RESPONSE OF POTASSIUM ON YIELD AND QUALITY OF SOYBEAN IN INCEPTISOL

By

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(Reg. No. 11/098)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
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of

MASTER OF SCIENCE (AGRICULTURE)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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2013

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I hereby declare that this thesis or part

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This is to certify that the thesis entitled, **"RESPONSE OF POTASSIUM ON YIELD AND QUALITY OF SOYBEAN IN INCEPTISOL"**, submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra, India in partial fulfilment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the results of a *bona fide* research work carried out by **MISS. PRADNYA GULABRAO JAMDADE,** under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

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LIST OF ABBREVIATION

%	: Per cent
C.D.	: Critical differences
cm	: Centimeter
Cu	: Copper
DAS	: Days after sowing
dSm^{-1}	: Deci siemon per meter
EC	: Electrical conductivity
et al.	: et alli (And others)
Fe	: Iron
g	: Gram (s)
GM	: Grand mean
g $plot^{-1}$	: Gram per plot
ha	: Hectare
i.e.	: Id est (that is)
K	: Potassium
K_2O	: Potash (Potassium oxide)
kg ha^{-1}	: Kilogram per hectare
kg	: Kilogram (s)
kg kg^{-1}	: Kilogram per kilogram
mg kg^{-1}	: Milligram per kilogram
Mg	: Magnesium
Mn	: Manganese
MOP	: Murate of potash
N	: Nitrogen
N.S.	: Non significant
$NaHCO_3$	: Sodium bicarbonate
NH_4OAc	: Ammonium acetate
No.	: Number
P_2O_5	: Phosphorus pentoxide
pH	: Puissance de hydrogen
q ha^{-1}	: Quintal per hectare
RBD	: Randomized Block Design
RD	: Recommended dose
S.E.	: Standard error
SSP	: Single super phosphate
viz.,	: Namely
Zn	: Zinc

ABSTRACT

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A candidate for the degree
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Research Guide	**:**	**Dr. S.R. Patil**
Department	:	Soil Science and Agricultural Chemistry

Potassium, an essential plant nutrient, has major role in crop production including legumes crops like soybean. Reviews in the literature on potassium application to soybean suggest that soybean needs potassium, absorb it and response to potash fertilizers in terms of yield and monetary returns. However, the Mahatma Phule Krishi Vidyapeeth, Rahuri has completely ignored potassium in the recommendation of general fertilizer prescription to soybean. Looking to the present status average productivity (10.58 q ha^{-1}) of Maharashtra State and its comparison with the national (10.64 q ha^{-1}) and international average productivity of soybean, there is scope to increase the state productivity of soybean with a application of potassium to soybean. It is, therefore, the present experiment was planed to ascertain the optimum dose of potassium to soybean in Inceptisol for enhancing productivity of soybean in the state and to make concrete suggestions to the University for reconsideration of recommendation of potash and their inclusion in general fertilizer prescription dose to soybean.

With the above facts and views, a present field investigation entitled, “Response of potassium on yield and quality of soybean in Inceptisol ” was conducted at Post Graduate Institute, Research Farm of Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* season, 2012-13 so as to find out the optimum dose of potassium for maximum economic yield of soybean.

The field experiment was laid out in a randomized block design with the seven treatments and four replications. The applied treatments were : T_1 (Absolute control); T_2 (RD: 50:75:00 N:P_2O_5: K_2O kg ha^{-1}); T_3 (RD + 20 kg K_2O ha^{-1}); T_4 (RD + 30 kg K_2O ha^{-1}); T_5 (RD + 40 kg K_2O ha^{-1}); T_6 (RD + 50 kg K_2O ha^{-1}) and T_7 (RD + 60 kg K_2O ha^{-1}).

The experimental soil was slightly alkaline in a reaction (pH 8.01), low in electrical conductivity (0.41 dSm^{-1}) and medium in calcium carbonate content (6.5%), low in available nitrogen (155 kg ha^{-1}), phosphorus (12.80 kg ha^{-1}) and medium in potassium (232 kg ha^{-1}) content.

The results obtained in the present investigation revealed that the growth parameters *viz.*, and plant height, number of branches per plant, chlorophyll content, nodule count were significantly influenced by various levels of potassium application. The significant highest height (47.65 cm), number of branches (12.25), chlorophyll content (53.71), effective nodules (24.16), number of pods per plants (41), test weight(14.94 g) were observed in treatment of application of RD+60 kg K_2O ha^{-1}(T_7). The highest grain (31.62 q ha^{-1}), straw (40.80 q ha^{-1}), protein (10.36 q ha^{-1}) and oil (6.38 q ha^{-1}) yield were recorded under the same treatment of RD + 60 kg K_2O ha^{-1} (T_7). The grain and straw yields were at par with treatments T_6 (RD + 50 kg K_2O ha^{-1}) and T_5 (RD + 40 kg K_2O ha^{-1}) while the protein and oil yield were at par with treatments T_6, T_5 and T_4.

The total uptake of nitrogen, phosphorus and potassium were significantly influenced by the potassium application and maximum NPK uptake was observed in the treatment T_7 (RD+60 kg K_2O ha^{-1}) treatment and it was at par with treatments T_6 and T_5.

Increase levels of potash resulted in to increase in soil fertility status after harvest of soybean with respect to all available nutrients. However, treatments plots of available N and P decreased over the initial status from all.

The highest soybean yield and quality were recorded in treatment T_7 however, the B:C ratio of soybean cultivation under treatments of various levels of potash was found maximum (2.47) in the treatment T_6 followed by treatments T_5 (2.46) and T_7 (2.46). The maximum monetary returns per Rs invested on potash fertilizer (Rs 6.93) was recorded by application RD + 40 kg K_2O ha^{-1} to soybean. Thus, from the above results of present study it can be concluded that application of 40 kg K_2O ha^{-1} along with recommended 50 kg N and 75 kg P_2O_5 is found most optimum dose of potash to soybean to harvest maximum economical yield and quality of soybean in Inceptisol.

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1. INTRODUCTION

Soybean [*Glycine max* (L) Merril] family leguminaceae and chromosome no 2n=40, is one of the most important oilseed leguminous energy rich crop. Soybean crop has been under cultivation in China since 2838 B.C. (Caldwell, 1973) as it has been an important part of Chinese diet This crop's importance could be realized more during World War II as a source of edible oil and nutritious food for armed forces.

Soybean is an excellent source of protein (38%) and also contains oil (18-20%) (Imas and Magen, 2007). This crop is also known as Gold for soil because it has many advantages such as less requirement of nitrogenous fertilizers, soil conservation and leaves beneficial effects on succeeding crop and also it is easy for cultivation. It is short duration and remunerative crop. This crop has contributed toward supporting the national economy and meeting the edible oil requirement of nation in the past two decades.

Besides as a source of oil and proteins, it is also used for a wide variety of products to consumer uses today. Soybean oil can be used in industry and edible products. It's meal is used for livestock feed, fish and pet feed and protein concentrations. Soybean meal can also be use as soy flour for baked goods, cereals and baby foods (Hauck *et al.*, 1972). Soybean is also used in preparation of low cost nutritionally balanced protein foods and drinks, which is most essential for protein deficient countries. (Meissel and Bocker, 1983). Because of important source of oil and protein, food and feed for animals, biodiesel production, drought tolerance, short duration and energy rich crop, nowadays farmers are preferring more cultivation of soybean. Thus, area under soybean is increasing day by day and it was 101.79 lakh hectares in *kharif* 2011 which is increased upto 105.88 lakh hectares in 2012 in India (Anonymous, 2012). Soybean is also fetching good market price and it has beneficial effect on succeeding crop, therefore, farmers are interested to grow more soybean.

Soybean covers worldwide area of which 90% is concentrated in U.S., Brazil, Argentina, China and India. In 2011-12, food grain production in India was a recorded as 257.4 million tonnes (4th Advance Estimates). Production of oilseeds was estimated at 30.0 million tonnes in India (Anonymous, 2012). In the year 2011-12, cultivated area under soybean in Maharashtra was 3,069 ha and production was 4,029 million tonnes (Anonymous, 2011). In fact, in the year 2011-12 the country achieved significant improvements in the yield levels of major agricultural crops. Notwithstanding the increase in yield levels in food crops, there is still exists a considerable gap between potential and actual yields even in high productivity irrigated areas with use of the current technology. For these areas, balanced use of fertilizers, micro nutrients, and water and soil saving technology may need to be considered. However, country has the lowest productivity of crops as compared to world. In India, Madhya Pradesh is a leading state in the both area and productivity of soybean and known as “Soybean state of India”.

Balance nutrition with all the essential plant nutrients and their supply is critical for sustainable and the highest crop production with better quality. After nitrogen, the potassium is the second most absorbed nutrients by the soybean (Flannery 1986, 1989).

In plants, potassium involved in many metabolic pathways of plant that effect dry matter yield and crop quality hence, potassium is called as the 'Quality element'. There are some reports of Nambiar and Ghosh (1984) and Aulakh *et al.* (1985) which informs that soybean crop has an average uptake of K in the range of 101 to 120 kg ha^{-1}. Potassium is vital to many plant processes owing to it's requirement for activation of 60 different enzymes involved in plant growth and it also stimulates new root hair formation as well as nodule development (Suelter, 1970). Essentiality of K has been found to be indispensible in biochemical processes, osmoticum synthesis and regulate stomatal movement (Dwivedi *et al.*, 1992). Plants well supplied with potassium loose less water due to a reduction in transpiration rate (Brag, 1972., Umar *et al.*, 1993). When K supply is inadequate, the stomata become sluggish-slow to respond and the water vapour is lost (Humble and Raschke, 1971). Potassium is important in photosynthesis in translocation of sugars within the plants and for transport of water and nutrients-nitrates, phosphates etc. through the xylem. Assimilates delivered through the phloem to the storage organs have finally to be converted into starch or metabolized for lipid and protein synthesis. These syntheses also require potassium (Evans and Wildes, 1971). Potassium has a role in making crops tolerant to water stress, in conferring winter hardiness and disease resistance and bringing about improvements in crop yield and quality (Sekhon, 1999). The positive effect of K application on resistance of soybeans to pests and disease was already reported by Megan (1997) and Gupta *et al.* (2003). Potassium improves size, appearance, texture, color, luster of grains that enhance market value. Because of involvement of K in all these important biochemical and physiological functions, potassium is called as 'Master cation'.

In nutrient management experiments on soybean, many researchers reported NPK to soybean for its maximum economic yields. A soybean crop needs 81 kg N, 54 kg K_2O and 8 kg P_2O_5 for every 10 qt of harvested grain (Flannery, 1986 and 1989). Dixit *et al.* (2011) noted that Directorate of Soybean Research, recommended rate of N, P_2O_5, K_2O and S to soybean is 20:80:40+20; respectively, as a part of the Integrated Nutrient Management System (INMS) of soybean and they also reported that application of 40 kg K_2O ha^{-1} to soybean grown in medium black soil recorded a maximum yield of 15.5 q ha^{-1}. Thus, review on K fertilization to soybean in various soils (Anuradha and Sharma, 1995; Bansal *et al.,* 2001; Gupta, 2003; Khan, 2006; Dixit *et al.,* 2011) suggest that adequate K fertilization is needed to achieve high yield potential of soybean with better quality and also create resistance in soybean to pest and disease.

The black soils of Maharashtra are high in available potassium, however, crops grown in black soils response well to potassium fertilizer; because, soil reserve potassium from Indian soils is getting depleted continuously and crop responses to potassium are increasing in time and space (Subba Rao *et al.,* 1993). In the investigations of net depletion of K (sum total of available and non–exchangeable K) from the soil profile, following repeated cropping cycles and losses of K from the soil were quantitatively much higher than expected. In the year 2020, the deficit of K in Indian agriculture has been projected to be around 8.1 million tones annum^{-1} (Katyal, 2001). There are many examples from long term fertilizer experiments (LIFE) conducted in India where a decline in the yield of crops occurred as a result of K deficiency (Lodha *et al.,* 2003; Rupa *et al.,* 2003). Thus, there has been an important need to investigate K nutrition for various crops including soybean grown on black soils so as to optimize the crop productivity in black soil.

Madhya Pradesh, Maharashtra and Rajasthan are major soybean growing states (Tamgadge *et al.,* 1996) where soybean grown in all types of soils. In these soybean growing regions, at present there is no any specific recommendation for K application to soybean where potassium is not applied to soybean and also not included in the general fertilizer prescriptions schedule of soybean (Bhatnagar and Joshi, 1999).

Naidu *et al.* (2011) reported that the available K status in Indian soils showed shift from medium to high in 1960-70 and now medium to low. Red, lateritic and shallow black soils have undergone K fertility depletion. Recent isolated studies indicated even in medium deep and deep black soils, K status has shifted from medium to low. Crops grown on these soils were found to suffer from K deficiency. The K deficiency in crops grown on these soils is further aggravated by imbalanced K use by farmers. Further, fertilizer recommendations are being made based on available K status, but significant proportion of plant needs is met from non exchangeable fraction of K. Therefore, there is a need to consider both the fractions of K in potash fertilizer recommendation to crops. The present general fertilizer recommendations prescription/dose recommended by the University which do not include K fertilization are being followed since four decades and hence, it is need to have revision and revalidation. Site specific fertilizer recommendations, if followed can minimize the fertility K depletion and maintain productivity and sustainability and also economize the fertilizer cost.

Thus, the above review on K fertilization to soybean and it's requirement suggests that soybean responds favorably to potassium nutrition in many ways, even potash rich soils are also responsible to potassium application. Therefore, it is felt that there is a need of very strong basis to continue the research on response of applied K nutrition to soybean. With this view, the present experiment entitled, "Response of potassium on yield and quality of soybean in Inceptisol", was planned to know the optimum potassium requirement to soybean for maximum economical yield. The objectives of present study are :

1. To evaluate optimum level of potassium requirement for maximum yield of soybean in Inceptisol.
2. To asses effect of different levels of potassium on nutrient uptake and quality of soybean.

2. REVIEW OF LITERATURE

Potassium, an essential, major primary plant nutrient play a significant role in several physiological and biochemical processes in plant and has major role in crop productivity and quality of crop produce. Potassium fertilization leads to numerous positive effects on the many plant functions. According to critical levels of potassium the soils are considered high in available K, however, the crop responds well to application of potassic fertilizers. A profitable response to application of K has not always been observed on Indian soils so as to warrant its blanket application (Zende, 1978)

According to review, there is wide gap between the recommendations of potassium application and its uptake. This chapter is confined with the review of research work carried out by different researchers on the effect of potassium on yield, quality and nutrient uptake of soybean and also their effect on soil properties. The literature available on above mentioned aspects is presented in this chapter under following headings.

2.1.a Occurrence and distribution of Inceptisol.

2.1.b Physical and chemical properties of Inceptisol.

2.2 Potassium fertility, release and uptake by soybean.

2.3 Effect of levels of potash on plant growth of soybean.

2.4 Effect of levels of potash on yield and quality of soybean.

2.5 Effect of levels of potash on nutrient uptake by soybean.

2.1.a Occurrence and distribution of Inceptisol

Indian Inceptisols are associated with Vertic soil properties and mostly occur in peninsular India extending from 8^0 45' and 26^0 N latitude to 68^0 and 78^0 45' E longitude covering an area of 27 million hectares constituting nearly 37 per cent of total black soils in India (Murthy *et al.*, 1982).

These soils are mainly distributed in the States of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orissa, Bihar and Uttar Pradesh.

2.1.b Physical and chemical properties of Inceptisol

Inceptisols are mineral soils that have one or more pedogenic horizons *viz.*, A, A_2, B, B_2 and C. Inceptisols are of any depth, but in general, these are categorized into medium depth having silty clay loam to clayey texture and smectite mixed with other clay minerals.

Indian Inceptisols are sandy clay loam, silty clay with clay content of surface and subsurface ranged from 13.9 to 42.6 % (Lal *et al.,* 1994). Benchmark Inceptisol soils of India is clay loam to silty clay (Srinivasa Rao *et al.,* 1998).

Indian Inceptisols have pH 7.9 to 9.3, organic carbon 0.1 to 0.72 %, calcium carbonate 7.5 to 25 per cent (Shinde and Raghuwanshi, 1982) and have soluble salts 0.20-0.9 dsm^{-1} (Lal, *et al.*, 1994) while Inceptisol of M.P.K.V, Rahuri campus have pH 8.19, soluble salts 0.54 dsm^{-1}, cation exchange capacity 36.5 Cmol (P^+) kg^{-1} (Chaudhari, 2001).

2.2 Potassium fertility, release and uptake by soybean

2.2.1 Potassium fertility status in soils of Maharashtra

The potassium content of the soils of Maharashtra varies widely depending upon the composition of the parent rocks and minerals from which they are formed, the degree of weathering, the climatic conditions and cropping history. Most of the medium black soils of Maharashtra are high in available K, but low in total K content as compared to other group of soils (Patil and Sonar, 1992).

Ghosh and Hasan (1976) reported that Maharashtra soils are rich in potassium however, profitable response to applied K has not always been observed.

In Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu, 28.5 to 48.0 per cent soils are high in potassium, whereas in Madhya Pradesh and Gujarat 71 to 100 per cent soils are so characterized. In these soils, K Saturation ranged from 0.6 to 9.9 per cent (Zende, 1978).

Talele *et al.* (1993) conducted laboratory incubation study in soils from nine locations in that, Paud (Inceptisol) contain about 1120 mg kg^{-1} total K.

Pharande and Raskar (1995) observed that due to intensive cropping on the Typic Chromustert (Kolhapur) and Udic Haplustalf (Kumbhoshi) showed low availability and K release capacity indicating possibility of depletion of reserve K. Hence, regular addition of K fertilizer is essential for maintenance of sustainable soil productivity.

2.2.2 Soil potassium release

The term potassium releasing power is the inherent capacity of the soils to supply K to growing plants from its natural source. As the quantity of exchangeable K in the immediate vicinity of the feeding tips of roots diminished, replenishment in this area takes place by the release of potassium from non-exchangeable pool.

Potassium availability to plants depends upon the amount and relative mobility of different forms of K including the rate of replenishment of available forms by reserve sources. Soil K is usually viewed as solution, exchangeable, fixed and structural K, among which soil solution K and exchangeable K are considered as available K (Wiklander, 1954).

Many soils contain water soluble K and/or exchangeable K depending on the transformations from the non-exchangeable forms to replenish the exchangeable or solution phases upon depletion (Doll and Lucas, 1973). The availability of K to the plants depends on dynamic equilibrium existing among the non-exchangeable, exchangeable and water soluble forms. The water soluble potassium is the form taken up directly by plants and microbes and is also subject to leaching (Sparks, 1980).

Debnath and Sanyal (1996) studied the release potential of non-liable potassium in some Entisols, Alfisols and Inceptisols of West Bengal and reported about the large reserves of step-K in these soils. The step-K contents were related to illite mineral of clay fraction.

The reactions of clay bearing minerals with complexing organic acids which are produced by addition of organic residues, industrial wastes and crop residues in relation to K release from soil needs more attention for better K fertilizer management.

On exhaustive cropping with N and P fertilizers without use of K fertilizers, the cumulative release of K was markedly lower than when N, P and K fertilizer were added to soil (Arvind and Muthuswamy, 1989). They further reported that, the cumulative release of K was enhanced from 210 to 310 ppm as the N, P and K input increased from 50 to 150 per cent, while it was only 190 ppm in N and P treatment, without K addition.

2.2.3 Potassium uptake by soybean

Field crops generally absorb potassium faster than they absorb N or P or build up dry matter. However, the rate of K absorption during the crop growth differs with the crop and the conditions of its growth (Tandon and Sekhon, 1988). Within limits there are variations in nutrient uptake per unit yields, depending upon crop yields, crop verities, type of soil and its K fertility status.

Nambiar and Ghosh (1984) and Aulakh *et al.* (1985) observed that K uptake in soybean has been estimated as about 101 – 120 kg ha^{-1}.

Bishit and Chandel (1996) worked at Pantnagar and reported that application of 20 kg N + 80 kg P_2O_5 + 40 kg K_2O + 5 kg Zn ha^{-1} recorded higher uptake of nitrogen and potassium whereas highest uptake of phosphorus was recorded with the application of 80 kg P_2O_5 + 40 kg K_2O + 10 t FYM ha^{-1}.

Hoeft *et al.* (2000) observed that mature soybean seed contains nearly 60 per cent of the total K in plant. Young seedling of soybean do not use much potassium, but the rate of uptake climbs to peak during the period of rapid vegetative growth, the potassium in vegetative part is transferred to seed during pod fill process.

Swarup *et al.* (2001) also stated that removal of 101 kg ha^{-1} of K has been reported in case of soybean. 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.

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^{-1}, 26.0-34.6 kg P ha^{-1}, 16.6-33.2 kg K ha^{-1} and 20 kg S ha^{-1}, keeping in view the adjustment based on soil test values. The reported crop uptake of these nutrients was 125-190 kg ha^{-1} of N, 19-43 kg ha^{-1} of P, 101-120 kg ha^{-1} of K and 9-22 kg ha^{-1} of S (Nambiar and Ghosh, 1984; Aulakh *et al.,* 1985). A similar report for K removal in Madhya Pradesh was made by Swarup *et al.* (2001).

2.3 Effect of levels of K on plant growth of soybean

Potassium is vital to many plant processes owing to it's requirement for activation of at least 60 different enzymes involved in plant growth (Suelter, 1970). Potassium is also important in translocation of sugars within the plants and for the transport of the water and nutrients. Due to all these important roles K levels affects the growth of plants and literature regarding to this is presented here.

Reddi *et al.* (1973) observed that with increasing nitrogen levels number of nodules of soybean decreases while increasing potassium levels increase in the number of nodules.

Jones *et al.* (1977) studied the effect of phosphorus and potassium on soybean nodules and seed yield. The experiment was conducted in greenhouse. Annul P rates of 0, 15, 30 and 60 kg per he were applied with 0 and 112 kg K ha^{-1} in one field experiment. In another, annual K rates of 0, 28, 56 and 112 kg ha^{-1} were applied with 0 and 6.0 kg P ha^{-1}. The result revealed that application of both P and K individually increased nodulation and pod formation with more response from K than P. The maximum response was obtained when both elements were added. Even though the soil was very low in available P when the experiment was initiated there was no seed yield response to more than 15 kg P ha^{-1}. A good yield response was obtained from 28 kg N ha^{-1} and to increasing rates of K when 60 kg P ha^{-1} was added, thus these results indicated the higher requirement of soybean for K than for P.

Raghuwanshi *et al.* (1988) worked on medium black cotton soil having 246, 14 and 1036 kg ha^{-1} of available N, P_2O_5 and K_2O respectively at college of Agriculture, Indore and found the optimum dose of 20:40:20 N, P_2O_5 and K_2O kg ha^{-1} for soybean.

Singh and Bajpai (1990) observed the effect of phosphorus and potash on growth and yield of rainfed soybean. The grain yield of soybean increased significantly with the increasing phosphorus levels up to 60 kg P_2O_5 ha^{-1}. Potash application to soybean significantly increased the number of pods per plant and grains per plant. But the application of potash did not influence the number of nodules per plant, nodule dry weight per plant, test weight and grain yield.

Grewal *et al.* (1994) studied the effect of split application of potassium on growth, yield and potassium accumulation by soybean on a loamy sand (Typic Ustochrept) soil. Soybean (cv. PK - 416) was given 25, 50 or 75 kg K ha^{-1} at sowing, half at sowing and half at flower initiation or one third each at sowing. Flower initiation and pod development. Best results were obtained with 50 kg K in 2 or 3 splits. Seed yield did not differ between 50 and 75 kg K. split application increased fertilizer use efficiency, LAI, crop growth rate and leaf chlorophyll content. Fertilizer use efficiency decreased with 75 kg K. At maturity the K *concentration* of seeds varied from 1.5 per cent without K application to 2.1 per cent with 75 kg K in three splits.

Permratatne and Oertii (1994) grown soybean cv. Maple arrow under controlled conditions in hydroponic or sand culture and given a nutrient medium containing 1.0, 5.0, 10.0 or 20.0 mM K. The dry matter yield, nodule parameters (nodule number, fresh weight of nodule per plant and average nodule weight) and total nitrogen uptake increased with increasing K supply. The lowest potassium level was deficient of normal growth, nodulation and N uptake, whereas 5.0 mM K was optimal level for these parameters.

Anuradha and Shrama (1995) conducted two field experiments on soybean during the post rainy season of 1991-92 and 1992-93 on deep Vertisols so to study the effect of four levels of potassium (0,25,50 and 75 kg ha^{-1}) on chlorophyll content. The 20:60 $N:P_2O_5$ kg ha^{-1} was applied. It was observed that potassium application improved leaf chlorophyll content *i.e.* application of 75 kg ha^{-1} K_2O recorded 2.0 and 2.02 mg g^{-1} on 60 days after emergence in two years respectively.

Dubey (1999) recorded the mean nodule count and nodule dry weight per plant significantly improved in soybean plant by application of 30 kg K_2O ha^{-1}.

Potassium fertilization elicits responses in soybean plants. These potassium fertilization responses can be achieved under a number of management regimes when the soil tests low for available K. Soybean yield increases can be obtained with K fertilization when grown under conventional tillage (Casanova 2000), conservation tillage (Borges and Mallarino, 2000, Buah *et al.*, 2000, Nelson *et al.*, 2005, Yin and Vyn, 2002, 2003, 2004), when the fertilizer was banded or broadcast (Borges and Mallarino 2000, Buah *et al.,* 2000, Yin and Vyn, 2002, 2003, 2004), and sometimes when the K is applied in a foliar application (Haq and Mallarino, 2005, Nelson *et al.*, 2005). The positive yield response to K can be attributed to increases in most of the yield components.

Singh *et al.* (2001) conducted a field experiment during the *kharif* season of 1994 and 1995 in Punjab to evaluate the response of soybean (cv. PK-416) to the combined application of N (30, 60 and 90 kg ha^{-1}), P (40, 60, and 80 kg P_2O_5 ha^{-1}), K (30 and 60 kg K_2O) and Zn (25 kg ha^{-1}). The growth attributes and grain yield of soybean significantly increased with the application of the fertilizers. The highest number of pods per plant (68.9) and seed yield (24.8 q ha^{-1}) were obtained at the fertilizer combination NPK Zn 90:80:60:25. The treatment NPK at 90:60:30 produced the highest 100 grain weight in soybean (16.6 g).

Novo *et al.* (2001) found that the application of potassium improved nodulation and N application.

Borges and Mallarino (2003) also found that potassium fertilization had a small and inconsistent effect on plant early-growth and grain yield responses in ridge till systems, regardless of fertilizer placement method used.

Brar *et al.* (2004) observed that with application of potassium influenced favourably all the growth parameters *viz.*, number of pods, weight of pods, weight of 100 grains, number of grains per pod, length of pods with potassium application up to 50 kg ha^{-1}.

Swaroop (2006) found that the application of 120 kg K_2O ha^{-1} had produced maximum length of root per plant, fresh and dry weight of nodules per plant, yield of green pods in pooled available P and K in soil.

Joshi (2007) studied management of potassium nutrition in soybean based cropping system in the state of M.P. and reported that soybean as well as soybean-wheat cropping system invariably responds favourably to potassium application up to 50-60 kg K_2O ha^{-1}. Other yield associated characters *viz.*, Number of nodules per plant, grain weight, grain per plant, chlorophyll content, *etc.* also increase on potassium application.

Dixit *et al.* (2011) reported that all the growth parameters are affected due to K application. They study was carried out in Ujjian district of M.P., India during *kharif* 2008 on five farmers' plots and reported that plant height, branches per plant, number of nodules per plant, nodule dry weight, pods per plant, test weight (weight of 100 seeds), grain and straw yield and harvest index were significantly affected by the application of 40 kg K_2O ha^{-1}, in comparison to farmer's practice where there was no application of K_2O.

2.4 Effects of levels of potash on yield and quality on soybean

Performance of India's agriculture sector since independence has been quite impressive and it is due to judicious use of fertilizers, use of improved seeds and technology. Food grain production has increased from 51 million tonnes in 1950-51 to 257.4 million tonnes in 2011-12 recording rise by more than five times (Anonymous, 2012). The growth in area of soybean (*kharif*) is 4.09 lakh ha^{-1} in 2012 but as compared to area, production is not so increased. It is well known that yield of crop vary due to several factors but soil and its composition *i.e.* nutrient availability has greater role in yield potential, large scale researches were carried out in order to study the effect of potassium fertilizers application on yield of food crops. Relevant literature regarding effect of fertilizer application on yield of soybean is presented here.

Quality refers to degree of excellence and suitability for specific utility of the plant product. Application of chemical fertilizers play a significant role in increasing yields of crops at the same time it affects quality of plant produce. The literature in respect of some quality parameters of soybean as influenced by K fertilizer application is presented here.

Talathi (1983) reported that application of 0, 37.5 and 75 kg K_2O ha^{-1} did not show any significant effect on the yield attributes, grain, straw and oil yield of soybean during *rabi* season under lateritic soil conditions.

Bharati *et al.* (1986) recorded significant increase in grain yield of soybean with soybean with application of 30 kg K_2O.

Kundu *et al.* (1990) conducted a long term field experiment continuing for 14 years (1973-1986) on a sandy loam soil, response of soybean and wheat to applied K. The year wise yield responses of soybean to applied K (at the rate 33.2 kg K ha^{-1}) shows gradually increase in K response with the increase in number of advancing years. Average (fourteen years) seed yield response of soybean to directly applied K was 15.49 kg ha^{-1} K in soil profile ranged between 50.00-135.60 K in exchangeable and non- exchangeable and 62.6-75.5 kg ha^{-1} profile respectively. Depletion of available and non-available exchangeable K in soil profile varied from 5.4-148.5 and 96.0-522.8 kg K ha^{-1} profile respectively.

Mondal *et al.* (1990) reported that mustard crop responded favourably to potassium up to 60 kg K_2O ha^{-1}.

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).

Joshi and Rudraradhya (1993) conducted a field experiment on a sandy loam soil during the *kharif* season of 1990 at Shimoga, Karnataka and found that soybean cv. Moneta were given 25 or 50 kg N+25, 50 or 75 kg K_2O ha^{-1} while seed yield were highest with 50 kg N+50 kg K_2O (4.3 t ha^{-1}).

Yadav *et al.* (1993) evaluated the response of soybean, rice, wheat, gram, black gram, potato and maize to potassium application in different districts of Uttar Pradesh and resulted that rainfed pulses gave yield response of 4.8 kg seed per kg K_2O with 20-30 kg K_2O ha^{-1} and also showed that an increase of about 8-12% in grain yield may be achieved due to application of K_2O alone.

Singh *et al.* (1993) observed that grain and stover yield of soybean significantly enhanced with the application of potassium up to 9.25 ppm.

Annaduri *et al.* (1994) studied the influence of potassium levels (0, 10, 20, 30, and 40 kg K_2O ha^{-1}) gave highest yield, oil content and benefit cost ration in both the crops sunflowers and soybean. The residual effect of K was seen when sunflowers followed by soybean and fresh addition of K to soybean also had a significant influence on growth, yield and oil content.

Singh *et al.* (1994) reported that soybean yield was highest (15.8 q) with 40 kg N + 80 kg P_2O_5 + 40 kg K_2O.

Sharma and Dixit (1994) conducted a field experiment on an acid alfisol silty clay loam soil and observed that application of lime up to 3.7 t ha^{-1} and potassium up to 30 kg K_2O ha^{-1}

significantly increased grain as well as at straw yield of wheat, soybean and linseed. The application of K_2O @ 30 and 60 kg K_2O ha^{-1} and lime up to 7.4 t ha^{-1} increased different forms of K as well as K fixing capacity of the soil significantly after the harvest of crops.

Deshmukh *et al.* (1994[a]) studied the response of soybean to phosphorus and potassium application in Vertisols of Akola and Amravati. The result showed that 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} improves the quality of grain and grain yield. Phosphorus and potassium application resulted in significant increase in protein and oil content of soybean grain. The interaction effect of P and K was found significant in oil yield only.

Deshmukh *et al.* (1994[b]) conducted a field experiment on soybean in vertisol at Punjabrao Deshmukh Krishi Vidyapeeth, Akola. The results showed that 60 kg P_2O_5 ha^{-1} significantly out yielded for growth, grain and straw yields. Application of K up to 60 kg K_2O ha^{-1} produced significantly favourable effects on the parameters, including test weight.

Grewel *et al.* (1994[a]) conducted a field experiment was conducted on loamy and soil involving four levels of K (0, 25, 30 and 75 kg K_2O ha^{-1}) and 4 levels of N (0, 60, 90 and 120 kg N ha^{-1}) on soybean cv. PK 416. Soybean responded significantly to potassium up to 50 kg K_2O ha^{-1} with 60, 90 and 120 kg N ha^{-1}. In the absence of N response of K was up to 25 kg ha^{-1} only. Response to N was up to 120 kg ha^{-1} when K was applied to soybean where as in the absence of K as a significant response was obtained up to 90 kg N ha^{-1}. The agronomic efficiency at 25, 50, 75 kg K_2O ha^{-1}

was 13.5, 10.3 and 6.1 g grains kg^{-1} applied K_2O. The efficiency for N application was 21, 18.4 and 14.5 g grains kg^{-1} applied N at 60, 90 and 120 N ha^{-1} respectively. Potassium and nitrogen increased leaf area index, chlorophyll content of leaves, yield attributes and consequently the seed yield.

Grewel *et al.* (1994[b]) conducted that on loamy sand soil having 135 kg ha^{-1} of available K, soybean responded to K application up to 50 kg K_2O ha^{-1}. Response to N (soil having 0.19% organic carbon) was up to 120 kg N 25 kg ha^{-1} when K applied to soybean.

Singh and Gangwar (1995) reported that the response of soybean to soil and applied N, P and K was studied in mollisol in Tarai region of Uttar Pradesh. The highest R^2 value *i.e.* 0.58 was obtained where regression of yield was tried on soil test values, fertilizer of doses and interaction between soil and fertilizer nutrient and among fertilizer. Nutrient quadratic model proved better as compared to liner model for prediction of yield response pattern of this crop to stimulant variations in soil fertility levels in N, P and K fertilizer doses.

Kumar and Singh (1996) concluded that the continuous cropping and chemical fertilizer use, it was found that grain yield, nutrient uptake and status of soil micronutrients were highest in plots received balanced NPK fertilization along with FYM. Imbalance proportion of fertilizer use such as N without P and K or NP without K resulted in significant reduction in crop uptake of micronutrient.

Rakeshkumar and Singh (1996) conducted a field trial with soybean in 1996 and reported that combinations of 50, 100 and 150 % of recommended NPK @ 25, 40 and 60 kg ha^{-1} gaves highest grain production with 100% NPK + 5 t ha^{-1} of FYM.

Inam *et al.* (1996) carried a field experiment at Aligarh, India on various crops (mustard, pigeon pea, gram) under different moisture levels (rainfed or 1, 2 or 3 irrigations) with six K_2O rates (0-150 kg ha^{-1}). Potassium application improved the ability of the crops to withstand water stress. The grain legume responded best to 75 kg ha^{-1} under rainfed condition whereas under irrigated condition, it was 50 kg ha^{-1}.

Megen (1997) conducted a study at Amlah, M.P. on effect of K application on seed quality character of soybean and reported that K application increased 100 grain weight (14.2 g) and oil content (21.5 %) and highest in 30-80-50/50 $N:P_2O_5:K_2O$ kg ha^{-1} while protein per cent was not increased significantly.

Madhavi *et al.* (1997) carried out experiment on sand loam soil having available nutrient status of 250, 50 and 161 kg ha^{-1} N, P_2O_5 and K_2O, respectively. They reported significant increase in seed yield of soybean over control due to application of 60 kg N + 80 kg P_2O_5 + 40 kg K_2O ha^{-1}.

Kanwar and Sekhon (1998) reported that imbalanced fertilization with more nitrogen, less phosphorous and potassium are common cause of low yield, low nutrient use efficiency and poor grain quality.

Bansal *et al.* (2001) reported that the grain yield of 25 and 55 q ha^{-1} in soybean and wheat can be achieved and sustained with adequate and balanced NPK application. Fertilizer doses of $N_{30}P_{80}K_{100}$ and $N_{100}P_{50}K_{100}$ resulted highest yield of soybean and wheat respectively. He also stated that optimum potash application also increased soybean oil content by about 10 %.

Borse *et al.* (2002) studied response of green gram to irrigation schedules and fertilizer levels at Central Campus of M.P.K.V., Rahuri. They reported that yield was significantly higher (1107 kg ha^{-1}) with 33 kg N, 35.9 kg P_2O_5 and 21.6 kg K_2O as compared to control.

Mondal *et al.* (2003) reported that highest dry matter production, yield components and seed yield were obtained when green gram was fertilized with 30 kg K_2O ha^{-1} and 30 kg S ha^{-1} under irrigated condition.

Borges and Mallarino (2003) also found that potassium fertilization had a small and inconsistent effect on plant early-growth and grain yield responses in ridge till systems, regardless of fertilizer placement method used.

Lokhande and Phrande (2004) conducted the field experiment to study response of soybean to potassium in soil series of Entisol and Inceptisol and reported that grain and straw yields were highest with application of 40 kg K_2O ha^{-1} in both series. The application of 40 kg K_2O ha^{-1} showed the highest protein content in Entisol whereas highest oil content was observed in Inceptisol.

Nelson *et al.* (2005) reported that foliar application of potassium to soybean increases yields of soybean. They conducted field research in 2001 and 2002 to determine soybean response to foliar-applied K fertilizer compared with a preplant application and evaluate the cost-effectiveness of these treatments. Potassium fertilizer (K_2SO_4) was either broadcast-applied at 140, 280, and 560 kg K ha^{-1} as a preplant application or foliar-applied at 9, 18, and 36 kg K ha^{-1} at different stages of soybean development. They stated that soybean grain yield increased 727 to 834 kg ha^{-1} when K was foliar-applied at 36 kg ha^{-1} at vegetative stages in 2001 and 2002. Foliar applied K at the reproductive stage of development increased grain yield but not as much as vegetative stage application timings.

Haq and Mallarino (2005) reevaluated the effects of phosphorus and potassium fertilization and placement on soybean oil and protein concentrations. Infrequent, small, and inconsistent increases in soybean oil and protein concentrations were observed with phosphorus and potassium fertilization, as well as a more frequent increase in grain yield. The authors concluded that increases in oil and protein concentrations from fertilization were unlikely. However, an increase in yield resulted in an increase of total production per unit area of oil and protein.

Khan (2006) reported that increase in oil content by 7% in soybean by K application in a study conducted at Indore.

Seguin and Zheng (2006) also investigated the effect of phosphorus, potassium, sulfur, and boron fertilization on soybean isoflavone content and seed oil and protein concentration, but found few significant changes due to fertilization. The authors speculated that the lack of response was probably due to high levels of fertility in the soil prior to conducting the experiment. They concluded that levels of phosphorus and potassium above adequate did not provide any significant response for any variable measured.

Slaton *et al.* (2006) reported that soybean yields were significantly increased by K fertilization at the different sites in the University of Arkansas. Application of ≥80 lb K_2O acre^{-1} produced near maximal soybean yields that were always significantly greater than the unfertilized control K and usually greater than 40 lb K_2O acre^{-1} at the three responsive sites. Application of 80 lb K_2O acre^{-1} increased soybean yields by 14 to 53 % compared to the unfertilized control.

Asghar-Ali *et al.* (2007) reported that potassium application increased seed yield gradually with increase in potassium level and maximum seed yield (2341 kg ha^{-1}) was obtained with 150 kg K_2O ha^{-1}.

Studies completed by Fernandez *et al.* (2009) agreed with Haq and Mallarino (2005) indicating that no changes in oil or protein concentrations occurred due to potassium fertilization in medium and high soil-test potassium environments.

Thakare and Tapare (2009) reported that potassium application to soybean affects yield and quality of soybean. The field experiment was conducted during *kharif* 2008 on Vertisols at PDKV, Akola with three graded levels of K (20, 30 and 40 kg ha^{-1}) and KNO_3 spraying. Soil application of 30 kg K_2O ha^{-1} along with 100% RD significantly recorded the higher yield of 2465 kg ha^{-1}. Foliar application 30 DAS and 60 DAS with 100 % RD recorded the highest soybean grain yield (2494 kg ha^{-1}). Application of 30 kg K_2O ha^{-1} along with 100 % RD significantly increased the nodule count.

The highest oil (21.93 %) and protein (42.92 %) content of soybean was recorded in the treatment receiving foliar application of 2 % KNO_3 sprayings.

Veiga *et al.* (2010), working with soybean, in a soil with 37 % clay, found an increase in oil content with increasing the potassium rates.

Kathmale *et al.* (2011) reported K application improves yield and quality of soybean. They conducted a field experiment during *kharif* 2009-10 at Agricultural Research Station, K. Digraj, Dist. Sangli in medium deep soil with four treatments of K (0, 20, 40 and 60 kg K_2O ha^{-1}) and foliar application of 1 and 2 % potassium at 30 DAS and 60 DAS. Soil application of 40 kg K_2O ha^{-1} recorded higher grain yield (21.57 kg ha^{-1}). Application of potassium also improved quality of soybean.

Krueger (2011) at Lowa State University, Ames, Lowa (USA) conducted a experiment on effects of phosphorus and potassium fertilization rate and placement method on soybean seed quality and long-term storability. The objectives were to determine the effect of different levels of phosphorus and potassium fertilization on soybean seed quality. Seed samples were obtained from a long-term phosphorus and potassium fertilization trial. Phosphorus and potassium treatments were combinations of four fertilization rates (0, 31, 63, 123 P_2O_5 and 0, 39, 78, 164 K_2O) and two placement methods (broadcast, side band). Results indicated that phosphorus and potassium fertility levels above optimum decreased seed quality. They also reported that high levels of phosphorus and potassium fertilization can affect seed quality and composition. Seed compositional changes also were observed in response to phosphorus and potassium fertilization. Many of these results were small and inconsistent, so we do not recommend applying excess fertilizer to improve these quality traits. However, a few of our observations of fertilization effects on seed composition warrant further investigation.

Dixit *et al.* (2011) reported that grain yield (15.5 q ha^{-1}), straw yield (29.5 q ha^{-1}) and harvest index (52.6 %) were significantly affected by the application of 40 kg K2O ha^{-1}, in comparison to farmer's practice where there was no application of K_2O. In experiment, K use efficiency increased with K application, which suggests that the higher application of potash should be tested. At 8.25 kg grain for each kg K_2O applied, application of 40 kg K_2O ha^{-1} brings an Incremental Cost Benefit Ratio (ICBR) of 15.06, which should be very lucrative for farmers.

Pande *et al.* (2012) conducted a greenhouse experiment at Mississippi Valley State University, (Itta Bena, MS), using two glyphosate-resistant soybean cultivars DK 4968 and Pioneer 95Y70 grown in a randomized complete block design. The treatments were foliar applications of K alone, Gly alone, K + Gly combined, and non- treated control (C). A higher concentrations of K, N, P, and B in leaves and seeds as a result of K and Glyphosate applications indicated that potassium and glyphosate enhanced the accumulation of these nutrients in leaves and seeds. Foliar application of potassium and Glyphosate treatments resulted in higher protein percentages in all treatments in DK 4968, while oil percentage decreased. However, in Pioneer 95Y70, protein decreased with Glyphosate treatment.

2.5. Effects of levels of potash on nutrient uptake by soybean

Plants absorb nutrients only in inorganic form. Availability of nutrients for plant growth and their uptake by plant depends on nutrient availability in soil which is influenced by fertilizer application. Also the phenomenon of nutrient interactions is another reason of nutrient availability. Here in this topic, relevant literature regarding the effect of K on nutrient uptake by soybean straw and grain is presented.

The long-term experimentation conducted on Vertisols of Jabalpur (M.P.) in soybean-wheat-maize fodder during 1987-88 and 1988-89 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. Due to NPK treatments nitrogen uptake increased from 71 to 196 kg ha^{-1}, phosphorus uptake from 5 to 19.6 kg ha^{-1}, potassium uptake from 45 to 112 kg ha^{-1}, uptake of Zn from 71 to 132 g ha^{-1}, Fe from 287 to 717 g ha^{-1}, Mn from 89 to 241 g ha^{-1} and Cu from 26 to 64 g ha^{-1}. Similar was the effect of application of K on the other crops under rotation (Annual Report 1987-88, 88-89).

Singh and Tomar (1991) conducted a greenhouse experiment on an alluvial soils of Uttar Pradesh. The results revealed that the application of K and FYM significantly increased the total K uptake. The K uptake also increased with increasing K levels associated with organic matter.

Bishit and Chandel (1996) worked at Pantnagar and reported that integrated application of 20 kg N + 80 kg P_2O_5 + 40 kg K_2O + 5 kg Zn ha^{-1} recorded higher uptake of nitrogen and potassium whereas highest uptake of phosphorus was recorded with 80 kg P_2O_5 + 40 kg K_2O + 10 t FYM ha^{-1}.

A field trail conducted by CSKKV, Palampur on *kharif* soybean and reported that for production of one quintal of economical produce 5.23 kg N, 2.75 kg P_2O_5 and 2.93 kg K_2O were required (Anonymous, 2000), these results were also supported by Anonymous, 1998.

A field trail on soybean conduced at Palampur on clay loam acid Alfisol having low N and P indicated that 3.99 kg P_2O_5 and 1.17 kg K_2O were required to produce one quintal of grain (Verma and Suri, 2000).

Ghosh and Gupta (2000) conducted a field trail on soybean based on targated yield approach on Mollisol and observed that 2.77 kg P_2O_5 and 5.37 kg K_2O were required to produce one quintal of grain.

Ghosh *et al.* (2001) observed that at highest level of N (80 kg ha^{-1}) and K (25 kg ha^{-1}) maximum yield of rapeseed was obtained followed by yield obtained with 80 kg N ha^{-1} along with 12.5 kg K ha^{-1}.

Borse *et al.* (2002) reported that total uptake of N, P and K (112.39, 37.97 and 100.50 kg ha^{-1}) of green gram was increased significantly with increase in fertilizer and it was maximum in fertilizer of $N_{33}P_{33.9}K_{21.6}$ kg ha^{-1}.

Nita-chand *et al.* (2002) conducted the experiment in West Bengal on effect of potassium and sulfer on mung bean and reported that application of 40 kg K_2O ha^{-1} shows significant increase in fertility of soil.

Murthy and Muralidharudu (2004) conducted a green house experiment in red sandy loam to study the castor to graded level of K application and to establish its critical limit. Graded levels of K application resulted in significant increase in dry matter yield, K concentration and uptake in castor at 30 days after sowing, critical K limits for castor plant at this stage was observed to be 1.72% and for soil 225 kg K ha^{-1}.

Joshi (2007) studied management of potassium nutrition in soybean based cropping system in the state of M.P. and reported that application of K to soybean 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.

Thakare and Tapare (2009) reported that Potassium uptake of soybean was significantly increased up to 30 kg K_2O ha^{-1}. Similarly, significantly highest N and P uptake was recorded up to 40 kg K_2O ha^{-1} during conduct of field experiment (*kharif* 2008) on Vertisols at PDKV, Akola with three graded levels of K (20,30 and 40 kg ha^{-1}) and KNO_3 sprayings.

According to Bernardi *et al.* (2010), an alternative for the producer would be to apply fertilizer in amounts to restore nutrients exported at harvest. In this respect, harvesting one tonne of soybean removes 18.7 kg K (Tanaka *et al.,* 1993), or 22.5 kg of K_2O from the soil. If the amount of K removed at harvest was not properly restored, some K mining would be expected to occur. The balance of K fertilization (K_2O applied and K_2O exported) indicates that a positive balance can only be achieved by supplying 80 to 120 kg of K_2O ha^{-1}. The average fertilization (80 kg K_2O ha^{-1}) used by the producer in this area could still lead to a small deficit of K supply. These findings are also in agreement with those reported by Bongiovanni and Lowenberg-Deboer (2004), that VRA of K improved fertilizer distribution.

3. MATERIALS AND METHODS

The present field experiment entitled, "Response of potassium on yield and quality of soybean in Inceptisol" was carried out at the Post Graduate Research farm of Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar during the year 2012-13, so as to study the effect of various levels of potassium applied to *kharif* soybean on yield and quality of soybean. In brief this study was aimed to find out the most optimum potassium fertilizer application for maximum productivity of soybean in the Inceptisol.

The details of field experiment, its conduct, observations, the materials used and analytical techniques (methods) adopted for chemical properties of experimental soil and also plant analysis are reported in this chapter under different sub heading.

3.1 Material

3.1.1 Experimental site

The present investigation was carried out at Post Graduate Research Farm (Block B, Survey No. 50) of the Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* season of 2012-13. The experimental field is situated in between 19^0 47' N to 19^0 57' N latitude and between 74^0 18' E to 74^0 19' E. The elevation above mean sea level is 435 m.

3.1.2 Climate

The field experimental site climatically belongs to semi-arid zone with an average annual rainfall of 519 mm. The meteorological data with respect to temperature, humidity and rainfall was obtained from the Chief Scientist, All India Coordinated Project for Research on Water Management, MPKV, Rahuri and presented in Table 1. The minimum and maximum temperature during growing period of soybean crop was 15.60^{0}C to 23.6^{0}C and 20.74^{0}C to 32.7^{0}C respectively. The minimum and maximum relative humidity during the crop growth period was 32 to 69 and 63 to 88 per cent in morning and evening; respectively. Total rainfall during the *kharif* crop growing period was 390.7 mm. Agro-climatically, this tract falls in Scarcity Zone having low rainfall and dry climate. However, Maximum rains were received during the 40th meteorological week i.e. 118.6 mm.

Table 1. Average weekly meteorological data recorded during the experiment period *kharif* 2012

Met week	Temperature (^{0}C)		Relative humidity%		Sunshine hrs	Wind speed km/hrs	Rain fall (mm)	Rainy days
	Max.	Min.	Mor.	Even.				
July, 2012								
27	31.4	23.4	74	56	03.6	06.4	043.3	3
28	32.7	23.3	71	53	04.4	07.5	004.8	1
29	31.5	23.6	75	58	02.8	06.6	003.6	1
30	29.7	23.3	73	63	00.2	07.7	001.0	0
31	20.74	15.71	77	69	01.3	07.6	023.6	2
August 2012								
32	30.6	22.6	79	55	02.1	07.4	000.8	0
33	31.6	21.5	75	57	04.8	07.6	000.0	0
34	32.5	21.9	73	48	06.3	05.5	000.0	0
35	21.16	15.88	79	62	03.2	03.5	031.4	2
September 2012								
36	29.6	22.6	81	64	02.3	07.1	060.2	2
37	30.1	22.1	76	62	04.1	07.6	015.8	2
38	30.4	21.4	86	57	03.2	01.9	069.0	2
39	31.6	20.2	81	48	07.9	01.9	000.0	0
40	31.4	21.7	88	62	03.7	01.4	118.6	5

Table 1 contd...

Met week	Temperature (°C)		Relative humidity%		Sunshine hrs	Wind speed km/hrs	Rain fall (mm)	Rainy days
	Max.	Min.	Mor.	Even.				
October 2012								
41	32.1	19.7	73	41	08.1	00.6	000.0	0
42	32.2	16.9	74	32	08.8	01.4	000.0	0
43	31.4	19.9	76	46	04.9	01.3	018.6	1
44	30.0	15.6	63	40	07.0	01.8	000.0	0

3.1.3 Experimental soil

The soil from the experimental site of present investigation was grouped under Inceptisol order which comprises of fine montmorillionitic isohyperthemic family of *Vertic Haplustepts*. The soil was medium black with a 70 cm depth having high swell shrink property. The initial values of chemical properties of experimental soil are reported in Table 2.

Table 2. Initial chemical properties of experimental soil

Sr. No.	Parameters	Value
I.	**Soil analysis**	
1.	pH (1:2.5)	8.01
2.	EC (1:2.5) (dSm^{-1})	0.41
3.	$CaCO_3$ (%)	6.5
4.	Organic carbon (%)	0.44
5.	Available N (kg ha^{-1})	155.0
6.	Available P (kg ha^{-1})	12.8
7.	Available K (kg ha^{-1})	232.0
8.	Fe (mg kg^{-1})	4.53
9.	Mn (mg kg^{-1})	7.64
10.	Cu (mg kg^{-1})	1.70
11.	Zn (mg kg^{-1})	0.46

3.1.4 Field experimental details

The cropping history of experimental field in preceding year (2011-2012) is presented in Table 3.

Table 3. Cropping history of the experimental field

Sr. No.	Years	Season		
		Kharif	***Rabi***	**Summer**
1.	2011-12	Soybean	Wheat	Maize exhaust crop

As the present experiment is on potassium nutrients studies, before conduct of an experiment, maize crop was grown on experimental site as an exhaust crop for development of uniform fertility gradient. The experimental field was prepared by one ploughing and two harrowing after the harvest of exhaust maize crop. The stubbles were removed from the field. The field experiment was laid out in randomized block design (Fig. 1) with seven treatments and four replications and the other details of field experiment are given below.

a. Experimental crop : Soybean
b. Variety : JS-335
c. Spacing : 30 x 10 cm
d. Seed rate : 45 kg ha^{-1}
e. Recommended dose of fertilizer : 50:75:00 $N:P_2O_5:K_2O$ kg ha^{-1}
f. Plot size :

		Hills/Line	Line
Gross area-	5.10 x 4.50 m	51	15
Net area-	4.50 x 3.90 m	45	13

g. Experimental design : Randomized Block Design
h. No of treatments : 7
i. Replications : 4

The details of the treatments used in the experiment are given below

Details of treatments for field experiment

T_1	:	Absolute control
T_2	:	R.D. (50:75:00 N:P_2O_5:K_2O kg ha^{-1}) *i.e* **(Recommended dose of fertilizer to soybean by M.P.K.V., Rahuri)**
T_3	:	R.D. + 20 Kg K_2O ha^{-1}
T_4	:	R.D. + 30 Kg K_2O ha^{-1}
T_5	:	R.D. + 40 Kg K_2O ha^{-1}
T_6	:	R.D. + 50 Kg K_2O ha^{-1}
T_7	:	R.D. + 60 Kg K_2O ha^{-1}

3.1.5 Organic manures

The well decomposed FYM was obtained from the Senior Scientist, Cattle Improvement Project, Department of Animal Science and Dairy Science, MPKV, Rahuri and mixed well in the experimental field at the rate of 5 tones ha^{-1}.

3.1.6 Fertilizer

The fertilizers *viz.* urea (46.0 % N), single super phosphate (16 % P_2O_5) and muriate of potash (60 % K_2O) were used for applying recommended dose of N, P_2O_5 and K_2O and dose required as per treatments to soybean and these fertilizers were procured from the Department of Soil Science and Agricultural Chemistry, MPKV, Rahuri.

3.1.7 Methods of application of manures and fertilizers

The fertilizers were applied to experimental plots as a basal dose to soybean as per treatments. The recommended fertilizers dose for soybean was applied to experimental plot as per treatment through band placement using Urea, SSP, MOP as a source of N, P_2O_5 and K_2O.

Rhizobium was applied @ 250 g/10 kg seed as seed treatment to soybean in all treatments.

Table 4. Quantity of potassium fertilizer applied (g plot^{-1})

Treatment	**K_2O kg ha^{-1}**	**K_2O g plot^{-1}**
T_1: Absolute control	00	00
T_2: Recommended dose	00	00
T_3: R.D.+ 20 kg K_2O ha^{-1}	20	76.00
T_4: R.D.+ 30 kg K_2O ha^{-1}	30	115.00
T_5: R.D.+ 40 kg K_2O ha^{-1}	40	153.30
T_6: R.D.+ 50 kg K_2O ha^{-1}	50	191.60
T_7: R.D.+ 60 kg K_2O ha^{-1}	60	230.00

3.1.8 Seed

The seeds of the soybean (cv. JS -335) were procured from the Department of Soil Science and Agril. Chemistry, MPKV, Rahuri.

3.1.9 Chemicals

The various chemicals used were analytical grade (A.R.) and procured from the Department of Soil Science and Agril. Chemistry, MPKV, Rahuri which were already purchased from Vijay Chemicals, Shrirampur, Dist. Ahmednagar.

3.1.10 Glassware

Glasswares used for the analytical work of soil, plant and grain samples were of borosil, pyrex, corning (India) made.

3.2 Methods

3.2.1 Collection of soil sample

Before sowing of soybean, the composite representative soil sample was prepared by taking ten soil samples (0-22.5 cm) from experimental field for monitoring initial fertility status of experimental plot.

The composite soil sample for each treatments were taken by collecting together three samples from each treatments after harvest of soybean. The all collected soil samples were processed by air drying under shade, grounded in wooden mortar and pestle, sieved through 2 mm sieve and were analyzed.

3.2.2 Collection of plant samples of soybean

Soybean samples at 30 DAS and 60 DAS and straw and grain samples after harvest from each treatments were collected for analysis, dried and stored well by labeling for subsequent analysis.

3.2.3 Details of the field operations

The details of field operations which were carried out during the period of field experimentation on soybean are presented in Table 5.

3.2.4 Growth studies

3.2.4.1 Plant height

Height of plant generally indicates the growth of a crops. The observations on plant height of soybean were recorded from the 30th days and 60th days. It was measured in cm from the ground level up to the base of the terminal leaf bud on the main stem.

Table 5. Calendar of the field operations for soybean during *kharif* season, 2012

Sr. No.	Operations	Frequency	Date
A. Preparatory tillage			
1.	Ploughing	1	15.06.2012
2.	Harrowing with tractor	1	23.06.2012
3.	Leveling of field		24.06.2012
4.	Preparation of layout	1	26.06.2012
5.	Preparation of bed and channels	1	26.06.2012
B. Application of organic matter and fertilizer as per treatment			
1.	Application of FYM	1	23.06.2012
2.	Application of fertilizers	1	13.07.2012
C.	**Sowing by dibbling**	1	13.07.2012
D. Post sowing operations			
1.	Gap filling	1	24.07.2012
2.	Thinning	1	05.08.2012
3.	Irrigation	5	14.07.2012, 21.07.2012, 07.08.2012, 14.08.2012, 25.08.2012
4.	Weeding	2	30.07.2012, 28.08.2012
5.	Hand hoeing	1	09.08.2012
E.	Harvesting	1	17.10.2012
F.	Threshing	1	22.10.2012

3.2.4.2 Number of branches per plant

The total numbers of branches of main stem of five selected soybean plants were recorded at 60 days after sowing.

3.2.4.3 Number of effective nodules per plant

The numbers of nodules per plant of soybean were measured at 50 per cent flowering for the selected five plants and value was average.

3.2.4.4 Chlorophyll content

For the determination of chlorophyll content, the sample of mature leaf (3rd leaf) was selected from the randomly selected three plants of soybean from each plot and measured with the help of Chlorophyll meter (Spad Index) at 30 DAS and 60 DAS and average value was recorded.

3.2.4.5 Number of pods per plant

The total number of pods from selected five sampled soybean plants was counted. The mean number of pods per plant was calculated.

3.2.4.6 Number of grain per pod

The total number of grain per pod from five sampled soybean plants was counted. The mean number of grain per pod was then calculated.

3.2.4.7 100 grain weight

The 100 grains from each of five selected plants of soybean were collected and weight was recorded.

Table 6. Details of the biometric and other observations recorded on soybean

Sr. No.	Particulars	Frequency	Observation recorded days after sowing	Number of plants for observation for plot
A. Pre harvest growth studies				
1.	Height of plant (cm)	2	30 and 60 DAS	5 plants
2.	Chlorophyll content	2	30 and 60 DAS	5 Plants
3.	Number of nodules	1	At 50% flowering	5 Plants
4.	Number of branches per plant	1	60DAS	5 Plants
B. Post harvest studies				
1.	Number of pods per plants	1	At harvest	5 Plants
2.	Number of grain per pod	1	At harvest	5 Plants
3.	100 grain weight.	1	At harvest	100 grains
4.	Seed and straw yield per net plot	1	At harvest	Net plot plants
C. Chemical studies				
1.	Initial and final soil analysis	1	At sowing and after harvesting	-
2.	NPK uptake	1	After harvest	-
3.	Protein and oil content	1	At harvest	-

3.2.4.8 Grain and straw yield per hectare

The grain yield per hectare (q ha^{-1}) was recorded after threshing all plants from the net plot. The grain yield in quintals per hectare was worked out from the yield of grains per net plot.

The straw yield per net plot was obtained by subtracting seed yield from biological yield of respective net plot. Then straw yield per hectare was worked out from the straw yield per net plot.

3.2.5 Chemical studies

3.2.5.1 Initial and final soil analysis

A composite soil sample up to 22.5 cm layer from the experimental area was collected prior to sowing. After harvest of the crop, soil samples up to 22.5 cm depth were taken from each net plot. These samples were analyzed to estimate the initial and final fertility status of the soil. The NPK content and other pertinent soil properties were estimated using the standard methods given in Table 7.

3.2.5.2 NPK content in plants

NPK content in plants was estimated at harvest by standard methods as given Table 7.

3.2.5.3 NPK uptake

The uptake of nitrogen, phosphorus and potassium by plant was calculated by multiplying per cent nitrogen, phosphorus and potassium content in plant with their respective yield.

3.3 Soil and plant analysis

Methods used for soil, plant and manure analysis are given in Table 7.

Table 7. Standard analytical methods used in the study

	Parameter	Method	Reference
Soil analysis (All initial and after harvest)			
A)	**Chemical properties**		
i.	pH (1: 2.5)	Potentiometry	Jackson (1973)
ii.	E.C. (1: 2.5)	Conductometric	Jackson (1973)
Iii	Available nitrogen	Alkaline permanganate	Subbaiah and Asija (1956)
iv.	Available phosphorus	Olsen's method	Watanable and Olsen (1965)
v.	Available potassium	Flame photometry NH_4OAC (pH=7)	Knudsen and Peterson (1982)
vi.	DTPA micronutrients (Fe, Zn, Mn, Cu)	DTPA method, Atomic absorption spectrophotometer	Lindsey and Norvell (1978)
B)	**Plant analysis**		
i.	Nitrogen	Macrokjeldahl (H_2SO_4 + H_2O_2 digestion)	Parkinson and Allen (1975)
ii.	Phosphorus	Vandadomolybdate yellow color method	Piper (1966)
iii.	Potassium	Flame photometry (H_2SO_4 + H_2O_2 digestion)	Jackson (1973)
iv	Crude protein	Micro-kjeldahl	Piper (1966)
v.	Oil content	Soxhlet extractor	Piper (1966)
vi.	Chlorophyll Content	Chlorophyll meter (Spad Index)	-

3.4 Yield

At physiological maturity soybean crop was harvested and yield of grain and straw of soybean crops was expressed as q ha^{-1}.

3.5 B:C ratio and Economics of potash fertilizer and monetary returns from soybean under influence of various levels of potash

The Benefit : Cost (B:C) ratio was calculated by taking cost of cultivation (Rs) and monetary returns (Rs) by soybean crop. The economics of fertilizer use in soybean crop was calculated by taking cost of total and potash fertilizer (Rs), monetary returns (Rs), returns per Rs invested on fertilizer and returns per Rs invested on potash fertilizer.

3.6 Statistical analysis

The data on growth attributing parameters, yield and nutrient uptake by soybean and soil fertility status was tabulated and processed statistically in RBD by using the methods described by Panse and Sukhatme (1985). The standard error (SE $\pm$) and critical difference (CD) values were computed from experimental data on soil and plant analysis and reported in result Table 8-13.

4. RESULT AND DISCUSSION

The field experiment was conducted during *kharif* season of the year 2012-13 by growing soybean variety JS-335 in Inceptisol so as to study the response of potassium on yield and quality of soybean. The results obtained are statistically analysed, interpreted, presented and discussed in this chapter under following subheadings.

4.1 Effect of levels of potash levels on growth attributing characters of soybean

The data pertaining to growth attributing characters *viz.*, height of plant (30 DAS, 60 DAS), number of branches, chlorophyll content (30 DAS, 60 DAS), effective nodules (at 50 % flowering), number of pods per plant, number of grains per pod, 100 grain weight as influenced by levels of potassium are presented in Table 8 and graphically depicted in Fig. 2a, 2b, 2c and 2d.

4.1.1 Height of plant

The results on plant height (Table 8 and Fig. 2a) showed that the application of potassium significantly influenced the plant height of soybean. The highest height (32.4 cm) of soybean at 30 DAS was observed with application of RD + 60 kg K_2O ha^{-1} (T_7) which was at par with the treatments of RD + 50 kg K_2O ha^{-1} (T_6) and RD + 40 kg K_2O ha^{-1} (T_5).

The lowest height of (24.75 cm) of soybean plant was observed in case of absolute control (T_1) where no fertilizers were applied and it was at par with the treatment T_2 in which recommended dose of fertilizers for soybean (50:75:00) was applied.

Table 8. Effect of levels of potash on yield attributing characters of soybean

Treatments	Height of plant (cm)		Chlorophyll content (spad index)		No of branches at 60 DAS	Effective nodules at 50% flowering	No of pods plant^{-1}	No. of grains pod^{-1}	100 grain weight (g)
	30 DAS	60 DAS	30 DAS	60 DAS					
T_1 : Absolute Control	24.75	32.00	32.11	44.73	7.35	14.91	30.75	2.05	10.30
T_2 : RD (50:75:00)	25.25	40.00	33.87	46.85	8.45	18.41	35.25	2.30	12.19
T_3 : RD + 20 kg K_2O ha^{-1}	27.00	42.30	34.58	46.80	9.40	19.16	36.25	2.55	13.03
T_4 : RD + 30 kg K_2O ha^{-1}	28.75	45.00	35.02	48.17	10.3	20.33	37.00	2.75	13.31
T_5 : RD + 40 kg K_2O ha^{-1}	32.00	46.70	40.37	52.77	11.85	22.41	39.50	3.00	14.31
T_6 : RD + 50 kg K_2O ha^{-1}	32.00	46.95	40.50	53.55	12.1	23.16	40.50	2.95	14.63
T_7 : RD + 60 kg K_2O ha^{-1}	32.40	47.65	40.59	53.71	12.25	24.16	41.00	3.00	14.94
GM	28.88	42.94	36.74	49.49	10.24	20.36	37.29	2.66	13.38
S.Em.$\pm$	0.55	0.11	0.28	0.32	0.05	0.21	1.64	0.08	0.06
CD at 5%	1.63	0.32	0.84	0.94	0.13	0.62	4.88	0.24	0.16

Similarly, the highest (47.65 cm) plant height at 60 DAS was also observed with application of RD + 60 kg K_2O ha^{-1}(T_7) followed by RD + 50 kg K_2O ha^{-1} (T_6), RD + 40 kg K_2O ha^{-1} (T_5) and RD + 30 kg K_2O ha^{-1} (T_4). The lowest (32 cm) soybean height at 60 DAS was noticed in case of absolute control followed by 40 cm was in the treatment with recommended dose.

In general, the data shows that higher values of plant height was observed in treatment T_7 (RD + 60 kg K_2O ha^{-1}) which was at par with T_6 and T_5. This increase in soybean height may due to application of higher dose of potash in these treatments.

Similarly Dixit *et al.* (2011) revealed that positive improvement in plant height under increased potash application.

4.1.2 Number of branches per plant

The data pertaining to number of branches per plant of soybean showed that number of branches per plant were significantly increases with increasing potash levels. The highest (12.25) numbers of branches were observed with application of RD + 60 kg K_2O ha^{-1} (T_7) to soybean, followed by the treatments T_6 and T_5. The absolute control treatment and R.D. treatment showed less number of branches (7.35 and 8.45, respectively) as compared to application of higher levels of potash.

Dixit *et al.* (2011) also reported that significant increase in number of branches were noticed with increasing potassium levels.

4.1.3 Chlorophyll content

The results regarding chlorophyll content in the leaves of soybean as influenced by potassium and recorded at 30 and 60 DAS are presented in Table 8 and Fig. 2b.

From data it is noticed that chlorophyll content increases as potash level increases and chlorophyll content was highest (40.59) in RD + 60 kg K_2O ha^{-1} (T_7) treatment followed by treatments T_6 and T_5 at 30 DAS and it was the lowest (32.22) in absolute control treatment and R.D. treatment (33.87).

Similar trends as like 30 DAS were observed in chlorophyll content, the highest chlorophyll (53.71) was observed in treatment RD + 60 kg K_2O ha^{-1} (T_7) which was at par with treatments T_6 and T_5. The lowest chlorophyll content was observed in control and recommended dose treatment (46.85).

It is documented that potassium is activator of many metabolic and enzymatic processes in plants including biosynthesis of chlorophyll (Suelter, 1970). Potassium nutrition is closely associated with process of photosynthesis and transport of photosynthate to storage organs (Evans and Wildes, 1971). This may explain the increase in chlorophyll content with an increase in levels of application of potash to soybean in this study.

The observations in present study on chlorophyll content under influence of potassium levels are in conformity with the earlier reports of Grewal *et al.* (1994) who noted that RD + 50 kg K_2O ha^{-1} with split doses showed increased leaf chlorophyll content. In another study of Anuradha and Sharama (1995) they observed that application of RD + 75 kg K_2O ha^{-1} recorded the highest chlorophyll content on 60 days after emergence.

4.1.4 Effective nodules

The data with respect to count of effective nodules has shown in Table 8 and Fig. 2c from which it is conducted that the highest number of effective nodules (24.16) were observed in treatment RD + 60 kg K_2O ha^{-1}(T_7) followed by the treatments T_6 and T_5 which were significantly superior over absolute control and R.D. treatments.

It is well known that potassium has also significant role in root development *i.e.* length and density of roots. The healthy roots are also responsible for root exudation phenomenon which improves the rhizosphere effect. The sufficiency of potash in rhizosphere and their concentration in roots enhances transport of absorbed nutrients and water. Potassium provides the roots with the necessary carbohydrates for best nodule functioning and have role in efficiency of nitrogen fixation by rhizobium in soybean plant (Imas and Magen, 2007). This role of potassium in roots and absorption and exudation may explain the enhancement of nodulation as there is increase in application of potash levels.

Similarly Novo *et al.* (2001), Swaroop (2006) and Dixit *et al.* (2011) reported significant increase in nodule count with increasing potash applications which confirm the observations in present study.

4.1.5 Number of pods plant^{-1}

The data with respect to number of pods plant^{-1} (Table 8 and Fig. 2d reflects that the highest number of pods (41) were noticed in treatment of RD + 60 kg K_2O ha^{-1} (T_7) which was on par with the treatments of T_6, T_5 and T_4. The lowest pods were noticed in absolute control and RD (35.25) treatments.

In earlier observations, we have noticed that potassium influences chlorophyll content and nodulation in soybean. It helps to fix nutrients by activating many plant enzymes. Potassium also regulates water absorption by root and water economy which may helps to convert nutrient flow to pod development.

Singh and Bajpai (1990) showed similar results as noticed in the present study. Singh *et al.* (2001) reported that application of RD + 60 kg K_2O ha^{-1} to soybean resulted the highest (68.9) number of pods $plant^{-1}$. Dixit *et al.* (2011) reported significant increase in number of pods with application 40 kg K_2O ha^{-1} to soybean. These earlier reports support to results on numbers of pods in the present study.

4.1.6 Number of grains pod^{-1}

According to data on number of grains pod^{-1} of soybean, the highest number of grains (3) were recorded in the treatment of RD + 60 kg K_2O ha^{-1} and which was at par with treatments T_6 and T_5. The lowest numbers of grains pod^{-1} were recorded in control and RD (2.30) treatments.

Singh and Bajpai (1996) and Singh *et al.* (1993) reported similar results as observed in the present study who were stated that potash application to soybean significantly increased grains per plant.

4.1.7 100 grain weight

The highest 100 grain weight (14.94 g) was observed in the treatment of application of RD + 60 kg K_2O ha^{-1} (T_7) followed by the treatments T_6 and T_5. It was the lowest (10.30 g) in absolute control and R.D. treatment (12.19 g).

Potassium is known to increase translocation of carbohydrates from leaves to grains and their conversion into starch. Additionally, K deficiency is known to impair the synthesis of high molecular weight compounds (proteins, starch and cellulose) in the cells which give rise to the accumulation of low molecular weight compounds, such as sugars and amino acids. Grain weight increase may relate to the function of K in the development of thicker outer walls in the epidermal cells, thus providing protection against pest attack (Imas and Magen, 2007).

Dixit *et al.* (2011) reported that application of K upto RD + 40 kg K_2O ha^{-1} produced significantly favorable effects on test weight (12.8 g). Similar results were also reported by Singh *et al.* (1993), Deshmukh *et al.* (1994) and Singh *et al.* (2001).

4.2 Effect of levels of potash on grain and straw yield

4.2.1 Grain yield

The data obtained on grain yield of soybean as influenced levels of potassium application is presented in Table 9 and graphically depicted in Fig. 3.

Table 9. Effect of levels of potash on grain and straw yield of Soybean and potassium use efficiency

Treatment	**Grain yield ($q\ ha^{-1}$)**	**Straw yield ($q\ ha^{-1}$)**	**Potassium use efficiency ($kg\ kg^{-1}$)**
T_1 : Absolute Control	20.27	25.54	-
T_2 : RD (50:75:00)	27.04	34.97	-
T_3 : RD + 20 kg K_2O ha^{-1}	28.01	36.78	4.85
T_4 : RD + 30 kg K_2O ha^{-1}	28.85	37.85	6.03
T_5 : RD + 40 kg K_2O ha^{-1}	30.98	40.26	9.85
T_6 : RD + 50 kg K_2O ha^{-1}	31.45	40.43	8.82
T_7 : RD + 60 kg K_2O ha^{-1}	31.62	40.80	7.63
GM	28.82	36.65	-
S.Em. $\pm$	0.46	0.75	-
CD at 5%	1.38	2.24	-

The significant variation in yield of soybean and marked differences in potassium use efficiency was observed due to application of various levels of potash to soybean in the present study.

The grain yield in present study ranged from 20.27 q ha^{-1} to 31.62 q ha^{-1}. The treatment of RD + 60 kg K_2O ha^{-1} (T_7) was significantly superior over absolute control and R.D. treatments with grain yield (31.62 q ha^{-1}) and which was on par with treatments T_6 and T_5. The lowest grain yield was observed in the treatment of absolute control and it was 27.04 q ha^{-1} in R.D. treatment.

The potassium is known to play role in absorption, translocation and many metabolic and physiological processes in plant and regulating growth and dry matter yield of plants. Potassium is associated with absorption of water, nutrients, synthesis and translocation of carbohydrates within the plant. These roles of K stimulates growth of plant. It activates more than 60 plant enzymes regulating many metabolic processes including essential processes of photosynthesis. All these functions with role in resistance against pest and diseases results in increased growth, availability and uptake of nutrients which is finally results in increase in grain yield. Martin and Prevel (1973) reported that if there is sufficiency of potassium then there will be increase in translocation of carbohydrates from leaves to grains. The significant role of K regarding in all growth parameters of soybean is already presented and discussed on preceding pages that also support for explaining increase in grain yield under increasing levels of potash to soybean.

The results of present investigation are in conformity with the earlier findings of Deshmukh *et al.* (1994a), Deshmukh *et al.* (1994b), Grewel *et al.* (1994a) and Singh *et al.* (1994) Singh *et al.* (2001), Dixit *et al.* (2011).

4.2.2 Straw yield

The straw yield data of soybean as influenced by potassium application is presented in Table 9 and Fig. 3 reveals that as like grain yield, straw yield also increased due to application of various levels of potassium to soybean.

The straw yield in present study ranged from from 25.54 q ha^{-1} to 40.80 q ha^{-1}. The highest straw yield (40.80 q ha^{-1}) was recorded in the treatment of RD + 60 kg K_2O ha^{-1} (T_7) which was on par with treatments T_6 and T_5. The lowest (31.85 q ha^{-1}) straw yield was observed in absolute control treatment, while R.D. (T_2) treatment recorded 34.97 q ha^{-1} straw yield.

Total dry matter in plants is the balance between gross photosynthesis and respiration. The higher respiration is always responsible reducing dry matter production in plants which is favoured by insufficient K concentration in plants. On the contrary, sufficient K concentration in plants is not only responsible for reduction in respiration but also responsible for photosynthesis and distribution of photosynthates among plants. (Turner and Barkus, 1980). Field crops generally absorbs potassium faster than they absorbs N or P and build up dry matter (Tandon and Sekon, 1988). In present study the increased straw yield of soybean with an increasing levels of potash is also supported by data of K nutrient uptake (Table 10) by soybean.

These results are in consistent with the earlier findings of Deshmukh *et al.* (1994b) and Dixit *et al.* (2011).

4.3 Effect of levels of potash nutrient uptake by grain and straw

4.3.1 Nitrogen uptake by soybean

The uptake of nitrogen by grain, straw and total uptake of nitrogen as influenced by application of levels of potash to soybean are presented in Table 10 and the same is graphically depicted in Fig. 4.

It is evident from the data presented in Table 10 that the application of increasing levels of potassium significantly increased nitrogen uptake by soybean grains and straw over the

Table 10. Effect of levels of potash on nutrient uptake by soybean (kg ha^{-1})

Treatment	Nutrient uptake by Grain (kg ha^{-1})			Nutrient uptake by Straw (kg ha^{-1})			Total nutrient uptake (kg ha^{-1})		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
T_1 : Absolute Control	99.28	11.59	10.03	16.12	4.98	33.26	115.41	16.72	43.30
T_2 : RD (50:75:00)	149.08	19.37	19.00	30.24	9.14	52.37	179.32	28.52	70.38
T_3 : RD + 20 kg K_2O ha^{-1}	157.35	21.21	20.30	34.27	10.19	57.20	191.62	31.40	77.51
T_4 : RD + 30 kg K_2O ha^{-1}	162.59	21.28	21.77	34.34	10.33	60.56	196.94	31.61	82.33
T_5 : RD + 40 kg K_2O ha^{-1}	175.62	23.79	23.71	38.71	11.79	65.91	213.83	35.71	89.62
T_6 : RD + 50 kg K_2O ha^{-1}	178.87	24.14	24.02	39.38	11.90	66.62	218.25	36.04	85.64
T_7 : RD + 60 kg K_2O ha^{-1}	179.88	24.62	24.50	39.80	12.06	61.80	219.68	36.69	86.31
GM	157.52	20.86	20.48	33.26	10.06	56.82	190.72	30.96	76.44
S.E.$\pm$	2.75	0.66	0.67	1.55	0.45	2.57	3.14	0.78	3.62
CD at 5%	8.17	1.96	2.00	4.61	1.33	7.62	9.32	2.31	10.75

absolute control and RD treatments. The total uptake of nitrogen in soybean crop ranged from 115.41 to 219.68 kg ha^{-1}. The treatment RD + 60 K_2O ha^{-1} (T_7) recorded the highest uptake of N, which was significantly superior over the treatments control and R.D. and which was at par with treatments T_6 and T_5. The maximum nitrogen uptake by soybean grain (179.88 kg ha^{-1}) and by soybean straw (39.80 kg ha^{-1}) was noted in treatment which was at par with T_6 and T_5. The minimum grain uptake was recorded in control and R.D. treatments which registered uptake values as 149.08 kg ha^{-1} in grain and 30.24 kg ha^{-1} in straw.

Thus, it was observed that the nitrogen uptake by grain, straw and total uptake of nitrogen by soybean crop was increased significantly with the application of increasing levels of potassium and which is statistically superior over control and R.D.

Blevins *et al.* (1978) concluded that potassium has an important role as a counter ion for the uptake and translocation of nitrate (NO_3^-) within the plant. The increase in nitrogen concentration in leaves and seed could be due to close relationship between K and nitrogen assimilation. Also nitrogen fixation by soybean relies on plant photosynthesis. Substanial amounts of photosynthates are required for N-fixing activity in mature nodule (Fujikake *et al.*, 2003). The increase in chlorophyll content and nodulation may help to increase uptake of nitrogen.

These results are agree with the previous findings of Permatatne and Oertii (1994), Bishit and Chandel (1996) and Joshi (2007).

4.3.2 Phosphorus uptake by soybean

The data in respect of uptake of phosphorus by soybean grain, straw and total uptake by the soybean plant are presented in Table 10 and Fig. 4.

The data regarding uptake of phosphorus by the soybean grain as influenced by the application of potassium revealed that the phosphorus uptake by the soybean grain significantly influenced by application of increasing levels of potassium over the treatments of control and R.D.

The total uptake of phosphorus by soybean ranged from 16.72 to 36.69 kg ha^{-1}. The maximum uptake (24.62 kg ha^{-1}) of phosphorus by soybean grain was noted in treatment of R.D. + 60 K_2O ha^{-1} (T_7) which was at par with the treatments T_6 and T_5 while in straw, the highest uptake was recorded in treatment T_7 (12.06 kg ha^{-1}) and it was at par with T_6, T_5, T_4 and T_3 treatments. The uptake of P in grain (19.37 kg ha^{-1}) and straw (9.14 kg ha^{-1}) was recorded in RD.

Thus, results of present investigation indicate that application of increasing levels of potassium fertilizer increased uptake of grain, straw and total uptake of soybean.

According to Turner (1987) potassium was found to regulate the transfer of nutrients to the xylem and also K influence phosphorus supply to xylem. These may be reasons to increase phosphorus uptake when K is sufficiently available to the plants.

The observations in the present study are similar to observations reported by Bishit and Chandel (1996) and Joshi (2007).

4.3.3 Potassium uptake by soybean

The uptake of potassium by soybean grain, straw and total uptake by crop as influenced by potassium application are presented in Table 10.

It is evident from data (Table 10 and Fig. 4) that application of increasing levels of potassium significantly increased the total potassium uptake by soybean over the control and R.D. The total uptake was ranged from 43.30 to 86.31 kg ha^{-1}. The maximum uptake by soybean grain (24.50 kg ha^{-1}) and straw (61.80 kg ha^{-1}) was reported in treatment T_7. In case of grain uptake, T_7 was at par with treatments T_6 and T_5, while in straw uptake, it was at par with T_6, T_5, T_4 and T_3 treatments. The uptake of R.D. in grain was 10.03 kg ha^{-1} and in straw was 33.26 kg ha^{-1}.

Thus, from the above data it is revealed that graded level potassium application significantly affected the grain, straw and total uptake of potassium.

Farmaha *et al.* (2011) found that potassium fertilization can increase above ground tissue accumulation, indicating that K fertilization can increase K cycling from the soil to plant which is later returned to the soil in the form of crop residue. Due to this reason there may be increase in uptake with graded levels of application of potassium in soybean.

These results are agree with the previous findings of Bishit and Chandel (1996) and Joshi (2007).

4.4 Effect of levels of potash on quality and yield of protein and oil in soybean

The data pertaining to protein and oil content in soybean grains as influenced by graded levels of potash is presented in Table 11 and the same is graphically depicted in Fig. 5.

Table 11. Effect of levels of potash on grain quality, yield of protein and oil in soybean

Treatment	Protein (%)	Protein yield (q ha^{-1})	Oil (%)	Oil yield (q ha^{-1})
T_1 : Absolute Control	27.97	5.56	18.00	3.65
T_2 : RD (50:75:00)	31.46	8.51	18.49	4.99
T_3 : RD + 20 kg K_2O ha^{-1}	32.09	8.98	19.40	5.43
T_4 : RD + 30 kg K_2O ha^{-1}	32.20	9.28	19.75	5.94
T_5 : RD + 40 kg K_2O ha^{-1}	32.26	9.99	20.09	6.22
T_6 : RD + 50 kg K_2O ha^{-1}	32.48	10.21	20.10	6.32
T_7 : RD + 60 kg K_2O ha^{-1}	32.48	10.36	20.20	6.38
GM	32.94	8.98	19.43	5.56
S.Em.$\pm$	0.21	0.16	0.03	0.13
CD at 5%	0.61	0.46	0.10	0.39

4.4.1 Protein content and yield

The application of potassium significantly increased the protein content and yield of soybean over the control and R.D.

The soybean grain protein content ranged from 27.47 % to 32.47 % and yield ranged from 5.56 to 10.36 q ha^{-1} due to effect of various levels of potassium under study. The highest protein content (32.47 %) noticed in the treatment RD + 60 kg K_2O ha^{-1} (T_7) which was at par with the treatments T_6, T_5, T_4 and T_3. The lower values of protein content was recorded in control and R.D. (31.47 %). Protein yield was highest (10.36 q ha^{-1}) in treatment T_7 which was at par with T_6 and T_5 while it was 8.51 q ha^{-1} in R.D.

Pande *et al.* (2012) explained that K and Zn have role in nitrogen metabolism and protein synthesis. Nitrogen is basic raw material for protein synthesis. Due to K, nitrogen synthesis increases as K activates enzymes which are involved in process of synthesis proteins. Reviewing all these roles of potassium, it can be concluded that protein synthesis may be enhanced due to sufficient supply of K to soybean crop.

Comparable results regarding protein content of soybean as influenced by K were obtained by Annaduri *et al.* (1994), Deshmukh *et al.* (1994), Magen (1997) and these confirm our results on protein content in the study.

4.4.2 Oil content and yield of soybean

The data pertaining to oil content and oil yield in soybean grain as influenced by application of various levels of potassium treatments are presented in Table 11 and Fig. 5.

The application of potassium significantly increased the oil content and oil yield of soybean over the control and R.D.

The oil content in soybean gain varied from 18 % to 20.20 %. The highest oil content (20.20 %) in soybean was observed in the treatment of 60 K_2O ha^{-1} along with recommended dose of fertilizer (T_7) which was at par with treatment T_6 followed by T_5. The lowest oil content was reported in treatment control and it was 18.49 % with R.D. treatment. The oil yield ranged from 3.66 to 6.38 q ha^{-1}. It was highest in T_7 (6.38 q ha^{-1}) and it was at par with T_6 and T_5 while it was low in control and R.D. (4.99 q ha^{-1}).

These results regarding oil content are in close conformity with the observations reported by Annaduri *et al.* (1984), Deshmukh *et al.* (1994), Anuradha and Sharma (1995) and Magen (1997).

4.5 Effect of levels of potash on chemical properties of soil after harvest

4.5.1 Soil pH

The data in respect of soil pH as influenced by application different potash levels to soybean is represented in Table 12 and Fig. 6a which reflects that application of higher potash levels resulted in variation in soil pH which was ranged from 8.03 to 8.06 after harvest of soybean.

4.5.2 Electrical conductivity

The data on electrical conductivity of soil after harvest of soybean is presented in Table 12 and Fig. 6b showed that application of higher levels of potash resulted in variation in soil electrical conductivity and it was ranged from 0.42 to 0.38 dSm^{-1}.

4.5.3 Organic carbon

The data with respect of organic carbon as influenced by different potash levels are presented in Table 12 and Fig. 6b revealed that there was increase in organic carbon content from

Table 12. Effect of levels of potash on chemical properties and available nutrients of soil after harvest of soybean

Treatment	pH	EC (dSm^{-1})	Organic carbon (%)	Nitrogen ($kg\ ha^{-1}$)	Phosphorus ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)
T_1 : Absolute Control	8.03	0.42	0.42	139.55	9.60	220.40
T_2 : RD (50:75:00)	8.03	0.41	0.44	148.95	11.45	223.20
T_3 : RD + 20 kg K_2O ha^{-1}	8.05	0.40	0.45	150.52	12.05	266.00
T_4 : RD + 30 kg K_2O ha^{-1}	8.05	0.40	0.49	150.52	12.18	271.60
T_5 : RD + 40 kg K_2O ha^{-1}	8.06	0.39	0.50	151.30	12.45	282.80
T_6 : RD + 50 kg K_2O ha^{-1}	8.06	0.39	0.50	152.09	12.52	285.60
T_7 : RD + 60 kg K_2O ha^{-1}	8.06	0.38	0.52	152.87	12.58	288.40
GM	8.05	0.40	0.48	149.40	11.84	262.57
S.Em.$\pm$	0.004	0.006	0.004	1.10	0.16	4.73
CD at 5%	0.01	0.02	0.01	3.28	0.48	14.06

0.42 % to 0.52 % as potash levels increased. The maximum organic carbon was observed in T_7 treatment (0.52 %) followed by treatment T_6 (0.50 %); T_5 (0.50 %) and T_4 (0.49 %). The minimum organic carbon was observed in treatment absolute control (0.42 %).

In plants 20 % of total photosynthates from above ground part of plant are returns to soil through root biomass and root exudates. At physiological maturity, soybean crop shades its older leaves in field and later on decomposition, it adds carbon to soil. These reasons may be explain for increase in organic carbon content in treated plots initial values of experimental field.

4.6 Effect of levels of potash on availability of nutrients (NPK) in soil after harvest

The data on soil fertility with respect to available NPK after harvest of soybean as influenced by application of various doses of K is recorded and reported in Table 12 and Fig. 7a.

The significant variations in available NPK were observed due to application of application of various doses of K.

The available NPK was found to be increased in treatments receiving potassic fertilizers over control and RD. However, the available N and P were found to be reduced over the initial soil values of N and P. With respect of available K, it was noted that available K at harvest of soybean was found to be increased with an increasing levels of K application to soybean.

Turner (1987) concluded that K was found to regulate the transfer of nutrients to the xylem. Where K supply is low N, P and micronutrients across the xylem is restricted. So in the present investigation availability of nutrients is increased as compared to treatments receiving no potassium. This role of K explained the changes in available N, P and micronutrients.

4.7 Effect of levels of potash on micronutrient status of soil after harvest

The data presented in Table 13 and Fig. 7b indicates that available micronutrient content of soil influenced significantly due to application of potash over control.

In soils deficient in both K and Zn synergistic interaction of Zn x K was observed on the grain yield of wheat (Gupta and Raj, 1983). Application of K decreased the grain yield while application of Zn or Zn + K increased the grain yield indicating growth limitation caused more due to lack of Zn than K. Generally application of K increased Cu concentration in plants when crops were supplied well with phosphorus (Waddington 1972).A synergistic interaction between K and Fe exists and is found to be due to the physiological relationship that exists between Fe, K and organic N. The synergistic effects occurred when both K and Fe were applied resulting in increased yields as well as K and Fe uptake (Gupta, 1986). In arable crops, K application has increased Mn levels in crops (Smith,1975).

It is known that soil K has synergistic relationship with essential nutrients in soil including micronutrients. These synergistic relationship may explain increased in available DTPA micronutrients after harvest of soybean under influence of various levels of K application.

Table 13. Effect of levels of potash on available micronutrient status of soil after harvest of soybean

Treatment	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
T_1 : Absolute Control	4.01	4.41	6.45	1.22
T_2 : RD (50:75:00)	4.06	0.43	6.50	1.51
T_3 : RD + 20 kg K_2O ha^{-1}	4.65	0.44	7.77	1.71
T_4 : RD + 30 kg K_2O ha^{-1}	4.93	0.45	8.00	1.76
T_5 : RD + 40 kg K_2O ha^{-1}	5.77	0.48	8.45	1.83
T_6 : RD + 50 kg K_2O ha^{-1}	5.90	0.51	8.59	1.87
T_7 : RD + 60 kg K_2O ha^{-1}	6.04	0.54	9.42	1.93
GM	5.05	0.47	7.88	1.69
S.Em.$\pm$	0.36	0.02	0.32	0.10
CD at 5%	1.07	0.06	0.96	0.29

The micronutrient concentration of iron and maganese was higher in treatment T_7 which was at par with T_6 and T_5. The zink concentration was higher in treatment T_7 and it was at par with T_6 and the copper concentration recorded higher in T_7 which was at par with T_6, T_5 and T_4. The lowest concentrations of all micronutrients were observed in absolute control.

4.8 Benefit: cost ratio of soybean

The data regarding to Benefit :Cost ratio is presented in Table 14. The higher gross monetary and net returns were obtained in treatment T_7 (RD + 60 kg K_2O ha^{-1}). The highest B:C ratio (2.46) was observed in treatment T_6 (RD + 50 kg K_2O ha^{-1}) while it was 2.45 in treatments T_5 and T_7.

On the basis of comparision of B:C ratios observed in all treatments, the treatments of T_5, T_6 and T_7 recorded more or less same B:C ratio. These observations further suggests to recommend treatment of RD + 40 kg K_2O ha^{-1} (T_5) for the maximum economic profit from soybean.

Table 14. Benefit: Cost ratio of soybean

Treat.	Yield (q ha^{-1})		Cost of cultivation (Rs.)	Gross monetary returns (Rs.)	Net returns (Rs.)	B:C Ratio
	Grain	Straw				
T_1	20.27	25.54	29210.00	56006.00	26796.00	1.91
T_2	27.04	34.97	33638.00	74405.60	40767.60	2.21
T_3	28.01	36.78	34220.12	77098.20	42878.08	2.25
T_4	28.85	37.85	34520.00	79409.00	44889.00	2.30
T_5	30.98	40.26	34814.00	85256.40	50442.40	2.45
T_6	31.45	40.43	35108.00	86532.20	51424.20	2.46
T_7	31.62	40.80	35402.00	87006.00	51604.00	2.45

4.9 Economics of potash fertilizer use and monetary returns from soybean crop under influence of various levels of potash

The data on yield, cost of potash fertilizer, returns, increased over potash fertilizer under influence of various levels of potash is presented in Table 15.

It is revealed from the data that the yield of soybean was increased from T_1 to T_7 treatments. The cost on total fertilizer was also increased from T_1 to T_7 treatments. The total returns per rupees invested on total fertilizers fertilizers was higher (2.05) in treatment T_6 while returns per rupees invested on potash fertilizer was maximum (6.93) in treatment T_5 (RD + 40 kg K_2O ha^{-1}). Besides this, the growth attributing characters yield, nutrient uptake and quality were also optimum in T_5 treatment. Therefore, it is concluded that treatment T_5 (R.D. + 40 K_2O ha^{-1}) is more profitable than that of other treatments for cultivation of soybean crop.

Table 15. Economics of potash fertilizer and monetary returns from soybean under infiuence of various levels of potash

Treat. Details	Yield ($q\ ha^{-1}$)		Cost of Fertilizer (Rs)		Monetary returns (Rs)	Increase over R.D. (Rs)	Returns/Rs invested on Fertilizer	Increase over R.D. (Rs)	Returns/Rs invested of potash Fertilizer
	Grain	Straw	Total	Potash					
T_1	20.27	25.54	-	-	56006	-	-	-	-
T_2	27.04	34.97	4428.00	-	74405.60	-	-	-	-
T_3	28.01	36.78	5010.12	582.12	77098.20	2692.60	0.53	-	-
T_4	28.85	37.85	5310.00	882.00	79409.00	5003.40	0.94	2310.80	2.61
T_5	30.98	40.26	5604.00	1176	85256.40	10850.80	1.93	8158.20	6.93
T_6	31.45	40.43	5898.00	1470	86532.20	12126.60	2.05	9434.00	6.41
T_7	31.62	40.80	6192.00	1764	87006.00	12600.40	2.03	9907.80	5.61

Note : Grain price – 2700 Rs. per quintal Straw price – 50 Rs. per quintal

Urea – 6.20 Rs. per kg SSP – 8 Rs. per kg

MOP – 17.64 Rs. per kg

5. SUMMARY AND CONCLUSIONS

A present field investigation entitled “Response of potassium on yield and quality of soybean in Inceptisol” was conducted at Post Graduate Institute, Research Farm of Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* season, 2012-13 so as to find out the optimum dose of potassium for maximum economic yield of soybean.

This experiment was laid out by taking soybean crop on Inceptisol. The field experiment comprised of seven treatments and four replications involving use of various levels of potassium fertilizers.

The representative surface composite soil samples (0-22.5 cm) were collected from each plot after harvest of soybean for soil chemical analysis. Then samples were air dried in shade and sieved through 2 mm sieve and were analysed for various parameters. The results obtained and reported from the present investigation are summarised and concluded under following subheadings.

5.1 Effect of levels of potash on growth attributing characters

The highest plant height at 30 DAS (32.4 cm) and (47.65 cm) at 60 DAS was observed with application of RD + 60 kg K_2O ha^{-1} (T_7) treatment. However, it was at par with treatments RD + 50 kg K_2O ha^{-1} (T_6) and RD + 40 kg K_2O ha^{-1} (T_5). The application of RD + 60 kg K_2O ha^{-1} recorded significantly highest number of branches (12.25) and highest grains per pod (3) and it was at par with treatments T_6 and T_5.

As regards to chlorophyll content, it was maximum (40.59) in the treatment T_7 at 30 DAS and 53.71 at 60 DAS which were at par with treatments T_6 and T_5. The highest responses in terms of effective nodule counts and test weight (14.94 g) seen with respect to RD + 60 kg K_2O ha^{-1} followed by treatments T_6 and T_5.The data pertaining to number of pods per plant showed that the highest number of pods (41) were with treatment T_7 which was at par with treatments T_6, T_5 and T_4.

Thus, looking at the data it is concluded that maximum response regarding to growth attributing characters was in treatment RD + 60 kg K_2O ha^{-1} (T_7). However, it was at par with treatments T_6 and T_5.

5.2 Effect of levels of potash on grain, straw yield of Soybean and Potassium use efficiency.

The highest response in terms of grain (31.62 q ha^{-1}) and straw (40.80 q ha^{-1}) yield of soybean was noticed with the application of RD + 60 kg K_2O ha^{-1} and it was at par with treatments T_6 and T_5. Potassium use efficiency was highest (9.85 kg kg^{-1}) in the treatment receiving 40 kg K_2O ha^{-1} along with recommended dose of fertilizers followed by the treatments T_6 (8.82 kg kg^{-1}) and T_7 (7.63 kg kg^{-1}). Potassium use efficiency was ranged from 4.85 to 9.85 kg kg^{-1} and it was the highest (9.85 kg kg^{-1}) in the treatment receiving RD + 40 kg K_2O ha^{-1} dose of fertilizer.

5.3 Effect of levels of potash on total nutrient uptake by soybean

From the mean values of total nutrient uptake of nitrogen, phosphorus and potassium was observed that treatment RD + 60 kg K_2O ha^{-1} was significantly superior over absolute control and recommended dose treatments. The total highest uptake of nitrogen (140.28 kg ha^{-1}) and phosphorus (36.69 kg ha^{-1}) were noticed in the T_7 and it were at par with treatments T_6 and T_5. The potassium uptake was also highest in the treatment T_7 and it was at par with treatments T_6, T_5, T_4 and T_3.

5.4 Effect of levels of potash on quality of soybean

The data regarding to protein and oil content shows that the increasing levels of potash significantly increased the protein and oil contents in treatments which received potash application in soybean. The protein content was observed highest in T_7 treatment which was at par with treatments T_6, T_5, T_4 and T_3 while oil content was highest in the treatment T_7 and it was at par with treatment T_6. The protein yield was highest (10.36 q ha^{-1}) in treatment RD + 60 kg K_2O ha^{-1} and it was at par with the treatments T_6 and T_5, while it was 8.51 q ha^{-1} in recommended dose treatment. The oil yield also increased from 4.99 to 6.38 q ha^{-1} from recommended dose treatment RD + 60 kg K_2O ha^{-1} and T_7 treatment was at par with treatments T_6 and T_5. Thus, it is concluded that protein yield was significantly increased in the treatment receiving potassium fertilizers.

5.5 Effect of levels of potash on chemical properties and availability of nutrients

Soil pH and organic carbon content were increased significantly in treatments receiving potassium than that of absolute control and recommended dose of fertilizers.

The availability of nitrogen, phosphorus and micronutrients significantly increased receiving potash doses and it was decreased as compared to initial values of available nitrogen while the availability of potassium is increased significantly with increasing levels of potassium.

5.6 Benefit : Cost ratio of soybean crop

The highest B:C ratio (2.46) was recorded with application of RD + 50 kg K_2O ha^{-1} (T_6) followed by the treatments T_5 (2.45) and T_7 (2.45). The RD treatment recorded B:C ratio (2.46). Thus, it is clear that B:C ratio was increased over the recommened dose due to application of potassic fertilizers.

5.7 Economics of potash fertilizer and monetary returns from soybean under influenced of various levels of potash

As regards to potash use efficiency and economy of fertilizer use in soybean application of RD + 40 kg K_2O ha^{-1} (T_5) resulted in higher returns per rupees invested on potash fertilizers. This clearly indicates that potassium fertilizer application is beneficial as per economic point of view.

CONCLUSIONS

The response of increasing levels of potash to soybean in Inceptisol was studied by monitoring yield, nutrient uptake and quality of soybean. The following conclusions were drawn from the results:

1. Soybean responded to potassium application @ 40 kg K_2O ha^{-1} along with RD (50:75:00 $N:P_2O_5:K_2O$ kg ha^{-1}) in Inceptisol resulting in increased yield attributing characters and yield upto 31.62 kg ha^{-1}.
2. Application of potassic fertilizers not only increased nutrient uptake of major nutrients but also protein, oil content and protein and oil yield in soybean.
3. The highest B:C ratio (2.46) was recorded by cultivation of soybean in Inceptisol with application of RD + 50 kg K_2O ha^{-1} while returns per rupees invested on potash fertilizer and potassium use efficiency were highest in the treatment receiving fertilizer dose RD + 40 kg K_2O ha^{-1}.

With view of all results, it is concluded that along with GRD 50:75:40 $N:P_2O_5:K_2O$ kg ha^{-1} is optimum for the highest profitable yield of soybean in Inceptisol.

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