Potassium Nutrition in Yield and Quality Improvement of Soybean

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Introduction

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".

The Soybean Crop

Soybean is one of the major oilseed crops of India covering about 6 million hectares. It has contributed towards supporting the national economy and meeting the edible oil requirement of the nation in the past two decades. At present, export of soymeal fetches foreign earnings equivalent to Rs. 15000 million Soybean oil, produced to the tune of about 0.8 million tonnes, is consumed in the country mostly for edible use. 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). 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).

It is a general practice among farmers of major soybean growing region to apply some nitrogen and phosphorus mostly through DAP or single super phosphate. 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).

The Soils of Soybean-growing Regions

Madhya Pradesh (M.P.), Maharashtra and Rajasthan are the major soybean growing states. In M.P., soybean is mainly grown in Malwa plateau, part of Deccan plateau and Central Highland in the state (Tamgadge *et al.*, 1996). Both M.P. and Maharashtra states grow soybean largely on vertisols and associated soils.

Soils of major soybean growing states 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, length of growing period and land use. These regions are AER 5, 6, and 10 which are briefly described in **Table 1**.

Table 1. The predominant soybean-growing agro-ecological regions

Agro-ecological region	Description
5	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.
6	Swell-shrink soils are the dominant group in the region with loamy to clayey Ustorthents, Chromusterts and Ustropepts. These soils are predominantly high in available K, but medium/medium to high in exchangeable K. Soils are neutral to moderately alkaline, calcareous and medium to high in organic matter.
10	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.

Although major soybean area lies in the above agro-ecological regions, the crop is not uncommon in other regions. The crop has wide adaptability and can be grown from north to south and east to west including the hill region of Himachal Pradesh, Uttar Pradesh and in north-eastern states and also on Deccan Plateau.

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 diphosphate (ADP) and phosphate into adenosine triphosphate (ATP) in the synthesis of amino-acids.

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: 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% of the total K in plant (Hoeft *et al.*, 2000). It is to be noted that on weight basis, soybean seed contains more than twice as much potassium as corn grain.

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 reproductive stages is going to reflect on yield of soybean.

K-uptake in soybean has been estimated as about 101-120 kg/ha K (Nambiar and Ghosh, 1984 and Aulakh *et al.*, 1985). Similar removal of 101 kg/ha of K has been reported in case of soybean in M.P. state by Swarup *et* *al.* (2001). 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. In general, the soybean is grown in semi-arid regions, particularly vertisols and associated soils and these soils are rich in potassium.

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 the 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 offtake 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 NRCS, Indore, it was observed that the leaf-litter in soybean was to the tune of about one tonne per hectare 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 20 to 100 kg K/ha through leaf drop (O.P. Joshi, unpublished).

The need of the cropping system/rotation is also to be kept in mind. K 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 *et al.*, 1985). A similar report for K removal in M.P. 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. 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 associate soils in K. By and large, no potassium is applied by farmers in the major soybean growing areas. Swarup *et al.* (2001) have reported an overall negative balance of potassium in M.P. 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).

Response of Soybean to Potassium

The K nutrition of soybean has not been paid due attention in the past. Information available is summarised as given below.

Response Realised in the Vertisol-Region: The results of experimentation on the effect of application of different combinations of NPK on the performance of soybean in black cotton soils of Akola during *'kharif'* season revealed improvement in yield attributing characters, yield and quality (oil and protein content) of soybean with increasing levels of NPK (Nagre *et al.*, 1991). It is difficult to work out the individual share of potassium in this study, but the contribution of potassium in the overall response can be well accepted.

The long-term experimentation conducted on vertisols of Jabalpur (M.P.) in soybean-wheat-maize fodder revealed that not only the yield of soybean was increased by 6%, but application of potassium at recommended levels also enhanced the uptake of major, secondary and some of the micronutrients (**Table 2**). Similar was the effect of application of K on the other crops under rotation.

Table 2. 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 (Mean over 1971-1989)

*Treatment**	*Yield*	*Uptake (kg ha^{-1})*						*Uptake (g ha^{-1})*			
	(kg ha^{-1})	*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).

Anuradha and Sharma (1995) found that the application of potassium increased the chlorophyll content, nitrate reductase activity, seed protein and oil content in soybean. Deshmukh *et al.* (1994) obtained the highest soybean yield and oil content with an application of 60 kg K_2O/ha at Amravati and 90 kg K_2O/ha at Akola in Maharashtra State.

More conclusive results on yield responses of soybean were obtained in experimentation organized by International Potash Institute for three years at Amlaha (M.P.) on vertisols by Magen (1997) where increased seed yield, oil and protein contents and nodulation was observed (**Table 3**).

The results have clearly brought out that the responses of K application on vertisols (having 112 ppm of available K) can be obtained up to 100 kg K_2O/ha. The split application at 35 days after sowing was still superior in obtaining response. The results offer reconsideration of recommended level of potassium application i. e. 20 kg K_2O/ha. In addition to above responses, resistance of plants against major insect-pests of soybean i.e. girdle beetle, semilooper and aphid attack was also realized (**Table 4**) based on pooled data for three years (Magen, 1997).

Table 3. Yield and yield parameters of soybean (data pooled for three years)

Treatment N-P-K	Yield (q ha^{-1})	100 grain weight (g)	Oil content (%)	Protein content (%)	Grain $plant^{-1}$ (no.)	Nodule $plant^{-1}$ (no.)
30-80-0	20.5	12.4	20.3	39.0	54.7	72.1
30-80-50	21.9	13.2	20.8	39.1	55.2	74.6
30-80-25/25	25.0	14.1	20.8	39.6	67.7	87.5
30-80-100	24.0	13.8	20.9	39.2	60.5	83.5
30-80-50/50	25.9	14.2	21.5	39.8	67.4	87.4
CD at 5%	0.71	0.24	1.14	NS	2.91	2.81

Source: Magen (1997) IPI Activity in India- Summary report for 1993-1997

Table 4. Effect of K application on resistance of soybean plants to insect-pests

Treatment N-P-K	Girdle beetle attack (%)	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). IPI Activity in India- Summary report for 1993-1997

In case of intercropping, not much information is available. However, Hegazy and Genaidy (1995) reported that the application of potassium sulphate improved the growth of soybean when either mono- or intercropped on clayey soil,. The relative K fertilizer efficiencies were reduced in intercropping compared to mon-ocropping thereby increasing the economic optimum K fertilizer rates.

Response Realised in Other Soils: Although the major soybean area is on vertisols and associated soils, the crop is cultivated and is further extending to other soil types as well. Significant responses of supplementation of K have been observed in other soils also. Normally crop responds to the application of nutrients in soils, which are low to medium in K. The research done at Iowa (USA) revealed that there have been frequent significant yield increases in soybean in the soils with medium soil test potassium values (68 to 100 ppm) on account of K applications (Mallarino *et al.*, 1993). Although, no response of K application up to 75 kg K_2O/ha was obtained on laterites of Maharashtra (Talathi, 1983), response of K application in alluvial tract of Uttar Pradesh in the farmers' field (32 trials) was obtained up to 60 kg K_2O/ha. Maximum response (56%) was obtained with $N_{20}P_{40}K_{20}$ over $N_{20}P_{40}K_0$, which decreased by increasing the levels of all the three nutrient elements. Dixit and Sharma (1993) reported that soybean seed yield increased following application of up to 12.5 kg K in silty loam soils of Palampur (Himachal Pradesh). Application of K also increased uptake of N, P and K. Unlike the results obtained at Jabalpur (as given in **Table 2**), the application of K decreased Ca and Mg uptake in these acid soils. The results of green house study showed that the soybean yielded highest with 27.75 ppm K in all types of soil (Singh *et al.,* 1993).

On loamy sand soil, split application of potassium was found beneficial than applying full dose at the time of planting. Soybean responded significantly up to 50 kg K_2O/ha when applied 50% at planting and 50% at flower initiation (two splits) or 1/3 at planting, 1/3 at flower initiation and 1/3 at pod development (three splits). The per cent agronomic efficiency, per cent physiological efficiency and per cent apparent K recovery reduced as the rate of applied K was increased from 50 to 75 kg K_2O/ha (Kolar and Grewal, 1994).

Grewal *et al.* (1994) observed that the soybean seed yield increased following application of up to 50 kg K_2O/ha when N was applied and up to 25 kg K_2O/ha in the absence of N in loamy sand soils of Punjab. On sandy clay loam soil, Annadurai *et al.* (1994) observed that the application of 40 kg K_2O increased the soybean seed yield and oil content. Rajagopal and Velu (1995) observed that the soybean responded to application of only up to 40 kg K_2O/ha and the magnitude of response was higher in *'kharif'* than *'rabi'* season. Application of 80 kg K_2O/ha with either 20 or 40 kg N/ha significantly increased the yield and yield attributes in sole and intercropping systems in sandy loam soils (Mandal and Pramanik, 1996). Application of 30 kg K_2O/ha or N x K interaction significantly increased the nodule number and yield attributes (Singh *et al.*, 1999). The application of N, P and K individually also increased the seed yield of soybean.

A long-term experiment was conducted in shallow sandy loam soil of Hawalbagh Farm, Almora (Uttranchal) with an application of 33.2 kg K/ha in combination with N, P and farm-yard manure in soybean-wheat cropping sequence (Ghosh *et al.*, 1998; Kundu *et al.*, 1990). It indicated the beneficial role of K in enhancing yield stability of soybean under rainfed condition. A gradual increase in K response was obtained with the increase in advancing years of cultivation from 1973 to 1997. The average response of soybean was 18.76 kg grain/kg K. The net depletion of K over years was high.

Identity-Preserved and Food-Quality Speciality Soybeans

Industry, farm-scientists and consumers alike have experienced a steadily growing market preference for identity- preserved (IP) and value-enhanced soybean. Soybean has gone beyond the stage of being a mere source of protein and oil. It has now established itself as a functional food (Riaz, 2000). The uses, products and value additions are so varied that cultivation of IP-soybeans becomes specific in approach right from the way the crop is cultivated and a variety chosen. It is predicted that IP-soybeans will constitute a sizeable portion of the grain market over the next few years. Currently, the largest demand for IP soybeans has been among producers of soyfoods who are looking for particular traits such as higher protein levels, reduced flavour profiles or even specific physical characteristics in the seed. Food-quality speciality soybean varieties with specific output traits are now available.

A smaller and more specialised sub-segment of the IP-soybean market is organically grown soybeans. Soybeans producers reap additional value or premium from organic crop. Less than one percent of U.S. soybeans are currently grown organically. Organic farming has increased to a $ 4.2 billion industry in the U.S and continues to expand.

A stage has been reached when, for the purpose of IP-produce and even organic farming, natural inputs like potassium are to be differentiated from harmful chemicals. Potassium is known to enhance food quality. The solution probably lies in having a mechanism of “input-declaration” which will meet the consumer's acceptance to allow the use of inputs like potassium application while screening out the undesirable ones.

Summary and Conclusion

Soybean has emerged as a major oilseed crop of India presently covering an area of about 6.0 million ha. 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. Soybean generally responds favourably to potassium application resulting in increased yield. Other yield-associated characters viz., number of nodules per plant, grain weight, grain per plant etc. also increase on potassium application. Increased oil and protein content in seed have also been observed. Potassium application has also been found to increase chlorophyll content and nitrate reductase activity. 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, semilooper and aphids has also been realised.

It is amply evinced that although soybean responds favourably to potassium nutrition in myriad ways, the potassium nutrition in soybean is presently far from adequate. It is felt that there is a very strong basis to continue and strengthen research, development and extension efforts on potassium nutrition as related to soybean, the non-cereal component of a major cropping system in India. A system-based approach, including residue management, is needed to promote balanced fertilizer application for increasing/optimising the production and for sustainability. Some of the important areas could be:

* Use of soil resource map(s) for generating soil-based agro-technology.
* Critical assessment of the K requirement of soybean and soybean-based cropping systems in different soils/agro-climatic regions of the country.
* Identification of the stages of plant growth when K is required most (split applications have already shown beneficial effects)
* Establishing the critical soil and foliar concentrations for soybean.
* Promoting use of integrated fertilizers or fertilizer-mixtures for balanced nutrition.

* Return of crop residues to the soil and its facilitation through the availability of necessary implements at the farm level.
* Screening the soybean varieties for their efficiency in utilising K from soil or applied source.
* The role of potassium in imparting resistance to insect-pests and diseases and in mitigating the effect of water stress in soybean is to be further vindicated and capitalized upon.
* Specifically assessing and utilizing the role of potassium in improving the quality of soybean, the functional food, is needed especially in view of the increasing food uses of soybean nationally and globally.
* Identification and incorporation of variables related to soil-site suitability and nutrients in order to develop models for predicting agricultural productivity.
* Perspective land use and fertilization plan for the region/area for high yet sustainable agricultural production in soybean-based systems.

References

Annadurai, K., Seshadri, P. and Palaniappan, S. 1994. Influence of potassium levels on yield and oil content in sunflower-soybean sequence. *Journal of Potassium Research* **10**(2): 124-129.

Anuradha, K. and Sarma, P. S. 1995. Effect of moisture stress and applied potassium on yield and biochemical parameters of soybean in vertisols. *Journal of Oilseeds Research* **12**(2): 275-278.

Aulakh, M. S, Sidhu B.S, Arora B.R and Bhajan-Singh 1983. Contents and uptake of nutrients by pulses and oil seed crops. *Indian Journal of Ecology* **12:** 238-242.

Bhatnagar, P. S. and Joshi, O. P.1999. Soybean in cropping systems in India Pp 39. *FAO Series on Integrated Crop Management*, Rome, Itly.

Carpenter, J.L. 1975. Potash crises in Saskatchauwan. *Fertilizer Progress* **6**(2): 8

Dev, G. 1995. Potassium – An essential nutrient Pp 113. i*n*: *Use of Potassium in Punjab Agriculture*. Potash and Phosphate Institute of Canada, India Programme, Gurgaon (Haryana), Dixit, S. P. and Sharma, P. K. 1993. Effect of lime and potassium on yield and uptake of nutrients in wheat (*Triticum aestivum*)-soybean (*Glycine max*)-linseed (*Linum usitatissimum*) cropping sequence in an acid alfisol. *Indian Journal of Agricultural Science* **63**(6): 333-339.

Deshmukh, V. N., Rangacharya, R. P., Rewatkar, S. S. and Solanke, B. U. 1994. Response of soybean to phosphorus and potassium application in Vertisol. *Journal of Potassium Research* **10**(4): 332-337.

Ghosh, B.N., Prakash, Ved and Singh, R.D. 1998. Yield response and nutrient use efficiency on soybean-wheat system in a long-term manurial experiment. *In* Proc. Long term soil fertility: management through integrated plant nutrient supply. Ed. Swarup *et al.* pp. 277-282.

Grewal, H. S., Kolar, J. S., Dalip Singh and Singh, D. 1994. Effect of potassium and nitrogen on growth and yield of soybean (*Glycine max* L.) Merr. *Journal of Potassium Research* **10**(2): 173-177.

Hegazy, M. H. and Genaidy, S. A. 1995. Potassium fertilization for some intercropping patterns in Egyptian Northern delta soils. *Egyptian Journal of Agricultural Research* **73**(1): 25-35.

Hoeft, R.G., Nafziger, E.D., Johnson, R.R. and Aldrich, R. 2000. Modern Corn and Soybean Production, MCSP Publications, USA, pp 353.

Keyser, H.H. and Fudi Li.1992. Potential for increasing biological nitrogen fixation in soybean. *Plant and Soil* **141:** 119-135.

Kolar, J. S. and Grewal, H. S. 1994. Effect of split application of potassium on growth, yield and potassium accumulation by soybean. *Fertilizer Research* **39**(3): 217-222.

Kundu, S., Bhatnagar, Y.K., Prakash, Ved, Joshi, H.C. and Koranne, K.D. 1990. Yield response of soybean-wheat rotations to K application in a long-term field experiment. *Journal of Potassium Research* **6**(2):70-78.

Magen, H. (1997) IPI Activity in India – Summary report for 1993-1997: Results from field experimentation and description of promotional activity, October 1997. International Potash Institute, pp 33.

Mallarino, A. P.; Webb, J. R. and Blackmer, A. M. 1991. Corn and soybean yield during 11 years of phosphorus and potassium fertilization on a high-testing soil. *Journal of Production Agriculture* **4**(3): 312-317.

Mandal, S. S. and Pramanik, C. K. 1996. Integrated fertilizer management with potassium in soybean and sesame under different cropping systems.

Journal of Potassium Research **12**(3): 298-304.

Mengel, D.B. and Barber, S.A. 1974. Rate of nutrient uptake per unit of corn root under field condition. *Agronomy Journal* **66:** 399-402

Nagre, K.T., Deshmukh, S.B., Bhalerao, P. D. and Thorve, P.V. 1991. Effect of sowing dates and fertilizers on growth, yield and quality of soybean varieties. *PKV Research Journal* **15:** 82.

Nambiar K. K. M. and Ghosh, A. B. 1984. Highlights of research of a Long - term Fertilizer Experiment in India (1971-1982). Tech. Bull. 1. Long-term Fertilizer Experiment Projects, IARI. pp. 100.

Pieri, C. 1983. Nutrient balance in rainfed farming systems in arid and semi-arid regions. *In* "Nutrient balances and the need for fertilizers in semi-arid and arid regions". International Potash Institute, Switzerland. pp. 181-209.

Raiz, M.N. 2000. Soybeans as functional foods. American Soybean Association, Asia Subcontinent publication. p. 1-5.

Rajagopal, A and Velu, G. 1995. Effect of irrigation and agronomic management practice for water use efficiency in soybean. *Madras Agricultural Journal* **82**(4): 274-278.

Sharma, Hariom, Nahatkar, S. and Patel, M.M. 1996. Constraints of soybean production in Madhya Pradesh: An analysis. *Bhartiya Krishi Anusandhan Patrika* **11**(2): 79-84.

Singh, J., Sharma. H. L., Singh. C. M. and Singh, J. 1993. Response of soybean to potassium nutrition in different agro-climatic zones of H.P. *Journal of Potassium Research* **9**(1): 38-43.

Singh, S., Gangwar, M. S., Singh, H. P. and Singh, S. 1999. Nodulation and biomass production in soybean as influenced by the application of nutrients. *Journal of Potassium Research* **15**(1-4): 127-130.

Swarup, A., Reddy, K.S. and Tripathi, A.K. 2001. Nutrient mining in agro-climatic zones of Madhya Pradesh. *Fertilizer News* **46**(4): 33-38 and 41-45.

Talathi, P.G. 1983. Effect of nitrogen, phosphorus and potassium fertilization on growth, yield and quality of soybean (*Glycine max* (L.) Merril), variety Monetta. M.Sc. (Agri.) Thesis, Kokan Krishi Vidyapeeth, Dapoli.

Tamgadge, D.B., S.T. Gaikawad, S.R. Naga Bhushana, K.S. Gajbhiye, S.N. Deshmukh and J. Sehgal. 1996. Soils of Madhya Pradesh: Their kinds, distributions, characterisations and interpretations) for Optimising Land Use. NBSS Publ. 59b (Soils of India Series 6), Nagpur, India. pp. 1-182.

Tiwari, S.P., Joshi, O.P. and Billore, S.D. 2001. Realisable yield potential of soybean varieties at farm level in India. In: Souvenir "Harnessing the soy potential for health and wealth", India Soy Forum 2001. SOPA, India. pp 108-112.

Tiwari, S.P. 2001. Shattering the production constraints in soybean-based cropping systems. *JNKVV Research Journal* **35**(182): 1-10.

Vedprakash, Kundu, S., Ghosh, B.N., Singh, R.D. and Gupta, H.S. 2001. Yield response patterns of soybean and wheat to K application and changes in K status in soil profile after 27 years of cropping in mid-hills of northwestern Himalayas. In : Proceedings of International Symposium on Importance of Potassium in Nutrient Management for Sustainable Crop Production in India Vol.1 Potash Research Institute of India, Gurgaon pp. 362-365.