increasing the chances of disease penetration (Perrenoud, 1990). Potassium is an imperative input for improving growth, yield and quality of roots, grains and shoots and raising lignin in tissues and thereby imparting stiffness at organ/whole plant level.

The bibliographical data (Perrenoud, 1990) relating to all pests and diseases indicate a beneficial effect in 65% and deleterious effect (increase disease or pests) in 28% of cases. Of the 2449 reports, K application resulted in decrease of 70, 63, 33, 41, and 69 per cent in fungal diseases, insects and mites, nematodes, viruses and bacteria, respectively. It is interesting to note that potassium had a beneficial effect in 87 % of cases in low K soils whereas in 66% of cases in soils sufficient or high in K. Similarly the average reduction in severity of fungal diseases was four times greater on low K soils. Insufficient K causes a pale leaf colour, which 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.

The experimentation/trials under real farm conditions sponsored by IPI at Sehore, Amhlah and Indore and other experimentation (Personal communication from Dr. A.N. Sharma, NRC for Soybean) in the state of Madhya Pradesh establishes that in soybean there has been significant reduction on the incidence of girdle beetle, semilooper and aphid at Amlah (Table 6), stem fly and girdle beetle at Sehore (Gupta, 2003) and blue beetle, stemfly, defoliators and girdle beetle at Indore on account of K application along with N and P. 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.*

Table 6. Effect of K application on infestation of insect-pests on soybean plants

Treatment N- P- K	Girdle beetle (%)	Semilooper attack (%)	Aphid attack (%)
30-80-0	4.6	4.6	2.8
30-80-50	4.0	3.7	1.7
30-80-25/25	3.6	3.3	1.6
30-80-100	3.8	3.6	1.5
30-80-50/50	3.4	2.9	1.4

Source: Magen (1997)

Sehore, M.P. India IPI-PRII-OilFed 1999

Fig. 5. Damage in presence (right) and absence (left)of K application

Table 7. Effect of soil and foliar application of potassium on insect infestation and disease incidence in soybean during *kharif* 2004 (NRC for Soybean)

Level of K_2O (kg/ha)	Infestation by			Incidence of		
	Blue beetle (mrl)	Stem fly (% Stem tunneling)	Defoliators (mrl)	Girdle beetle (%)	Collar rot (% mortality)	Myrothecium leaf spot (PDI)
Control	5.9	13.91	1.3	8.35	9.17	38.57
25 basal	2.0	3.87	1.0	2.17	6.07	28.45
50 basal	1.8	2.87	0.8	2.06	4.61	22.58
75 basal	1.3	0.00	0.7	4.70	5.60	22.88
12.5 basal + 12.5 at flowering	1.8	5.25	0.7	4.70	5.60	22.88
25 basal + 25 at flowering	1.8	3.36	0.7	3.29	4.17	26.69
37.5 basal + 37.5 at flowering	1.6	3.01	0.7	2.47	2.29	27.57
2 spray @ 0.5%at flowering and one week thereafter	5.1	4.66	0.7	4.37	2.09	29.33
4 spray @ 0.5%at flowering and at one week interval thereafter	5.1	4.17	0.6	4.12	2.63	32.12

Source: e-ifc-subscribe@ipipotash.org. Reported by E. A. Kirkby

Potassium vs Seed Quality

The increasing potassium application to soybean has been reported to progressively decrease the weathering damage (Tetrazolium test, percentage of nonvarible seeds) and improves standard germination, emergence in sand, vigour (Franca Nato *et al.*, 1984). They also reported improvement in seed K (1.31 to 1.74%) content and test weight of soybean seeds (10.2 to 15.8 g/100 seeds) with increasing levels (control to 200 kg K_2O/ha) of K application. Vanangamudi *et al.* (1986) from Coimbatore, India also reported that an improvement in germination, dry matter production, vigour index, oil content, and protein content in soybean seed impregnated with potassium solution. Sale and Campbell (1986) reported that a reduction in K supply to soybean plants to deficiency levels during both vegetative and reproductive development resulted in reductions not only in yield, but also in oil and K concentration in the seed and concomitant increase in seed protein concentration. They suggested that potassium-deficient soils are likely to produce crops with low yields and low seed oil levels; the crop may respond to K fertilizers as late as anthesis.

The IPI sponsored research at Sehore, Amlah and Indore has brought out that the potassium application not only betters the appearance (size, lusture and seed health) of the seed of soybean and wheat but also improves oil content in seeds of soybean. In 10 on-farm trials over 3 years in the soybean-wheat system at Sehore, MP, optimum potash application increased soybean oil content by about 10% (Bansal *et al.*, 2001). Similar increase in oil content by 7 per cent in soybean by K application was recorded in a study conducted at Indore (Khan, 2006).

Table 8. Effect of K application on seed quality- characters of soybean (Amlah)

Treatment N- P- K	100 grain weight (g)	Oil content (%)	Protein content (%)
30-80-0	12.4	20.3	39.0
30-80-50	13.2	20.8	39.1
30-80-25/25	14.1	20.8	39.6
30-80-100	13.8	20.9	39.2
30-80-50/50	14.2	21.5	39.8
CD at 5%	0.24	1.14	NS

Source: Modified from Magen (1997)

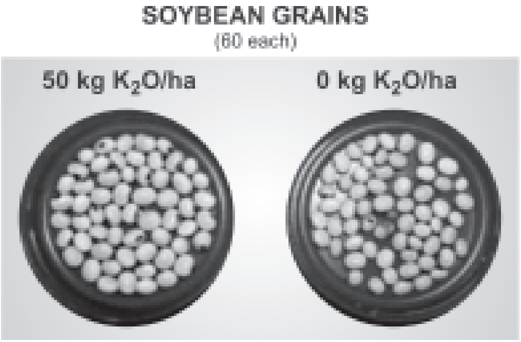

Fig. 6. Effect of 50 kg K_2O/ha applied to soybean crop. IPI-NRC for Soybean project in Indore, Madhya Pradesh (Photo by P. Imas)

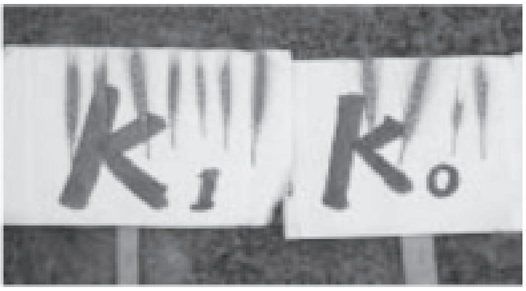

Fig. 7. Effect of K application on number of spikes in wheat. IPI-NRC for Soybean project in Amlah, Madhya Pradesh

Conclusion

Soybean is the premier oilseed crop of India presently covering an area of about 8.7 million ha, which is likely to produce over 9.0 million tonnes. It is predominantly grown in vertisols and associated soils of central India, which are generally rich in potassium. There appears to be an anomaly between the recommendation, uptake and actual application of potassium in case of soybean. Soil K levels in these soils also reveal the depletion. Soybean as well as soybean-wheat cropping system invariably responds favourably to potassium application up to 50-60 kg K_2O/ha, particularly when applied in two equal splits as basal and 50 per cent flowering. Other yield associated characters viz. number of nodules per plant, grain weight, grain per plant, etc. also increase on potassium application. Increased oil content in seed has also been reported. Potassium application has also been found to increase chlorophyll content and nitrate reductase activity and Fe-stress commonly exhibited by swell-shrink soils. Application of potassium in soybean also results in enhanced uptake of other major and some of the micronutrients. Several of these beneficial effects transcend the soybean crop and are carried along to other crops succeeding soybean. In addition to above response, resistance of soybean plants against major insect-pests of soybean viz. girdle beetle, semi-looper and aphids has also been realized. Being a quality element, it has also improved the seed appearance in case of soybean as well as wheat.

The supplementation of nutrients through fertilizer carriers is sub-optimal to this high energy acquiring crop. The information generated so far clearly brings out that the application of adequate and balanced quantities of nutrients can break the yield barrier of 1 tonne per hectare even in soils showing high level of available potassium. The information suggests that this is high time to reconsider the recommended level of K application to soybean crop to harness more quality seed contributing quality edible oil and support offsetting the import bill on oil and enhanced foreign income by increased exports of soya meal.

Since majority of research efforts have undergone to investigate soybean-wheat cropping system for K nutrition, there is need to further investigate other major cropping system soybean-chickpea widely adopted by the farmers and other intensive systems like early soybean-table potato/garlic/onion-late wheat, and less adopted but potential cropping systems like soybean-safflower and soybean-rapeseed-mustard. Some research efforts are also warranted on intercropping systems like soybean + pigeon pea/ maize/sorghum/finger millet, etc.

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Management of Potassium Nutrition in Soybean Based Cropping Systems in the State of Rajasthan

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Abstract

In Rajasthan, the magnitude of response to applied K varies with initial K status of the soils. If soil testing is low in available K, the responses are higher. The districtwise available potassium status and fertility index shows that soils of the area adopting soybean-wheat cropping system are medium in fertility index as well as in available potassium. Studies on potassium balance has lagged behind in the state because of the general impression that soils are well supplied with this element and that for most of the crops there is little need for potassium fertilizer. Though, the response of potash application in soybean based cropping sequences is not as spectacular as that of N, P and S but looking to its role in balance nutrition and maintenance of long term sustainability, it is essential to apply maintenance dose of K to all the soils and crops. The response of soybean-wheat cropping sequence to potassium in South-eastern part of Rajasthan which also covers command area clearly indicates the changing pattern of response over the years specially under irrigated conditions. This brings out the necessity to constantly monitor potassium status in order to take corrective measures for crop production. Further, it is an established fact that potassium improves water use efficiency and helps to maintain crop yields under moisture stress. Thus, the role of applied K at higher moisture tension should be publicized in full swing. The role of K in combating moisture stress needs special emphasis looking to the vast area of the state (71%) being under rainfed agriculture. Similarly, the reduction in the incidence of diseases like pod blight, bacterial leaf blight in soybean, and black rust of wheat also indicates for evaluating the need of potassium for sustainable crop production.

Introduction

Soybean has emerged as major oilseed crop and brought a dynamic socio-economic change across the world. The major soybean growing states in India are M.P., Maharashtra, Rajasthan, Karnataka and Andhra Pradesh. In Rajasthan, the area under soybean cultivation has increased to about 0.7 m ha during the year 2005-06 from 0.55 m ha during 2004-05. The districts covered under this crop are Kota, Bundi, Baran, Jhalawar and part of Chittorgarh and Banswara. Soybean-wheat is the main cropping system adopted by the farmers in Rajasthan. The productivity of these crops can be obtained by simultaneously improving nutritional and cultural practices, controlling of pests and diseases along with growing improved varieties. There are intricate interactions between these factors, which combine to give large increase in yield. Possibly, the most striking and widespread interaction for soybean-wheat production that found to exist between HYVs and fertilizers (Arnon, 1999). The requirement of potassium for normal growth and development in all living organisms is well established. Next to nitrogen and phosphorus, potassium is a limiting fertilizer element in Indian soils. The information that is available from other parts of the world indicates that wherever the application of nitrogen results in reduction of oil content, this adverse effect is corrected by the application of potassium.

Nutrient Use Patter n in Rajasthan

Rajasthan has total geographical area of 34.22 million hectare out of which cropped area covers 20.69 million hectare with cropping intensity of 123.2. The yield of soybean in the state vis-à-vis in the neighboring states of Madhya Pradesh and Maharastra are low. In Rajasthan, currently plant nutrient viz. N, P, K, Zn and S are of importance. The magnitude of response to applied K varies with initial K status of the soils. If soil testing is low in available K, the responses are higher. The contribution of fertilizer K in increasing crop yields over the years has improved. The state has shown progressive increase in fertilizer nutrient use over the years with current use of 0.78 million tonnes (N=0.56 mt; P_2O_5=0.20 mt; K_20=0.011 mt) or 36.55 kg/ha of cropped area (Table 1). Further, the total fertilizer consumption during 2003-04, was 22.94 kg/ha in *kharif* and 67.25 kg/ha in *rabi* which shows the ratio 61:28:1 and 48:14:1 in both the seasons, respectively. The consumption of potassium in soybean-wheat growing districts is given in Table 2.

Table 1. Fertilizer use pattern in Rajasthan ('000 t)

Year	N	P_2O_5	K_2O	Total
1995-1996	486.4	150.5	5.7	642.6
1999-2000	546.0	246.9	6.3	817.2
2003-2004	563.2	204.7	10.6	778.5

Table 2. District wise potash consumption in Rajasthan (2003-04)

District	Potash (K_2O) consumption (tonnes)		
	Kharif	*Rabi*	**Total**
Kota	379	1031	1410
Bundi	161	511	672
Baran	129	274	403
Jhalawar	34	223	257
Chittorgarh	231	628	859
Banswara	31	58	89
Udaipur	22	52	74

Potassium Status of Rajasthan Soils

The work conducted by various scientists on the status of potassium in different soil groups of Rajasthan is given in Table 3. The districtwise available potassium status and fertility index shows (Table 4) that soils of the area adopting soybean-wheat cropping systems are medium in fertility index as well as in available potassium.

Table 3. Potassium status in Rajasthan soils

Soil Group	Region/Forms of Potassium (me/100g) Total K	Water soluble K	Exchangeable / Available K	HCl-K	HNO_3-K	References
Arid soil	-	0.03- 0.13	0.14-0.82	1.70-8.00	0.54-1.85	Joshi *et al.* (1978)
Medium black	19.61-22.43	-	-	9.61-11.69	3.28-4.05	Lodha and Seth (1970)
Black soil	-	0.005-0.225	0.25-0.66	3.20-10.09	1.28-2.82	Bhati (1981)
Red and yellow	23.97-26.15	-	-	9.92-10.89	2.61-5.13	Lodha and Seth (1968)

Table 4. Districtwise available potassium status and fertility index of Rajasthan soils

K status	Fertility index	District
Tending to medium (TTM)	1.68 to 2.00	Bharatpur, Alwar, Barmer, Bikaner, Jaisalmer and Churu
Medium (M)	2.01 to 2.33	Ajmer, Jalore, Nagaur, Banswara, Udaipur, Dungarpur, **Kota, Bundi, Baran, Jhalawar, Chittorgarh,** Tonk, Bhilwara, Jaipur, Sawai Madhopur, Jhunjhunu and Sikar
High (H)	Above 2.33	Ganganagar

Table 5. Soil potassium status of soybean-wheat growing region of Rajasthan

District	No. of Samples analysed	Available Potassium status Low	Medium	High	Nutrient Index
Banswara	676	27.2	51.2	22.6	1.974
Chittorgarh	5,481	29.2	49.3	21.6	1.925
Bundi	580	13.6	61.8	24.6	2.110
Kota	4,231	21.2	60.2	18.6	1.974
State Average		26 %	52 %	22 %	

Soil Test Methods for Potassium

Among the various approaches used for assessment of nutrient requirements of crops, soil testing is most widely used tool for giving location and crop specific fertilizer recommendations. This includes appropriate laboratory test as an index of nutrient availability and calibration of test result with crop response from field trials. The most common method used for testing K in soils is extracting soil with 1 M ammonium acetate (pH 7.0) and classifying these into low, medium and high categories on the basis of test results and finally making fertilizer recommendations. Considerable work has been done on screening of soil test methods and approaches of K in Rajasthan soils (Swami and Lal, 1970; Bohra, 1980; Bhati, 1981; Mann, 1981; Yadav and Swami, 1984; Singh 1995; Swami *et al*. 1997 and Rathore *et al*. 2000). The critical limits and correlation between different K methods with dry matter yield, K content and K uptake is given in Table 6.

Critical Limits of Potassium

The deficiency, sufficiency and higher limits of potassium varied with the crop, variety location and soils. The soil critical limit of potassium in Vertic Ustochrepts of Western India was 145 kg/ha. Similarly, the critical concentration of K in the pod at 30 DAS and the same in haulm at harvest was 0.9 and 0.46 per cent, respectively. However, Hallmark *et al.* (1985) evaluated 0.14, 2.69 and 0.18 P/N, N/K and P/K ratios as DRIS norms respectively in soybean. These ratios may also be used to give fertilizer recommendation in the crop. Tandon (1993) suggested deficient, sufficient and high limits in soybean plants as 1.26-1.70,1.71-2.50 and > 2.51 %, respectively while Gill (1988) gave critical soil exchangeable K lev̄el as 0.10 to 16 Cmol kg^{-1} and 0.14 Cmol kg^{-1}, respectively for soybean.

Table 6. Co-efficient of co-relation between different K parameters and dry matter yield, K content and uptake

K soil test	Dry matter yield	K content	K uptake
Exchangeable K (0.370)	0.696*	0.602**	0.722**
Available K (0.440)	0.654**	0.596**	0.681**
Mogron's method (0.105)	0.677*	0.603**	0.637**
Mehlich reagent (0.490)	0.599**	0.530**	0.587**
DTPA-AB method (0.330)	0.707**	0.620**	0.665**

Figures in parenthesis are critical limit in me/100 gm soil;*significant at 5% level ;** significant at 1% level

Potassium Removal by Crop

The removal of potassium by oilseed crops varies from 30 kg by groundnut to 126 kg by sunflower per tonne of economic produce (Table 7). The removal of K by per tonne of soybean is 57 kg, while the recommended application rate of potassium for oilseed crops across the state varies from nil to 45 kg K_2O/ha under irrigated conditions. This shows a gap between removal and application of K. In general, the removal of potassium in oilseed crops involving cropping systems account for 40-50 % of the total nutrient uptake from all the crops put together.

Table 7. K removal by different crops

Crop	Area ('000 ha)	Production ('000 t)	Potassium requirement (kg)	Potassium removal (kg/tonne of produce)
Soybean	6312	6940	189	57.0
Groundnut	7632	8980	229	30.06
Rapeseed & Mustard	6859	6130	206	41.76
Sunflower	2000	1180	60	126.2
Sesame	874	670	26	64.18
Linseed	536	280	11	53.57

Response of Soybean to Applied Potassium

Oilseeds and cereals are energy rich crops and require relatively higher amount of nutrients for their optimal performance and yield. The amount of nutrient removal varies according to the genotype, productivity level/growing conditions, soil type and management. Paradoxically while their nutrient requirements are high, the general usage of N and P itself is sub-optimal than the recommended and potassium use is negligible due to popular belief that Indian soils are rich in potassium. The majority of soils of soybean-wheat growing areas come under medium category of nutrient index as well as K status indicating potential areas where use of K fertilizers expected to give increased efficiency of its utilization and profitable returns in crop production.

Swami and Yadav (1995) illustrated that out of total trials conducted on soybean, 75% trials gave positive response to the application of potassium. Similar case was with groundnut. However in mustard, the response was low (Table 8). The need for an appropriate balance between P and K was emphasized for soybean by Jones *et al* (1977). He suggested that in crop production an adequate level of K is required for obtaining maximum responses to added P.

The magnitude of response to applied K in Rajasthan varied with initial available K status of soils. In soils testing low in available K the magnitude of response was highest while in soils with medium K status, the responses were of intermediate order. Almost all types of crops have shown positive responses to applied potassium. In an experiment conducted at Agricultural Research Station, Kota during 2003 and 2004 on medium K containing soils the yield of soybean increased by 36.7 and 48.5 per cent over control (Table 9).

Table 8. Distribution of response of oilseeds to potassium application in India

Crop	Total number of trials	Positive response	No response	Negative response
Soybean	426	321 (75%)	82	23
Groundnut	702	524 (74%)	139	39
Mustard	354	28 (7.9 %)	-	326
Sesame	95	39 (41 %)	11	45
Sunflower	52	38 (73 %)	12	02

Table 9. Effect of potassium application in soybean

Treatment	Seed yield (Kg/ha)		
	2003	2004	Mean
Control	1181	1293	1237
K_{20}*	1502	1881	1692
K_{40}*	1542	1936	1739
CD at 5%	112	161	

* Irrespective of NP

Potassium Use in Wheat Grown After Soybean

In an experiment wheat grown after soybean responded to potassium applied @ 30 kg K_2O/ha in medium available K containing soils at Kota. However, non-significant difference in K response was obtained between K_{30} and K_{50} treatments

(Table10). Application of K at 60 kg K_2O/ha in conjunction with N and P gave positive response in augmenting the grain and straw yield of wheat over control (Table 11). Grain yield, N, P, K and protein content in grain were significantly higher with the treatment of 60 kg K_2O/ha (Gupta *et al.*, 2001). Similarly under AICRP, out of 76 trials conducted on cultivators field in Bundi district of Rajasthan involving various combination of N, P and K, where wheat was grown after soybean the mean response to K obtained at 30 kg K_2O over N_{60} P_{30} was 167 and at 60 Kg K_2O over N_{120} P_{60} was 104 kg/ha.

Table 10. Effect of K application in wheat after soybean

Treatment	Grain yield (q/ha)
Control	42.92
K_{30}	48.30
K_{50}	49.12
CD at 5%	3.12

Table 11. Effect of K on the yield and chemical makeup of wheat

K levels (kg/ha)	Yield (q/ha) Grain	Straw	Chemical make up of grain (%) N	P	K	Protein
K_{30}	33.94	53.65	2.36	0.612	0.513	13.46
K_{45}	38.11	54.56	2.39	0.642	0.516	13.67
K_{60}	39.50	56.10	2.37	0.709	0.531	13.51
CD (P=0.05)	1.88	0.55	0.021	0.013	0.005	0.086

Table 12. Response of wheat (kg/ha) to potassium on cultivator's fields in Rajasthan

District	No. of Expt.	Average response to $N_{60}P_{30}$	N_{120} P_{60}	$N_{60}P_{30}$ K_{30}	$N_{120}P_{60}$ K_{60}	Mean response to K at K_{30} over N_{60} P_{30}	K_{60} over N_{120} P_{60}
Bundi	76	1634	2666	1801	2770	167	104
Chittorgarh	56	780	1463	1079	2028	299	565

K Balance in Soybean Based Crop Rotation

In Rajasthan studies on potassium balance has lagged behind because of the general impression that soils are well supplied with this element and that for most of the crops there is little need for potassium fertilizer. However, some of the work conducted in neighboring states on soybean-wheat as being narrated here. Hegde and Sudhakara (2001) while comparing the fertilizer use and uptake of potassium at the current rate of recommendation stated that even at the highest K use efficiency (50), the contribution of added fertilizer potassium will be a mere 6.2 while the rest 93.8 of the uptake is supported from the soil and other sources. As most of the potassium is left in the stalks and the stalks without any economic value are being collected out of field during land preparation and those with fodder value are also removed, there is a serious negative balance of potassium in oilseeds production. The consequences of continuous cropping without potassium application resulted a negative net balance (-19.4 kg/ha) especially with soybean-safflower-sesame cropping sequence (Golakayia and Patel, 2001). Similarly experiment conducted at IISS, Bhopal for seven years showed 345-635 kg/ha total depletion of potassium under soybean-wheat cropping system because K applied was always less than the removal of K by the crops and the residues were not recycled (Table 13).

Table 13. Potassium balance in a vertisol after 7 years of continuous application of FYM in soybean-wheat cropping system (kg/ha)

Treatment	K additions through fertilizer			Crop	K	K Depletion		
FYM ($t\ ha^{-1}$)	FYM	Fert.	Total	removal	balance	0-15 cm	16-30 cm	Total 0-30 cm
0	0	430	450	1124	- 694 (99)	-585	-50	-635
4	196	430	626	1372	- 746 (106)	-660	-20	-680
8	392	430	822	1530	- 708 (101)	-600	-80	-680
16	784	430	1214	1680	- 466 (66)	-355	+10	-345

Potassium Management in Soybean-Wheat Cropping Sequence

Results of fourteen years of experimentation on potassium management in soybean-wheat crop rotation revealed that an increase of 47.8 % was observed when potassium was applied with N and P. The increase was 26.5% under the similar conditions in sunflower-soybean crop rotation (Kunau, 1990). This established the role of K in balance nutrition for crop sequences. The experiment conducted under AICRP soybean at ARS, Kota further showed the role of K in balance nutrition of soybean-wheat cropping sequence by increasing the yield of soybean by 11 per cent and that of wheat by 8 per cent when basal application of potassium was raised from 20 to 40 kg K_2O/ha in combination with different doses of N and P (Table 14).

Table 14. Nutrient management for sustainability of soybean-wheat cropping system

Fertility levels	Soybean Seed Yield (kg/ha)					Wheat Yield (kg/ha)					Wheat equivalent Yield (kg/ha)			
	2000	2001	2002	2003	Mean	2000-01	2001-02	2002-03	2003-04	Mean	2000	2001	2002	Mean
$N_{40}:P_{40}:K_{40}$	1914	2632	1549	2045	2035	4904	5880	5380	5742	5476	5545	5716	5462	5574
$N_{20}:P_{20}:K_{20}$	1702	2432	1353	1847	1834	4510	5397	5040	5380	5082	4973	5035	5018	5009
No F (Control)	1322	2149	1050	1650	1543	4095	4650	4091	4697	4483	4243	4389	4025	4219
CD (P=0.05)	133	119	108	112		144	168	335	218		296	395		

Though, the response of potash application in soybean based cropping sequences is not as spectacular as that of N, P and S but looking to its role in balance nutrition and maintenance of long term sustainability, it is essential to apply maintenance dose of K to all the soils and crop. The response of soybean-wheat cropping sequence to potassium in South-eastern part of Rajasthan which also covers command area clearly indicates the changing pattern of response over the years specially under irrigated conditions. This brings out the necessity to constantly monitor potassium status in order to take corrective measures for crop production. Further, it is an established fact that potassium improves water use efficiency and helps to maintain crop yields under moisture stress. Thus, the role of applied K at higher moisture tension should be publicized in full swing. The role of K in combating moisture stress needs special emphasis looking to the vast area of the state (71%) being under rainfed agriculture. Similarly, the reduction in the incidence of diseases like pod blight, bacterial leaf blight in soybean, and black rust of wheat also indicates for evaluating the need of potassium for sustainable crop production.

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Management of Potassium Nutrition in Soybean Based Cropping Systems

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Abstract

Cultivation of soybean has been increasing rapidly and now it has made unique place among the traditional oilseeds in the country because of its diverse adaptability, high protein content, better oil quality and multiple uses. On account of its agronomic suitability, is being grown extensively as pure, inter, relay or sequence crop. Presently, it is first in area and production among oilseed crops grown in the country and productivity level raised from 426 kg/ha (1970) to 1208 kg/ha (2003-04). However, the average productivity is still very low in comparison to other countries and unbalanced fertilizer application is attributed as one of the reason. Moreover, the nutrient use pattern under this system is inadequate and mainly dominated by N and P fertilizer. The potassium is considered as one of the most essential nutrient, especially the available form and has been found to be very crucial for plant growth. Balance nutrition supply (NPK) to soybean-wheat system gave response varying from 537-1719 kg/ha over control. The corresponding values of agronomic efficiency ranged between 11 to 28 kg grain/kg nutrients. The Site Specific Nutrient Management (SSNM) approach gave 12 to 86 per cent and 104 to 312 per cent soybean and wheat yield, respectively in a system over the state recommendation.

Introduction

Presently, soybean is the most important oilseed crop of India. It has shown phenomenal growth in area, which increased from 30,000 ha in 1969 to 6.5 m ha in 2003-04 (FAI, 2004). The per cent share of soybean to total oilseed production was 23 during 1995-96, which got increased to the tune of 32.5% by end of 20th century (Fig.1). The pre-dominant soybean growing states are Madhya Pradesh (47%), Maharashta (15%) and Rajasthan (9%). It is also referred as "Miracal crop" mainly due to its high protein (38-42%) content, moderately balanced amino acid, oil content (18-22%) and 20-30% extractable substance (FAO, 1982). These factors make soybean an integral component of human diet and cattle feed in Asia.

In addition, its high agronomic suitability and economic feasibility led to grow it as pure crop as well as intercrop with maize, pigeonpea and cotton. Soybean leaves considerable residual effects to the succeeding crop, with respect to better physical conditions and improves soil fertility, which is of special importance for Indian soil (Kalwe and Rani, 2005). An analysis of production trend over a decade 1984-1994 encompassing the productivity growth rate as 15-20% per annum resulted mainly due to sizeable growth in area and production of soybean to the tune of about 4.6 and 5.7 times, respectively (Table 1).

Table 1. Growth and sources of growth in soybean production in India

Particulars	Area (000, ha)	Production (000, tonnes)	Yield (kg/ha)
Triennium average (up to 1984)	743	524	708
Triennium average (up to 1994)	4176	3503	827
Absolute increase	3466	2979	119
% Increase	462	569	17
% Increase due to yield		18	
% Increase due to area		82	

The increase in productivity per ha accrued was only 1.17 times. The contribution towards total production by area and productivity was 82% and 18%, respectively. It has been realized that its productivity has not been improved adequately and imbalance supply of plant nutrients in general and ignorance of K from fertilization schedule in particular. It is, therefore, well understood that unless soybean is provided with required fertilizer input to produce sufficient biomass it is not expected to generate high yields.

Major Cropping Systems Involving Soybean

Large area under soybean is spread over central Indian niche covering Madhya Pradesh, Maharashtra, and Rajasthan states. Generally, it is grown as a monsoon season crop under rainfed situation mainly under vertisols and associated soils. It has resulted increased cropping intensity and profitability. On account of its coincidence with rainy season and relatively good yield than other *kharif* crops under rainfed conditions it has replaced less remunerative crops like sorghum and minor millets, etc. Now its cultivation has spread to northern and southern regions also and efforts are being made to increase its yield potential by genetic and agronomic manipulations.

Soybean in peninsular and northeastern region is grown during *rabi*/ spring season (November to April). In Bundelkhand and Malwa region, its cultivation is largly practiced in rainy season followed by rapeseed, mustard/ wheat on conserved soil moisture. Under irrigated conditions, soybean is largely grown in soybean-wheat cropping system, while soybean-chickpea cropping system is prevalent under rainfed situations. Apart from this, cropping systems like soybean-potato, soybean-sunflower, soybean-rapeseed and mustard, soybean-garlic systems are found highly remunerative in terms of equivalent yield, income and soil fertility. Some of the predominant soybean based cropping systems are being given in Table 2.

Soybean is also grown successfully as intercrop owing to its several virtues like comparative tolerance to drought and shade, efficient light and moisture utilization, ability to fix atmospheric N.

The most common soybean intercrops are cotton in Maharashtra and Madhya Pradesh, maize in Himachal Pradesh and Uttarakhand and finger millets in Tamil Nadu.

Nutrient Requirement of Soybean Based Systems

As discussed, productivity of soybean is low due to inadequate and unbalanced use of fertilizers. Since major area of this crop (> 70%) falls under rainfed, poor fertility and lack of fertilizer use conditions. Being oil and energy rich crop, its requirement towards major and micronutrients is very high. A soybean crop producing 2217 kg grain/ha removed 71 kg N, 31 kg/ha P_2O_5, 57.7 kg/ha K_2O, 6.7 kg/ha S, 14 kg/ha Ca, 7.6 kg/ha Mg, 77 g/ha Zn, 346 g/ha Fe, 83 g/ha Mn and 30 g/ha Cu (Tandon and Sekhon, 1988; Pasricha and Tandon, 1993).

Table 2. Soybean-based cropping sequences and intercropping systems

Zone	Cropping sequence		Inter-/mixed-/companion cropping
Central	Major:	Soybean-chickpea (R)	Soybean + pigeon pea
		Soybean-wheat (I)	Soybean + corn
	Others:	Soybean-potato (I)	Soybean + sorghum
		Early soybean-garlic (I)	Soybean + cotton
		Soybean-pigeon pea (R)	Soybean + groundnut
		Early soybean-safflower (R)	Soybean + pearl millet
		Early soybean-rapeseed/mustard	Soybean in fruit (mango/guava orchards)
Southern	Major:	Soybean-wheat-groundnut (I)	Soybean + pigeon pea
		Soybean-finger millet-beans (I)	Soybean + finger millet
		Wheat-soybean-finger millet-peas (I)	Soybean + sorghum
			Soybean in fruit (mango/guava orchards)
Northern Plain	Major:	Soybean-wheat (I)	Soybean + pigeon pea
		Soybean-potato (I)	Soybean + corn
		Soybean-chickpea (R)	Soybean + sorghum
			Soybean in fruit (mango/guava orchards)
Northern	Major:	Soybean-wheat (I)	Soybean + corn
		Soybean-peas (I)	Soybean + pigeon pea
	Others:	Soybean-lentil (R)	
		Soybean-toria (R)	

I= Irrigated; R= Rainfed

Source: Tiwari and Joshi, (2002)

The projected estimates of major nutrients for oilseed production by 2010 to satisfy more than one billion population of the country will be 49.4 m tonne and about 6 m tonne of plant nutrients (2.90 m tonne N, 1 m tonne P_2O_5 and 2.4 m tonne K_2O) would be the crop removal. Further estimate also indicate that soybean has to share 17% of total production, which needs 0.76 m tonne N, 0.17 m tonne

P_2O_5 and 0.55 m tonne K_2O (Table 3). Under these circumstances, it is not possible to increase oilseed production from its present state to the target fixed by 2010 unless one goes by the attainable yields demonstrated by adoption of full package of improved practices, which can be adopted by farmers on millions of hectares.

Table 3. Nutrient removal by rainfed oilseed crops

Crops	Production from unirrigated areas		Nutreint uptake (kg/ tonne grain)			Nutrient removal (000, tonnes)		
	000, tonnes	% of total	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Groundnut	6.121	76	58.5	17.3	23.9	358	106	146
Rapeseed/ mustard	1.452	35	54.1	25.0	70.1	79	37	102
Soybean	1.889	78	75.0	16.5	54.8	142	31	104
All oilseeds	11.467	66	-	-	-	682	224	525
Pulses + oilseeds	-	-	-	-	-	1251	380	1095

Source: Katyal and Reddy (1997)

It is pronounced that about 80-90% of N need of the legume crops could be contributed through biological nitrogen fixation (BNF) under good management practices. Since soybean is grown mainly under rainfed condition in India, where BNF is unlikely to contribute such huge amount of N. Thus results presented in various reports, suggested that contribution of phosphate solublising bacteria and organic sources with higher use efficiency due to good agronomic management practices will be half of the total P requirement (Katyal and Reddy, 1997; Reddy and Sudhakar Babu, 1997). Similarly, 80% of K requirement can be met through organic sources, the remaining has to come from mineral fertilizers. Again critical appraisal of the nutrients removal and oilseed production revealed that a large quantity N, P_2O_5 and K_2O (142, 31, 104 thousand tonnes) will be removed to produce 1.9 thousand tonnes soybean production (Table 3). Thus it is clear that for sufficient biomass and sustained potential yield, optimum and balanced supply of nutrients seems a priority.

Potassium Management in Soybean Based Cropping Systems

Amongst, three major nutrients (N, P and K), K seems to have the greatest effect on oil biosynthesis. Potassium being an essential element helps to over come the environmental impediments e.g. drought, waterlogging, salinity and low/ high temperature by forming organometallo complex which in turn saves tissues and plant organs by regulating hydration, synergistic and antagonistic reactions and endergonic process in cells. It further helps to regulate stomatal movement and control water loss through osmo-regulation. However, under saline and alkaline conditions, K competes with Na, and maintain low N:K ratio and induces tolerance through stabilizing chemiosmotic potential in plants. Despite this, the essentiality of K has been found to be indispensable in biophysical process such as activation of bio-chemical reaction, chemi-osmotic energy regulation especially to ovate the injuries of stresses environment (Dwivedi *et al.*, 1992). Since major area of soybean falls under rainfed situations, potassium plays vital role to counter a biotic stresses.

Potassium use in soybean is quite low as evident from negative balance between K removal by soybean (0.55 m tonne) and almost nil addition (Tiwari *et al.*, 2003). On-farm studies conducted under AICRP on CS and several other field trails have confirmed that soybean cultivation using optimum level of N and P but with low rate or no application of K results in low yield and depletion of K reserve from soil (Kalwe and Rani, 2005). Data from the long-term (27 years) fertilizer experiments in India (Table 4) clearly show that over a long term the response to N (in the absence of P and K) decreased, while the response to P and K increased over time. This shows that in areas where crops are fertilized with heavy doses of N without adequate P and K application, there is heavy mining of soil P and K and adequate replenishment of primary plant nutrients is necessary to sustain crop production (Prasad, 2005). This further affect the declining factor productivity of nitrogen at several locations of AICRP-CS (Yadav, 1998). Research evidences from centers of AICRP-CS indicating a linear yield trend with increasing K rates 0 to 60 kg/ha at Kota, and 0 to 40 kg/ha at Sehore and Indore in soybean-wheat sequence. The production functions fitted to the soybean and wheat grain yield showed quadratic type of curves (Fig. 2). The optimum K fertilization rates (K_{opt}) for soybean as computed from the quadratic curves, were 54.5 kg/ha at Kota, 56.4 kg/ha at Sehore and 60.8 kg/ha at Indore. The corresponding optimum K rates for succeeding wheat were 52.4, 55.0 and 48.4 kg/ha, respectively.

Table 4. Changing nutrient ratio (kg grain/kg nutrient) for primary plant nutrients (PPN) under soybean-wheat system

Soil and crops	Nitrogen		Phosphorus		Potassium	
	1973-77	1992-96	1973-77	1992-96	1973-77	1992-96
Ranchi (Alfisols)						
Soybean	-10.4	-8.4	6.1	10.6	4.1	20.6
Wheat	-7.8	-1.4	29.9	38.2	1.0	15.9
Jabalpur (Vertisol)						
Soybean	-26.0	8.4	7.9	7.7	2.9	13.7
Wheat	7.0	0.5	20.2	41.1	8.4	6.0

Source: Swarup and Srinivasa Rao (1999)

Studies further revealed that oil content of soybean was negatively correlated with N rates and positively with P and K rates (Hegde and Sudhakarbabu, 2004). Increasing NPK rates from 100 to 150% under yield maximization trials conducted under AICRP-CS also confirmed the significant positive effect on soybean yield and oil content (Anonymous, 1995-1999). These results were in close conformity with the results of other studies wherein use of K in appropriate balance of other nutrients helps in avoiding excesses and deficiencies of nutrients and produces good quality (Brulsema, 2001).

Means to Enhance K Use Efficiency Under Soybean Based Cropping Systems

Balanced fertilization

The concept of balanced nutrition for sustainable productivity of soybean-based cropping system is yet to sink into the minds of researchers and growers. One conspicuous reason of low use of P and K fertilizer was because of decontrol of these fertilizers. This led the high N use causing more mining of P, K, secondary and micro-nutrients. Presently, most of the farmers are applying di-ammonium phosphate for supplying N and P. This leads to non-addition of essential elements such as K and S to the system, which ultimately affect the productivity of soybean.

Field experiments conducted at cultivators' field under AICRP-CS indicated that balance NPK nutrition under soybean-wheat system enhanced the system productivity by 12%, 23%, 19% and 10% at Chindewara, Wardha, Nagpur and Tikamgarh, respectively over treatment kept devoid of K (Table 5). The agronomic efficiency (AE) computed for kg grain/kg nutrient applied were also improved with K application in balanced nutrition and the highest efficiency was noticed at Tikamgarh.

Alike soybean-wheat system, on-farm results of K application along with N and P under soybean-*Jowar* at Ambajogoi, and soybean-potato and soybean-chickpea at Wardha also had tremendous response over NP alone. The corresponding yield gain in soybean due to K nutrition was to the tune of 2.03 to 3.81 q/ha, respectively (Table 6). The succeeding wheat also benefited due to balanced nutrition and had additional yield of 3.55 to 12.4 q/ha. The results further suggest the synergistic effect of P and K nutrition on system productivity at all the locations. Among different cropping system, higher K use efficiency was recorded under soybean-potato system, possibly due to higher K requirement of potato crop in the system.

Site-specific nutrient management (SSNM)

The results of diagnostic survey conducted in a collaborative project under AICRP-CS and IRRI-IPNI revealed that for a wide range of soils and cropping systems the farmer apply more than the recommended doses of nitrogen and phosphorus , but ignore replenishment of the other nutrients. The main reason for the not use of other elements was unawareness about the benefits of other major and micro-nutrients. Secondly, the farmers were well acquainted about the benefits of K application but availability was identified as limitation. The unbalanced use of fertilizers not only aggravates the deficiency of potassium (K), sulphur (S) and micronutrients in the soil, but it also proves uneconomic and environmentally unsafe (Dwivedi *et al*., 2006; Singh *et al*., 2006). To realize high yield of most of the crops with the cultivation of HYVs, the SSNM approach has been considered as a useful option. The SSNM considering indigenous nutrient supply of the soil and productivity targets is a strategy that may provide sustained high yield on one hand and restoration of soil fertility on the other hand (Doberman *et al*., 2004).

Table 5. On-farm productivity of soybean- wheat system as influenced by balanced nutrient management options

Nutrient	Grain yield (kg/ha)			Response (kg grain/ ha)			Agronomic efficiency (kg grain /kg nutrient)		
applied	Soybean	Wheat	System	Soybean	Wheat	System	Soybean	Wheat	System
Chindewara									
Control	992	1959	2951	-	-	-	-	-	-
N	1198	2453	3651	206	494	700	-	-	-
NP	1493	3049	4541	295	596	891	8	23	15
NK	1314	2874	4188	116	421	537	7	13	11
NPK	1652	3454	5106	159	406	565	9	17	13
CD	61	124	-	-	-	-	-	-	-
Wardha									
Control	1090	1538	2628	-	-	-	-	-	-
N	1435	2103	3538	345	565	910	-	-	-
NP	1766	2577	4342	331	474	805	10	22	15
NK	1741	2585	4325	306	482	788	12	11	12
NPK	2084	3238	5322	319	661	980	11	18	15
CD	153	179	-	-	-	-	-	-	-
Nagpur									
Control	1292	2077	3369	-	-	-	-	-	-
N	1586	2646	4232	294	569	863	-	-	-
NP	1863	3088	4951	277	442	719	8	20	13
NK	1922	3144	5066	336	498	834	13	12	12
NPK	2283	3608	5891	420	520	940	12	15	14
CD	178	158	-	-	-	-	-	-	-
Tikamgarh									
Control	924	3506	4430	-	-	-	-	-	-
N	994	4360	5354	70	854	924	-	-	-
NP	1292	5781	7073	298	1421	1719	9	55	28
NK	1057	4863	5920	63	503	566	4	15	11
NPK	1460	6301	7761	168	520	688	9	33	22
CD	29	105	-	-	-	-	-	-	-

The SSNM approach enables to enhance the productivity level substantially. It has further been noticed that present level of production can be accrued from less area by following SSNM and area saved could be utilized for diversification by growing other high value crops. The results of the field experiments on soybean-wheat system conducted during 2004-06 under AICRP-CS by following SSNM concept at Kota, Sehore and Indore have shown discernible advantages for attaining high productivity level of soybean (16 to 21 q/ha) and wheat (57 to 74 q/ha) as against existing state average of 11 to 14 q/ha for soybean and 18 to 28 q/ha for wheat. The magnitude of increase over state recommended dose of fertilizer to the system varied between 8-27% in soybean and 18-36% in wheat at these locations (Table 7). The main advantage attributed through SSNM was due to restoring of soil fertility through restricting the drain of native nutrient reserves. The ensured availability of all required nutrients in time, and space are considered crucial to achieve the target yield levels.

Table 6. On-farm productivity of different soybean based cropping systems as affected by balanced nutrient management

Nutrient applied	Grain yield (kg/ha)			Response (kg grain/ ha)			Agronomic efficiency (kg grain/kg nutrient)		
	Ist crop	IInd crop	System	Ist crop	IInd crop	System	Ist crop	IInd crop	System
Ambajogoi, Soybean- Jowar system									
Control	1071	1266	2337	-	-	-	-	-	-
N	1216	1553	2769	145	287	432	-	-	-
NP	1323	1711	3034	107	158	265	4.1	8.8	6.0
NK	1326	1811	3137	110	258	368	4.4	7.8	6.3
NPK	1567	2066	3633	244	355	599	6.9	10.1	8.5
CD	48	103	-	-	-	-	-	-	-
Wardha, Soybean-Potato system									
Control	1778	7138	8916	-	-	-	-	-	-
N	2019	10138	12157	241	3000	3241			
NP	2500	12425	14925	481	2287	2768	14.6	48.7	34.6
NK	2297	11200	13497	278	1062	1340	11.1	17.1	15.4
NPK	2703	13663	16366	203	1238	1441	11.8	32.3	25.2
CD	96	679	-	-	-	-	-	-	-
Wardha, Soybean-chickpea system									
Control	1469	1263	2732	-	-	-	-	-	-
N	1675	1744	3419	206	481	687	-	-	-
NP	1950	1924	3874	275	180	455	8.3	10.6	9.1
NK	1941	1956	3897	266	212	478	10.6	17.0	11.4
NPK	2331	2344	4675	381	420	801	11.3	17.6	13.7
CD	85	123	-	-	-	-	-	-	-

Source: AICRP-CS Report

Table 7. Comparative performance of different nutrient management option on productivity of soybean-wheat system

Nutrient management option	Soybean			Wheat		
	Kota	Sehore	Indore	Kota	Sehore	Indore
Site- specific nutrient management	1567	1872	2100	5700	6191	7380
State recommendation (SR)	1452	1592	1654	4844	4988	5429
State average (SA)	1400	1130	1130	2794	1789	1789
% Increase over SR	8	18	27	18	24	36
% Increase over SA	12	66	86	104	246	312

Source: AICARP-CS Annual Report

Integrated plant nutrient supply system (IPNS)

Large inputs of plant nutrients are needed in multiple cropping systems to attain high productivity and sustain it over long periods. Organic manures cannot alone meet the heavy demands of nutrients because of their limited availability and restricted nutrient supply. A complementary use of organic manures and mineral fertilizers may meet the goal of adequate and balanced supply of required N, P, K, S and micronutrients to crops.

Table 8. Effect of inorganic and organic sources of nutrients on seed quality and productivity of soybean (Pooled of two years)

Treatment	Seed quality		Seed yield (q/ha)
	Crude protein (%)	Oil content (%)	
Control (inoculated)	34.42	19.03	6.89
25 Kg N/ha	37.92	16.00	9.25
50 Kg N/ha	37.04	18.72	8.94
5 t FYM/ha	35.73	19.23	8.00
1 t neem cake/ha	35.44	17.03	10.72
25 Kg N + 1 t neem cake/ha	37.92	18.85	15.17
50 Kg N + 1 t neem cake/ha	37.04	19.65	12.33
25 Kg N + 5 t FYM/ha	38.06	16.83	15.67
50 Kg N + 5 t FYM/ha	37.63	18.17	12.03
Recommended NPK (20:60:40)	38.94	18.92	13.25
CD at 5%	NS	1.78	2.72

Source: Saxena *et al.* (2001)

The soybean seed yield with 25 kg N + 1 tonne neem cake/ha and recommended NPK was significantly more than the other only chemical and organic source of nutrition (Table 8). Besides increase in yield, neem-cake also helps in reducing insect-pest population. Another study conducted under AICRP-CS also confirmed that soybean equivalent yield was highest only in the treatments where organic and inorganic sources were judiciously applied. (Anonymous, 1995-99).

Table 9. Removal and addition of K during 27 crops cycle of soybean-wheat-maize (fodder)* cropping system

Treatment	Fertilizer K added in 27 crop rotation (kg/ha)	Available K (kg/ha)		Total K uptake (kg/ha)	Contribution of non-exchangeable K (kg/ha)	% Contribution of non-exchangeable K
		Before cropping (1971)	Afer cropping (1999)			
Control	0	370	252	3247	3129	96.4
100%	0	370	263	4418	4311	97.6
100% NP	0	370	235	10067	9932	98.7
100% NPK	2117	370	308	11826	9647	81.6
100% NPK + FYM	4142	370	324	14094	9906	70.3

*Maize crop was discontinued in the system since 1995

Source: Singh and Swarup (2000)

Long-term studies conducted on integrated nutrient management in soybean-wheat system revealed that continuous use of 5 tonnes FYM along with recommended NPK for 27 crop cycle not only restricted K mining by reducing non-exchangeable K contribution to grain formation but also enhanced K uptake to the system (Table 9). On this basis, recommendations for balanced nutrient supply through IPNS approach for central plateau and hills, and western plateau and hills have been made for high yield realization (Table 10).

Table 10. Package of IPNS recommendations practices for soybean-wheat system

Zone	Fertilizer recommendation	IPNS package
Central plateau and	Soybean: 20 Kg N + 60 Kg P_2O_5 + 20 Kg K_2O/ha + B + S	Soybean: 10 kg N + 25 Kg P_2O_5 (through Boronated SSP) + 4 t FYM + *Rhizobium* + 25 kg zinc sulphate/ ha in alternate year
Hills	Wheat: 120 kg N + 60 kg P_2O_5 + 40 kg K_2O/ha	Wheat: 90 Kg N + 45 kg P_2O_5 /ha (through SSP)
Western plateau and hills	Soybean: 20 Kg N + 60 Kg P_2O_5 + 20 Kg K_2O/ha + B + S	Soybean: 10 kg N + 25 Kg P_2O_5 (through Boronated SSP) + 4 t FYM + *Rhizobium* + 25 kg Kg zinc sulphate/ha in alternate year
	Wheat: 120 kg N + 60 kg P_2O_5 + 40 kg K_2O/ha	Wheat: 90 Kg N + 45 kg P_2O_5 /ha (through SSP)

Conclusion

The nutrient use pattern under different soybean based systems is not only inadequate but also dominated by N and P fertilizers and use of K fertilisers is neglected in most cases. K additions through the prevailing practices of manuring and residue recycling, as well as the meagre inputs through K fertilisers, are not enough to match the K removal by the system, leading to negative K balance of varying extent in the soils. For realizing high yield of soybean (2-2.5 t/ ha), balance supply of nutrients (NPK and S) is a priority and must be followed at extensive scale.

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Nutrient Management of Soybean in Non-traditional Areas of Northern India

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Abstract

The soybean which is grown extensively in states like Madhya Pradesh, Maharashtra and Rajasthan could not become an established crop in northern part of the country due to low productivity, lack of assured marketing system, non-availability of package for its successful cultivation, limited mechanization, lack of promotion for domestic utilization of soybean as a food and feed and lack of remunerative support price to compete with profitability from rice crop. It has been observed that regular application of FYM and NPK fertilizers increased the crop yield substantially. The response of crop to application of sulphur and zinc on deficient soils has also been reported. The prospects to increase area under soybean in non-traditional area of northern part of country seem to be good provided that its productivity is to be increased to nearly 3 tonnes per hectare.

Introduction

Soybean (*Glycine max)* designated as 'golden bean' rich in protein (40%) and moderate in cholesterol free oil (20%) has established its potential as an industrial vital and viable oilseed crop in India. It is grown extensively in Madhya Pradesh, Maharashtra, and Rajasthan and in some parts of Karnataka, Uttar Pradesh, Tamil Nadu and Andhra Pradesh as a pure and/or intercrop (Rao *et al*., 1995 ; Singh *et al.,* 2002). It is grown on an area of 8.0 m ha with the production of 7.5 m t and the production is likely to increase to 18.0 m t by the year 2025. It has the potential to bridge the gap between the demand and supply of edible oil and protein. India's unusually rapid development of soybean is based on a highly area-specific expansion.

The rice-wheat is the predominant cropping system in Northern India, particularly Punjab. However, the cultivation of rice in this region resulted in severe ecological imbalance (Aulakh *et al*., 2001). The overexploitation of groundwater is causing the drastic decline in the level of groundwater (Hira and Khera, 2000). Thus, there is a need to shift a substantial area under rice cultivation to another high value crops like soybean. The prospects to increase area under soybean in northern part of country seem to be good provided that its productivity is to be increased to nearly 3 t/ha. Being a legume it can fix approximately 125-150 kg N/ha (Chandel *et al*., 1989), thus may add nutrient to soil and also improve the physico-chemical properties of soils (Saraf and Patil, 1995).

Lack of soybean to become an established crop in northern India seems to be due to low productivity, lack of assured marketing system, non-availability of package and practices for its cultivation, limited mechanization, lack of promotion for domestic utilization of soybean as a food and feed and lack of remunerative support price to compete with rice. The present paper is an attempt to review the research conducted in northern states of India on nutritional management of soybean crop.

Integrated Nutrient Management (INM)

The crop production system will be sustainable if it maintains or improves the soil quality .The basic concept underlying the principles of INM is maintenance and improvement of soil fertility for sustainable crop productivity on long term basis. This may be achieved through combined use of all natural resources, nutrients and their scientific management for optimum growth of crop in a cropping system.

The plant stand of soybean grown on a sandy soil increased with the application of 4 t wheat straws by 104 and 269% during two years compared with the unmulched control. In a loamy sand soil deficient in N, seed inoculation with *Rhizobium* increased seed yield from 0.84 t/ha with the untreated control to 1.42 and 2.18 t/ha with inoculation or inoculation + mulch, respectively. Mulching without inoculation was not effective (Sekhon and Kaul, 1978).

The crop rose under the influence of *B. japonicum* and *B. japonicum* + phosphorous solubilizing bacteria (PSB) significantly increased seed yield by 8.36 and 10.67%, respectively, over no inoculation. Also the *B. japonicum* + PSB treated plots had the highest available N and P content in soils. Between inoculants, *B. japonicum* proved superior in improving available N status of soil over PSB, but for available P, PSB proved superior over *B. japonicum*. The productivity and profitability of soybean were influenced by *Bradyrhizobium* inoculation along with nitrogen and potassium application. The plant height, leaf area index, number of nodule per plant, nodule dry weight, and nitrogenase activity was highest with *Bradyrhizobium* inoculation (Praharaj and Dhingra, 2003).

Soybean contributes considerable biomass of N to the soil through left over biomass. The left over biomass of soybean comprised of shatter leaves (after senescence) and nodulated roots, in addition to organic biomass contributed through fine root decay and exude during the growing period. Leaf fall during crop legume development and the nodulated roots can each contain up to 40 kg N/ha (Bergersen *et al.*, 1989; Buresh and De Datta, 1991) and yield benefit of the succeeding non legume crops are very often attributed to the residue fixed N locked in the left over crop biomass.

Annual biomass N input to soil from soybean through leaf fall, roots and nodule varied from 3.55 to 36.49, 14.10 to 47.69 and 2.98 to 15.21 kg/ha, respectively (Table 1). Continuous application of farmyard manure (FYM) @ 10 t/ha in combination with recommended dose of NPK increased N input to the soil. Annual total N input to soil through all sources (left over biomass) of soybean with the application of NPK+ FYM was 99.4 kgN/ha against 20.6 kg N/ha in control. Continuous addition of N through FYM and left over biomass of soybean over the period of 27 years not only resulted in marked increase of total N content in soil but also caused significant reduction in C: N ratio (Ved Prakash *et al.*, 2002a).

Annual addition of biomass through leaf fall, roots and nodules was 144 to1254, 641 to 2338 and 73 to 313 kg/ha, respectively under rainfed soybean cropping system. Regular application of farmyard manure in combination with NPK showed significant increase in total biomass addition to the soil. On an average, the leaves, root and nodules of soybean contained 37.8, 34.2 and 31.5% carbon, respectively.

Application of P fertilizer to both soybean-wheat cropping system (Tanwar *et al.*, 2004) maintained the proper soil health and balance sheet of nitrogen and phosphorus. However, application of FYM at 10 t/ha (with and without PSB) improved the N status of the soil but the P status at the end of system was less over initial status. The magnitude of depletion of P decreased with the higher levels of its application.

Table 1. Average annual N input to the soil from left over biomass of soybean under different fertilizer and manurial treatments

Treatments	Average biomass addition to soil (kg ha^{-1}) through			Annual N input (kg ha^{-1})				Average N input to soil for each kg
	Leaf fall	Root	Nodule	Leaf fall	Root	Nodule	Total	seed produced (g N kg^{-1} seed)
Control	144	641	73	3.55	14.10	2.98	20.63	31.64
NP	390	1016	117	8.81	21.54	5.01	35.36	36.08
NK	132	772	90	30.5	12.97	2.93	18.95	26.67
NPK	836	1437	220	20.56	23.99	8.62	53.17	32.73
N-FYM	1137	1729	259	32.17	35.79	9.50	77.46	33.65
NPK-FYM	1254	2338	313	36.49	47.69	15.21	99.39	35.80
Mean	648	1322	178.7	17.43	26.01	7.37	50.82	32.76
CD (P=0.05)	57.4	122.5	18.6	2.16	2.35	1.04	4.96	3.11

Source: Ved Parkash *et al*. (2002a)

Nitrogen Management

In legumes, heavy dose of nitrogen is not generally recommended, because they are able to grow well on soil nitrogen, nitrogen stored within cotyledons and derived from nitrogen fixation. A soybean crop yielding 2.5 t/ha is estimated to absorb 125 kg N, 43 kg P, 101 kg K, 22 kg S, 35 kg Ca and 19 kg Mg (Tandon, 1990). Therefore, a more balanced approach in respect to crop nutrition is needed on high N-fertile soils but in a low to moderately fertile soils, an efficient strain followed by proper crop nutrition management will fulfill the above constraints. With the proper fertilizer management practices it is possible to target the soybean yield up to 3.0 t/ha (Verma and Bhagat, 1996).

Time of N application

Productivity of soybean was also affected by the time of N application (Ralli and Dhingra, 2003). Application of N at the later stages of crop growth on a loamy sand soil at Ludhiana had no significant effect on number of pods and pod weight per plant. Similarly, other parameters remained unaffected. Straw yield increased significantly when N was top dressed at pre-flowering (8.2%), flowering (15.1%) or pod formation (16%) stage. Harvest index decreased significantly when N was top dressed at the later stages of crop growth.

Application of 60 kg N/ha resulted in 22.1 and 21.1% increase in seed yield during the first and second year over 30 kg N/ha (Table 2). The oil and protein contents of seeds remained at par at all levels of N, while oil and protein yields increased significantly up to 60 kg N/ha. During both years, minimum seed yield was observed when N was applied as basal applications. Two methods of splitting of N were at par but significantly superior to all basal application (Singh *et al.*, 2001).

Table 2. Effect of time and rate of nitrogen and sulphur application on yield of soybean

Treatments	**Seed yield (q/ha)**		**Oil (kg/ha)**		**Protein (kg/ha)**	
	1995	**1996**	**1995**	**1996**	**1995**	**1996**
N (kg ha^{-1})						
30	15.83	16.18	308	321	579	611
60	19.33	19.59	375	387	724	752
90	19.91	20.16	384	392	753	781
CD (P=0.05)	0.89	0.84	20	21	41	42
N (application time)						
AB	17.37	17.64	336	346	637	665
$^1/_2$B+$^1/_2$T	18.57	18.53	360	368	698	724
$^1/_2$B+$^1/_4$T+$^1/_4$F	19.13	19.46	371	386	720	754
CD (P=0.05)	0.89	0.84	20	21	41	42

AB= All basal, B=Basal, T= Tillering, F= flowering

Source : Singh *et al.* (2001)

Phosphorous Management

Phosphorus is also one of the limiting plant nutrients affecting the productivity of soybean. It is an important constituent of protein and nucleic acids. Thus, adequate supply of phosphorous improves seed and oil yield and protein content in soybean. The effect of different rates and modes of phosphorus application in soybean-wheat production system (Aulakh *et al.*, 2003) showed a significant response to the application of P up to 80 kg P_2O_5 ha^{-1} by soybean when preceding wheat did not receive any fertilizer P. However, where wheat received 60 kg P_2O_5 ha^{-1}, the response to succeeding soybean was restricted up to 60 kg P_2O_5 ha^{-1}. Thus, a direct application of 60 kg P_2O_5 ha^{-1} to both soybean and wheat was required to meet their P needs (Fig.1). It also enhanced fertilizer P use efficiency and P recovery; partitioned total biomass produced to grain yield, and optimized cost effectiveness.

Out of direct, cumulative and residual methods, direct application of P yielded the best results. Soybean crop grown under residual P application had less yield compared to those grown under direct P (Table 3). Direct application of P at 60 kg ha^{-1} resulted in higher yields of both crops of gobhi sarson and soybean. Application of P to soybean alone gave higher agronomic efficiency than application to gobhi sarson.

Application of 60 kg P/ha to either of the crops produced lower physiological efficiency than application of 30 + 30 kg P/ha to both the crops (Singh *et al.*, 2000).

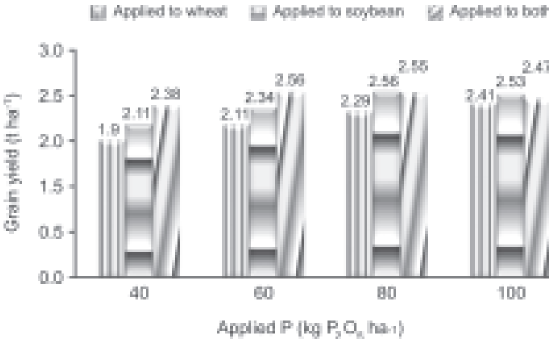

Fig.1. Grain yield of soybean (mean of three years) as influenced different rates and frequencies of applied fertilizer P in a soybean-wheat cropping system

The kinetics of P desorption and P uptake by soybean in different soils of Punjab and Himachal Pradesh (India) as influenced by phosphorus fertilizer and poultry manure (PM) application were best described by Elovich kinetic equation (Toor and Bahl, 1999). The values of kinetic constants of the Elovich and Parabolic equations increased with the increase in the level of fertilizer phosphorus, with and without PM. The predictions of the P bioavailability, both from the soil and fertilizer material can be obtained from the rate of P desorption. Application of PM helped in maintaining crystalline products of phosphate in metastable or poorly crystalline forms in the calcareous and non-calcareous soils, while in the acidic soils, PM might have chelated Fe and Al ions thereby transforming the mineral P towards higher solubility.

The chemical composition and different phosphorus compounds in the seed and its protein fractions of soybean were effected by phosphorus fertilization (Kapoor and Gupta, 1977). The concentrations of phosphorus compounds in the seed and its protein fractions were enhanced under the influence of soil phosphorus. Crude protein, true protein, phosphorus, magnesium, and iron contents of the seed increased under the influence of phosphorus but the amount of nitrogen free extract and calcium decreased slightly. The major form of P in the seed was constituted by Phytic acid P followed by nucleic acid P and phospholipid P.

Table 3. Effect of level and pattern of P application on seed yield of soybean

Treatments	Seed yield (q/ha)		P_2O_5 removal (kg/ha)		S removal (kg/ha)	
	1993-94	1994-95	1993-94	1994-95	1993-94	1994-95
P_2O_5 (kg/ha)						
Control (0)	11.6	11.1	12.3	11.5	8.1	7.2
30	13.9	14.5	17.3	18.1	11.3	10.3
60	15.3	17.0	22.8	24.2	15.0	14.2
90	15.7	17.3	25.3	26.6	17.1	15.6
CD (P=0.05)	1.1	1.6	3.7	4.0	2.6	2.2
P application pattern						
Residual	13.3	14.7	17.5	18.2	11.9	11.0
Direct	15.6	16.6	22.5	21.0	15.1	14.5
Cumulative	16.0	17.5	25.5	26.7	16.4	14.6
CD (P=0.05)	1.1	1.6	3.7	4.0	2.6	2.2

Source: Singh *et al.* (2000)

Sulphur Management

Sulphur plays important function in plant growth and metabolism. It enhances oil formation in seeds like soybean. In oilseed, sulphur is required for the synthesis of fatty acid as well as proteins, especially the synthesis of S containing amino acids like cysteine and methionine. Sulphur is also thought to be essential for synthesis of oil, certain-B vitamins and chlorophyll. It plays an important role in improving the quality and marketability of the produce. Sulphur could improve crop quality by increasing the oil, protein and amino acids content (Tandon, 1993).

The dry matter yield of plant, the total removal of S from the soil by plants and the contents of SO_4-S, protein S and non-protein organic S in the plant was increased with the application of S as ^{35}S-labelled $CaSO_4$, $(NH_4)_2SO_4$ nd Na_2SO_4 (Fig. 2). There was a decline in each plant attribute with increase in S level when applied in the form of Na_2SO_4. Radio assay measurements indicated that relatively more fertilizer S was metabolised into protein at lower than at higher levels of S. The content in plants of fertilizer-derived S increased while percentage utilization of applied S decreased with increase in S level (Dhillon and Dev, 1980)

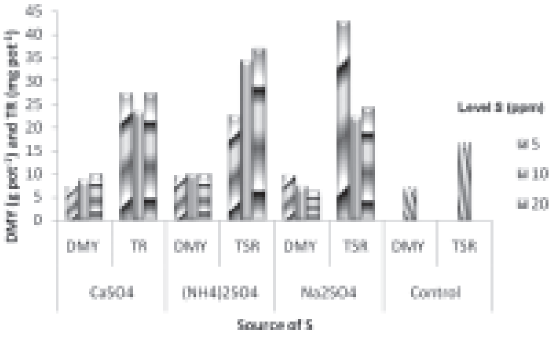

Fig. 2. **Effect of graded doses of different sulphate sources on dry matter yield (DMY) and total sulphur removal (TSR) by soybean plant (Adapted from Dhillon and Dev, 1980)**

Dev and Saggar (1974) studied the effect of sulphur application on changes in ratios of total-N: S and protein-N: S in 12 soybean cultivars. The total-N: S tended to decrease and protein-N: S to increase with increase in applied S. Total-N: S tended to become constant, while protein-N: S continued to rise with application of sulphur. In 8 of the 12 cultivars total-N: S and protein-N: S became similar to each other at S levels slightly higher than 25 ppm. When the intersection point of the ratios was taken as the critical level of S for the cultivar, the results indicated varietal differences. At 25 ppm S, total-N: S ranged from 14:1 to 18:1, and the protein-N: S from 12:1 to 24:1.

Integration of S with N and P increased yield and harvest index of soybean grown in the net house in typic Ustrochrept soil. Nitrogen and phosphorus interacted significantly to increase the percentage of S derived from fertilizer in the straw. Increasing N levels increased S uptake in grain and straw. Phosphorus application increased S uptake by increasing the yield and preventing S adsorption by phosphate (Ghosh, 2004).

Potassium Management

Potassium plays an important role, either direct or indirect in major plant processes such as photosynthesis, respiration, protein synthesis, enzyme activation, water uptake, transpiration, stomatal movement, osmoregulation, growth and yields of plant. Studies related the positive effect of K fertilization on BNF through improved photosynthesis, transport of photosynthates to nodules, increased root growth, or a combination of these factors (Weber, 1985). Potassium is 'elusive' in the soil with respect to plant availability. Crop response to K indeed depends on K supplying power of soil and K requirements of crop and on growing conditions. It is generally considered that most of soils of Indo-gangetic plains are adequate in K supply (Singh *et al.,* 2002). The intensive cropping with high yielding varieties makes considerable demands on soil nutrients resources and the soil which is now considered sufficient in available potassium, may not be able to maintain this condition for long.

There was constant and successive increase in grain yield of soybean with successive increase in the level of lime up to 3.70 t/ha (Table 4). The application of K @ 30 and 60 kg K_2O/ha significantly increased the yield of soybean on silty clay loam at Palampur, Himachal Pradesh (Dixit and Sharma, 1995). However, in some Alfisols the response of wheat to potassium was quite marked but not that of soybean grown in rotation with wheat. Higher levels of applied K seemed to compensate for lower moisture availability in potato crop (Shankhayan and Bhardwaj, 1987).

Table 4. Effect of lime and potassium level on seed yield of soybean

Treatments	Seed yield (q ha^{-1})
Lime (t CaO/ha)	
Control (0)	15.0
1.85	20.4
3.70	23.4
7.40	24.9
CD (P=0.05)	1.5
Potassium (kg K_2O/ ha)	
Control (0)	18.4
30	21.5
60	22.8
CD (P=0.05)	1.3

Dixit and Sharma (1995)

The average of 27 yield data of a long term experiment showed a significant response to applied K, with 69.9% increase in the yield of soybean and 20% increase in yield of wheat (Ved Prakash *et al.*, 2002b). The total removal of K by the crops exceeded the K applied on the soil showing a negative K balance, in the range of 73.9-937.3 kg/ha in different treatments. Continuous annual application of recommended rates of NPK and FYM to soybeans resulted in higher productivity of wheat and the build up of available K and relatively lower mining of K from the non-exchangeable pool.

Zinc and Molybdenum Management

Zinc is involved in several enzyme, protein synthesis and seed production for oilseed crops. Intensive agriculture and heavy use of macronutrients lead to large removal of micronutrients especially Zn, causing nutrients imbalance in the soil. Zinc deficiency is an important yield limiting factor in soybean grown in north India plains (Chandel *et al.*, 1989).

Twelve nutrient combinations comprising of three levels each of nitrogen (30, 60 and 90 kg/ha) and phosphorus (40, 60 and 80 kg P_2O_5/ha). Two levels of potassium (30 and 60 kg K_2O/ha) and a single level of zinc (25 kg/ha) along with control were tested by Singh *et al.* (2001). Zinc fertilization in combination with N, P and K significantly increased the growth attributes and grain yield of soybean. The highest numbers of pods per plant and seed yield were obtained with the joint application of N, P, K and Zn at the rates of 90, 80, 60, and 25 kg/ha, respectively (Table 5.).

The effect of molybdenum application on the yield and uptake by soybean grain in an Alfisol (Sharma and Minhas, 1986) revealed that the application of molybdenum either to soil or through the seed increased the yield of soybean as well as the uptake of molybdenum by the grains. The interaction effect of Mo treatments and methods of its application was significant. Seed application was more effective than soil application in increasing the Mo uptake by grains. Molybdenum application also resulted in a significant increase in nitrogen and protein content of soybean grains.

Table 5. Effect of nitrogen, phosphorus, potassium and zinc application on yield attributes and seed yield of soybean

Treatments	Pods/plant	Grain/pod	100-grain wt. (g)	Seed yield (q/ha)
$N_0P_0K_0$	31.6	1.96	11.5	14.6
$N_{30}P_0K_0$	34.7	1.98	11.6	16.4
$N_{30}P_{40}K_0$	45.1	1.99	12.6	17.4
$N_{30}P_{40}K_{30}$	43.7	1.99	12.6	17.9
$N_{60}P_{40}K_{30}$	45.1	2.01	12.7	17.6
$N_{60}P_{60}K_{30}$	44.5	2.05	12.9	18.2
$N_{60}P_{80}K_{30}$	51.4	2.03	14.1	18.9
$N_{90}P_{40}K_{30}$	51.9	2.12	14.4	19
$N_{90}P_{60}K_{30}$	65.9	2.14	16.6	22.3
$N_{90}P_{80}K_{30}$	47.2	2.07	13.5	17.7
$N_{90}P_{80}K_{60}$	45.0	1.84	12.3	17.1
$N_{90}P_{80}K_{60}Zn_{25}$	68.9	2.14	16.1	24.8
CD (P=0.05)	8.51	NS	2.29	3.45

Singh *et al.* (2001)

Nutrient Interactions

For maximum seed yield and enhancement of protein and oil synthesis in soybean, the balanced nutrition plays an important role. Combined applications of P up to 35 kg P/ha and S up to 40 kg S/ha levels showed a synergistic effect, however, together application of P and S @ 52.2 kg P/ha showed antagonistic effect on plant growth and on cross-utilization (Aulakh *et al.*, 1990). The availability of native soil P and S were promoted by fertilizer P and S as reflected by their percentage removal by the crop. The efficiency of native S was almost doubles than that of native P.

Application of phosphate and molybdenum at flowering and maturity influenced the carbohydrates level of soybean (Singh *et al.*, 1973). Application of P and Mo increased the protein and oil percentage in the seeds and total water-soluble carbohydrates levels in leaves, stems and seeds at maturity. The application of phosphate and molybdenum significantly increased seed yield and protein content and total N uptake at maturity of soybean (Singh *et al.*, 1972).

Effect of Cropping Sequence

Generally, the fertilizer dose is recommended on the basis of individual crop response to direct application of nutrients without apportioning the weightage to the previous crop and fertilizers applied to them in sequences. Since a crop utilizes a limited part of applied nutrient favorable results have been obtained on succeeding crop. So it is important to study the residual effect of nutrient in particular cropping sequences.

Direct application of P to soybean benefited the crop significantly as compared to residual P where as the response to direct and cumulative patterns of P application were found statistically similar in soil testing medium in available P (Singh *et al.*, 2000). However, direct application of P gave higher agronomic efficiency than residual P.

Chakor and Kumar (1988) reported that out of treatments involving five levels of fertilizer @75, 100 or 125% of the recommended NPK rates (120 + 60 + 60 kg/ha) for maize alone and in combination with 100% of the recommended NP rates (20 + 80 kg/ha) or only P rates for soybeans, the application of 125% of the recommended NPK rates for maize gave the highest yields of both crops (Fig. 3).

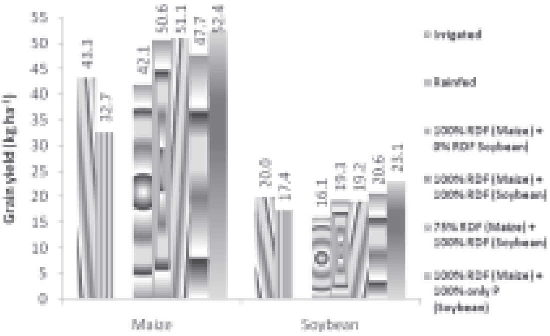

Fig. 3. Effect heavy doses of nitrogen and phosphorus, and their interactive affect with potassium and zinc application on yield attributes and seed yield of soybean (Adapted from Chakor and Kumar, 1998)

In other field trials when maize was grown alone, with soybean in alternate rows, or in one row maize and 2 rows soybeans, the maize yield grown alone with full dose of fertilizer were similar to those with half fertilizer when intercropped with soybeans (Tripathi and Singh, 1983). Thus, besides providing additional crop, intercropping with soybean saves fertilizer and gives additional income to the farmers. The application of 100% recommended dose of N and P_2O_5 to soybean and maize crops significantly increased yield components and yields of soybean and maize, biological indices and economic indices (net returns and B: C ratio). However, seed yield of soybean declined and grain yield of maize increased with increasing N level of maize up to 120% of recommended dose. Intercropping of soybean with maize resulted in slight reduction in yield attributes and seed yield of soybean when compared with those recorded with sole soybean (Khokhar *et al.*, 2004).

Under rainfed conditions, intercropping of soybean in maize had no adverse effect on grain yields of maize, gave additional total seed yield and decreased weed density and dry matter accumulation by weeds, compared with maize in pure stands. Nutrient uptake by maize in pure and mixed stands was similar, but it was higher in weeds in maize in pure stands. Yields of pure and mixed crops were higher with applied fertilizers at 80 kg N + 80 kg P_2O_5/ha than with 40 kg N + 40 kg P_2O_5/ha (Guleria, 1978).

Soil Amendments

Lime and liming material are used for correcting soil acidity and changing lime and phosphate potential for better crop growth. Gypsum also acts as a soil amendment and a source of sulphur. The application of lime (1.5 or 3.0 t/ha) and gypsum (2.7 or 5.4 t/ha) influenced the root distribution and plant growth of soybean grown on Northwest Himalayan acid Alfisols (Kumar and Verma, 1998). Incorporation of lime and gypsum brought significant increase in the root mass density of soybean. However, gypsum application was superior to lime in the lower soil depths and even lower rate of gypsum (2.7 t/ha) was more effective than higher rate of lime (3.0 t/ha). Likewise, shoot: root ratio increased with successive increments of P, lime and gypsum. Plant growth parameters like plant height, number of branches per plant of soybean were improved by the application of lime, gypsum and phosphorus. The efficacy of lime over the gypsum was superior in improving the productivity of soybean by decreasing different forms of aluminium (Al) and soil acidity in an Alfisol (in Himachal Pradesh, India) (Verma and Singh, 1996).

In a wheat-soybean-linseed (*Linum usitatissimum*) based cropping sequence, lime and potassium application increased the lime potential, whereas the effect was reversed in the case of phosphate potential in an acidic Alfisol. The effect of potassium was less than that of lime. The increase in lime potential and decrease in phosphate potential following lime and potassium addition significantly increased the grain yield of all the test crops (Dixit and Sharma, 1995). Wheat and soybean crops responded significantly in terms of yield and P uptake to phosphate, lime and gypsum application in acidic soil an Alfisol (in Himachal Pradesh, India) Gypsum was the superior amendment for wheat and lime for soybean on acid soils (Verma and Singh, 1996).

Effect of Soil Compaction and Moisture Stress

Soil compaction and moisture stress along with nitrogen affected the nodulation and yield of soybean (Katoch *et al*., 1983). The number and weight of nodules per plant were greater with 30 kg N/ha than in the control. The effect of moisture stress was most detrimental to nodule formation when it occurred at pod formation. Protein content of the seed was decreased by moisture stress at the pod-forming or reproductive stage. Soil compaction significantly decreased nodulation, straw yield and protein content of the seed.

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