

RESPONSE OF GRADED LEVELS OF PHOSPHORUS AND
POTASSIUM ON YIELD AND QUALITY OF FRENCH BEAN
cv. CONTENDER UNDER MID-HILL CONDITIONS OF
HIMACHAL PRADESH

THESIS

BY

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Submitted in partial fulfilment of the requirements for the
Degree of

MASTER OF SCIENCE

IN

HORTICULTURE

(VEGETABLE CROPS)



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DEDICATED

to

My Nephew

Never Born, Never Died

Just Visited the Planet Earth

Late Anamika

(24 Oct, 1990 - 22 June, 1994)

Dr A K Joshi,
Assistant Scientist.

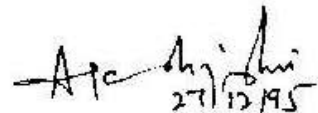
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CERTIFICATE-I

This is to certify that the thesis entitled "**Response of phosphorus and potassium on yield and quality of French bean cv. Contender under mid-hill conditions of Himachal Pradesh**", submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE in HORTICULTURE (Vegetable Crops)** to Dr. Y S Parmar University of Horticulture and Forestry, is a bonafide record of research work carried out by **Mr. Surendra Singh (H-92-14-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

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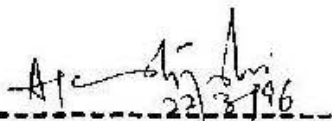


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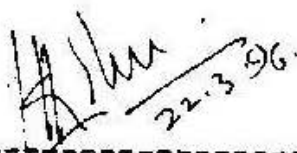
This is to certify that the thesis entitled "Response of phosphorus and potassium on yield and quality of French bean cv. Contender under mid-hill conditions of Himachal Pradesh", submitted by Mr. Surendra Singh to Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan in partial fulfilment of the requirements for the award of the degree of MASTER OF SCIENCE in HORTICULTURE (Vegetable Crops), has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the Representative of the Dean.


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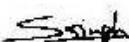
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Place: Nauni
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(Surendra Singh)

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Chapter - 1

INTRODUCTION

The soaring momentum of vegetarian movement has put the importance of vegetables at apex in day-to-day life of common man. Consequently the search is on for more production from the shrinking land resources to meet the rocketing demand of the expanding population, particularly in a country like India. French bean (*Phaseolus vulgaris* L.), native to south Mexico and central America (Smartt, 1990), has been widely adapted over a larger geographical range.

The production of fresh market beans varies from season-to-season and region-to-region. The yields are generally higher in temperate (monsoon crop) than the tropical (winter crop) zones (Sharma and Joshi, 1993). Over the past decade, India has observed a tremendous increase of 52000 MT, (1994) in green pod yield over 45000 MT in 1984 (Anonymous, 1995a). In Himachal Pradesh, French bean is grown over an area of 2073 ha with the annual production of 19206 MT; about 93.7 per cent of the total produce is exported to the plains and only 6.2 per cent is used for the home consumption (Anonymous, 1990). Therefore, it fetches remunerative returns to the farmers. This strategy has boosted the economy of growers as well as the state.

The kidney bean is a nutritionally rich vegetable, which not only supplies its mineral nutrients to the human beings but also ameliorates the soil texture and structure by fixing the atmospheric nitrogen. Generally, the common bean is grown for immature fleshy pods as vegetable or mature pods as pulse (Nonnecke, 1992), whereby, it acts as curative to many human diseases. Most of the modern french bean cultivars are now bush types (Bassett, 1986) and are more popular due to early bearing, easy cultivation, harvesting and more fertilizer responsive as compared to pole types. The bush bean cultivar "Contender" predominates among the Indian farmers due to its wider adaptability and prolific bearing capacity.

Phosphorus, plays a key role in energetic metabolism and biosynthetic reactions as a component of adenosine triphosphate and other phosphorelated compounds. Because of the functions of phosphorus in the growth and metabolism of plants, deficiency leads to a general reduction in most of the development processes including cell division, cell expansion, respiration and photosynthesis (Terry and Ulrich, 1973). The regulatory function of Pi (inorganic phosphate), in photosynthesis and carbohydrate metabolism of leaves, can be considered as one of the major factors limiting growth, particularly during reproductive stage (Marschner, 1986). Potassium is known to influence and alter the physiological, biochemical and histological mechanisms of plants. It has an

important role, either direct or indirect, in major endogeneous plant processes such as photosynthesis, respiration, enzyme activation; metabolism of proteins, carbohydrates and lipids; translocation of photosynthates, growth and development (Dev, 1991). Potassium is often enunciated a "quality element" for crop production. It also promotes resistance in plants against diseases, insects-pests and induces tolerance to environmental stresses (Beaton, 1989).

Vegetables usually produce high biomass in shorter time and remove larger quantities of nutrients as compared to other crops. French bean, being a leguminous crop, is least cared for fertilizer application even when fitted in the intensive cropping sequence. On the other hand, uptake of NPK from the soil is enhanced. The soil is depleted of nutrients which ultimately hampers the soil productivity. To overcome this malady better nutrient management is required. The P and K are being considered as important parts of fertilizer use strategies. Therefore, judicious application of costly inputs, particularly fertilizers, is much useful for improvement of yield potential as well as the quality of any crop. Scanty information is available on the rate of potassium application with phosphorus in increasing the yield and quality of bush type French bean.

The present study was designed to evaluate the response of graded levels of P and K on growth, yield and quality of French bean. It will help in standardizing the fertilizer dose for exploiting the maximum genotypic worth of French bean and shall be of practical and economical value to the farmers. Therefore, the present investigations were formulated with the following objectives:

- 1) To find out the optimum levels of P and K for obtaining maximum green pod yield of French bean.
- 2) To study the effect of P and K interaction on different growth, yield and quality characters.
- 3) To workout the economics of P and K application.

Chapter - II

REVIEW OF LITERATURE

The phosphorus and potassium have the direct effects on various growth, yield its component characteristics and quality attributes of French bean. Although scientific information is available on the phosphorus and potassium nutrition in common bean but the information with respect to the dwarf varieties of French bean is still lacking. A brief review of literature available on the relevant aspects is presented in this chapter under the following sub-heads:

2.1 Effect of Phosphorus

Phosphorus is a fascinating plant nutrient. It is involved in a wide range of plant processes such as cell division, development of good root system and ensuring timely and uniform ripening of the crop. It is needed most by young, fast growing tissues and performs a number of functions related to growth and development, photosynthesis and utilization of carbohydrates. It is a constituent of Adenosine diphosphate (ADP) and Ribose nucleic acid (RNA), being the two most important components in life processes.

2.1.1 Growth characteristics

Bush type French bean is cultivated extensively

throughout the mid hill regions of Himachal Pradesh but due to poor status of available phosphorus and improper fertilizer application practices, it does not perform better as compared to European and American countries (Yadav and Pathak, 1963; Knott, 1966). Edje et al. (1973) observed increase in plant height with the increase in the levels of phosphorus. Pande et al. (1974) found that the number of branches per plant in French bean were increased with higher levels of P_2O_5 (125 kg/ha).

Mahatanya (1976) studied the effect of phosphorus on bean cv. Canadian Wonder and found that plant height, and leaf area index increased with the increasing levels of phosphorus from 0-60 kg/ha. Gupta et al. (1983) found the beneficial effects of phosphorus on plant growth characters viz., plant height, number of branches, number of leaves per plant in French bean. Vidal and Junqueira (1984) reported that phosphorus application significantly increased the percentage of bean plant survival. Ronzelli et al. (1986) also reported that plant stand and growth were significantly influenced by the application of phosphorus in French bean. Application of phosphorus @ 50 kg/ha induced maximum expansion of leaf area in French bean (Manrique, 1986). The application of 80 kg P_2O_5 /ha showed its significant superiority over 40 kg and control on plant height (34.48 cm), number of branches (6.98) per plant of French bean cv. Contender (Chandra et al., 1987).

The phosphorus efficiency was related to the uptake efficiency of the plant which was determined by both root-shoot ratio and absorption rate per unit of root-influx (Fonse et al., 1988). Significant increase in plant growth was also reported by Srinivas and Naik (1990).

2.1.2 Yield and its component characteristics

Pande et al. (1974) obtained 34.35 per cent higher green pod yield with phosphorus at 125 kg/ha in French bean. Sharma et al. (1976) recorded maximum yield of 160.83 q/ha with the application of 90 kg P₂O₅/ha. However, Gupta et al. (1983) reported 120 q/ha yield of green pods with the application of 120 kg P₂O₅/ha under Bangalore conditions. However, increase in number of pods per plant was observed with the application of P at other levels also.

Prabhakar et al. (1984 and 1986) reported that the bean yield increased with phosphorus application upto 75 kg P₂O₅/ha at IIHR, Bangalore. Buzetti et al. (1984) recorded highest pod yield and maximum number of pods per plant with 100 kg P₂O₅/ha.

Manrique (1986) studied the response of French bean to phosphorus application in USA and depicted that the green pod yield responded favourably upto 100 kg P₂O₅/ha. Under mid hill conditions of Solan, Singh (1987) observed significant linear increase in green pod yield of French bean upto 40 kg

P₂O₅ application and the optimum dose was found to be 79.7 kg/ha.

Prabhakar et al. (1987a) studied the direct, residual and cumulative effects of phosphorus fertilization in French bean - cabbage-okra cropping system and reported that French bean and cabbage yields increased with the phosphorus level upto 75 kg P₂O₅/ha. They further concluded that fertilization at the rate of 75 kg P₂O₅/ha would build up the soil phosphorus to support three crops in sequence even in intensive vegetable farming system. The maximum number of pods (11.36) per plant and green pod yield (65.58 q/ha) were also observed with 80 kg P₂O₅/ha (Chandra et al., 1987).

Singh et al. (1989) reported that the application of 42 kg P₂O₅/ha did not prove significantly superior to that of 28 kg P₂O₅/ha in green pod yield (2.87-3.28 t/ha). Stalin et al. (1989) stated that the application of 60 kg P₂O₅/ha as super phosphate in two equal splits (50% basal and remaining 50% at flowering) gave higher green pod yield and number of pods per plant. The pod yield of French bean ranged from 38.30 q/ha (28 kg P₂O₅/ha) to 41.40 q/ha (42 kg P₂O₅/ha) and the yield was significantly higher over 14 kg P₂O₅/ha application (Singh and Singh, 1990). Similarly, Srinivas and Naik (1990) found that green pod yield increased significantly with phosphorus application in bean crop.

Gajanan et al. (1990) obtained higher green pod yield in French bean cv. Selection-9 with different sources of phosphorus over control. Chakrawarti et al. (1990) reported that increasing levels of phosphorus from 0-75 kg P_2O_5 /ha significantly improved the yield and yield attributes such as pod length, pod diameter, number of cluster per plant, number of pods per cluster, number of seeds per pod and weight of 10-green pods. Thangaraj and Rangaswamy (1994a) obtained maximum green pod yield, pod length and pod breadth of rainfed French bean through enriched phosphorus as compared to direct applied phosphorus.

2.1.3 Quality and NPK uptake

Loneragan and Asher (1967) observed that the efficiency with which P is utilized to produce yield, i.e. the amount of P required by the plant to produce one unit of dry matter, which refers to the P concentration in plants to produce 80 per cent of maximum yield, is oftenly termed as internal P requirement. The uptake efficiency of plant, which is the ability of the root system to acquire P from soil and accumulate it in the shoots, depends on the capability of the roots to absorb P, the active life time of roots and amount of root per unit of shoot.

Mahatanya (1976) found that the P application increased P content in the plants by increasing their total dry weight. Though P application increased P content, yet,

it reduced potassium content in bean (Barkas, 1981). There was increased dry weight per plant with increasing levels of phosphorus application (Vidal and Junqueira, 1984). Prabhakar et al. (1984) reported that application of phosphorus to the level of 75 kg P_2O_5 /ha significantly increased uptake of phosphorus by the plants. Prabhakar et al. (1986) also reported the response of French bean-cabbage-okra cropping sequence to phosphorus application and observed that P uptake increased with P level upto 75 kg per ha. Application of P increased nodulation, dry matter yield, tissue N yield and increased P uptake (Ssali and Keya, 1986). Fohse et al. (1988) studied external and internal P requirement and P uptake efficiency in beans and observed maximum relative shoot dry weight and P uptake upto 40 mg/100 g P fertilization. Application of different levels of phosphate fertilizers to bush type French bean cv. premier significantly influenced the N, P and K concentrations in pods and leaves with the application of 60 kg P_2O_5 /ha (Stalin et al. 1989).

Srinivas and Naik (1988) found that phosphorus fertilization had significant influence on total dry matter production, protein content in pods and N concentration in leaf, stem and pods of French bean. Application of 75 kg P_2O_5 /ha increased the per cent crude protein in green pods of French bean (Chakrawarti et al., 1990).

2.2 Effect of Potassium

Potassium is involved in numerous metabolic pathways within the plant. Over 60 enzyme systems are activated by potassium, which affects vegetative as well as reproductive growth indices in plants (Ludwick, 1992). Being one of the three major nutrients, potassium is not only taken up in higher amounts than the others, but also acts as chemical 'Traffic Policeman', regulating the management of other nutrients in the plant system. Potassium has been called by many other names such as root booster, stalk strengthener, food former, an enzyme activator, a breathing regulator, water stretcher, sugar and starch transporter, protein builder, wilt reducer and disease retarder (Kanwar, 1985).

2.2.1 Growth characteristics

Ali and Ocida (1972) could enhance the growth of *Phaseolus vulgaris* L. by increasing the supply of potassium. Stanev and Chichev (1973) observed that the addition of potassium in soil, has increased significantly the growth, leaf area and number of branches per plant.

A nutritional study was conducted by Petrov and Gagarina (1981), where upon they analysed that the French bean productivity depended on the potassium concentration in Knop's nutrient solution ranging from 0.10 - 2.75 mM for the best growth of bean plants. Potassium has been reported to develop leaves with thickened cuticles and strong epidermal

cells which help to control the incidence of diseases (Sekhon and Singh, 1982). Passarinho and Ricardo (1988) suggested that earliness of flowering in bean cultivars is positively correlated with efficiency of K utilization. Ludwick (1992) reported that potassium affects the photosynthesis rate of plants directly, which ultimately affects the growth rate and coloration of leaves (healthy green colour).

2.2.2 Yield and its component characteristics

Potassium can be of special concern in production of vegetable crops for the fresh market. It is required in large amounts, similar to and frequently greater than nitrogen (Ludwick, 1992). Since potassium is directly or indirectly involved in most plant processes e.g., regulation of enzyme systems, photosynthesis, respiration, protein synthesis, translocation of food material etc. hence, its shortage can result in low crop yield, quality and profitability (Usherwood, 1993).

French bean showed the positive response to direct potassium application @ 50 kg/ha, grown in Okra-cabbage-French bean cropping system. The cumulative effect of K on two crops (cabbage and French bean) recorded similar yields when the Okra and French bean, or cabbage and French bean were fertilized; but higher when all the three crops were fertilized with K (Prabhakar et al., 1987b). The snap bean

pod yields was increased significantly with K fertilization as reported by Evanylo and Zehnder (1989).

2.2.3 Quality attributes and NPK uptake

Potassium (K) is often described as the "quality element". A shortage of K adversely affects photosynthesis, respiration, translocation, a number of enzyme systems and protein synthesis. This frequently results in small or misshapen produce, more disease and insect damage, and shorter shelf-life (Ludwick, 1992).

Higher potassium levels resulted in enhanced transfer rate of nitrogen compounds from soluble to insoluble fractions, due to the effect of potassium on protein synthesis. Presence of adequate amounts of potassium was necessary for synthesis of organic acids. Adequate concentrations of potassium favoured translocation of amino acids and carbohydrates in plants (Duke and Collins, 1985).

Evanylo and Zehnder (1989) observed that the nutrition accumulation in snap bean was increased with K fertilization. The cumulative uptake of K in the cropping sequence, of beet root - tomato - French bean, increased with the increase in K levels (Rao and Subramanian, 1990).

When K is deficient, rate of photosynthesis declined and plants with greater respiratory rate, lead to decreased dry matter production (Dev, 1991). Potassium stimulated the

synthesis of true proteins in plants from the amino acid building blocks (Usherwood, 1993).

2.3 Complementary effects of P and K

The snap bean pods exhibited a sequentially additive interaction. In this case the per cent response either to P or K was unchanged, whether applied alone or in combination. Both P and K, then comply with the Mitcherlich version of the "Law of Minimum", which states that the decrease in yield is proportional to the degree of supply in relationship to the need (Wallace, 1989). The interaction between P and K affects the plant growth, yield and yield attributes by affecting the various plants metabolic activities.

2.3.1 Growth Characteristics

Edje et al. (1973) reported significant increase in plant height with the increasing levels of P and K. The number of branches per plant in French bean also increased with the addition of 50 kg P_2O_5 along with 50 kg K_2O/ha (Augustinussen, 1973). Smith (1977) observed increased weight of bean vine with the application of P in combination with K.

The effect on plant height and number of branches were the best with 50, 90, 40 and 50, 60 and 60 kg N, P, K per hectare, respectively in French bean (Thangaraj and Rangaswamy, 1994b). Singh and Tripathi (1994) found that the

higher levels of fertilizers significantly influenced the vegetative growth parameters of French bean i.e. plant height, branches per plant and compound leaves per plant.

2.3.2 Yield and its component characteristics

Verma and Mandal (1966) reported that 23 kg N, 68 kg P_2O_5 and 45 Kg K_2O per hectare, increased the yield of French bean. With the increase in fertilizer levels i.e. P and K, the yield and number of pods per plant were increased significantly (Edje et al., 1973). The total green pod yield in French bean also increased with the addition of 50 kg P_2O_5 along with 50 kg K_2O/ha (Augustinussen, 1973). Eira et al. (1974) deduced that P_2O_5 @ 60 to 240 kg/ha enhanced yield, K_2O , however, decreased the production where the economic rate of P application was 55 kg/ha.

Saxena and Locascio (1975) found that the highest total yields were obtained with the lower doses of N, P and K (79, 67 and 112 kg/ha) application. Yields were greatly reduced by higher doses of N, P and K (158, 67 and 224 kg/ha). Pannerselvan (1980) found that the highest yield was obtained through the application of N, P and K at 50, 100, 50 kg per hectare. Dekov et al. (1982) recommended the optimum dose of phosphorus (80 kg/ha) and potassium (30 kg/ha) for rainfed conditions, on the basis of higher yield in French bean. The highest rates of phosphorus and potassium each with 1120 kg/ha application produced significantly higher

yields of pods than did the lower rates (Mack, 1983). The significant differences between P and K treatments were observed by Anez and Tavira (1987) for number of pods per plant in French bean.

Application of P&K each at 100 kg/ha with addition to nitrogen @ 150 kg/ha recorded highest pod yield (228.40 q/ha) in French bean (Ivanov et al., 1987). Silva and Vizzotto (1988) found maximum pod yield of 13.5 t/ha, with the application of 60:150:60 kg/ha, N:P:K, respectively. Number of pods and pod length significantly improved with combined application of 100 kg P_2O_5 and 25 kg K_2O /ha (Gupta, 1988).

Thangaraj and Rangaswamy (1994b) observed that the bean yield and its attributes were the best performers with the application of 75, 60 and 20 kg N, P and K per hectare. Highest green pod yield of French bean was obtained (134.8 and 153.6 g/ha) with the application of 62.5:100:100 kg N:P:K/ha during 1992 and 1993 (Singh and Tripathi, 1994).

Quality and NPK uptake

It is well known that nitrogen fixation by Rhizobium is enhanced in host plants if it is well supplied with P and K (Mangel et al., 1974). Pannerselvan (1980) reported that application of N, P and K increased the dry matter content and uptake of nutrients and there was a positive correlation between yield and nutrient uptake. Application of phosphorus

(80 kg/ha) and potassium (30 kg/ha) under rainfed conditions, improved protein content in French bean (DeKov et al., 1982). Shanmugavelu (1989) reported that the highest content of N, P and K occurred in pods, followed by leaves and stem.

Chapter - III

MATERIALS AND METHODS

The present investigations were conducted at the Experimental Farm of the Department of Vegetable Crops, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh) during the Kharif seasons of 1993 and 1994. Details of the materials used and techniques employed during the course of experimentation have been given in the following text.

3.1 GENERAL

Location

The experimental farm of the Department of Vegetable Crops, is situated at Nauni about 15 km from Solan (on Solan-Rajgarh Road) at 30°-51' N latitude and about 77°-11' E longitude. The elevation of the farm is 1260 m above mean sea level. It falls in the mid hill zone of Himachal Pradesh comprising of sub-temperate sub-humid climate.

Climate

May and June are the hottest months and December to February are the coldest ones. The annual rainfall ranges between 1000 to 1300 mm; out of which nearly 75 per cent is received during June to September. Winter rains are received during the months of January and February with occasional snowfall.

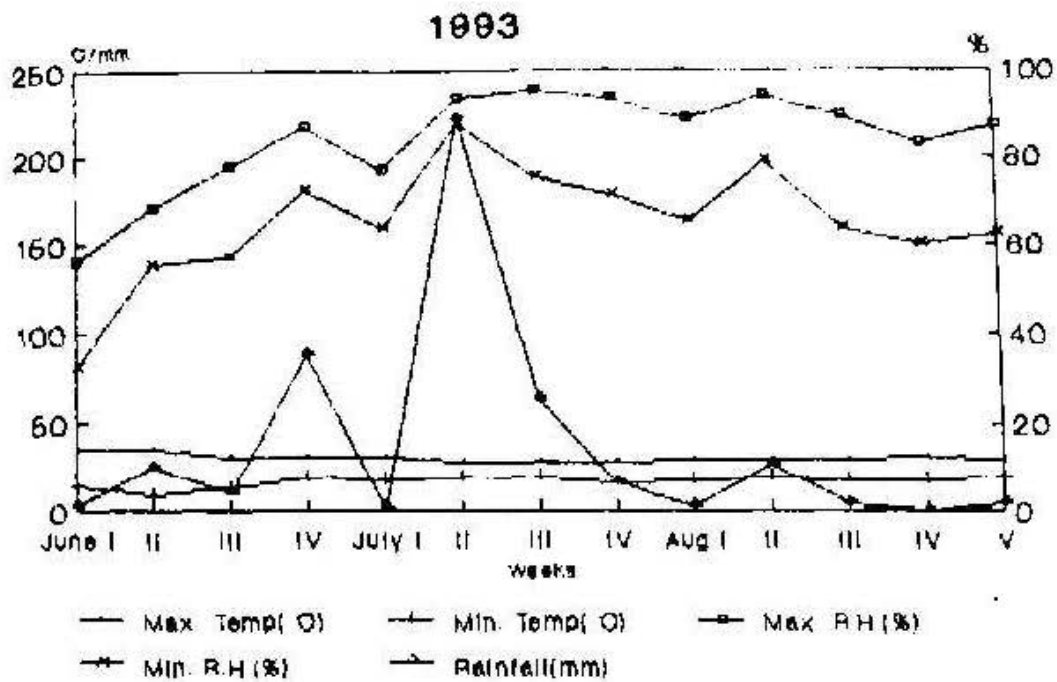


Fig:1. Meteorological mean data (weekly)

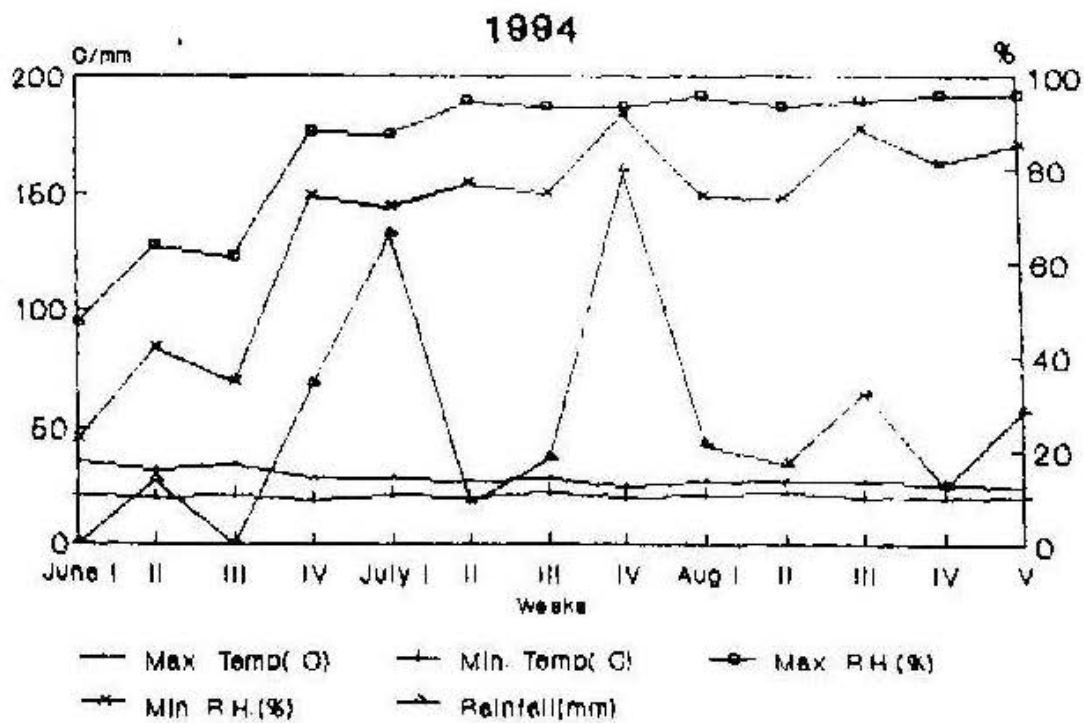


Fig:2. Meteorological mean data (weekly)

Mean weekly meteorological data recorded at the Agro-meteorology Observatory of the Department of Soil Science pertaining to the period of experimentation, have been delineated graphically in Fig. 1 and 2 and given in Appendix-I. The minimum and maximum temperatures remained almost normal and varied between 14°C to 36.5°C and 16.5°C to 36°C, respectively. High percentage of humidity during July to August months favoured the luxuriant crop growth. Weather conditions were also favourable for the incidence and spread of disease (angular leaf spot) and insect (blister beetle).

Physico-chemical properties of the soil

Composite soil samples, were collected before sowing from the experimental field at 0-15 cm depth to get the initial nutrient status of the soil. The composite samples were run for mechanical and chemical analysis and the results are presented in Table 1. It is evident from the data that the soil of the experimental area was loam in texture and neutral in reaction. The fertility of the experimental site was medium in respect of available nitrogen, phosphorus and potassium and rich in organic carbon content.

Table 1. Physico-chemical characteristics of the soil before sowing

Components	Contents		Methods employed
	1993	1994	
A. Mechanical analysis			
Coarse sand(%)	28.73	29.15	International
Fine sand(%)	15.25	13.71	Pipette method
Silt(%)	34.13	32.28	(Piper, 1966)
Clay(%)	21.72	24.52	
Texture	Loam	Loam	
B. Chemical analysis			
Available nitrogen (kg/ha)	419.50	425.25	Alkaline permanganate method (Subbiah & Asija, 1956)
Available phosphorus (kg/ha)	48.20	45.50	Olsen's method (Olsen et al., 1954)
Available potassium (kg/ha)	278.70	273.60	Ammonium acetate method using flame photometer (Jackson, 1967)
Organic carbon(%)	0.97	1.02	Walkley & Black's rapid titration method (Piper, 1966)
Soil pH	6.97	7.05	1 : 2.5 soil water suspension glass electrode method (Jackson, 1967)

3.2 EXPERIMENTAL TECHNIQUES

To study the response of phosphorus at different levels viz. 0, 40, 80 and 120 kg P_2O_5 /ha alone or in combination with four levels of potassium at the rate of 0, 30, 60 and 90 kg K_2O /ha were applied to bean cv. Contender. The phosphorus was applied as single super-phosphate (16% P_2O_5) and potassium as muriate of potash (60% K_2O) as basal doses. Constant amount of nitrogen at the rate of 45 kg/ha was given in two split doses in the form of Calcium Ammonium Nitrate (25% N). Half dose of the N was applied at the time of sowing and the remaining as top dressing at the time of earthing up one month after sowing.

Technical Programme

The technical programme pertaining to "Response of phosphorus and potassium on yield and quality of French bean cv. Contender under mid hill conditions of H.P." is detailed as under:

Treatments

All possible combinations of P and K:

A. Levels of P_2O_5 (Kg/ha)

P1	-	0
P2	-	40
P3	-	80
P4	-	120

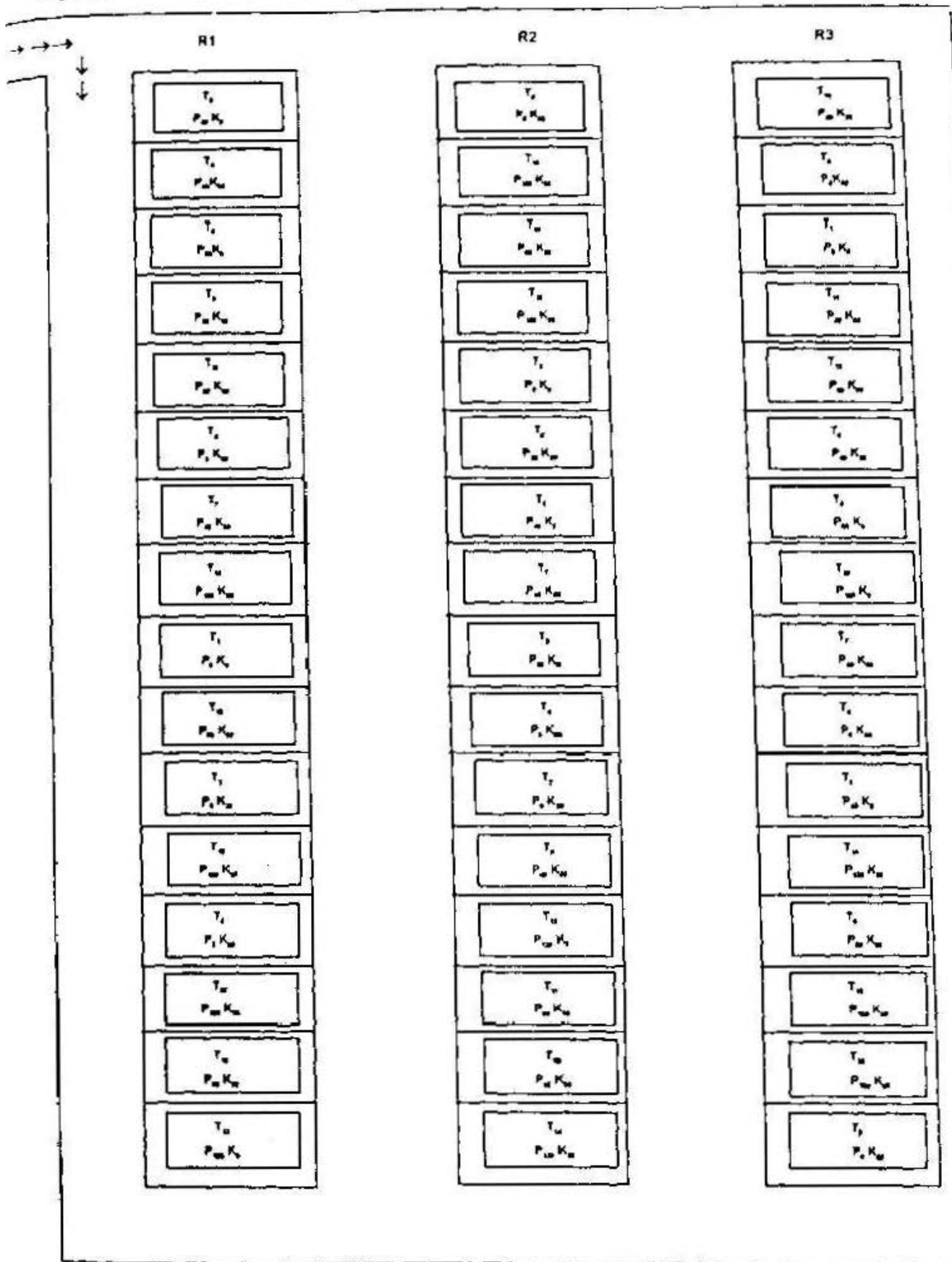
B. Levels of K₂O (kg/ha)

K1	-	0	
K2	-	30	
K3	-	60	
K4	-	90	
Total treatments	--	16	
Design	--	Randomized Block Design (RBD)	
Replications	--	3	
Plant spacing	--	45 x 15 cm	
Plot size:			
Gross	--	3.15'x2.5 m (accommodating 7 lines 45 cm apart and 2.5 m long)	
Net	--	2.25x2.0 m (5 inner rows 2.0 m long leaving 0.25 m on the either side of the rows).	
Variety used	--	Contender	
Basal application	--	45 kg N/ha (in two splits)	
Date of sowing	--	June 16	

Field Techniques**Lay out of the experiment**

The experiment comprising of 16 treatments was laid out in a randomized block design (RBD) with three replications. The treatments were allocated randomly to each plot using random number (Fig.2a). Each plot comprised of seven rows, containing 16 plants per row and hence maintaining 112 plants in each plot.

Fig. 2 a. Lay out plan for experiment.



Experimental planting

The cultural practices such as banding, weeding, hoeing and plant protection against insect pests were carried out during the crop growth periods to ensure healthy crop stand, but no fungicides were sprayed during the course of experimentation. Irrigations were applied as and when required. The details and dates of agronomic operations followed during the course of experimentation have been presented in Appendix-II.

OBSERVATIONS RECORDED

The data were recorded on ten randomly selected plants for all the characters, except quality attributes for which the observations were recorded from composite sample of 100 g green pods in each plot. The plants were marked at random excluding the border plants.

I. Growth and Development

Plant stand after 15-days after sowing (15 DAS)

Number of plants those emerged after fifteen days after sowing in different treatments were counted and percentage was worked out by the following formulae:

$$\frac{\text{Number of plants emerged}}{\text{Number of seeds sown}} \times 100$$

Number of days to 50-per cent flowering

The day on which fifty per cent plant population in each plot came into flowering, was reckoned for recording this trait. Number of days were calculated from the date of sowing to the date of 50 per cent flowering.

Number of days taken to first picking

The day on which the first green pods were harvested in each plot, was taken into consideration. Number of days were computed from the date of sowing to the date of first harvest.

Number of branches per plant

The total number of branches (primary and secondary) arising from the main stem were counted and mean number of branches per plant were worked out.

Leaf area (cm²)

A sample of 10 leaflets was taken to measure the leaf area, from the marked plants in each plot at the time of second picking. The leaflets were straightened by pressing in long book sheets for 24 hours and the leaf area (cm²) was recorded directly on Li-Cor-3100 Automatic leaf area meter.

Plant height (cm)

The plant height was measured in centimetres from the

ground level to the tip of the highest leaflet of the plant at the final picking stage.

II) Yield and its component characteristics

Pod length (cm)

Ten pods, randomly chosen at second picking from tagged plants, were measured from the point of attachment to the tip of the pod in centimeters and the mean pod length was worked out.

Pod girth (cm)

After recording the pod length, the same pods were used for recording the pod girth from suture to suture with the help of Vernier Calliper. The mean pod girth was recorded in centimeters.

Number of pods per plant

The total number of pods harvested at every picking on the marked plants were taken into consideration to work out the mean number of pods per plant.

Total green pod yield per plant(g)

Total green pod yield of ten randomly marked plants from each plot was recorded after each harvest and average green pod weight per plant was expressed in grams.

Green pod yield per hectare (q/ha)

The total yield of green pods harvested from net plot was converted into q/ha.

III) Quality Attributes

Protein content of green pods

The nitrogen content was determined by microkjeldahl method. The per cent total protein content was calculated by multiplying per cent nitrogen by a common factor of 6.25 (AOAC, 1980).

Per cent dry matter

The samples of freshly harvested green pods, weighing 100 g from each plot, were oven dried at 65°C for about 70 hrs until a constant in the sample weights was achieved. The difference between the initial weight and the final weight as considered as dry matter percentage. **Dry matter accumulation**

Two plants (from outer rows) at random were selected from each plot at second picking. The green pods were separated from the plants to have the separate dry matter accumulation by the vegetative and reproductive parts. These samples were washed with tap water and then with 0.1 N HCl and finally with distilled water to make them free of extraneous matter. The samples were oven dried at 65°C till uniformly constant weight was attained. Dry weight thus

obtained, was expressed in kg/ha for plants (leaves & stems) and green pods separately by the following formulae.

$$\text{Dry matter accumulation (kg/ha)} = \frac{\text{Dry weight of two plants(g)} \times 10000}{\text{Area covered by two plants} \times 1000}$$

severity of angular leaf spot

The severity of angular leaf spot was recorded at 60 days matured crop of French bean. Twenty five leaflets from the marked plants from each treatment were taken, examined for disease spots and infection was rated according to the following scale.

Rating	Number of spots per leaflet
0	-- No infection
1	-- 1-5 spots
2	-- 6-10 spots
3	-- 11-15 spots
4	-- 16-20 spots
5	-- 21 or more spots

Disease intensity was determined according to the formulae given by Suhag (1972) as:

$$\text{Disease intensity (\%)} = \frac{N_0 + N_1 + N_2 + N_3 + N_4 + N_5}{\text{Total No. of leaves} \times \text{No. of highest rating}} \times 100$$

where,

N = Number of leaflets in each category.

Chemical Plant Studies

Oven dried plant (leaves & stem) and pod samples as described in Section 3.3 were ground to powdery mass and subjected to chemical analysis.

The samples were digested in di-acid (4:1 - nitric acid:perchloric acid) mixtures. The aliquat was diluted in double distilled water and filtered into 100 ml volumetric flask. In order to have complete transfer of the digested material, three washings were given with double distilled water and volume was made to 100 ml. Phosphorus in the extract was determined by Vanado-molybdo phosphoric yellow colour method (Jackson, 1973). Potassium was determined by flame photometric method (Jackson, 1967).

Separate digestion was carried out for nitrogen estimation using concentrated H_2SO_4 and digestion mixture as suggested by Jackson (1973). After digestion, the total nitrogen was estimated by modified Kjeldahl Method (A.O.A.C., 1980).

NPK uptake (kg/ha)

Nitrogen, phosphorus and potassium uptake by plants (leaves and stem) and green pods in kg/ha was worked out according to the formulae.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content(\%)} \times \text{Dry matter (kg/ha)}}{100}$$

Total nutrient uptake in each treatment was calculated by summing up the nutrient uptake by both pods and plants at second picking stage.

NPK status of soil

After the harvest of the crop, surface soil samples 0-15 cm depth were collected from each plot. Samples were dried, ground and mixed thoroughly and used for the determination of available nutrient contents viz., N, P and K by using the standard methods as given in Table 2.

Response curves and maximum/optimum dose of P and K

The proper method to study the fertilizer response of yield-dose relationship, is to fit the data in a quadratic function response curve. The quadratic production function of the pooled data was fitted as:

$$Y = a + bP + cP^2 \dots \dots \dots (1)$$

where,

Y = is the expected yield (kg/ha) for given level of P;

P = is the phosphorus dose (kg/ha);

a, b, c = are the coefficients indicating transformed ratios of phosphorus at different levels (Gomez and Gomez, 1983).

The quadrate function was considered the most appropriate for fertilizer response analysis in the present studies, as it gives diminishing marginal productivity and is

consistent with the law of diminishing returns. Yield maximising rate of phosphorus P (max) was obtained by differentiating Y with respect to zero.

Thus,

$$\frac{dy}{dn} = b + 2cP = 0 \dots\dots\dots(2)$$

$$2cP = -b \dots\dots\dots(3)$$

$$P(\text{max}) = \frac{-b}{2c} \dots\dots\dots(4)$$

At the optimum level, the value of the additional produce obtained by a unit increment in nutrient will just balance the extra cost of the fertilizer. This shows that the optimum dose depends on the relative prices of the nutrient and the produce. Hence, equating equation (2) with the cost price ratio (q/p), where q is the cost of one unit of phosphorus and p is the price per kg of the produce lead to the following formula for determining the optimum dose of phosphorus 'P (opt)' which may be defined as the most profitable dose or profit maximising rate of phosphorus.

$$b + 2cP = \frac{q}{p} \dots\dots\dots(5)$$

$$P(\text{opt}) = \left| \frac{q}{p} - b \right| \frac{1}{2c}$$

Similarly, optimum and maximum doses of potassium were determined.

Economic Analysis

After taking into consideration the variables as well as fixed inputs and corresponding rates, the cost incurred on each treatment was worked out (Appendix II). Simultaneously gross returns were worked out for each treatment based on market price of the marketable produce. Net returns were worked out by deducting the cost incurred from the gross returns of the particular treatment.

Statistical Analysis

All the data relating to growth and development, yield and its component characteristics, quality attributes and nutrient uptake were statistically computed in RBD design as proposed by Panse and Sukhatme (1961) and Cochran and Cox (1963). The treatment effects were tested at 5 per cent level of significance. The data recorded for two years, were pooled as permitted by Bartlett's test of Homogeneity and described by Gomez and Gomez (1983).

Chapter - IV

EXPERIMENTAL RESULTS

4.1 GROWTH AND DEVELOPMENT CHARACTERISTICS

4.1.1 Plant stand(%)

The fertilizer treatments in the form of phosphorus and potassium did not influence the plant stand statistically, as revealed by computation of the data in Table 3.

4.1.2 Days to fifty per cent flowering

The ANOVA of pooled data in Appendix-II revealed significant effects of phosphorus, potassium year and P x K interactions on days to fifty per cent flowering. However, the character remained unaffected with PxY, KxY and PxKxY interactions.

It was observed that phosphorus application @ 80 kg/ha, resulted in early flowering (33.63 days), while P₁₂₀ and P₄₀ were at par with P₈₀. In case of potassium application, minimum (33.71) days to fifty per cent flowering were recorded at 60 kg K₂O/ha, which was non-significant to K₃₀ and K₉₀ (Table 3 and Fig.3).

The environmental conditions in 1993 were statistically congenial for earliness than 1994.

Table 2. Effect of phosphorus and potassium on plant stand(%) after 15 DAS of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	83.33	82.15	83.3	84.82	83.48	83.33	84.03	83.34	86.81	84.38	83.33	83.09	83.89	85.81	83.93
K ₃₀	83.93	84.23	85.71	84.82	84.67	83.63	85.42	87.15	87.50	86.94	83.81	84.82	86.43	86.16	85.31
K ₆₀	84.23	83.63	87.80	87.50	85.79	84.72	88.53	88.89	86.81	87.24	84.48	86.08	88.34	87.16	86.51
K ₉₀	83.34	84.52	87.54	85.41	85.20	85.07	87.46	88.89	87.50	87.23	84.20	85.99	88.21	86.46	86.22
Mean	83.71	83.63	86.17	85.64	84.79	84.20	86.36	87.07	87.15	86.20	83.95	85.00	86.62	86.40	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.759	1.074	1.074	1.518	1.518	2.148	3.038
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of phosphorus and potassium on days to 50 per cent flowering of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	34.33	34.00	34.00	32.67	33.75	35.67	35.33	35.00	34.33	35.08	35.00	34.67	34.50	33.50	34.42
K ₃₀	34.00	33.67	33.7	33.33	33.67	35.00	34.67	34.33	34.00	34.50	34.50	34.17	34.00	33.67	34.08
K ₆₀	34.00	33.67	31.67	33.67	33.25	35.00	34.00	32.67	35.00	34.17	34.50	33.83	32.17	34.33	33.71
K ₉₀	33.00	32.67	33.00	33.67	33.08	34.33	34.33	34.67	35.00	34.58	33.67	33.50	33.83	34.33	33.83
Mean	33.83	33.50	33.08	33.33	33.44	35.00	34.58	34.17	34.58	34.58	34.42	34.04	33.63	33.96	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.164	0.232	0.232	0.329	0.329	0.465	0.657
CD(P=0.05)	0.34	0.47	0.47	NS	NS	0.94	NS

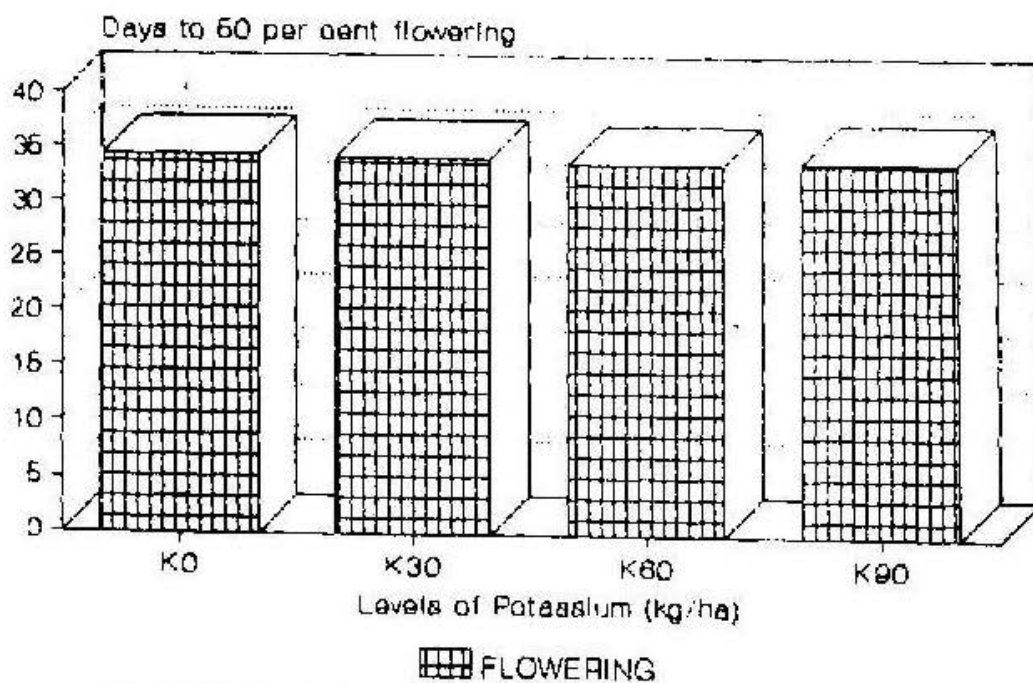
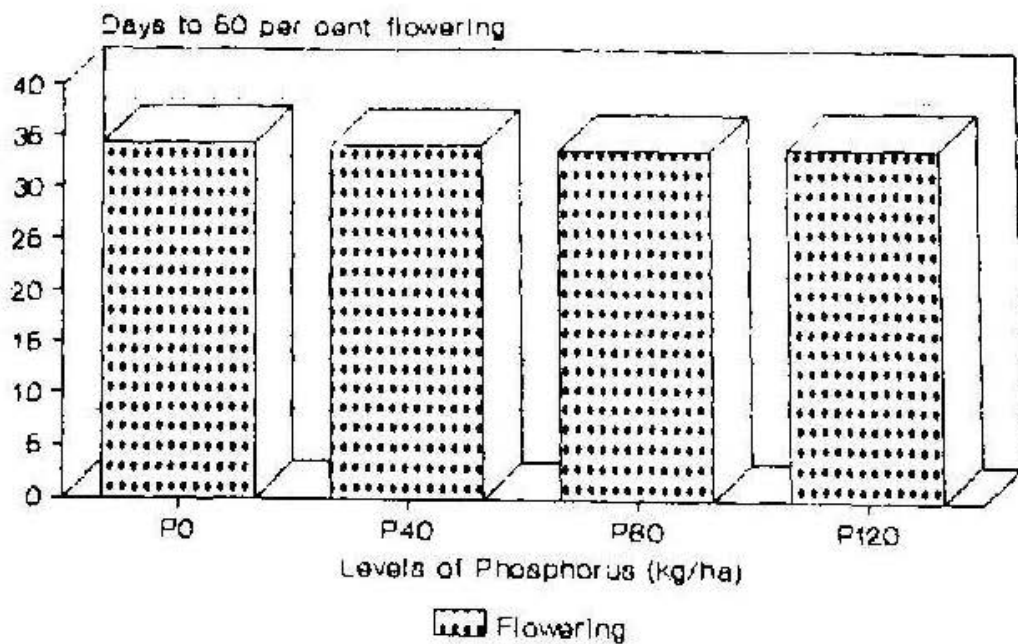


Fig.3. Effect of phosphorus and potassium on days to 50 % flowering of French bean cv. Contender

The combined effect of P x K at 80 kg P₂O₅ and 60 kg K₂O per hectare made the crop to flower in 32.17 days after sowing, which was 2.83 days earlier to the control.

4.1.3 Days to first picking

A cursory glance of the pooled data in Table 4 and analysis of variance (Appendix-II) extrapolated that the days to first picking of French bean, was significantly affected by years and various levels of phosphorus and potassium either alone or in combination. However, the interaction effects of P_xY, K_xY and P_xK_xY were found to be non-significant.

Application of phosphorus induced early maturity over the control at the rate of 80 kg P₂O₅/ha (46.82 days). This treatment was at par with P₄₀ and P₁₂₀. Similar effects were observed with the potassium application of 60 kg K₂O per hectare (46.79 days). This dose was also showing non-significant differences with the higher (K₉₀) and lower (K₃₀) levels of potassium. Minimum days to first picking were also recorded at P₈₀xK₆₀ level (46.00).

4.1.4 Number of branches per plant

An analysis of variance (Appendix-II) indicated significant differences among the various levels of phosphorus and potassium, year and P_xK & K_xY interactions on number of branches/plant in French bean. However, P_xY, P_xK_xY were found to be non-significant.

An inquisition of the pooled data (Table 5) showed that the number of branches per plant significantly increased with the increasing levels of phosphorus application and maximum (8.87) number of branches per plant were recorded at 120 kg P_2O_5 /ha, which was at par with 80 kg P_2O_5 /ha. In case of potassium application, at 60 kg K_2O /ha, recorded maximum (8.60) number of branches per plant which was at par with 90 kg K_2O /ha. The climatic factors in the year 1993 were favourable for K application to produce more number of branches per plant, than in 1994.

Maximum number of branches/plant (9.80) were recorded with the combined application of 80 kg P_2O_5 and 60 kg K_2O /ha.

4.1.5 Leaf area (cm^2)

The mean leaf area as depicted in the Table 6 and ANOVA in Appendix-II, was significantly influenced with the application of phosphorus and potassium. The test of homogeneity was found significant and hence the pooled analysis could not be carried out. Interaction effects of P x K were found to be non-significant during both the years.

Leaf area significantly increased with the application of phosphorus and potassium and maximum values were recorded at P_{80} (510.53 cm^2) and P_{120} (561.74 cm^2) in 1993 and 1994, respectively. In case of potassium, the leaf area was maximum at K_{90} (484.81 cm^2 and 503.43 cm^2), which was at par with K_{60} , during 1993 and 1994.

Table 6. Effect of phosphorus and potassium on leaf area (cm²) of French bean cv. Contender

Treatments	1993					1994				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	337.78	351.38	442.44	476.07	401.92	345.23	356.93	426.30	526.20	413.67
K ₃₀	380.61	428.60	504.04	479.47	446.18	357.17	423.73	473.00	564.40	456.83
K ₆₀	386.35	438.11	545.60	512.35	470.60	420.17	452.60	541.33	575.93	497.51
K ₉₀	380.45	453.62	550.05	555.12	484.81	393.33	469.00	570.93	580.43	503.43
Mean	371.30	417.93	510.53	505.75		378.98	427.82	502.89	561.74	

	1993			1994		
	P	K	PxK	P	K	PxK
S. Ed±	15.364	15.364	30.728	22.581	22.581	45.161
CD (P=0.05)	31.37	31.37	NS	46.11	46.11	NS

Table 7. Effect of phosphorus and potassium on Plant height (cm) of French bean cv. Contender

Treatments	1993					1994				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	30.27	36.93	39.60	40.33	36.78	30.17	36.67	39.67	41.93	37.11
K ₃₀	35.93	40.03	42.63	42.00	40.15	37.37	42.67	47.33	45.17	43.13
K ₆₀	40.17	40.80	44.30	43.93	42.30	39.30	45.50	50.20	50.73	46.43
K ₉₀	38.33	40.17	43.47	43.37	41.33	40.33	43.37	50.43	53.40	46.88
Mean	36.18	39.48	42.50	42.41		36.79	42.05	46.91	47.81	

	1993			1994		
	P	K	PxK	P	K	PxK
S. Ed±	0.546	0.546	1.094	2.399	2.399	4.799
CD (P=0.05)	1.12	1.12	2.23	4.90	4.90	NS

4.1.6 Plant height (cm)

The observations recorded on plant height (cm), as influenced by various treatments, have been presented in Table 7. The test of homogeneity was found significant and hence the pooled analysis for two years was not performed.

Plant height was significantly increased with the increase in levels of phosphorus and potassium and taller plants were obtained with the lower doses of phosphorus (80 kg/ha) and potassium (60 kg/ha), during 1993, in comparison to the higher doses of these nutrients i.e. P₁₂₀ and K₉₀ during 1994.

Plant height was also seen to be influenced by PxK interaction during 1993. Maximum plant height (44.30 cm) was recorded at the application of 80 kg P₂O₅ in conjugation of 60 kg K₂O per hectare.

4.2 YIELD AND ITS COMPONENT CHARACTERISTICS

4.2.1 Pod length (cm)

An analysis of variance (Appendix-II) showed significant effects of phosphorus, potassium and year on the pod length of the cv. Contender. The interaction effects of PxY, KxY & PxK were significant, while PxKxY effects were non-significant (Table 8 and Fig.4).

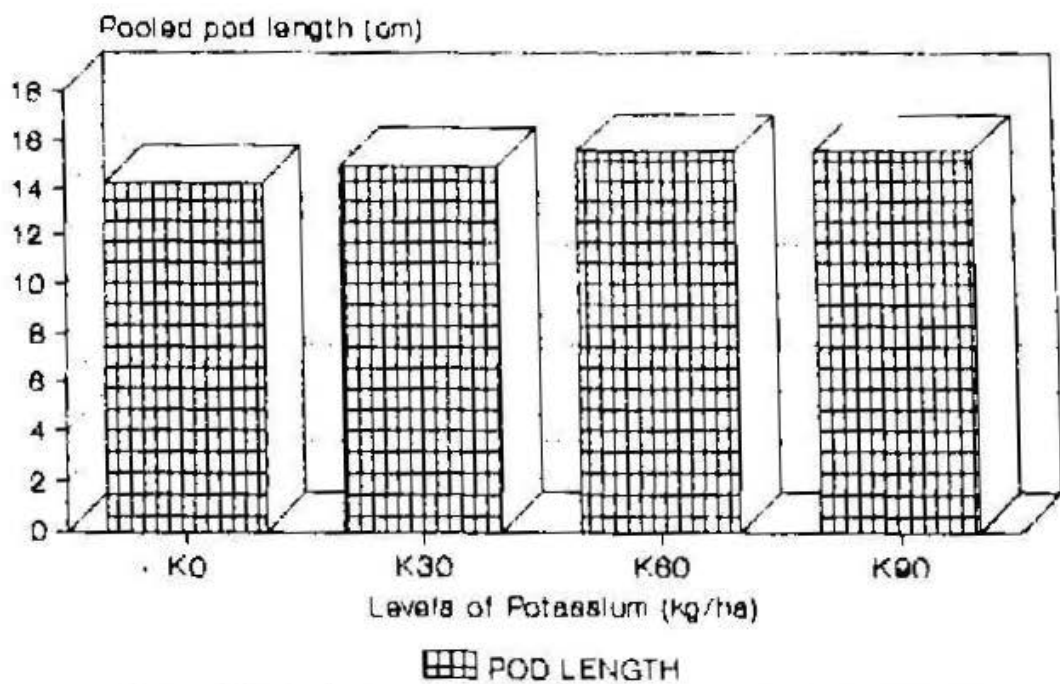
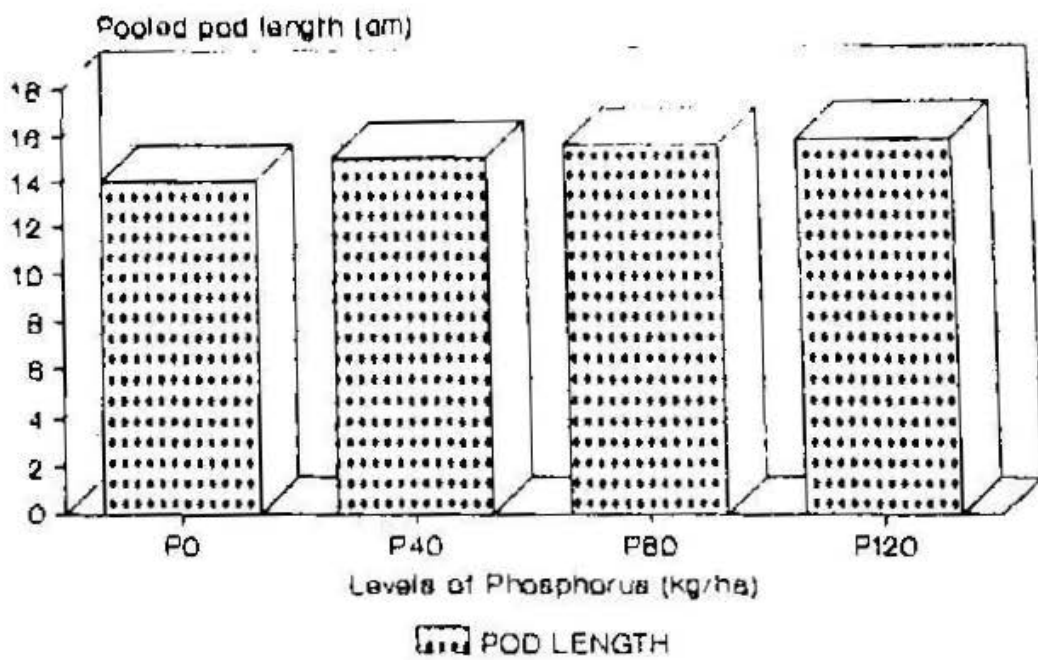


Fig-4. Effect of phosphorus and potassium on pod length(cm) of French bean cv. Contender

Phosphorus @ 120 kg/ha, recorded maximum pod length of 15.71 cm, which was at par with 80 kg P_2O_5 /ha. Similarly, higher doses of potassium i.e. 60 kg and 90 kg/ha, both recorded maximum pod length of 15.33 cm. The combined application of phosphorus @ 120 kg and potassium @ 90 kg per hectare produced longest pods (16.18 cm), which was non-significantly different from $P_{120} \times K_{60}$, $P_{80} \times K_{60}$ and $P_{80} \times K_{90}$. Pod length was drastically reduced in 1994 as compared to 1993. The environment was more congenial for phosphorus and potassium application in the former year than in the latter.

4.2.2 Pod girth (cm)

A cursory glance of the pooled data in Table 9 and analysis of variance (Appendix-II) extrapolated that the pod girth of French bean, was significantly affected by various levels of phosphorus and potassium. However, the individual effect of years and interaction affect of $P \times Y$, $K \times Y$, $P \times K$ and $P \times K \times Y$ was found to be non-significant.

An inquisition of the pooled data indicated that the pod girth increased with the successive levels of phosphorus application. It was maximum (3.13 cm) at P_{120} , which was at par with P_{80} . In case of potassium application, maximum pod girth (3.15 cm) was recorded @ 60 kg K_2O /ha, which was at par with 90 kg K_2O /ha.

4.2.3. Number of pods per plant

A perusal of the pooled data (Table 10 and Fig.5) revealed significant effect of phosphorus, potassium, years and PK interactions on the number of pods per plant in French bean. However, interaction effects of PY, KY and PKY were found to be non-significant (Appendix-II).

Maximum number of pods per plant (21.47) were produced at P_{80} , which was showing non-significant differences with P_{120} . Potassium application @ 60 kg K_2O/ha also produced maximum (21.42) number of pods per plant and was at par with higher level (K_{90}). The agro-climate in 1994, enhanced the overall number of pods per plant in French bean cv. Contender. The combined application of phosphorus and potassium at $P_{80} \times K_{60}$ produced the highest (24.42) number of pods/ plant. This increase was 102.15 per cent higher over the control (P_0K_0).

4.2.4 Green pod yield per plant (g)

The data recorded on green pod yield/plant in 1993 and 1994, was found to be homogenous and hence, pooled analysis of variance (Appendix-II) was conducted. Table 11 extrapolates that the application of phosphorus and potassium, individually or in combination, had significantly influenced the green pod yield per plant, whereas year, PY, KY and PKY effects were non-significant.

Table 10. Effect of phosphorus and potassium on number of pods per plant of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	11.13	13.27	16.47	16.93	14.45	13.03	14.40	17.47	18.43	15.83	12.08	13.83	16.97	17.68	15.14
K ₃₀	15.50	18.33	20.37	19.33	18.38	15.63	19.07	22.67	20.17	19.38	15.57	18.70	21.52	19.75	18.88
K ₆₀	16.03	20.30	22.43	22.47	20.31	15.77	21.77	26.40	26.17	22.53	15.90	21.03	24.42	24.32	21.42
K ₉₀	16.53	19.70	21.47	21.87	19.89	16.57	21.13	24.50	25.77	21.99	16.55	20.42	22.98	23.82	20.94
Mean	14.80	17.90	20.18	20.15	18.26	15.25	19.09	22.76	22.63	19.93	15.02	18.50	21.47	21.39	
							Pooled		Y	P	K	PxY	KxY	PxK	PxKxY
							S.Ed.±		0.458	0.648	0.648	0.917	0.917	1.296	1.833
							CD (P=0.05)		0.94	1.32	1.32	NS	NS	2.65	NS

Table 11. Effect of phosphorus and potassium on green pod yield per plant (g) of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	69.00	82.17	110.33	109.67	92.79	76.17	88.83	106.00	105.33	94.08	72.58	85.50	108.17	107.50	93.44
K ₃₀	91.67	112.50	128.33	128.33	115.21	97.83	122.83	137.00	125.33	120.75	94.75	117.67	132.67	126.83	117.98
K ₆₀	107.00	131.67	151.33	150.60	135.15	101.33	136.00	169.20	166.33	143.17	104.17	133.83	160.27	158.47	139.19
K ₉₀	106.73	131.17	150.00	150.83	134.68	107.33	132.02	159.67	169.67	142.17	107.03	131.59	154.83	160.25	138.43
Mean	93.60	114.38	135.00	134.86	119.46	95.67	119.92	142.97	141.67	125.04	94.63	117.15	138.99	138.26	
							Pooled		Y	P	K	PxY	KxY	PxK	PxKxY
							S.Ed.±		2.752	3.892	3.892	5.505	5.505	7.785	11.009
							CD (P=0.05)		NS	7.95	7.95	NS	NS	15.90	NS

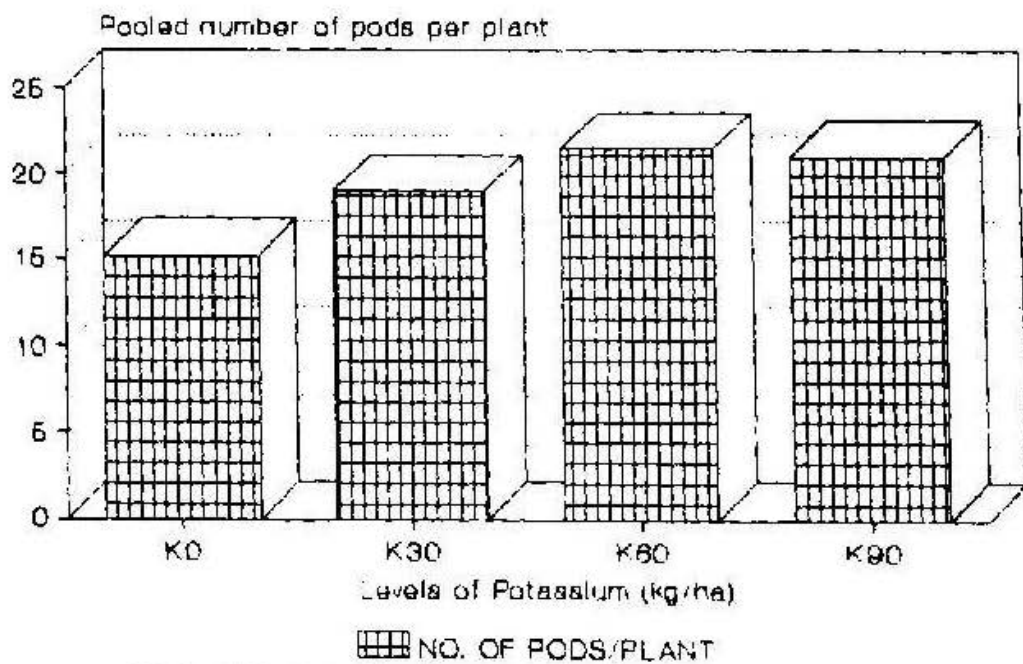
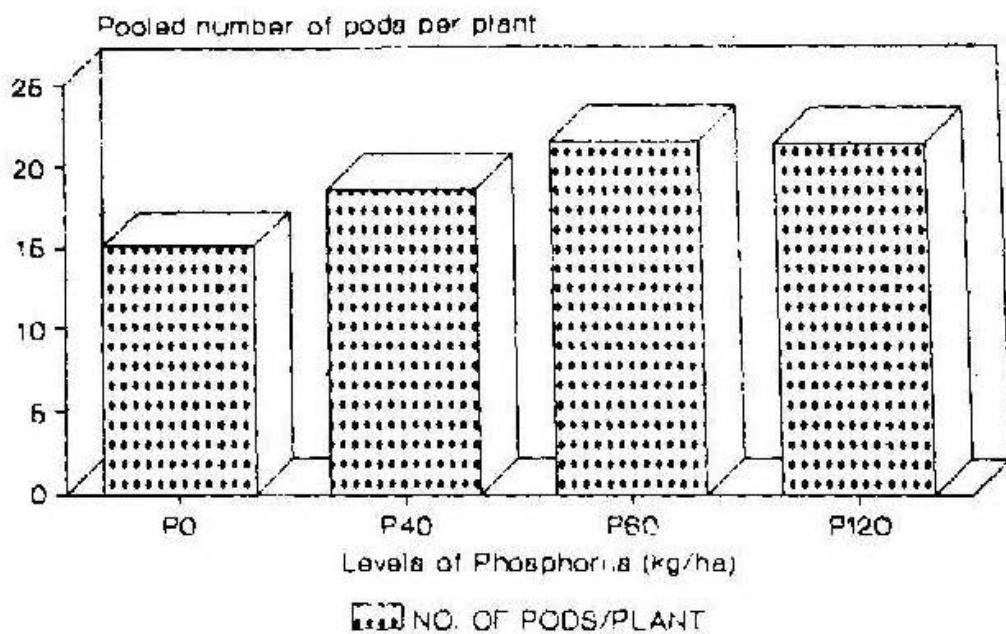


Fig.5. Effect of phosphorus and potassium on number of pods per plant of French bean cv. Contender

Application of P_2O_5 @ 80 kg/ha, produced maximum green pod yield per plant (138.99 g), which was at par with 120 kg P_2O_5 /ha. Potassium application at K_{60} recorded maximum green pod yield/plant (139.19 g), which was at par with K_{90} .

The green pod yield per plant, influenced significantly by the PxK interaction, was maximum (160.27 g) at 80 kg P_2O_5 along with 60 kg K_2O per hectare. It gave an overall increase of 120.79 per cent as compared to the control (P_0K_0).

4.2.5 Green pod yield per hectare (q/ha)

The mean performance of cv Contender for green pod yield (q/ha) as influenced by the main effects of P and K, and PxK interactions have been presented in Table 12 and illustrated graphically in Figure 6. An inquisition of the pooled analysis of variance (Appendix-II) indicated significant differences among the various levels of phosphorus and potassium, year effects and interaction effects of PxK on green pod yield of French bean. However, PxY, KxY and PxKxY was found to be non-significant.

Application of phosphorus @ 80 kg P_2O_5 /ha significantly out yielded, (99.70 q/ha), the other phosphorus doses except P_{120} . Potassium when applied @ 60 kg K_2O /ha produced maximum pod yield (100.17 q/ha), which was statistically superior to other potassium levels. The

climatic conditions in the year 1994 were congenial for enhanced production of green pods.

Green pod yield of French bean, as influenced significantly by the combined application of P and K, was maximum (112.96 q/ha) at $P_{80} \times K_{60}$. It was 90.10 per cent higher than the control ($P_0 \times K_0$).

4.3 QUALITY ATTRIBUTES

4.3.1 Protein-content in green pod (%)

The pooled analysis of variance (Appendix-II) revealed significant effects of phosphorus, potassium and their interactions on protein-content in green pods of French bean. The effects of $P \times Y$, $K \times Y$ and $P \times K \times Y$ and year were found to be non-significant.

The data in Table 13 and Figure 7 revealed that the higher doses of phosphorus i.e. P_{80} and P_{120} produced maximum protein-content (1.89%). A linear increase was observed with the increasing levels of potassium upto K_{60} , however, a non-significant decline was observed at K_{90} .

The combined application of phosphorus and potassium @ 80 kg P_2O_5 and 60 kg K_2O per hectare, produced highest protein-content (1.95%) in green pods.

4.3.2 Per cent dry matter content in pods

Per cent dry matter content of pods, as influenced by

Table 12. Effect of phosphorus and potassium on green pod yield (q/ha) of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	55.33	66.81	74.30	77.11	68.39	63.50	80.50	84.82	80.46	77.32	59.42	73.66	79.56	78.79	72.85
K ₃₀	72.74	82.74	99.56	87.19	85.56	78.27	84.27	98.64	101.46	90.66	75.51	83.51	99.10	94.32	88.12
K ₆₀	76.63	92.37	110.96	112.26	98.30	85.72	95.69	114.96	112.23	102.15	81.18	94.03	112.96	112.25	100.17
K ₉₀	81.40	90.37	104.37	111.48	96.91	87.72	97.96	109.96	109.68	101.33	84.56	94.17	107.16	110.58	99.12
Mean	71.53	83.07	97.30	97.01	87.29	78.81	89.60	102.09	100.96	92.86	75.17	86.34	99.70	99.00	
							Pooled		Y	P	K	PxY	KxY	PxK	PxKxY
							S.Ed.±	2.017	2.853	2.853	4.035	4.035	5.706	8.068	
							CD(p=0.05)	4.12	5.83	5.83	NS	NS	11.65	NS	

Table 13. Effect of phosphorus and potassium on protein content (%) in green pods of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	1.42	1.60	1.77	1.82	1.65	1.44	1.61	1.75	1.82	1.65	1.43	1.61	1.76	1.82	1.65
K ₃₀	1.58	1.71	1.90	1.90	1.77	1.59	1.69	1.90	1.89	1.77	1.58	1.70	1.90	1.89	1.77
K ₆₀	1.75	1.87	1.94	1.94	1.87	1.75	1.87	1.95	1.94	1.88	1.75	1.87	1.95	1.94	1.88
K ₉₀	1.75	1.81	1.94	1.95	1.86	1.75	1.83	1.94	1.91	1.86	1.75	1.82	1.94	1.93	1.86
Mean	1.63	1.75	1.89	1.90	1.79	1.63	1.75	1.88	1.89	1.79	1.63	1.75	1.89	1.89	
							Pooled		Y	P	K	PxY	KxY	PxK	PxKxY
							S.Ed.±	0.015	0.022	0.022	0.031	0.031	0.043	0.061	
							CD(p=0.05)	NS	0.04	0.04	NS	NS	0.09	NS	

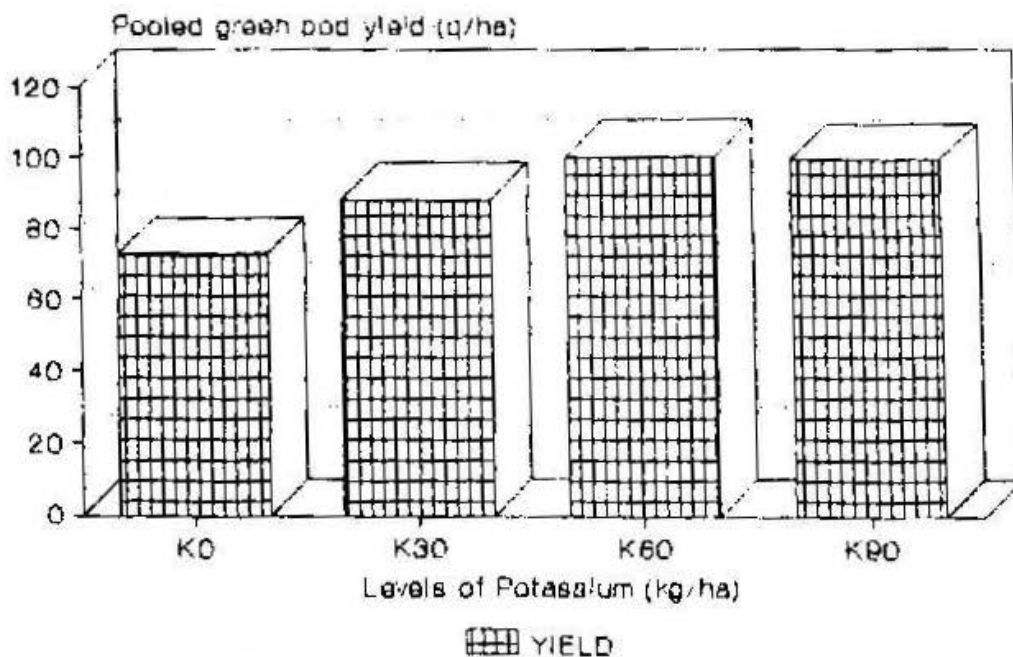
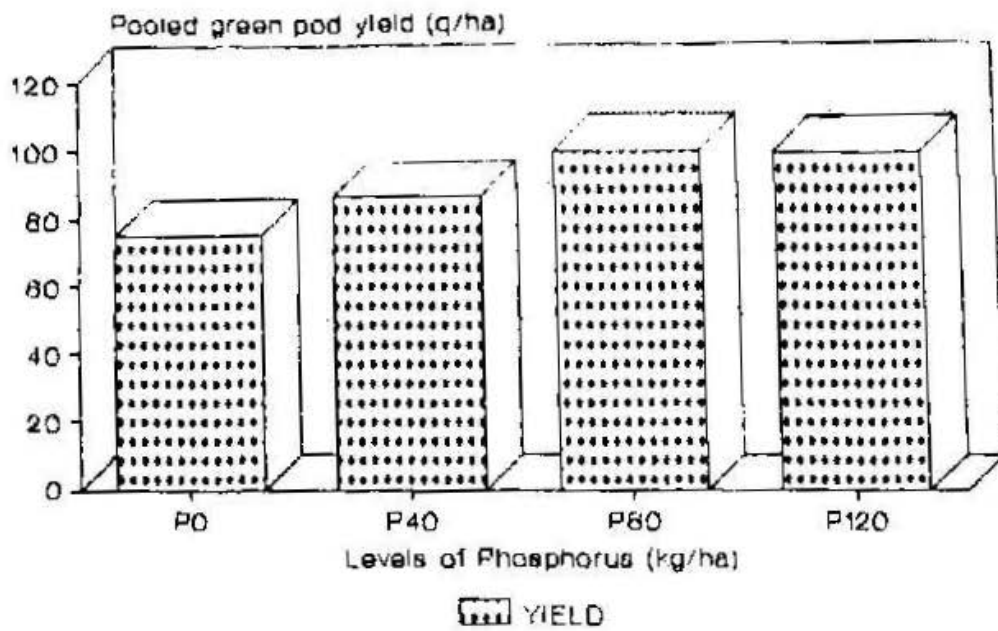


Fig.6 Effect of phosphorus and potassium on green pod yield (q/ha) of French bean cv. Contender

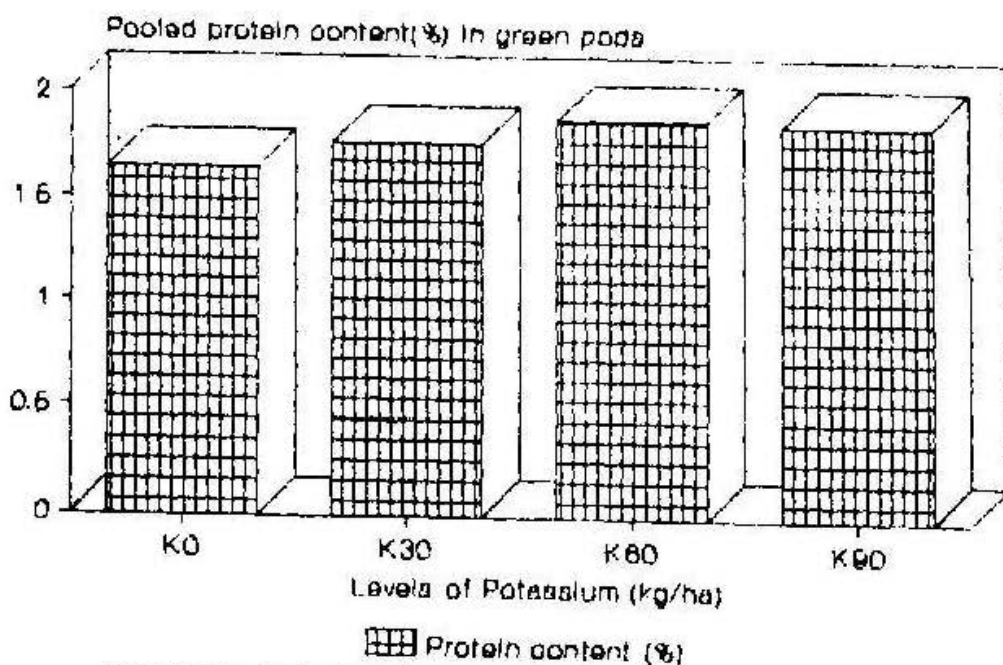
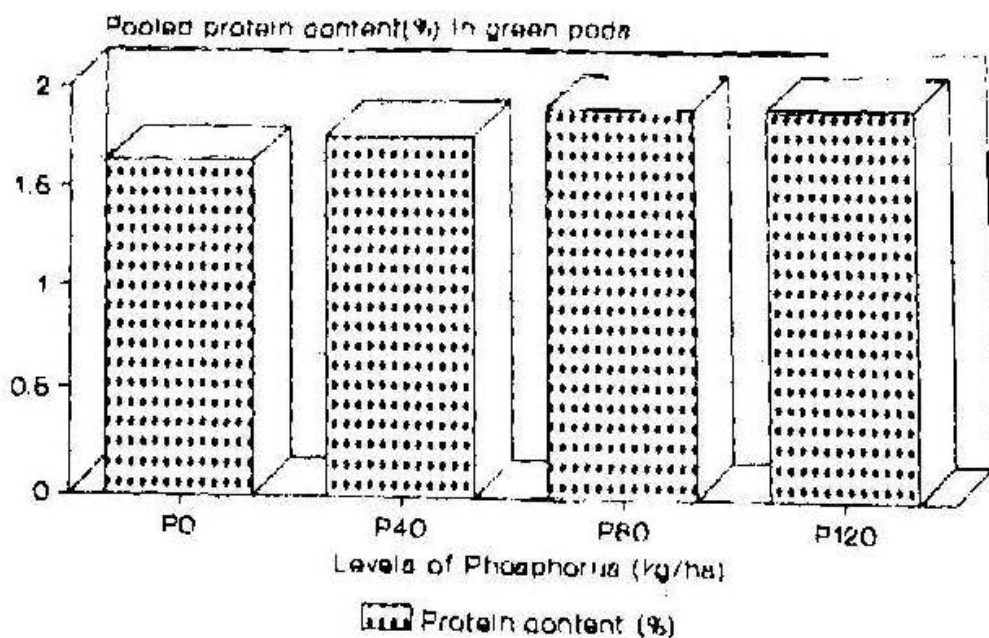


Fig:7. Effect of phosphorus and potassium on protein content (%) in green pods of French bean cv. Contender

various treatments has been presented in Table 14 (Fig. 8) and their pooled analysis of variance (Appendix-II) revealed significant effects of phosphorus, potassium and P x K interaction on the dry matter content of the pods. However, year, P x Y, K x Y and P x K x Y effects were found to be non-significant.

It is evident from the pooled data that the dry matter content in pods significantly increased with the increasing levels of phosphorus and maximum dry matter content (9.0%) was recorded at 80 kg and 120 kg P_2O_5 per hectare. Similar trend was observed in case of potassium application and the maximum value was recorded at K_{90} (8.95%), which was at par with 60 kg K_2O /ha. Maximum dry matter content was recorded with the combined application of 120 kg P_2O_5 and 90 kg K_2O per hectare (9.19%).

4.3.3 Per cent dry matter in plant

The effect of various levels of phosphorus and potassium on the dry matter content of plants (stem + leaves) at second picking stage has been presented in Table 15 and Figure 9. The corresponding pooled analysis of variance (Appendix-II) have shown significant effects of phosphorus, potassium and their interactions on dry matter in plants, while year, P x Y, K x Y and P x K x Y effects were found to be non-significant.

Table 14. Effect of phosphorus and potassium on per cent dry matter in pods of French bean cv. Contender

Treatments	1993					1994					Pooled						
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean		
K ₀	7.15	7.85	8.55	8.59	8.04	7.13	7.97	8.52	8.60	8.06	7.14	7.91	8.54	8.60	8.05		
K ₃₀	7.83	8.27	8.98	9.10	8.55	7.84	8.26	9.01	8.99	8.53	7.84	8.27	9.00	9.05	8.54		
K ₆₀	8.54	8.87	9.15	9.16	8.93	8.56	8.88	9.17	9.18	8.95	8.55	8.88	9.16	9.17	8.94		
K ₉₀	8.55	8.90	9.16	9.18	8.95	8.57	8.89	9.18	9.19	8.96	8.56	8.90	9.18	9.19	8.95		
Mean	8.02	8.47	8.96	9.01	8.62	8.03	8.50	8.97	8.99	8.62	8.02	8.49	9.00	9.00			
Pooled											Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±											0.058	0.082	0.082	0.12	0.12	0.164	0.020
CD (p=0.05)											NS	0.17	0.17	NS	NS	0.33	NS

Table 15. Effect of phosphorus and potassium on per cent dry matter in plant at 2nd picking stage of French bean cv. Contender

Treatments	1993					1994					Pooled						
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean		
K ₀	6.84	7.16	7.40	7.41	7.20	6.90	7.19	7.42	7.43	7.24	6.87	7.18	7.41	7.42	7.22		
K ₃₀	7.33	7.59	7.76	7.79	7.62	7.31	7.43	7.79	7.81	7.59	7.32	7.51	7.78	7.80	7.60		
K ₆₀	7.62	7.88	8.37	8.43	8.08	7.58	7.62	8.42	8.45	8.02	7.60	7.75	8.40	8.44	8.05		
K ₉₀	7.63	7.92	8.43	8.45	8.11	7.61	7.64	8.44	8.46	8.04	7.62	7.78	8.44	8.46	8.07		
Mean	7.35	7.64	7.99	8.02	7.75	7.35	7.47	8.02	8.04	7.72	7.35	7.56	8.00	8.03			
Pooled											Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±											0.028	0.039	0.039	0.056	0.056	0.079	0.0112
CD (p=0.05)											NS	0.08	0.08	NS	NS	0.16	NS

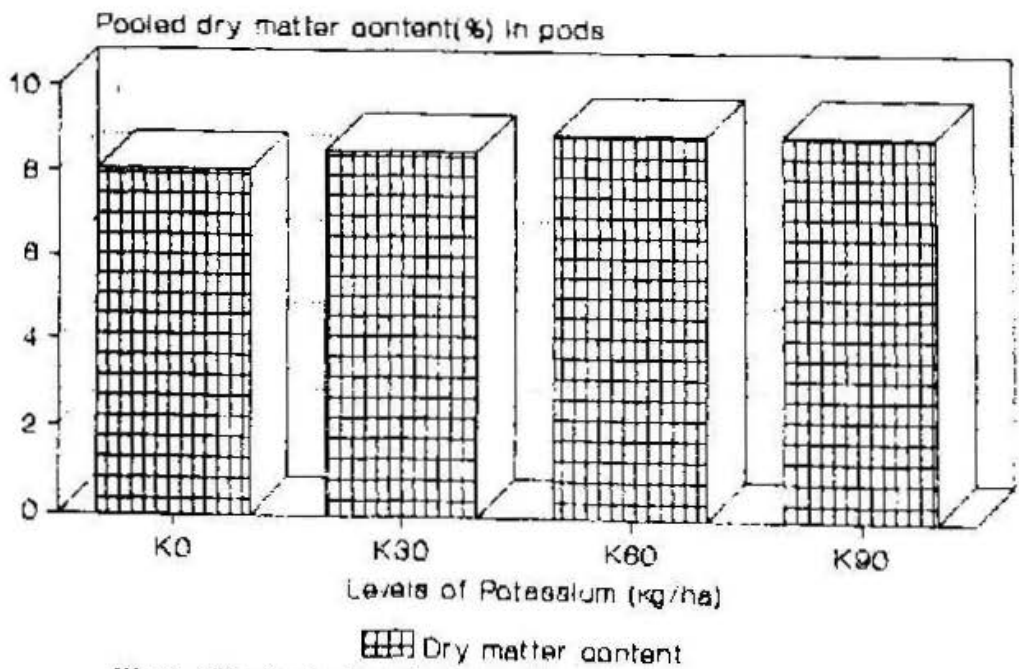
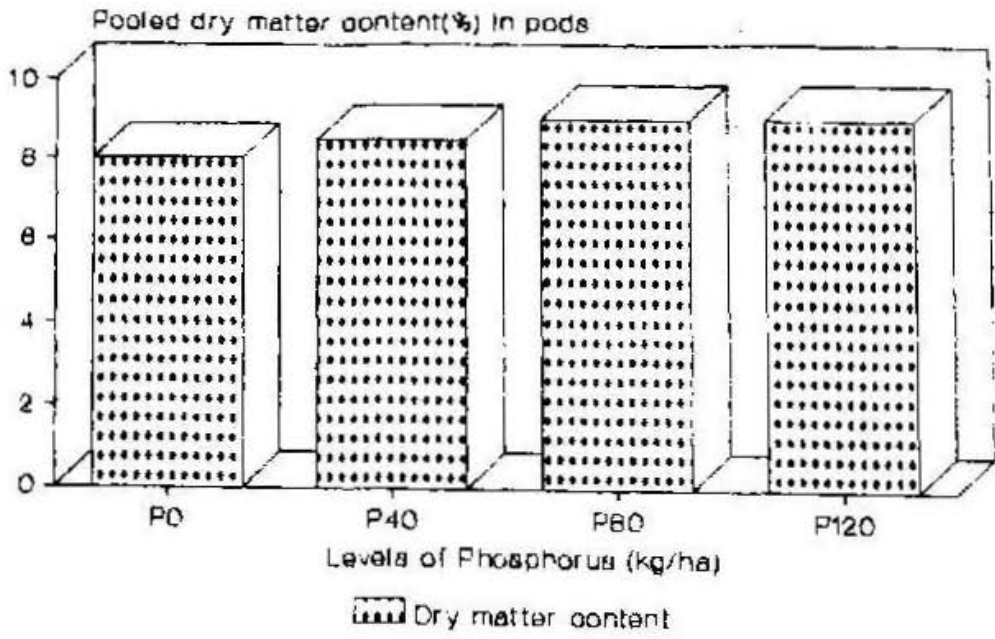


Fig:8. Effect of phosphorus and potassium on dry matter content(%) in pods of French bean cv. Contender

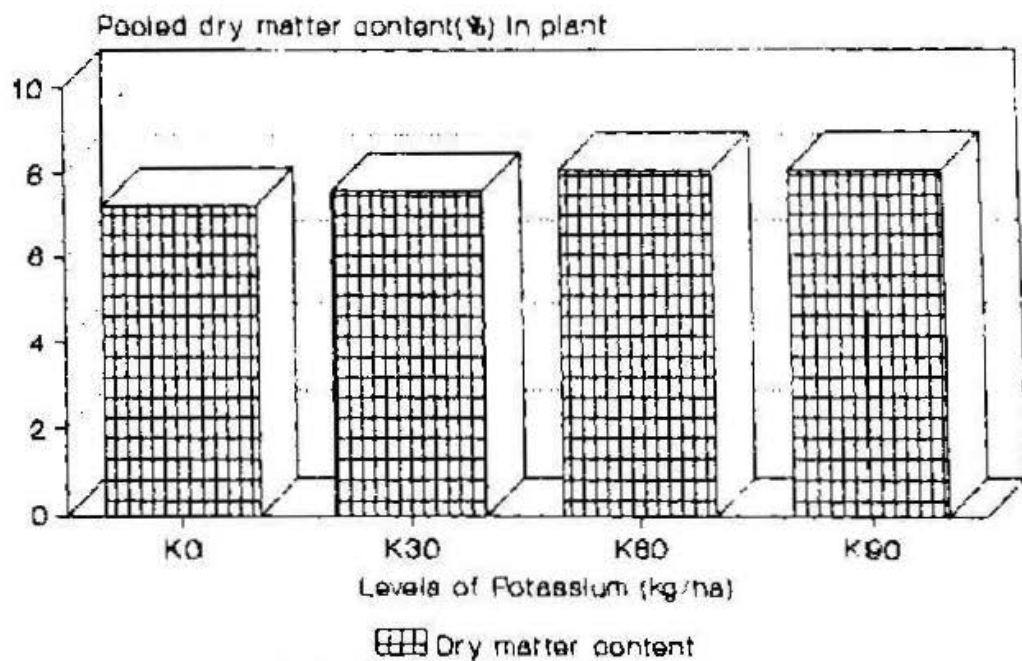
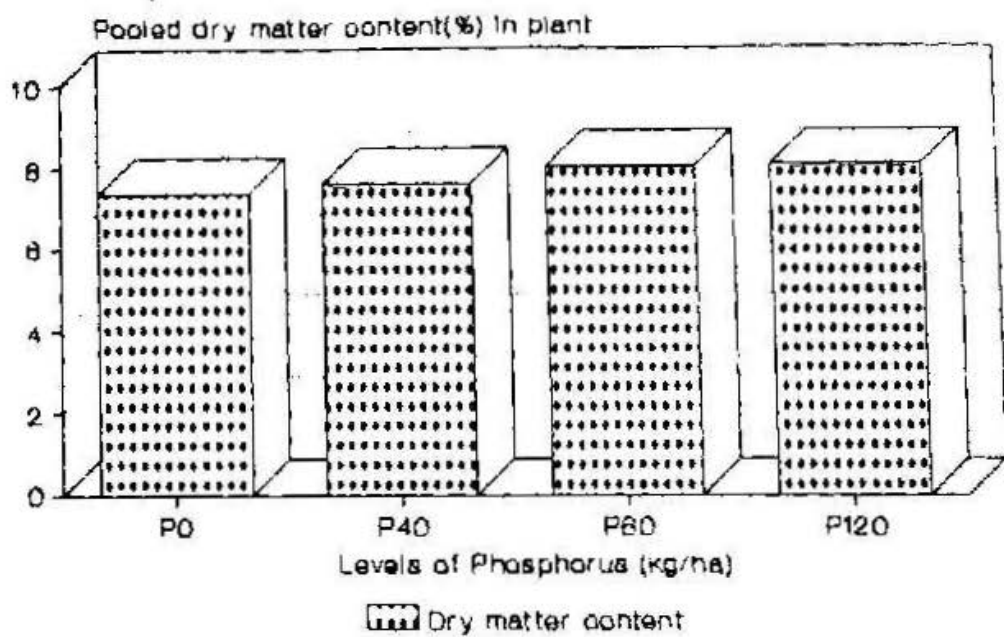


Fig.9. Effect of phosphorus and potassium on dry matter content(%) in plant of French bean cv. Contwinder

An inquisition of the pooled data deduced linear progress in the dry matter content of plants with the application of phosphorus and potassium as well. Dry matter content produced at P₁₂₀ (8.03%) was at par with P₈₀ and that produced at K₉₀ (8.07%) was statistically comparable to K₆₀. The same doses produced 8.46% dry matter in plants when applied in conjugation.

4.4 DRY MATTER ACCUMULATION

4.4.1 Dry matter accumulation by pods (kg/ha)

The pooled analysis of variance pertaining to dry matter accumulation by pods (Appendix-II) deduced significant effects for phosphorus, potassium, years and interaction effects of PxK. The interaction effects of PxY, KxY and PxKxY were found to be non-significant (Table 16).

A linear increase in dry matter accumulation was observed upto P₈₀ which recorded 897.42 kg/ha dry matter accumulation and was at par with P₁₂₀. In case of potassium, maximum dry matter accumulation (898.84 kg/ha) was recorded at K₆₀ and was at par with K₉₀. However, the interaction effect at P₁₂₀ x K₆₀ gave the maximum dry matter accumulation (1033.98 kg/ha). The dry matter accumulation by pods was more in 1994 than 1993.

4.4.2 Dry matter accumulation by French bean plant (kg/ha)

The analysis of variance for dry matter accumulation

(kg/ha) by bean plant (leaves + stem) revealed significant influence of individual and combined application of phosphorus and potassium (Appendix-II). However, the effects of year, P_xY, K_xY and P_xK_xY were found to be non-significant.

The maximum dry matter accumulation (1738.15 kg/ha) by plant was observed with the application of 120 kg P₂O₅/ha, which was at par with P₈₀. In case of potassium application, highest dry matter accumulation (1745.03 kg/ha) was recorded at 60 kg K₂O/ha, which was showing statistical proximity with 90 kg K₂O/ha.

Maximum dry matter accumulation (1951.23 kg/ha) was observed with the combined application of 120 kg P₂O₅ and 90 kg K₂O/ha (Table 17).

4.4.3 Total dry matter accumulation by the crop (kg/ha)

The pooled analysis of variance (Appendix-II) deduced significant effects of phosphorus and potassium either alone or in combination on the total dry matter accumulation by the bean crop (pod + plant). Year, P_xY, K_xY and P_xK_xY effects were found to be non-significant.

It can be revealed from the pooled data (Table 18; Fig.10) that the highest (2648.91 kg/ha) dry matter accumulation by bean crop was observed at P₁₂₀, which was at par with 80 kg P₂O₅/ha. In case of potassium application,

Table 16. Effect of phosphorus and potassium on dry matter accumulation (kg/ha) by pods of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	395.39	523.41	636.96	661.41	554.29	452.31	639.20	722.46	700.24	628.55	423.85	581.31	679.71	680.82	591.42
K ₃₀	567.63	684.73	894.44	794.71	735.38	606.79	695.07	887.15	900.04	772.26	587.21	689.90	890.79	847.37	753.82
K ₆₀	653.67	819.60	1014.42	1038.17	881.46	735.60	846.32	1053.20	1029.78	916.22	694.63	832.96	1033.81	1033.98	898.84
K ₉₀	697.74	803.73	961.23	1023.75	871.61	748.60	868.25	1009.51	1007.48	908.46	723.17	835.99	985.37	1015.61	890.04
Mean	578.61	707.87	876.76	879.51	760.69	635.82	762.21	918.08	909.38	806.37	607.22	735.04	897.42	894.45	
								Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
								S.Ed. ±	18.501	26.165	26.165	37.002	37.002	52.329	74.004
								CD (P=0.05)	37.78	56.43	53.43	NS	NS	106.88	NS

Table 17. Effect of phosphorus and potassium on dry matter accumulation (kg/ha) by plants of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	1167.41	1276.79	1441.73	1435.80	1330.43	1208.14	1322.71	1456.05	1468.39	1363.82	1187.78	1299.75	1448.89	1452.09	1347.13
K ₃₀	1298.76	1476.54	1600.74	1617.28	1498.33	1359.51	1471.11	1639.99	1596.78	1516.85	1329.14	1473.82	1620.37	1607.03	1507.59
K ₆₀	1494.56	1615.55	1894.81	1912.59	1729.38	1511.60	1621.48	1937.77	1971.85	1760.68	1503.08	1618.52	1916.29	1942.22	1745.03
K ₉₀	1492.84	1631.85	1911.11	1921.73	1739.38	1522.22	1616.57	1881.09	1980.74	1750.16	1507.53	1624.21	1896.10	1951.23	1744.77
Mean	1363.39	1500.18	1712.10	1721.85	1574.38	1400.37	1507.97	1728.73	1754.44	1597.88	1381.88	1504.08	1720.41	1738.15	
								Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
								S.Ed. ±	11.744	16.608	16.608	23.487	23.487	33.216	46.974
								CD (P=0.05)	NS	33.91	33.91	NS	NS	67.83	NS

maximum value (2659.52 kg/ha) was observed at 60 kg K_2O /ha, which was statistically comparable to 90 kg K_2O /ha.

Maximum dry matter accumulation (3005.83 kg/ha) was observed at 120 kg P_2O_5 and 60 kg K_2O /ha, when applied in combination.

4.5 SEVERITY OF ANGULAR LEAF SPOT (%)

The pooled analysis of variance (Appendix-II) revealed significant effects of different levels of potassium application on disease severity which were also significantly variable over the years. While different levels of phosphorus, interaction effects of PXY, KXY, PxK and PxKXY were found to be non-significant.

The disease severity was reduced with the increasing levels of potassium (Table 19; Fig.14). Minimum angular leaf spot severity (21.49%) was observed at the highest level of potassium (90 kg K_2O /ha), however, it was at par with 60 kg K_2O /ha. The severity was comparably lesser in 1993 than 1994.

4.6 CHEMICAL STUDIES IN PLANTS

4.6.1 Per cent nitrogen content in pods

The ANOVA of the pooled data on N-content in pods of French bean (Appendix-II) revealed significant influence of various levels of phosphorus, potassium and their interactions. The effects of year, PXY, KXY and PxKXY were found to be non-significant.

TABLE 18. EFFECT OF PHOSPHORUS AND POTASSIUM ON TOTAL DRY MATTER ACCUMULATION (kg/ha) BY CROP OF FRENCH BEAN CV. CONTENDER

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	1607.20	1845.93	2093.01	2129.80	1918.98	1660.45	1961.91	2178.51	2168.63	1992.38	1633.83	1903.92	2135.76	2149.21	1955.68
K ₃₀	1927.10	2156.01	2534.45	2391.66	2252.31	1966.30	2166.18	2527.14	2496.82	2289.11	1946.70	2161.09	2530.80	2444.24	2270.71
K ₆₀	2165.27	2441.09	2952.19	3010.02	2642.14	2247.20	2467.80	2990.97	3001.63	2676.90	2206.23	2454.44	2971.58	3005.83	2659.52
K ₉₀	2219.96	2420.33	2842.32	3004.48	2621.76	2270.82	2484.83	2757.27	2988.21	2625.28	2245.39	2452.58	2799.80	2996.35	2623.53
Mean	1979.88	2215.84	2605.49	2633.99	2358.80	2036.19	2270.18	2613.47	2663.82	2395.92	2008.04	2243.01	2609.48	2648.91	
								Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
								S.Ed.±	23.190	32.796	32.796	46.381	46.381	65.592	92.761
								CD(P=0.05)	NS	66.97	66.97	NS	NS	133.94	NS

Table 19. Effect of phosphorus and potassium on "severity of angular leaf spot (%) of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	25.25	25.93	24.77	23.80	24.94	27.32	26.38	26.45	25.07	26.30	26.28	26.16	25.61	24.43	25.62
K ₃₀	23.00	23.10	20.82	23.43	22.59	24.68	24.17	22.87	23.13	23.71	23.84	23.63	21.84	23.28	23.15
K ₆₀	21.98	21.22	19.68	21.87	21.19	23.80	22.35	20.02	23.32	22.37	22.89	21.78	19.85	22.59	21.78
K ₉₀	21.37	20.48	19.78	22.47	21.03	22.30	22.25	21.03	22.20	21.95	21.83	21.37	20.41	22.33	21.49
Mean	22.90	22.68	21.26	22.89	22.43	24.53	23.79	22.59	23.43	23.58	23.71	23.24	21.93	23.16	
								Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
								S.Ed.±	0.554	0.784	0.784	1.108	1.108	1.567	2.217
								CD(P=0.05)	1.13	NS	1.60	NS	NS	NS	NS

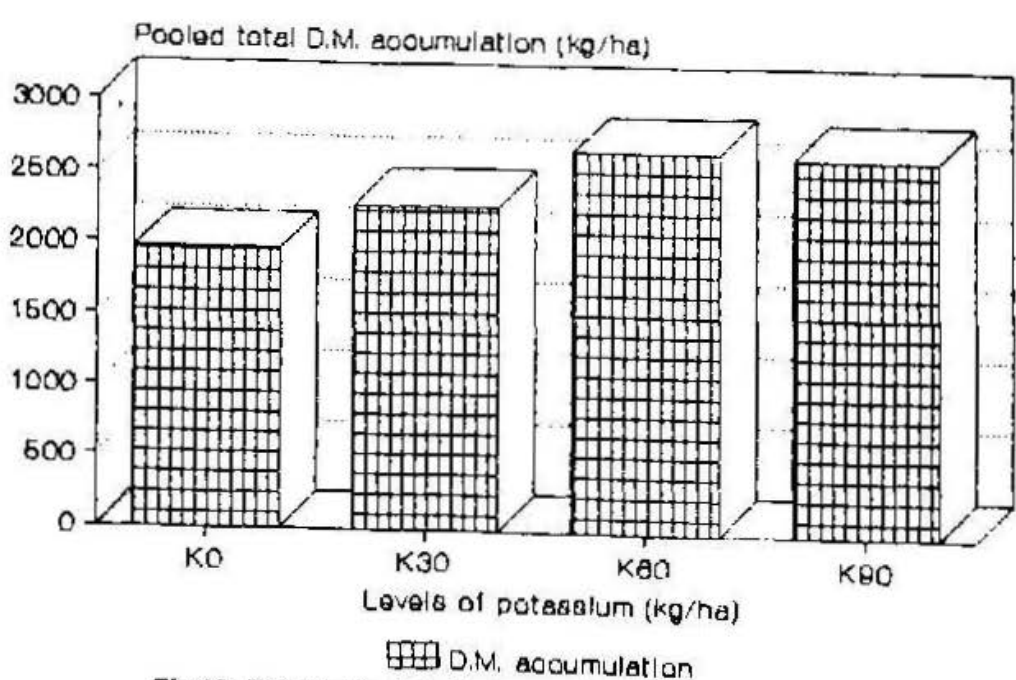
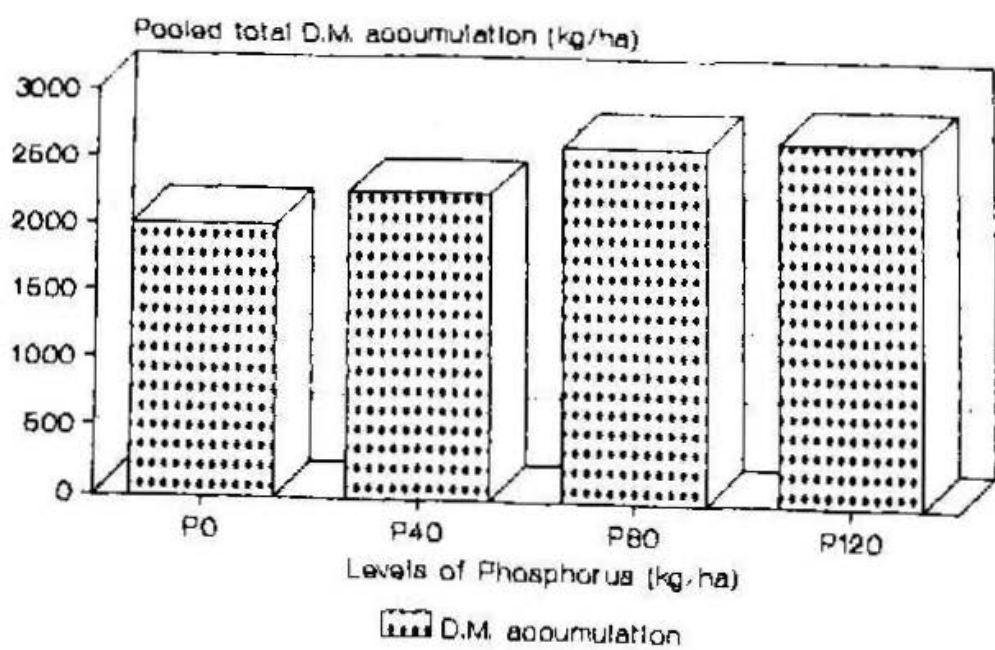


Fig-10. Effect of phosphorus and potassium on dry matter accumulation(kg/ha) by crop of French bean cv. Contender

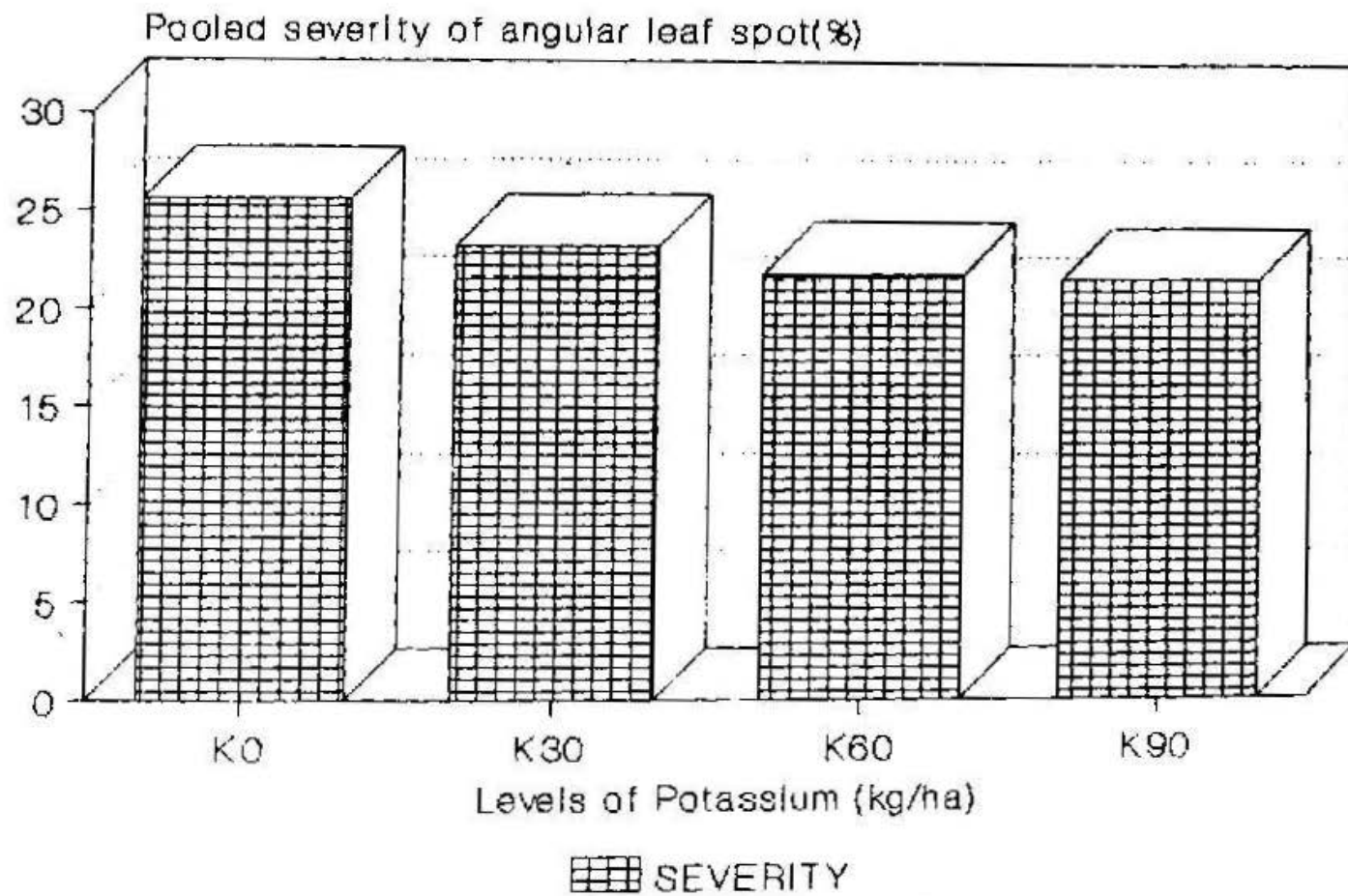


Fig:14. Effect of potassium on severity of angular leaf spot (%) of French bean cv. Contender

The concentration of nitrogen in the pods was significantly increased with the successive increase of phosphorus levels and maximum (3.37%) nitrogen content was recorded at P₁₂₀, which was at par with P₈₀ (Table 20). In case of potassium application, maximum N-content was observed at K₆₀, however, declined at higher potassium application (K₉₀). Combined application of P and K, also significantly increased N-content in pods and maximum (3.40%) concentration was recorded at P₈₀ x K₆₀.

4.6.2 Per cent phosphorus content in pods

The pooled analysis of variance (Appendix-II) indicated significant differences for P and K & PxK treatments. On the other hand, the effects of year, PxY, KxY and PxKxY were found to be non-significant.

The highest P concentration (0.44%) was recorded at 120 kg P₂O₅/ha, which was at par with 80 kg P₂O₅/ha (Table 21). In case of potassium application, maximum P-content (0.40%) was observed @ 90 kg K₂O/ha, however, it was showing non-significant differences with K₆₀ and K₃₀. Significant increase in P concentration of bean pod was observed with the combined application of phosphorus and potassium, the highest being 0.47 per cent at P₁₂₀ x K₉₀.

4.6.3 Per cent K-content in pods

The ANOVA of the pooled data (Appendix III) have shown

significant effects of phosphorus, potassium, year and PxK interaction on K-content in the pods. However, the interaction effects of PxY, KxY and PxKxY were found to be non-significant.

Application of phosphorus @ 120 kg/ha, produced highest (2.55%) K-content in pods, which was at par with P₈₀. K-content was significantly increased with the successive levels of potassium application and the maximum (2.56%) concentration was observed at 90 kg K₂O/ha, which was non-significant with K₆₀.

The concentration of K in pods also increased with combined application of P and K and maximum (2.75%) value was observed at 120 kg P₂O₅ and 90 kg K₂O per hectare, respectively. In 1994, K concentration in pods was more as compared to 1993 (Table 22).

4.6.4 Per cent Nitrogen content in bean plants

The pooled analysis of variance for N-content in bean plants at second picking stage of the crop (Appendix-II) showed significant effects of phosphorus and potassium application. While year and interaction effects of PxY, KxY, PxK, and PxKxY were found to be non-significant (Table 23).

Content of Nitrogen in plants significantly increased with the increasing doses of phosphorus and highest N concentration (2.67%) was recorded at 120 kg P₂O₅/ha, which

was at par with 80 kg P_2O_5 /ha. In case of potassium application, maximum N-content (2.67%) in plants was observed at 60 kg K_2O /ha, but thereafter, it showed a declining trend at higher level (90 kg K_2O).

4.6.5 Per cent phosphorus content in bean plants

The corresponding analysis of variance (Appendix-II) showed significant differences due to the application of phosphorus and potassium, while years effect and interaction effects of $P \times K$, $P \times Y$, $K \times Y$ and $P \times K \times Y$ were found to be non-significant.

The pooled data revealed significant increase in the phosphorus treatments and the highest P-content (0.43%) was recorded at P_{120} , which was at par with P_{80} . Similar trend was observed in case of potassium application, where maximum (0.40%) concentration of P in plants was recorded at 90 kg K_2O /ha, however, it was at par with 60 kg K_2O /ha (Table 24).

4.6.6 Per cent potassium content in plants

The pooled analysis of variance (Appendix-II) on pooled data computed significant effects of phosphorus and potassium application either alone or in combination on K-content in bean plants. However, year and $P \times Y$, $K \times Y$, $P \times K \times Y$ effects were found to be non-significant.

Treatments	1993					1994					Pooled						
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean		
K ₀	1.80	2.01	2.18	2.20	2.05	1.87	2.09	2.25	2.28	2.12	1.84	2.05	2.22	2.24	2.09		
K ₃₀	2.08	2.22	2.42	2.43	2.29	2.15	2.31	2.49	2.50	2.36	2.12	2.27	2.46	2.47	2.33		
K ₆₀	2.21	2.44	2.67	2.68	2.50	2.29	2.52	2.76	2.78	2.59	2.25	2.48	2.72	2.73	2.54		
K ₉₀	2.23	2.45	2.69	2.70	2.52	2.31	2.53	2.77	2.79	2.60	2.27	2.49	2.73	2.75	2.56		
Mean	2.08	2.28	2.49	2.50	2.34	2.16	2.36	2.57	2.59	2.42	2.12	2.32	2.53	2.55			
										Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
										S.Ed. ±	0.016	0.023	0.023	0.033	0.033	0.046	0.066
										CD (p=0.05)	0.03	0.05	0.05	NS	NS	0.09	NS

Table 23. Effect of phosphorus and potassium on per cent N-content in plants at 2nd picking stage of French bean cv. Contender (dry weight basis)

Treatments	1993					1994					Pooled						
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean		
K ₀	2.43	2.48	2.51	2.58	2.50	2.44	2.51	2.54	2.58	2.51	2.44	2.50	2.52	2.58	2.51		
K ₃₀	2.47	2.55	2.66	2.65	2.58	2.49	2.57	2.66	2.67	2.60	2.48	2.55	2.66	2.66	2.59		
K ₆₀	2.56	2.64	2.72	2.74	2.67	2.56	2.62	2.76	2.77	2.68	2.56	2.63	2.74	2.75	2.67		
K ₉₀	2.49	2.58	2.67	2.67	2.60	2.52	2.60	2.68	2.68	2.62	2.51	2.59	2.68	2.68	2.61		
Mean	2.49	2.56	2.64	2.66	2.59	2.50	2.58	2.66	2.68	2.60	2.50	2.57	2.65	2.67			
										Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
										S.Ed. ±	0.016	0.017	0.017	0.024	0.024	0.040	0.048
										CD (p=0.05)	NS	0.04	0.04	NS	NS	NS	NS

An inquisition of the pooled data (Table 25) reveals that the K-content significantly increased with the increasing levels of phosphorus application. The maximum K-content (2.50%) in plants was observed at 120 kg P_2O_5 /ha, which was at par with 80 kg P_2O_5 /ha. Similar trend was observed in case of potassium application, where maximum K concentration (2.53%) was recorded at 90 kg K_2O /ha, which was exhibiting non-significant differences with 60 kg K_2O /ha.

Interaction effects of PxK on potassium content in plants was significant and the highest value (2.72%) was recorded at 120 kg P_2O_5 along with 90 kg K_2O /ha.

4.7 NPK UPTAKE

4.7.1 Nitrogen uptake by pods (kg/ha)

Analysis of variance (Appendix-II) indicated significant effects of phosphorus, potassium and their interactions on N-uptake by pods. However, effects of year, PxY, KxY and P_XK_XY were found to be non-significant.

The results presented in Table 26 showed that maximum N-uptake (30.03 kg/ha) was recorded at 120 kg P_2O_5 application, which differed non-significantly from 80 kg P_2O_5 /ha. potassium application at 60 kg/ha recorded the highest (30.21 kg/ha) N-uptake, which was non-significantly higher than 90 kg K_2O /ha (29.11 kg/ha). The highest value of 35.11 kg/ha was observed at 80 kg P_2O_5 coupled with 60 kg K_2O /ha.

Table 24. Effect of phosphorus and potassium on per cent P-content in plants at second picking stage of French bean cv. Contender (dry weight basis).

Treatments	1993					1994					Pooled							
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean			
K ₀	0.26	0.32	0.36	0.39	0.33	0.29	0.32	0.36	0.39	0.34	0.28	0.32	0.36	0.39	0.34			
K ₃₀	0.28	0.36	0.39	0.41	0.36	0.31	0.35	0.40	0.43	0.37	0.30	0.35	0.39	0.42	0.37			
K ₆₀	0.31	0.38	0.43	0.44	0.39	0.34	0.37	0.43	0.45	0.40	0.33	0.38	0.43	0.44	0.39			
K ₉₀	0.33	0.39	0.44	0.45	0.40	0.35	0.38	0.44	0.46	0.41	0.34	0.39	0.44	0.45	0.40			
Mean	0.30	0.36	0.40	0.42	0.37	0.32	0.36	0.41	0.43	0.38	0.31	0.36	0.41	0.43				
											Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
											S.Ed. ±	0.007	0.009	0.009	0.014	0.014	0.019	0.028
											CD (P=0.05)	NS	0.02	0.02	NS	NS	NS	NS

Table 25. Effect of phosphorus and potassium on per cent K-content in plants at second picking stage of French bean cv. Contender (dry weight basis)

Treatments	1993					1994					Pooled							
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean			
K ₀	1.76	1.98	2.13	2.16	2.01	1.77	2.01	2.13	2.17	2.02	1.76	2.00	2.13	2.17	2.01			
K ₃₀	2.11	2.18	2.29	2.40	2.25	2.13	2.25	2.40	2.39	2.29	2.12	2.22	2.35	2.40	2.27			
K ₆₀	2.23	2.39	2.67	2.69	2.50	2.22	2.42	2.72	2.71	2.52	2.23	2.41	2.70	2.70	2.51			
K ₉₀	2.25	2.44	2.68	2.70	2.52	2.24	2.45	2.74	2.73	2.54	2.25	2.44	2.71	2.72	2.53			
Mean	2.09	2.25	2.45	2.49	2.32	2.09	2.28	2.50	2.50	2.34	2.09	2.27	2.47	2.50				
											Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
											S.Ed. ±	0.014	0.020	0.020	0.028	0.028	0.040	0.057
											CD (P=0.05)	NS	0.04	0.04	NS	NS	0.08	NS

4.7.2 Phosphorus uptake by pods (kg/ha)

The ANOVA of pooled data in Appendix-II revealed significant effects of phosphorus, potassium and P x K interaction on P-uptake by bean pods, while the effects of year, P x Y, K x Y and P x K x Y were found to be non-significant.

The pooled data (Table 27) revealed that with the increase in phosphorus fertilization, the P-uptake by pods was also significantly increased. Maximum P-uptake (4.00 kg/ha) was observed at 120 kg P₂O₅ per hectare, which was at par with P₈₀. Similar trend was observed in case of potassium application, where, highest P uptake (3.63 kg/ha) was recorded at 90 kg K₂O per hectare, which was non-significant with 60 kg K₂O/ha.

In case of combined applications of phosphorus and potassium, the maximum P-uptake (4.73 kg/ha) was at P₁₂₀ x K₆₀ and P₁₂₀ x K₉₀.

4.7.3 Potassium uptake by pods (kg/ha)

A perusal of the ANOVA (Appendix-II) revealed significant effects of phosphorus, potassium, P x K interactions and years on K-uptake (kg/ha) by pods of French bean while interaction effects of P x Y, K x Y and P x K x Y were found to be non-significant.

The pooled data in Table 28 extrapolated increased K-uptake by the pods with the successive increase in P application. Maximum K-uptake (23.06 kg/ha) was recorded at P₁₂₀, which was at par with 80 kg P₂O₅/ha. In case of potassium application, maximum K-uptake was recorded @ 60 kg K₂O/ha (23.11 kg/ha), which was non-significant with 90 kg K₂O/ha. Agro-climatic conditions in 1994 were congenial for K-uptake as compared to 1993.

4.7.4 Nitrogen uptake by bean plants (kg/ha)

The analysis of variance of N-uptake by bean plants (Appendix-II) depicted significant differences among phosphorus and potassium, either alone or in combination, treatments. Year effects were also found to be significant, while P_xK_xY, P_xY or K_xY interaction effects were non-significant.

An inquisition of the pooled data (Table 29) revealed significant increase in N-uptake with the successive increase in the levels of phosphorus. The highest N-uptake (46.46 kg/ha) was observed at P₁₂₀, which was showing statistical proximity with P₈₀. In case of potassium application, maximum N-uptake (46.76 kg/ha) was recorded at 60 kg K₂O/ha, which was at par with 90 kg K₂O/ha.

Combined application of phosphorus and potassium gave highest N-uptake (53.44) at P₁₂₀ K₆₀.

Table 28. Effect of phosphorus and potassium on "K-uptake" (kg/ha) by pods of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	7.08	10.50	13.98	14.55	11.53	8.87	13.27	16.27	15.87	13.57	7.96	11.86	15.12	15.21	12.55
K ₃₀	11.81	15.22	21.67	19.44	17.04	13.01	16.07	22.12	22.47	18.42	12.41	15.65	21.89	20.96	17.73
K ₆₀	14.46	19.88	27.10	27.77	22.30	16.90	21.12	29.06	28.63	23.92	15.68	20.50	28.08	28.20	23.11
K ₉₀	15.61	19.69	25.97	27.62	22.22	16.39	21.90	27.93	28.10	23.58	15.98	20.80	26.95	27.86	22.90
Mean	12.24	16.32	22.18	22.35	18.77	13.79	18.09	23.84	23.77	19.87	13.01	17.21	23.01	23.06	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.486	0.687	0.687	0.972	0.972	1.375	1.945
CD (P=0.05)	0.99	1.40	1.40	NS	NS	2.81	NS

Table 29. Effect of phosphorus and potassium on "N-uptake" (kg/ha) by plants at 2nd picking stage of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	28.36	31.99	36.19	37.03	33.39	29.18	33.19	36.93	37.94	34.31	28.77	32.59	36.56	37.49	33.85
K ₃₀	32.08	37.69	42.52	42.80	38.77	33.90	37.51	43.71	42.61	39.43	32.99	27.60	43.11	42.71	39.10
K ₆₀	38.30	42.61	51.61	52.33	46.21	38.69	42.48	53.49	54.46	47.30	38.50	42.55	52.55	53.44	46.76
K ₉₀	37.23	42.10	51.02	51.25	45.42	38.37	42.03	52.11	53.15	46.42	37.80	42.11	51.57	52.20	45.90
Mean	33.99	38.62	45.34	45.85	40.95	35.03	38.80	46.56	47.06	41.87	34.51	38.71	45.95	46.46	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.359	0.507	0.507	0.717	0.717	1.01	1.434
CD (P=0.05)	0.73	1.03	1.03	NS	NS	2.07	NS

4.7.5 Phosphorus uptake by bean plants (kg/ha)

The analysis of variance (Appendix-II) indicated significant effects of phosphorus and potassium application and interaction effects of PxK on P-uptake by plants (leaves+stem) at second picking stage. However, the effects of year and PxKxY were found to be non-significant.

A cursory glance of the pooled data (Table 30) revealed that P-uptake was maximum at 120 kg P₂O₅/ha which was declining statistically with the respective lower dose. Similar trend was observed in case of potassium application, where highest P-uptake (7.19 kg/ha) was recorded at 90 kg K₂O/ha. Both the doses of P and K, when applied in conjugation, also resulted in maximum (8.89 kg/ha) P-uptake.

4.7.6 Potassium uptake by bean plants (kg/ha)

It is evident from the analysis of variance (Appendix-II) that the K-uptake (kg/ha) by bean plants (leaves + stem) at second picking stage, was significantly influenced with the application of phosphorus and potassium, either alone or in combination. However, the effects of year, PxY, KxY and PxKxY were found to be non-significant.

An inquisition of the pooled data (Table 31) showed increasing trend of K-uptake with the increasing levels of phosphorus and highest value (43.82 kg/ha) was recorded at 120 kg P₂O₅/ha, which was at par with P₈₀. Similar trend was

observed in case of potassium application and maximum K-uptake (44.90 kg/ha) by plants was recorded at K₉₀, which was at par with K₆₀.

The K-uptake at second picking stage increased significantly with the combined application of phosphorus and potassium and highest K-uptake (53.09 kg/ha) was recorded at 80 kg P₂O₅ coupled with 90 kg K₂O/ha.

4.7.7 Total removal of nitrogen by the crop (kg/ha)

The removal of N by bean crop (pods+plants) was significantly influenced with the application of phosphorus and potassium, either alone or in combination. Year effects were also found to be significant while PxY, KxY and PxKxY was non-significant (Appendix-II).

An examination of the pooled data (Table 32; Fig.11) indicated that the removal of N by bean crop increased significantly with the increasing levels of phosphorus and maximum removal i.e. 76.49 kg/ha was observed at 120 kg P₂O₅/ha, which was at par with P₈₀. The highest removal of nitrogen (76.97 kg/ha) by the crop was observed, when potassium was applied @ 60 kg K₂O/ha. At higher level (i.e. 90 kg K₂O/ha) of potassium application there was decrease in N removal by the crop, although both the doses were at par. In 1994, agroclimatic conditions were congenial for more nitrogen removal as compared to 1993.

Table 32. Effect of phosphorus and potassium on "Total removal of N" (kg/ha) by crop of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	40.93	48.71	60.61	59.47	52.43	43.74	53.88	60.76	61.58	54.99	42.33	51.29	60.67	60.53	53.71
K ₃₀	50.34	60.32	72.87	69.31	63.21	55.41	60.23	73.62	72.83	65.52	52.87	60.28	73.25	71.07	64.37
K ₆₀	59.76	70.19	86.02	87.44	75.85	62.77	70.91	89.29	89.40	78.09	61.27	70.55	87.66	88.42	76.97
K ₉₀	60.08	68.39	83.62	85.26	74.34	62.82	70.66	81.11	86.60	75.30	61.46	69.53	82.37	85.93	74.82
Mean	52.78	61.90	75.78	75.37	66.46	56.19	63.92	76.17	77.60	68.48	54.48	62.91	75.99	76.49	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.803	1.136	1.136	1.606	1.606	2.271	3.212
CD (P=0.05)	1.64	2.32	2.32	NS	NS	4.63	NS

Table 33. Effect of phosphorus and potassium on "Total Removal of P" (kg/ha) by crop of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	3.97	5.73	7.66	8.29	6.41	4.62	6.32	7.83	8.65	6.86	4.30	6.03	7.74	8.47	6.64
K ₃₀	5.16	7.67	9.69	10.06	8.14	5.89	7.64	10.01	10.80	8.59	5.53	7.66	9.85	10.43	8.37
K ₆₀	6.59	9.25	12.51	13.10	10.36	7.29	9.20	13.07	13.73	10.82	6.94	9.22	12.79	13.42	10.59
K ₉₀	7.04	9.42	12.63	13.31	10.60	7.45	9.53	12.94	13.82	10.94	7.25	9.47	12.78	13.57	10.77
Mean	5.69	8.02	10.62	11.19	8.88	6.31	8.17	10.96	11.75	9.30	6.00	8.10	10.79	11.47	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.Ed.±	0.195	0.275	0.275	0.389	0.389	0.550	0.770
CD (P=0.05)	0.4	0.56	0.56	NS	NS	1.12	NS

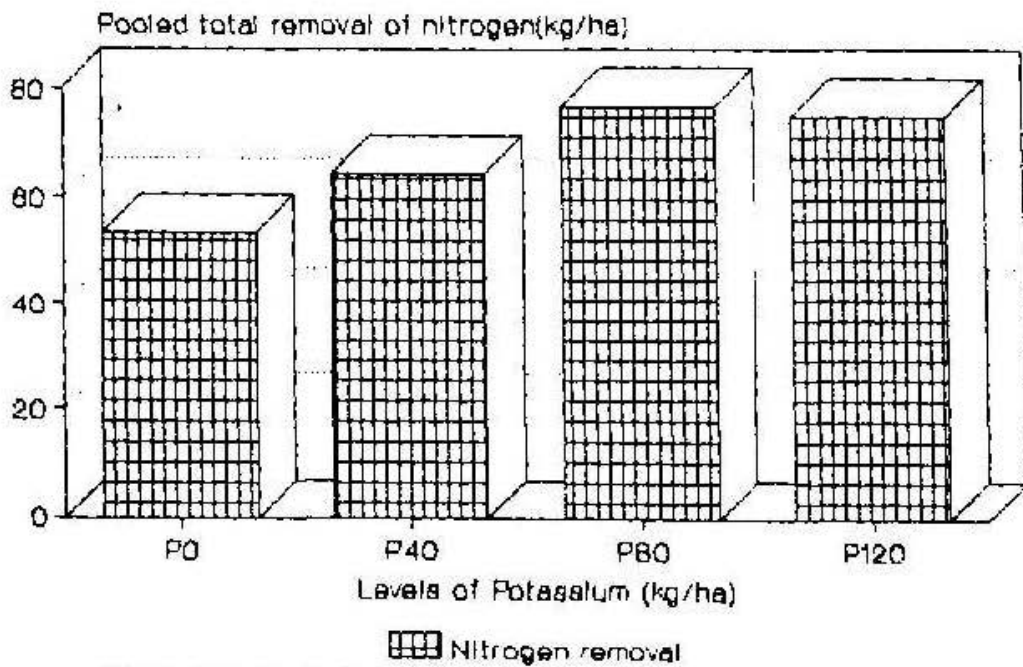
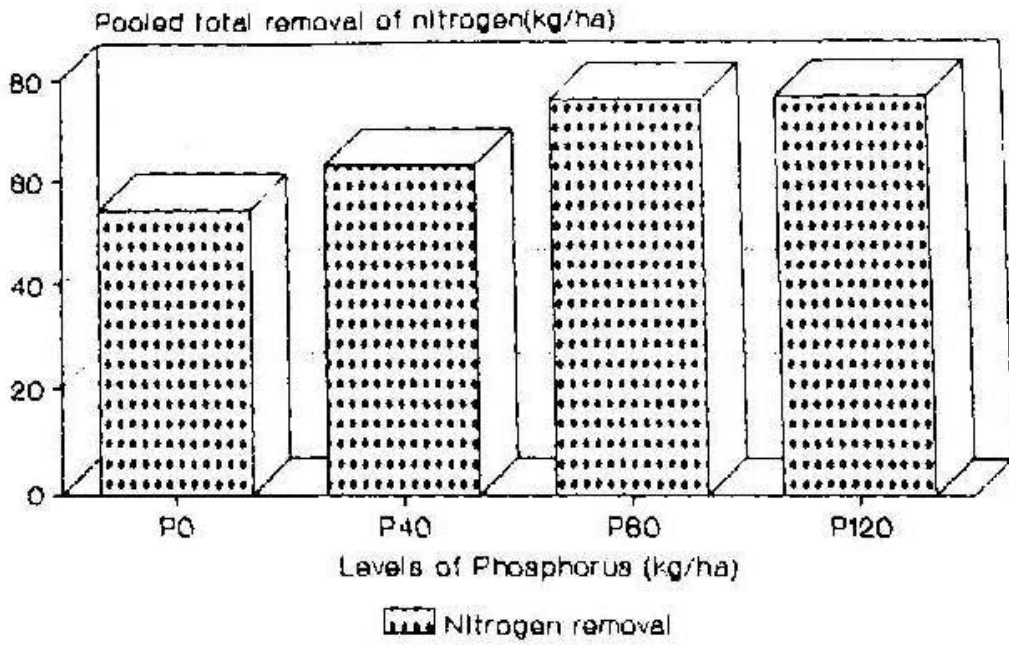


Fig:11. Effect of phosphorus and potassium on total removal of nitrogen(kg/ha) by crop of French bean cv. Contender

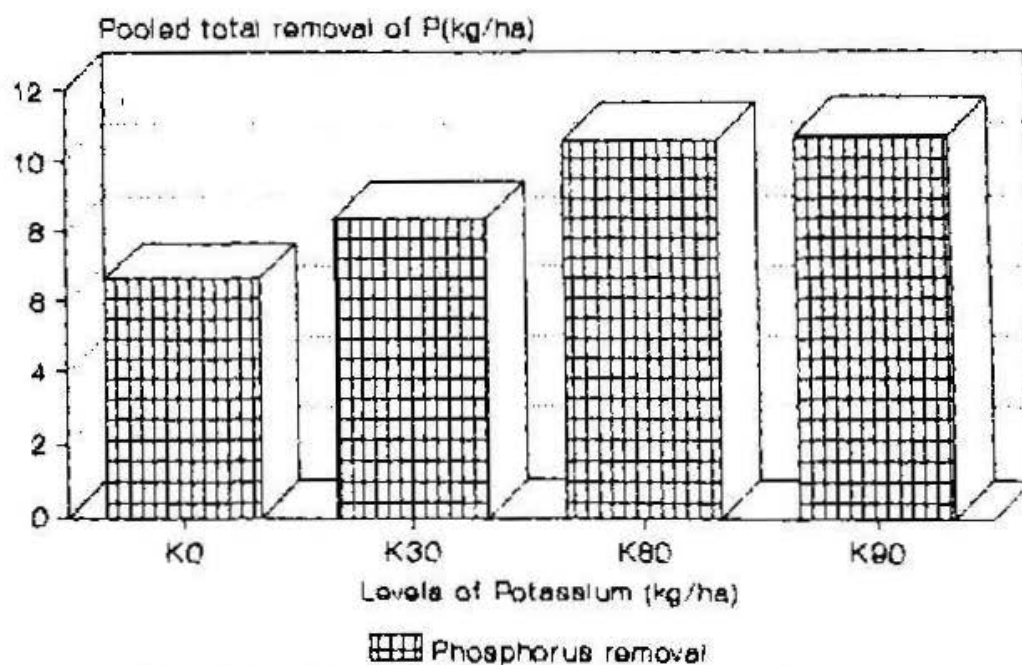
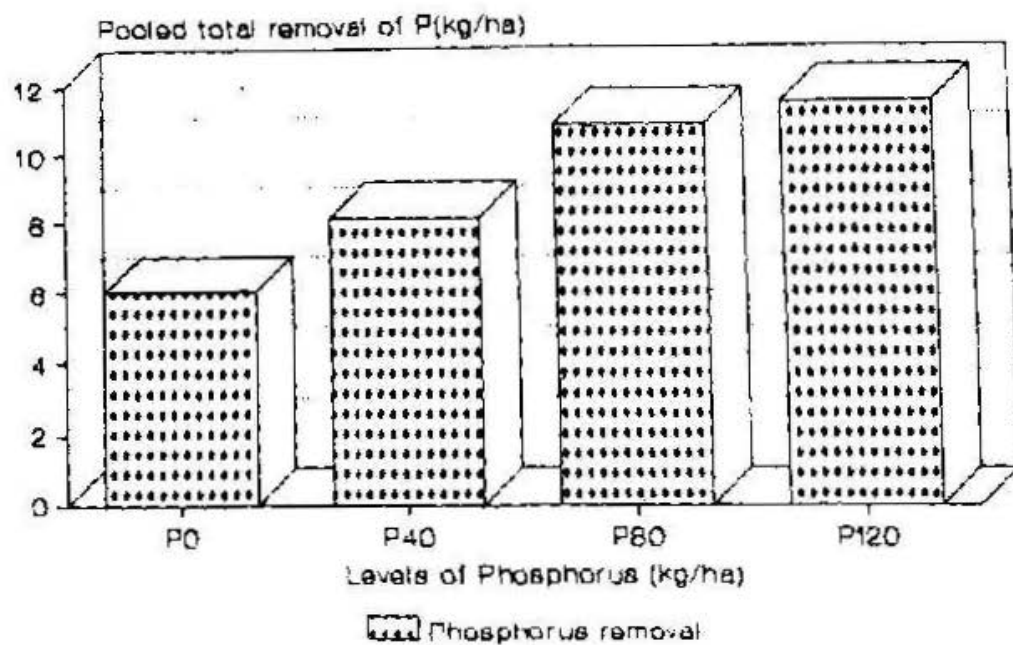


Fig.12. Effect of phosphorus and potassium on total removal of phosphorus(kg/ha) by crop of French bean cv. Contender

Maximum nitrogen-uptake by the crop (88.42 kg/ha) was recorded at 120 kg P_2O_5 and 60 kg K_2O /ha, when applied in combination.

4.7.8 Total removal of phosphorus by bean crop (kg/ha)

Significant effects of phosphorus, potassium, P x K interaction and year on total removal of P by the crop, and non-significant effects of P x Y, K x Y and P x K x Y revealed through the analysis of variance (Appendix-II).

The highest removal of P (11.47 kg/ha) by the crop was recorded with the application of 120 kg P_2O_5 /ha, which was at par with P_{80} . Similar trend was observed in case of potassium application and the highest removal of P by crop (10.77 kg/ha) was recorded at 90 kg K_2O /ha, which was at par with 60 kg K_2O /ha. In 1994, climatic factors were favourable for total removal of P by the crop.

In case of P x K application, maximum removal of P (13.57 kg/ha) was observed with the application of 120 kg P_2O_5 and 90 kg K_2O per hectare (Table 33; Fig.12).

4.7.9 Total removal of potassium by bean crop (kg/ha)

The analysis of pooled data pertaining to the effects of phosphorus, potassium, P x K interaction and year, showed significant differences, while P x Y, K x Y and P x K x Y were having non-significant effects (Appendix-II).

An inquisition of the data, presented in Table 34 and Figure 13, revealed that the total removal of K by the crop (pods + plants) significantly increased with the successive increasing levels of phosphorus and maximum value (66.62 kg/ha) was recorded at 120 kg P_2O_5 /ha, which was at par with P_{80} . In case of potassium application, maximum K-removal by crop (67.63 kg/ha) was observed at 90 kg K_2O /ha, however, it was non-significant with K_{60} . Agro-climatic conditions were congenial for K-removal by the crop in 1994 as compared to 1993.

Maximum removal of K (80.67 kg/ha) was obtained at combined application of 120 kg P_2O_5 and 60 kg K_2O /ha. However, it was at par with $P_{80} \times K_{90}$, $P_{120} \times K_{90}$ and $P_{80} \times K_{60}$.

4.8 SOIL CHEMICAL ANALYSIS

Available NPK status in soil after harvesting

An analysis of variance (Appendix-II) showed significant effect of phosphorus, potassium and year on the available NPK (kg/ha) status of soil after harvesting the bean crop. The interaction effects of $P \times Y$, $K \times Y$, $P \times K$ and $P \times K \times Y$ were found to be non-significant.

4.8.1 Available nitrogen (kg/ha)

Table 35 revealed that available N content in soil decreased significantly with the increase in dose from P_0 (410.03 kg/ha) to P_{120} (402.88 kg/ha). It was at par with P_{80}

Table 34. Effect of phosphorus and potassium on "Total Removal of K" (kg/ha) by crop of French bean cv. Contender

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	27.62	35.76	44.69	45.56	38.40	30.19	39.85	47.36	47.74	41.29	28.91	37.81	46.03	46.65	39.85
K ₃₀	39.21	47.40	58.42	58.26	50.82	41.96	49.18	61.50	60.40	53.26	40.59	48.29	59.96	59.33	52.04
K ₆₀	47.74	58.51	77.74	79.22	65.80	50.44	60.41	81.76	82.13	68.69	49.09	59.46	79.75	80.67	67.24
K ₉₀	49.20	59.46	80.58	79.57	67.21	50.44	61.42	80.14	80.11	68.05	49.82	60.49	80.36	79.84	67.63
Mean	40.94	50.29	65.36	65.65	55.56	43.26	52.74	67.69	67.59	57.82	42.10	51.51	66.52	66.62	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.E.d. ±	0.686	0.969	0.969	1.370	1.370	1.939	2.743
CD (p=0.05)	1.40	1.98	1.98	NS	NS	3.96	NS

Table 35. Available nitrogen in soil (kg/ha) after harvest

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	411.73	411.43	409.60	406.77	409.88	415.20	414.50	412.00	411.30	413.25	413.47	412.97	410.80	409.03	411.57
K ₃₀	409.27	410.10	405.70	401.60	406.67	413.10	410.10	407.20	406.40	409.20	411.18	410.10	406.45	404.00	407.93
K ₆₀	405.77	406.93	403.13	400.33	404.04	412.30	408.20	404.10	400.20	406.20	409.03	407.57	403.62	400.27	405.12
K ₉₀	404.73	402.73	400.33	397.12	401.24	408.10	406.10	403.40	399.30	404.22	406.42	404.42	401.87	398.23	402.73
Mean	407.88	407.80	404.69	401.47	405.45	412.18	409.73	406.68	404.30	408.22	410.03	408.76	405.68	402.88	

Pooled	Y	P	K	PxY	KxY	PxK	PxKxY
S.E.d. ±	0.809	1.144	1.144	1.618	1.618	2.289	3.237
CD (p=0.05)	1.65	2.34	2.34	NS	NS	NS	NS

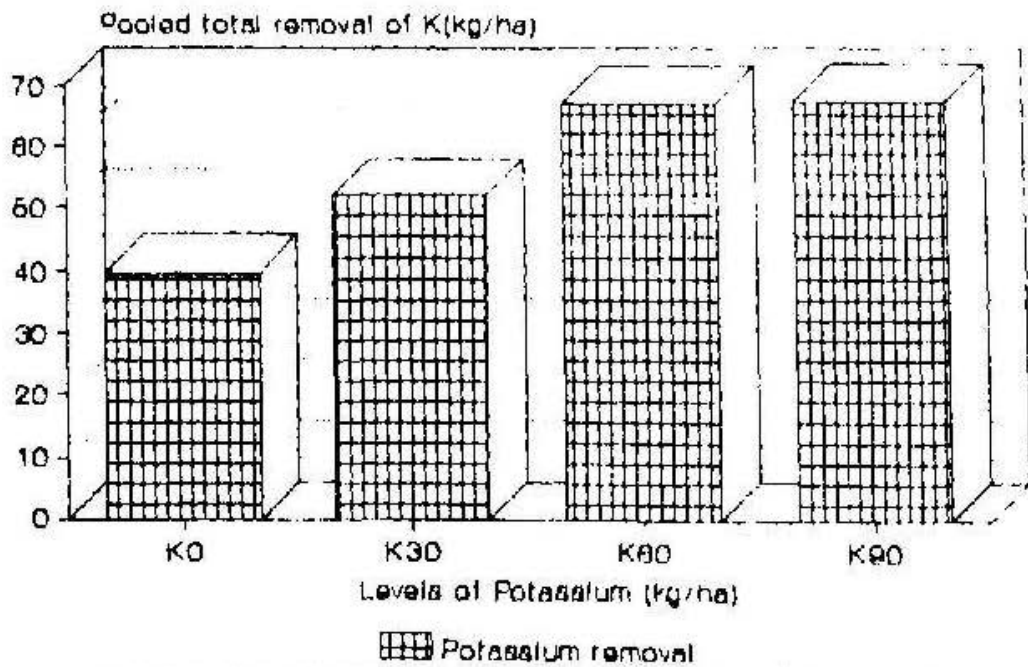
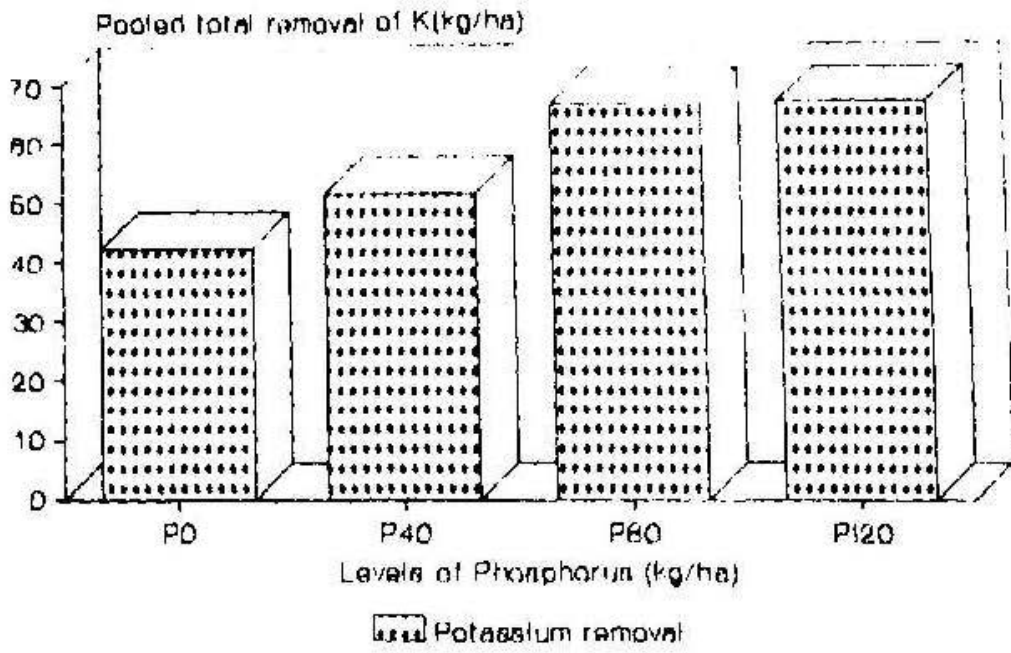


Fig.13. Effect of phosphorus and potassium on total removal of potassium(kg/ha) by crop of French bean cv. Contender

and P₁₂₀. Similar trend was observed in case of potassium application and minimum available N (402.13 kg/ha) was recorded at 90 kg K₂O per hectare which was at par with K₆₀. In 1994, available N in soil was more as compared to 1993.

4.8.2 Available phosphorus (kg/ha)

A perusal of the pooled data (Table 36) revealed that available P content in soil increased significantly with the increase in levels of phosphorus and maximum value was recorded at P₁₂₀ (51.44 kg/ha), which was at par with P₈₀. Application of potassium, however, recorded reverse effects by showing a decrease in available P content of soil with an increase in potassium levels. Available phosphorus content in soil after harvesting the crop was higher during 1994 as compared to 1993.

4.8.3 Available potassium (kg/ha)

The observations recorded on this attribute indicated significant differences for phosphorus and potassium application (Table 37). Available potassium reduced with the higher dose of phosphorus, being maximum at 120 kg P₂O₅. Maximum available potassium content (265.05 kg/ha) was recorded with 90 kg K₂O/ha, which was at par with K₆₀. In 1993, available K in soil was higher than in 1994.

Table 35. Available phosphorus in soil (kg/ha) after harvest

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	39.80	46.10	51.30	53.10	47.58	41.83	48.30	54.27	55.10	49.88	40.82	47.20	52.78	54.10	48.73
K ₃₀	37.70	43.90	50.10	51.90	45.90	39.70	45.90	52.30	52.90	47.70	38.70	44.90	51.20	52.40	46.80
K ₆₀	36.10	42.10	49.80	49.10	44.28	37.90	44.80	51.80	50.70	46.23	37.00	43.30	50.80	49.90	45.25
K ₉₀	35.40	41.60	49.20	49.50	43.93	37.10	44.10	51.20	49.23	45.41	36.25	42.85	50.20	49.37	44.67
Mean	37.25	43.43	50.10	50.90	45.42	39.13	45.70	52.39	51.98	47.30	38.19	44.56	51.25	51.44	
							Pooled	Y	P	K	PxY	KxY	PxK	PxKxY	
							S.Ed.±	0.409	0.579	0.579	0.819	0.819	1.158	1.638	
							CD _(P=0.05)	0.84	1.18	1.18	NS	NS	NS	NS	

Table 37. Available potassium in soil (kg/ha) after harvest

Treatments	1993					1994					Pooled				
	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean	P ₀	P ₄₀	P ₈₀	P ₁₂₀	Mean
K ₀	252.40	250.20	249.50	248.30	250.10	250.40	245.20	244.50	246.30	246.60	251.40	247.70	247.00	247.30	248.35
K ₃₀	259.80	260.10	258.40	257.10	258.85	255.80	256.10	254.40	254.10	255.10	257.80	258.10	256.40	255.60	256.98
K ₆₀	266.10	263.70	262.90	262.80	263.88	266.10	260.70	254.90	256.80	259.63	266.10	262.20	258.90	259.80	261.75
K ₉₀	267.20	266.90	266.00	265.10	266.30	268.20	262.90	264.00	260.10	263.80	267.70	264.90	265.00	262.60	265.05
Mean	261.38	260.23	259.20	258.33	259.78	260.13	256.23	254.45	254.33	256.28	260.75	258.23	256.83	256.33	
							Pooled	Y	P	K	PxY	KxY	PxK	PxKxY	
							S.Ed.±	0.579	0.819	0.819	1.159	1.159	1.639	2.318	
							CD _(P=0.05)	1.18	1.67	1.67	NS	NS	NS	NS	

4.9 QUADRATIC PRODUCTION FUNCTION FOR PHOSPHORUS AND POTASSIUM

Quadratic equations fitted to the pooled data of green pod yield, generated the response curves for P and K which have been graphically represented in Fig 15 and 16.

The response curve (Table 38) was found to be linear. It revealed the optimum dose of 108.98 kg P_2O_5 /ha with an expected yield of 9970.52 kg/ha. The dose can vary from 80 kg P_2O_5 to 117.19 kg P_2O_5 per hectare and maximum expected yield can be 9982.84 kg/ha.

The optimum level of potassium was 76.93 kg K_2O per hectare with an expected green pod yield of 10021.93 kg/ha. Maximum potassium application rate could be 78.41 kg K_2O per hectare with a yield potential of 10022.59 kg/ha.

4.10 ECONOMICS

The economics of 16 phosphorus and potassium treatment combinations for Contender variety of French bean were worked out for marketable green pod yield on the pooled data and are presented in Table 39 and Appendix-III.

Application of 80 kg P_2O_5 in conjugation with 60 kg K_2O /ha gave the maximum net returns to the tune of Rs.34911.18/ha. These returns were higher by Rs.26328.3 over the P_0K_0 treatment. Higher costs of P and K fertilizers reduced the gains at P_{120} and K_{90} .

Table 38. Response functions (Pooled data)

Nutrient	Regression equation	Optimum level (kg/ha)	Expected green pod yield (kg/ha)	Maximum level (kg/ha)	Expected green pod yield (kg/ha)
P	$Y=7435.75+43.468P-0.18546P^2$	108.98	9970.52	117.19	9982.84
K	$Y=7235.6 +71.087K-0.4533 K^2$	76.93	10021.93	78.41	10022.59

Price per unit of phosphorus = Rs.16.00 per kg
 Price per unit of potassium = Rs. 7.07 per kg
 Price rate of French bean pods= Rs. 5.25 per kg

Fig:15.RESPONSE CURVE
Phosphorus Vs Yield

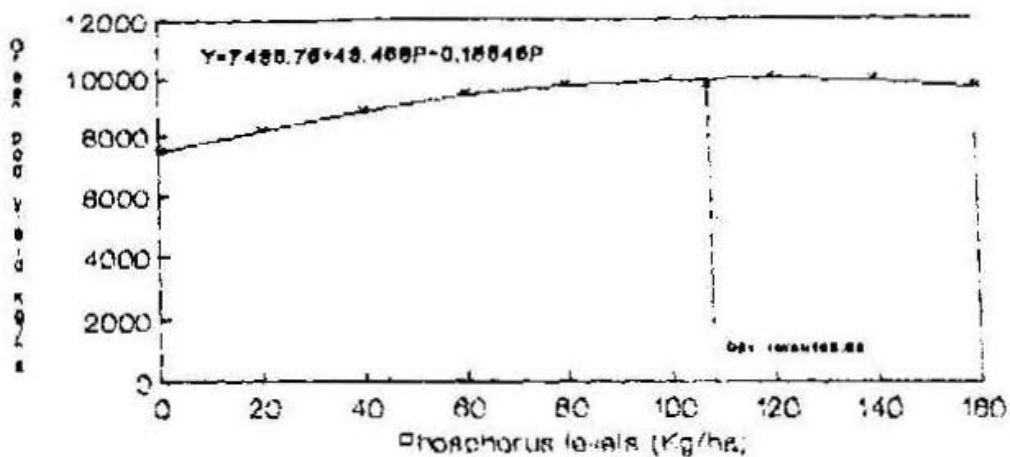


Fig:16.RESPONSE CURVE
Potassium Vs Yield

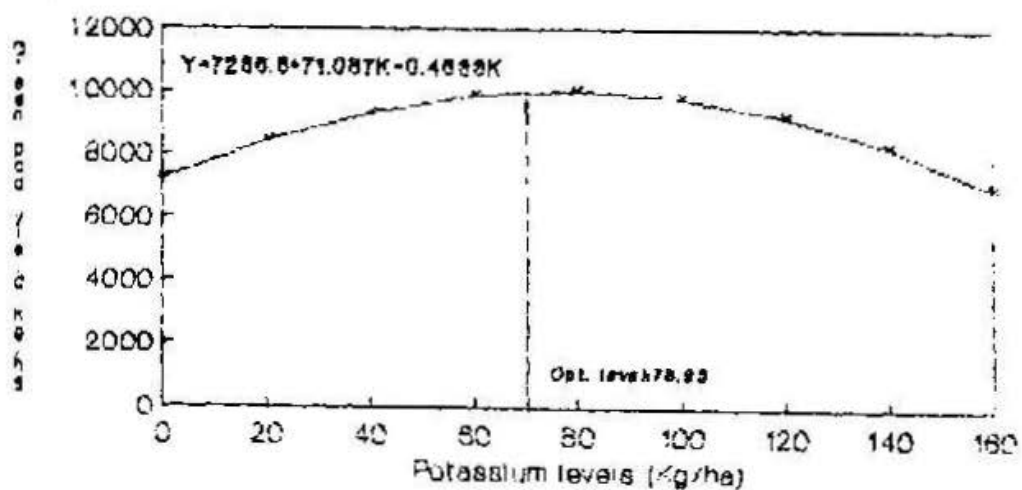


Table 39. Economics

Treatments	Fixed input*	Expenditure (Rs./ha)				Green pod** yield (q/ha)	Gross income (Rs./ha)	Net income (Rs./ha)
		P ₂ O ₅ #	K ₂ O***	Additional labour charges	Total			
P ₀ K ₀	22612.62	0.0	0.0	0.0	22612.62	59.42	31195.50	8582.88
P ₀ K ₃₀	22612.62	0.0	212.1	72.0	22896.72	75.51	39642.75	16746.03
P ₀ K ₆₀	22612.62	0.0	424.2	72.0	23108.82	81.18	42619.50	19510.68
P ₀ K ₉₀	22612.62	0.0	636.3	96.0	23344.92	84.56	44394.00	21049.08
P ₄₀ K ₀	22612.62	640.0	0.0	72.0	23324.62	73.66	38671.50	15346.88
P ₄₀ K ₃₀	22612.62	640.0	212.1	72.0	23536.72	83.51	43842.75	20306.03
P ₄₀ K ₆₀	22612.62	640.0	424.2	96.0	23772.82	94.03	49365.75	25592.93
P ₄₀ K ₉₀	22612.62	640.0	636.3	96.0	23984.92	94.17	49439.25	25454.33
P ₈₀ K ₀	22612.62	1260.0	0.0	72.0	23944.62	79.56	41769.00	17824.38
P ₈₀ K ₃₀	22612.62	1260.0	212.1	96.0	24180.72	99.10	52027.50	27846.78
P ₈₀ K ₆₀	22612.62	1260.0	424.2	96.0	24392.82	112.96	59304.00	34911.18
P ₈₀ K ₉₀	22612.62	1260.0	636.3	120.0	24628.92	107.16	56259.00	31630.08
P ₁₂₀ K ₀	22612.62	1920.0	0.0	96.0	24628.62	78.79	41364.75	16736.13
P ₁₂₀ K ₃₀	22612.62	1920.0	212.1	96.0	24840.72	94.32	49518.00	24677.28
P ₁₂₀ K ₆₀	22612.62	1920.0	424.2	120.0	25076.82	112.25	58931.25	33854.43
P ₁₂₀ K ₉₀	22612.62	1920.0	636.3	120.0	25288.92	110.58	58054.50	32765.58

* = Fixed input as detailed in Appendix-III;

** = Sale rate of green pod of French bean Rs.5.25 per kg as average of both the years;

*** = Cost of K₂O @ Rs.7.07 per kg;

= Cost of P₂O₅ @ Rs.16.00 per kg

Chapter - V

DISCUSSION

A number of edaphic and climatological factors influence the performance of any crop under a given environment. These factors control metabolic processes taking place in the plant system. Such processes are activated by climatological factors like timely sowing of the crop and judicious supply of growth inputs, of which, the fertilizer application is of paramount importance.

French bean, being a leguminous vegetable, gives better response to phosphorus and potassium than nitrogen fertilizers (Gupta, 1988; Wallace, 1989 and Singh and Tripathi, 1994). Hence, it was deemed essential to work out the optimum requirements of phosphorus and potassium for French bean.

In order to standardize the economical dose of P and K nutrients on the growth and development, yield and its component characteristics and quality parameters of French bean, four levels each of phosphorus (0, 40, 80 and 120 kg/ha) and potassium (0, 30, 60 and 90 kg/ha) were evaluated. The results so obtained have been explicated in the following text.

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In order to standardize the economical dose of P and K nutrients on the growth and development, yield and its component characteristics and quality parameters of French bean, four levels each of phosphorus (0, 40, 80 and 120 kg/ha) and potassium (0, 30, 60 and 90 kg/ha) were evaluated. The results so obtained have been explicated in the following text.

GROWTH AND DEVELOPMENT CHARACTERISTICS

Phosphorus and potassium are known to play a vital role in the growth and development of a plant, more particularly in French bean where the nitrogen requirement is met by the fixation of the atmospheric nitrogen.

Plant stand

Plant stand was not influenced by phosphatic and/or potassic fertilizers. It seems that plant stand is dependent upon the seed vitality and vigour which is least affected by the externally applied factors. The findings of Gupta (1988) are in consonance with the present results.

Days to maturity

Early flowering and picking in bean are the desirable physiological characters. It is evident from the pooled data that phosphorus and potassium played pronounced effect on early maturity, which was observed at P₈₀xK₆₀ levels. Same dose of phosphorus and potassium when applied alone induced earliness in cv. Contender.

The agro-climatic factors prevailing during 1993 conceded the crop to mature early as compared to in 1994. In the previous year of experimentation, mean temperature at vegetative phase was lower, relative humidity was higher and rainfall was more resulting in rapid completion of vegetative phase.

Early maturity may be confined to the axiom that phosphorus plays a key role in energetic metabolism and biosynthetic reactions as a component of ADP and RNA, which governs cell multiplication resulting in rapid completion of vegetative growth (Terry and Ulrich, 1973). Potassium influences more than 60 enzyme systems and translocates sugars from the site of photosynthesis to their storage depots which results in bud formation (Ludwick, 1992 and Usherwood, 1993). Thereupon, phosphorus motivated the early completion of vegetative phase and potassium, on the other hand, induced transitional phase in the plant body, hence, resulting in early maturity. Moreover, potassium in combination with phosphorus is responsible for early crop maturity (Usherwood, 1993).

P is essential for earliness and uniform ripening (Shanmugavelu, 1989). Parrerselvan (1980) reported that P induced early flowering and advanced the harvest by three to four days. Passarinho and Recardo (1988) found earliness in flowering in bean cultivars is positively correlated with efficiency of potassium utilization. Earlier workers viz. Saito et al. (1963) and Tanaka and Kamachi (1982) had also observed early flowering with the increase in soil fertility.

Leaf area (cm²)

Increased leaf area is responsible for induced photosynthetic surface which may result in enhanced

photosynthesis. The character was mainly influenced by the application of phosphorus and potassium both in 1993 and 1994. However, greater leaf area was recorded in 1994 as compared to 1993. This may be attributed to high rainfall during 1994.

Phosphorus is known to increase the leaf expansion (Fernando, 1958). Similar results have also been observed by Mahatanya (1976) and Manrique (1986) with respect to phosphorus application in French bean. Mangel and Arneke (1982) found that potassium is the predominant one among the cations in the cell sap. At the deficiency range, only 30 mMK is present in the sap of bush beans, while the concentrations measured in the range of good potassium supply, were about five times higher. Consequently, the osmotic potential decreased. As the total water potential was changed only a little by higher potassium supply, the turgor pressure was increased by 3 bar due to K. This means that the internal pressure on the cell wall is higher, the consequence of this enhanced turgor pressure being greater will cause cell elongation and thus a higher growth rate when K supply is improved. Stanev and Chichev (1973) also observed that the leaf area increased significantly with the addition of potassium in soil.

Number of branches

Bush beans have cymose type of branching pattern,

which bears flowers/pods on those branches. So, more the number of branches, more will be yield. The pooled analysis of the data revealed significant effect of P and K on number of branches at 80 kg P₂O₅ and 60 kg K₂O per hectare, either alone or in combination.

The present results are in line with Pande et al. (1994), Gupta et al. (1983), Chandra et al. (1987) for phosphorus application. Similarly, Stanev and Chichev (1973) also observed that the number of branches in bean plants increased with the application of potassium. Potassium is known to promote the number and enlargement of the internodes (Aasi, 1992). Therefore, each node might have given rise to individual branch. Augustinussen (1973), Thangaraj and Rangaswamy (1994b) and Singh and Tripathi (1994) also found that the number of branches per plant significantly increased with the combined application of P and K in French bean. Phosphorus responsible for cell multiplication, might have strengthened the development of branches in the presence of K.

Plant height

Plant height was significantly increased with the lower doses of phosphorus (80 kg/ha) and potassium (60 kg/ha), during 1993, in comparison to the higher doses (P₁₂₀ and K₉₀) during 1994. However, their combined application (P₈₀×K₆₀) gave maximum plant height (44.30 cm), during 1993,

whereas the interaction effects were non-significant in 1994.

Phosphorus increases the meristematic activity (Fernando, 1958) and improves the development of the vascular system (Ragalev, 1957). Potassium, on the other hand, promotes vegetative growth, internodal length and enhances the turgor pressure, which is the driving force of cell elongation and thus the longitudinal growth is obvious (Zimmermann, 1978).

The results with respect to P application, confirmed the findings of Gupta (1983), Chandra et al. (1987) and Srinivas and Naik (1990), while Ali and Ocida (1972) and Stanev and Chichev (1973) found taller plants with the increasing levels of potassium. The increase in plant height due to combined application of P and K had also been reported by Thangaraj and Rangaswamy (1994b) and Singh and Tripathi (1994).

YIELD AND ITS COMPONENT CHARACTERISTICS

Pod length (cm)

The pooled data revealed significant linear increase in pod length with phosphorus application (0 to 120 kg P_2O_5 /ha), though the differences at P_{80} and P_{120} were non-significant. Similarly pod length was also increased by potassium application and highest value (15.53 cm) was recorded with higher (K_{60} and K_{90}) doses of potassium. The

interacting effect of $P_{120} \times K_{90}$, which was at par with $P_{80} \times K_{60}$, $P_{80} \times K_{90}$ and $P_{120} \times K_{60}$; recorded maximum pod length (16.18 cm). Phosphorus fertilization had significant influence on pod length of French bean. The findings are in line with Pande et al. (1974), Singh (1987), Singh et al. (1989), Chakrawarti et al. (1990) and Thangaraj and Rangaswamy (1994a). Combined effect of P and K on pod length has also been observed by Thangaraj and Rangaswamy (1994b) and Singh and Tripathi (1994).

Potassium is an indispensable cation for plant growth, influencing a number of physical, physico-chemical and metabolic pathways at the cellular level and ultimately affect the growth and productivity of a plant (Barker and Maynard, 1969). Under such situation though the exact reason remains elusive, yet it might have increased the pod length.

Pod girth (cm)

It is evident from the pooled data that the pod girth was significantly affected with the application of phosphorus and potassium and maximum pod girth was recorded at P_{120} (3.13 cm) and K_{60} (3.15 cm). The increase in pod girth due to phosphorus application have been reported by various workers (Pande et al., 1974; Singh, 1987; Singh et al., 1987 and Chakrawarti et al., 1990). However, the increase in pod girth with K supply may be due to higher rate of photosynthesis, translocation and greater number of endosperm cells (Beringer

and Schacherer, 1982). Besides, it enhances the turgor pressure which leads to cell elongation (Mangel and Arneke, 1982).

Number of pods per plant

Number of pods per plant were significantly influenced with the application of phosphorus and potassium either alone or in combination. Maximum number of pods were recorded at P₈₀ (21.47) and K₆₀ (21.42) and when applied in combination i.e. P₈₀xK₆₀ (24.42).

Increase in number of pods per plant seems to be the result of increased number of branches, giving rise to nodes bearing profuse flowering under the influence of higher levels of P and K. Ultimately, each flower matured into pod, as potassium along with phosphorus is responsible for crop maturity (Usherwood, 1993). Similar findings with respect to the application of phosphorus (Pande et al., 1974; Singh, 1987; Chandra et al., 1987 and Chakrawarti et al., 1990) and potassium (Prabhakar et al., 1987b and Evanylo and Zehnder, 1989) or their combination (Gupta, 1988 and Singh and Tripathi, 1994) have been reported.

Green pod yield

Green pod yield in French bean is a multivariant parameter. Yield is directly and positively correlated with leaf area (Watson, 1956), number of pods and nodes bearing

Pods and indirectly with number of branches, plant height and pod length, as postulated by Sharma and Joshi (1993). The pooled data extrapolated that the green pod yield was significantly influenced by 80 kg P_2O_5 and 60 kg K_2O per hectare, either alone or in combination. The optimum doses of P and K were deduced to be 108.98 kg P_2O_5 and 76.93 kg K_2O per hectare, respectively.

Number of pods and branches per plant, plant height and pod length etc. were also significantly affected by the phosphorus at 80 kg P_2O_5 per hectare, which are known to be the directly or indirectly contributing characteristics of green pod yield (Sharma and Joshi, 1993). These characters were also showing the same response to phosphorus and potassium nutrients.

Since, potassium is directly or indirectly involved in most of the plant processes as, regulation of enzyme systems, photosynthesis, respiration, protein synthesis, translocation of food material etc., hence these can be reasons, why the deficiency of potassium can result in low crop yield, quality and profitability (Usherwood, 1993). Ludwick (1992) had opined that potassium plays a pivotal role in the uniform ripening of the crop, growth rate, firms stems and stalks, longer self life, less cells and waste and ultimately gives higher market grade.

The complementary effects of phosphorus and potassium on the green pod yield of French bean can be enshrined in the similar response produced jointly by the two elements on plant height, number of branches, leaf area, pod length, number of pods, dry matter accumulation and uptake of N, P and K by pods and plants, respectively. Since, these effects were of the same type, the mechanism of the complementary action of phosphorus and potassium shall be operative through the efficient functioning of the photosynthetic surface and the increased accumulation of photosynthates.

Olericulturists, working on fertilizer requirements of beans since 1974 and the recent scientists viz., Singh and Singh (1990), Srinivas and Naik (1990), Gajanan et al. (1990), Chakrawarti et al. (1990), Thangaraj and Rangaswamy (1994a) were holding the same views that the green pod yield is improved with the increasing levels of phosphorus in French bean. Similarly, French bean have shown the positive response to direct potassium application as reported by Prabhakar et al. (1987b) and Evanylo and Zehnder (1989). Complementary effects of P and K on green pod yield of French bean have also been observed by earlier workers (Ponnerselvan, 1980; Dekov et al., 1982; Thangaraj and Rangaswamy, 1994b and Singh and Tripathi, 1994).

The green pod yield was more in 1994 than 1993. Joshi et al. (1993) deduced that high temperature during vegetative

phase and declining temperature at reproductive phase favourable for good growth and high yield. On the other hand, high temperature and low humidity prevailing during the reproductive phase resulted in enhanced yield (Sharma and Verma, 1982)

QUALITY ATTRIBUTES

French bean serves as the cheapest source of proteinous food to the mal-nurished population of India. In the present studies, it was found that the protein content in green pods was significantly influenced by different levels of phosphorus and potassium. The higher levels of phosphorus i.e. P₈₀ and P₁₂₀ produced the same amount of protein (1.89%). A linear increase was observed with the increasing levels of potassium upto K₆₀ (1.88%), however, a non-significant decline was observed at K₉₀. The combined application of phosphorus and potassium i.e. P₈₀×K₆₀, produced the highest protein content (1.95%) in green pods of French bean. Similar results were also obtained by Srinivas and Naik (1988) and Chakrawarti et al. (1990). They have assigned the reason for higher protein content to the higher nitrogen utilization by way of supply of phosphorus must have enhanced the protein synthesis in French bean. Phosphorus enhances the rhizobium activity in the rhizosphere by increasing the root biomass which absorbs nutrients more frequently from the soil solution. It is also involved

through ATP in the activation of amino-acids for the synthesis of protein moiety of this compound.

The possible explanation, that the potassium stimulates the synthesis of true proteins in plants from amino acid building blocks (Duke and Collins, 1985 and Ludwick, 1992) and also helps in the utilization of plant nitrogen towards synthesis of proteins (Dev, 1991), holds good. It is well known that nitrogen fixation by *Rhizobium* is enhanced in host plants well supplied with P and K (Mengel et al., 1974) and improved protein content in pods of French bean (Dekov et al., 1982).

Dry matter content and accumulation

The pooled data extrapolated a linear progress in the dry matter content of pods, plants as well as dry matter accumulation by crop (pods+plants). These parameters were maximum at 80 kg P_2O_5 and 60 kg K_2O either alone or in combination which showed non-significant differences with higher doses of P and K. Similar views were expressed by Mahatanya (1976), Panneerselvan (1980), Vidal (1984), Ssali and Keya (1986), Fohse et al. (1988) and Srinivas and Naik (1988).

Combined application of phosphorus and potassium results in better root development and improved photosynthesis (Usherwood, 1993). Due to the fact, French

bean cv. Contender might have absorbed and utilized the food nutrients from rhizosphere more efficiently.

The reason for the better dry matter content and accumulation at higher levels of P can be well explained in the words of Tisdale and Nelson (1966), who regarded phosphate compounds as 'energy currency' within the plants. The energy derived from the metabolism is stored in phosphatic compounds for subsequent use in growth and development.

The increase in dry matter can be attributed to increased photosynthetic area (explicated under leaf area) which intercepts more radiation and greater availability of potassium in the soil. By regulating stomatal movement and checking transpiration, potassium improved water use efficiency by increased dry matter production (Rajgopal, 1985). Dev (1991) and Ludwick (1992) have opined that the rate of photosynthesis is declined when potassium is deficient and plants with greater respiratory rate lead to decreased dry matter production.

Angular leaf spot

Angular leaf spot causes as high damage to the French bean crop upto 55.66 per cent (Anonymous, 1995b), which is a major threat to the farmers. However, it can be managed by potassium application, as seen in the present studies. The

highest levels of potassium (K_{90}) registered the minimum (21.49%) disease severity as compared to lower levels and control (25.62%). There was not any significant effect ear marked with phosphorus and combined application of P and K.

Potassium improves plant health and natural resistance to many leaf, root and shoot diseases (Usherwood, 1993). Disease resistance mainly achieved by thickening the epidermal layer (Ludwick, 1992) which avoids the penetrance and discourage the establishment of the fungus into the plant system. Potassium have also been reported to develop leaves with thickened cuticle and strong epidermal cells which helps in checking the incidence of diseases (Sekhon and Singh, 1982).

Nutrient content and uptake

Nutrient uptake is a product of dry matter production and concentration of the particular nutrient element in question. The content and uptake of N, P and K by different plant parts (pods and stem+leaves) and total removal of nutrients by the crop, increased with the increasing levels of phosphorus and potassium. However, N content and uptake decreased with higher levels of K application i.e. 90 kg K_2O per hectare.

The increase in nutrient content and uptake of NPK might be due to the increased phosphorus and potassium

supply, rendering more nutrients available to the plant and, thereby, resulting in accumulation of NPK in various plant parts as a result of efficient translocation (Smith, 1977; Yacheva, 1977; Pannarselvan, 1980). However, the increasing levels of one nutrient showed the depressing effect on the uptake of other nutrients. This may be due to the competition among the nutrients, possibly due to monovalency, for entrance into the plant system (Tisdale and Nelson, 1969).

N-content and uptake

The content and uptake of nitrogen by pods, plants (stem+leaves) and total removal of N by the bean crop increased with successive increase in levels of phosphorus. similar observations were also reported by Kapoor (1985). Stalin et al. (1989) and Srinivas and Naik (1990) found that phosphorus fertilization had significant influence on N concentration in leaf, stem and pod of French bean. The increase in N content can be attributed to positive response to P application. It may be due to the synergistic interaction between P and K, when adequate P was applied (Kanwar et al., 1982).

Nitrogen content and uptake by pods and plants and total N removal by crop were significantly increased with the increasing levels of potassium and maximum values were recorded at K₆₀. However, a declining trend was observed at higher levels of potassium application i.e. 90 kg K₂O per

hectare. This may be due to NH_4^+ and K^+ having the same ionic radius and are subjected to fixation by clay particles with one another, thereby altering their release (Welch and Scott, 1961).

Wu et al. (1969) reported that abundant supply of phosphate and potassium to soybeans had a beneficial effect on N_2 fixation by *Rhizobium japonicum*. It may be due to better rhizobial activity, greater root vigour and more effective utilization of soil moisture, which ultimately improve the nutrient uptake. Smith (1977) and Mack (1983) reported that higher fertilizer rates tended to increase N concentration in leaves of snap beans.

P-content and uptake

Maximum P-content and uptake by plants were recorded at higher levels of P and K alone or in combination. The results are in conformity with the findings of Mahatanya (1976) who also found phosphorus application increased P content in the plants by increasing their total dry weight. Prabhakar et al. (1984) observed that the application of phosphorus upto 75 kg/ha increased the P uptake by French bean crop. P content in pods and leaves significantly increased with the increasing levels of P fertilization (Stalin et al., 1989). Bains (1969) reported that the applied potassium levels showed significant association with P content of bean plants. Similarly, interaction of P x K also improved the P content pods and plants and total removal of P by the crops. It may be

sequentially additive interaction (Wallance, 1989), which induced absorption of P by French bean crop.

K-content and uptake

The increase in K contents with increasing levels of phosphorus has also been reported by Mamonova (1978), Blichki *et al.* (1982) and Stalin *et al.* (1989). In case of potassium application, K content and uptake by different plant parts and the crop were increased significantly and maximum values were recorded at higher levels of potassium i.e. K₉₀ which was at par with K₆₀. Similar trend was reported by Singh and Singh (1994) regarding the K uptake by the grain and straw of soybean with the application of potassium upto 80 kg K₂O/ha. K content increased with increasing levels of potassium has also been observed by Munro *et al.* (1978) and Sartain and Forbes (1983) in cole crops. Applied phosphate levels showed positive association with K contents in pods as reported by Bains (1969). Both phosphorus and potassium improved K content and its uptake by bean plants may be attributed to extensive root system and vigorous vegetative growth. Exchangeable K increased with increasing potassium fertilization (Martel and Zizka, 1975). He also observed uptake of NPK at the highest rate of added P and K in soil.

Available NPK status of soil

In the present studies, there were significant

differences for the availability of NPK elements with the addition of phosphorus and potassium in soil. The higher applications of P and K showed an increase in the availability of these nutrients in the soil after harvest of the bean crop as expected, but reduced N and K was observed with increasing doses of phosphorus. Similarly, reduced availability of N and P content in soil was observed with the increasing levels of potassium. This may be a consequence of more vegetative growth and more utilization of these nutrients by crop. Similar findings were observed by Sharma (1991) and Syota (1993).

Economics

The net returns of Rs.34911.18 per hectare were obtained at P₈₀×K₆₀. The higher levels of P and K at 120kg P₂O₅ and 60 kg K₂O per hectare showed a decrease in net returns by Rs.2145.60. Application of P and K beyond 80 kg and 60 kg per hectare, respectively would not be advisable considering the high costs of phosphate and potassic fertilizers. Therefore, application of phosphorus and potassium is suggested to be applied at 80 kg P₂O₅ and 60 kg K₂O per hectare, in combination, in French bean. Similar views were expressed by Gupta *et al.* (1983) and Singh (1987).

Chapter - VI

SUMMARY AND CONCLUSIONS

The present investigations on the "Response of graded levels of phosphorus and potassium on yield and quality of French bean cv. Contender under mid hill conditions of Himachal Pradesh", were undertaken at the Experimental Farm of the Department of Vegetable Crops, Dr YS Parmar University of Horticulture and Forestry, Solan, HP during Kharif season of 1993 and 1994. The experiment was laid out in Randomized Block Design with three replications. The treatments comprised of four levels of phosphorus (0, 40, 80 and 120 kg P_2O_5 /ha) and potassium (0, 30, 60 and 90 kg K_2O /ha). The broad objective of the study was to explore the optimum levels of P and K to get the maximum returns, thereby, avoiding deficiency of any nutrient, on one hand, and excessive application on the other hand. The results pertaining to P and K management have been summarized in the following text.

- The application of P and K did not affect plant stand rather it seemed to be a character controlled by genetic factors.
- Early flowering in French bean was induced with the increasing levels of P and K upto 80 kg P_2O_5 and 60 kg K_2O per hectare. The interaction of $P_{80} \times K_{60}$ recorded minimum days to 50 per cent flowering (32.17). Minimum days taken to the first picking were 46.00 at $P_{80} \times K_{60}$.

- Leaf area significantly increased with the increasing levels of P and K and was maximum at P₈₀ (510.33 cm²) and K₆₀ (484.81 cm²) in 1993 and at P₁₂₀ (561.74 cm²) and K₉₀ (503.43 cm²) in 1994.
- The number of branches per plant was enhanced with the application of phosphorus and potassium in soil. Maximum number of branches per plant were observed at P₈₀ and K₆₀, when applied either alone or in combination.
- The overall plant height showed a differential response to P and K in both the years. Application of P₈₀ and K₆₀ recorded the highest increase in plant height during 1993 in comparison to higher levels of these nutrients in 1994 (P₁₂₀ and K₉₀). However, the interaction effects were significant in 1993 where the taller plants were produced at P₈₀×K₆₀.
- Maximum pod length and girth were recorded with 120 kg P₂O₅ and 60 kg K₂O per hectare. Among the interactions, maximum pod length was observed at P₁₂₀×K₉₀ (16.18 cm), whereas such effects were non-significant for pod girth.
- The number of pods per plant were significantly influenced by P and K and was maximum with the application of 80 kg P₂O₅ and 60 kg K₂O per hectare, either alone or in combination.
- Application of phosphorus and potassium 80 kg P₂O₅ and 60 kg K₂O per hectare, either alone or in combination, were the best suited to increase green pod yield. However, one factor quadratic response function fitted to the yield data indicated 108.98 kg P₂O₅ and 76.93 kg K₂O per hectare as optimum levels. The corresponding green pod yield was 9970.52 kg and 10021.93 kg/ha, respectively, which was 34.08 per cent and 38.51 per cent more than the respective controls.

- The various quality parameters viz., protein and dry matter content in green pods showed inconsistent results with higher doses of phosphorus and potassium. Maximum protein could be obtained with P_{80} , K_{60} and their interacting levels.
- Similarly, dry matter content and accumulation in pods and plants and total dry matter accumulation by the crop was also increased by 80 kg P_2O_5 and 60 kg K_2O per hectare. Improvement in quality is also directly affected by the plant health and vigour.
- Potassium application @ 60 kg K_2O/ha might have resulted in the lignification of epidermal cells and increased the production of phenolic compounds, which contributed to reduce the severity of angular leaf spot disease in French bean.
- The content and uptake of all the three (NPK) plant nutrients by the pods and plants and their total removal by the crop was significantly influenced by higher levels of phosphorus and potassium. However, application of potassium beyond 60 kg K_2O/ha , reduced N content and uptake which may be due to the antagonistic effect of the K^+ with other nutrients.
- Maximum available phosphorus (51.44 kg) and potassium (264.55 kg) contents were observed at 120 kg P_2O_5 and 90 kg K_2O per hectare. However, the increasing levels of phosphorus had a depressing effect on nitrogen and potassium availability. Similarly higher levels of potash application decreased the availability of nitrogen and phosphorus in soil after harvesting of the bean crop.

CONCLUSION

The crystal clear results obtained from the present studies, revealed significant effects of phosphorus and potassium on the growth and development, quality and production potential of French bean cv. Contender. The highest doses of P_{120} and K_{90} influenced the leaf area, plant height, pod length significantly, whereas, the lower doses of P_{80} and K_{60} had the favourable effects on the days to 50 per cent flowering, days to first picking, number of branches, number of pods and green pod yield. However, both these combinations were at par to each other. Therefore, $P_{80} \times K_{60}$ was the most beneficial dose where the net returns for Rs.34911.18 per hectare were obtained which was higher by Rs.26238.30 per hectare to the control.

The optimum levels of phosphorus and potassium, worked out by one factor quadratic function, were 108.98 kg P_2O_5 and 76.93 kg K_2O per hectare. The expected yield potential was 9970.52 kg and 10021.93 kg/ha, respectively. Keeping in view the rising costs of phosphate and potassic fertilizers, the application of phosphorus and potassium beyond 80 kg P_2O_5 and 60 kg K_2O per hectare, seems futile.

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*Original not seen

APPENDICES

APPENDIX-I
 MEAN WEEKLY METEOROLOGICAL DATA OF CROP GROWTH PERIOD
 (June-August, 1993 and June-August, 1994)

Month	Week	Temperature(°C)		Relative humidity		Rainfall (mm)
		Maximum	Minimum	Maximum	Minimum	
1993						
June 7	I	36.5	19.0	56.4	32.4	4.0
June 14	II	36.0	10.0	68.4	55.0	25.0
June 21	III	31.0	14.0	77.9	57.4	11.4
June 28	IV	31.0	19.0	87.5	72.7	88.8
July 5	I	32.0	18.5	77.5	63.0	2.0
July 12	II	29.0	19.0	93.5	88.0	222.8
July 19	III	29.0	19.0	95.7	75.5	63.8
July 26	IV	29.0	17.0	93.7	71.3	17.2
August 2	I	30.5	18.5	89.0	65.4	4.0
August 9	II	30.0	19.5	94.4	79.3	27.2
August 16	III	30.5	17.5	89.5	64.0	4.8
August 23	IV	31.0	17.5	83.0	60.0	-
August 30	V	29.5	19.7	87.3	62.5	4.2
1994						
June 6	I	35.5	21.5	47.5	22.4	-
June 13	II	32.0	20.8	64.0	42.0	27.0
June 20	III	34.0	21.9	61.5	34.9	-
June 27	IV	29.2	19.3	88.7	74.4	68.4
July 4	I	28.3	21.7	87.9	71.9	132.2
July 11	II	27.8	20.7	95.0	77.0	18.4
July 18	III	28.9	22.2	93.7	74.7	36.4
July 25	IV	25.1	20.7	94.0	92.5	160.8
August 1	I	27.6	21.7	95.9	74.1	42.2
August 8	II	28.0	22.5	94.0	74.0	34.8
August 15	III	26.9	21.0	94.7	88.8	65.0
August 22	IV	26.5	20.9	96.2	81.2	25.0
August 29	V	25.1	20.2	96.3	85.3	56.8

APPENDIX-II

Analysis of variance for characters under study in French bean (*Phaseolus vulgaris* L.)

MEAN SUM OF SQUARE

Source of variation	df	Per cent plant stand after 15 DAS			Days to 50 per cent flowering			Days to first picking			No. of branches per plant		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication													
a)	2	12.0468	4.21875		1.08398	0.14648		0.26953	0.64453		0.18826	0.05659	
b)	4			8.13281			0.61523			0.45703			0.23891
Year (Y)	1			47.6458			13.5130*			20.1667*			2.19092*
Phosphorus (P)	3	20.5590	22.7118	37.6597	0.97265	1.38932	2.53906*	1.27691	0.55469	1.58333*	12.3623*	11.9015*	24.0339*
Potassium(K)	3	11.5382	22.1424	32.4097	1.02821	1.72265	2.34462*	0.83247	2.05469*	2.55556*	2.93063*	6.58759*	9.12505*
PxY	3			5.6736			0.03733			0.25000			0.22998
KxY	3			1.34028			0.62066			0.33333			0.39317*
PxK	9	2.80903	4.40162	4.47453	1.62023*	1.37022*	2.76013*	0.40769	1.24103	1.45370*	0.20451	0.27317	0.37129*
PxKxY	9			2.71065			0.14959			0.19444			0.10643
Error													
a)	30	17.7829	9.90451		0.70551	0.59023		0.53758	0.57925		0.10248	0.14486	
b)	60			13.8438			0.64787			0.55842			0.12367

Contd....

Source of variation	df	Leaf area/10 leaflet		Plant height (cm)		Pod length (cm)			Pod girth (cm)		
		1993	1994	1993	1994	1993	1994	Pooled	1993	1994	Pooled
Replication											
a)	2	2438.50	4482.50	0.81406	5.3437	0.10107	0.22656		0.00668	0.01937	
b)	4							0.16381			0.01303
Year (Y)	1							5.8984*			0.00258
Phosphorus (P)	3	55094.8*	78180.6*	107.461*	308.934*	2.46354*	13.9731*	13.9570*	0.03736*	0.04554*	0.0824*
Potassium(K)	3	15838.3*	20810.00*	69.4201*	243.958*	1.00173*	11.7621*	9.81293*	0.05410*	0.07619*	0.12553*
PxY	3							2.47873**			0.00052
KxY	3							2.94965**			0.00478
PxK	9	1298.77	1584.59	5.154*	6.4305	6.30787*	1.66016*	4.61515*	0.00258	0.00274	0.00450
PxKxY	9							0.18287			0.00080
Error											
a)	30	1416.35	3059.35	1.794	34.549	0.128559	0.16973		0.00667	0.00734	
b)	60							0.14914			0.00701

Contd. ...

Source of variation	df	No. of pods per plant			Green pod yield/plant (g)			Green pod yield (q/ha)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication										
a)	2	3.81592	12.9288		2.34375	44.8956		97.8125	100.850	
b)	4			8.37240			94.4770			99.3312
Year (Y)	1			67.3372*			718.541			746.25*
Phosphorus (P)	3	77.4903*	151.650*	222.746*	4692.81*	5940.11*	10594.29*	1863.31*	1435.76*	3283.19*
Potassium(K)	3	85.5572*	112.263*	195.792*	4828.81*	6395.08*	11167.95*	2296.18*	1617.35*	3882.19*
PxY	3			6.39539			38.5972			15.8889
KxY	3			2.02908			55.8749			31.5556
PxK	9	11.4766*	16.1552	24.5934*	262.753	2919.72*	1959.39*	772.176*	412.638*	745.278*
PxKxY	9			1.84303			122.338			43.9628
Error										
a)	30	3.79248	6.29110		155.559	208.068		88.1170	107.250	
b)	60			5.04179			181.813			97.6836

Source of variation	df	Protein content in green pods (%)			Dry matter content in pods (%)			Dry matter content in plants (%)			Dry matter accumulation by pods(kg/ha)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication													
a)	2	0.00332	0.00255		0.11975	0.40124*		0.00146	0.04649		14099.00	12481.00	
b)	4			0.00294			0.26049			0.02110			13290.00
													50100.00*
Year (Y)	1			0.00004			0.00081			0.02425			
Phosphorus (P)	3	0.20576*	0.17864*	0.38359*	2.60826*	2.51200*	5.11767*	1.20100*	1.54490*	2.69558*	254140.67*	216509.11*	469695.50*
Potassium(K)	3	0.12577*	0.12590*	0.25158*	2.21090*	2.19770*	4.40673*	2.20330*	1.76793*	3.95860*	280522.91*	221089.56*	499428.88*
PxY	3			0.00053			0.00189			0.02942			949.791
KxY	3			0.00011			0.00211			0.01231			2181.791
PxK	9	0.00698	0.00684	0.01537*	0.12913	0.12408	0.24940*	0.03106*	0.06816*	0.09221*	46212.56*	26163.75*	44155.64*
PxKxY	9			0.00045			0.00378			0.00717			2823.546
Error													
a)	30	0.00594	0.00530		0.09050	0.070103		0.01371	0.02420		8100.667	7329.667	
b)	60			0.00562			0.080303			0.01896			8214.977

Contd....

Source of variation	df	Dry matter accumulation by plants (kg/ha)			Total dry matter accumulation by crop (kg/ha)			Incidence of angular leaf spot(%)			N-content in pods (%)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication													
a)	2	148.000	2588.000		5520.00	35184.00		0.398437	2.065429		0.00046	0.00283	
b1	4			1368.000			20352.12			1.2319336			0.00165
Year (Y)	1			13232.00			33152.000			31.68359%			0.00053
Phosphorus (P)	3	362934.2*	354907.5*	716723.8*	1202417.8*	1057262.20*	2256568.8*	7.445529	7.7419705	13.920573	0.05046*	0.03242*	0.08188*
Potassium(K)	3	466187.5*	444159.1*	909655.2*	1416881.9*	1223242.6*	2635264.00*	39.3214*	46.284506*	85.406685*	0.01103*	0.01153*	0.02225*
PxY	3			1121.75			3100.500			1.270399			0.00101
KxY	3			688.027			4864.000			0.202687			0.00033
PxK	9	6354.666*	12112.881*	16895.40*	28449.195*	21882.084	46482.98*	2.21289	2.2121677	3.502747	0.00370	0.00313	0.00500*
PxKY	9			1572.166			3854.23			0.921442			0.00187
Error													
a)	30	2297.69	4322.133		11403.017	14411.018		5.745833	9.0009546		0.00266	0.00219	
b)	60			3309.901			12907.017			7.373383			0.00243

Contd. ...

Source of variation	df	K-content in plant (X)			N-uptake by pods (kg/ha)			P-uptake by pods (kg/ha)			K-uptake by pods (kg/ha)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication													
a)	2	0.00549	0.00234		13.7382	14.5468		0.621292	0.07148		10.5313	8.91010	
b)	4			0.00392			14.1425			0.34638			9.72070
Year (Y)	1			0.01599			39.6132			1.05004			61.5794*
Phosphorus (P)	3	0.41290*	0.46813*	0.87784*	329.990*	258.289*	585.541*	13.1124*	13.7469*	26.8471*	288.285*	284.4105*	572.561*
Potassium(K)	3	0.69468*	0.70525*	1.39850*	327.479*	242.947*	566.277*	6.87760*	6.83276*	13.7097*	315.551*	288.069*	603.011*
PxY	3			0.00322			2.74176			0.01228			0.13411
KxY	3			0.00138			4.15321			0.00065			0.61066
PxK	9	0.00887	0.01036*	0.01829*	57.2706*	55.3558*	71.9170*	0.55857	0.32074	0.8182*	16.4195*	9.962	12.9628*
PxKxY	9			0.00093			4.06928			0.06115			1.41827
Error													
a)	30	0.00606	0.00358		11.1434	9.00812		0.39193	0.147678		6.2787	5.0646	
b)	60			0.00482			10.0757			0.269805			5.67165

Contd....

Source of variation	df	N-uptake by plant (kg/ha)			P-uptake by plant(kg/ha)			K-uptake by plant(kg/ha)			Total removal of N by crop (kg/ha)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication													
a)	2	3.03515	1.02735		0.12402	0.35607		0.77734	4.18750		8.99218	34.6328*	
b)	4			2.03125			0.24005			2.48242			21.8124
Year (Y)	1			20.0625*			0.97973			13.3177			97.8645*
Phosphorus (P)	3	388.368*	420.375*	807.284*	26.6810*	24.8245*	51.1878*	622.671*	625.429*	1247.82*	1496.81*	1258.56*	2746.27*
Potassium(K)	3	438.207*	453.259*	891.274*	18.0807*	17.0024*	35.0659*	873.474*	831.239*	1702.28*	1430.96*	1318.41*	2746.27*
PxY	3			1.46525			0.31784			0.27256			9.08669
KxY	3			0.19788			0.01738			2.42529			3.10058
PxK	9	7.03732*	13.3197*	19.2986*	0.33156	0.48963	0.78165*	23.2242*	27.0686*	46.5145*	14.2968	26.4195	33.1909*
PxKxY	9			1.05555			0.03948			3.77953			5.53602
Error													
a)	30	2.95459	3.21709		0.34792	0.30542		3.94887	4.15598		18.0951	12.85559	
b)	60			3.08584			0.32667			4.05243			15.4755

Contd....

Source of variation	df	Total removal of P by crop(kg/ha)			Total removal of K by crop(kg/ha)			Available N in soil (kg/ha)			Available P in soil (kg/ha)			Available K in soil (kg/ha)		
		1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled	1993	1994	Pooled
Replication																
a)	2	1.12219	0.73535		14.1640	4.64765		10.5000	17.0000		1.35937	2.95750		0.87500	6.12500	
b)	4			0.92863			9.40585			13.7500			2.14864			3.50000
Year (Y)	1			4.25130*			122.791*			181.667*			85.1250*			254.667*
Phosphorus (P)	3	77.1869*	75.8658*	152.776*	1757.44*	1723.19*	3480.35*	111.556*	142.667*	247.222*	490.641*	468.456*	957.174*	10.9722	87.2611*	74.4444*
Potassium(K)	3	47.0988*	45.8864*	92.9650*	2228.77*	2067.86*	4291.05*	163.333*	185.556*	346.778*	33.6762*	46.094*	79.0764*	566.194*	651.417*	1209.11*
PxY	3			0.27669			0.30585			7.64443			1.92364			16.4444
KxY	3			0.02018			5.61794			2.55554			0.69443			8.44447
PxK	9	0.87960	1.26066	2.06459*	44.6695*	47.0075*	90.3124*	2.37037	6.81481	4.25925	1.20746	1.00781	1.81714	6.08333	14.41675	10.66759*
PxKxY	9			0.07573			1.3565			4.92592			0.39815			9.70371
Error																
a)	30	1.20272	0.61475		14.6956	7.88325		13.1667	18.2667		4.81354	3.23976		9.30000	6.83056	
b)	60			0.90874			11.2897			15.7167			4.02665			8.06528

* Significant at 5 per cent level of significance.

APPENDIX-III

COST OF CULTIVATION FOR FRENCH BEAN (vegetable type)

Fixed Input

(Rs./ha)

1. Preparatory Tillage

i)	3 ploughing @ Rs.500/- each	Rs. 1500.00
ii)	3 plankings @ Rs.100/- each	Rs. 300.00
iii)	Cost of FYM (10 t/ha) @ Rs.120/t	Rs. 1200.00
iv)	Labour charges on carriage and application of FYM 12 unit labour @ Rs.24/-	Rs. 288.00
v)	Preparation of beds, channels etc. 50 unit labour @ Rs.24/-	Rs. 1440.00

2. Cost of seed (foundation):

i)	Seed rate - 75 kg/ha @ Rs.50/kg	Rs. 3750.00
ii)	Labour charges for sowing - 10 unit labour @ Rs.24/-	Rs. 240.00

3. Interculture operations

i)	One weeding+gap filling - 50 unit labour @ Rs.24/-	Rs. 1200.00
ii)	Hoeing and earthing up - 50 unit labour @ Rs.24/-	Rs. 1200.00

4. Irrigation

	3 irrigations - 9 unit labour @ Rs.24/-	Rs. 216.00
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5. Fertilizers

i)	45 kg N/ha @ Rs. 8/- per kg CAN @ Rs.200/q - 50% basal and 50% top dressing	Rs. 360.00
ii)	Labour charges - 4 unit labour @ Rs.24/-	Rs. 96.00

6. Plant protection measures

i)	Cost of weedicide and insecticide	Rs. 1000.00
ii)	4 sprays, 16 unit labour @ Rs.24/-	Rs. 384.00

7. Harvesting

i)	3 pickings of green pods, 45 unit labour @ Rs.24/-	Rs. 1080.00
ii)	Transportation charges - Rs.400/- each picking	Rs. 1200.00

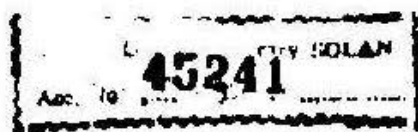
8. Rental charges of land @ Rs.20000/year

Rs. 5000.00

9. Miscellaneous charges

Rs. 1500.00

	Total:	Rs.21954.00
	Interest on capital investment @ 12% (3 months)	Rs. 658.62
	Grand Total	Rs.22612.62



Title of thesis : Response of graded levels of phosphorus and potassium on yield and quality of French bean cv. Contender under mid-hill conditions of Himachal Pradesh

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Major subject : Vegetable Crops

Minor subject(s) : i) Plant Physiology ii) Soil Science

Degree awarded : M.Sc. Horticulture (Vegetable Crops)

Year of award degree : 1998

Total pages in thesis : 97+XII+III

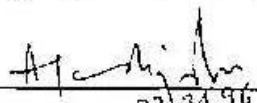
Number of words in the abstract : 300

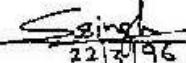
ABSTRACT

The present investigations on the "Response of graded levels of phosphorus and potassium on yield and quality of French bean cv. Contender under mid-hill conditions of Himachal Pradesh", were undertaken at the Experimental Farm of the Department of Vegetable Crops, Dr Y S Parmar University of Horticulture and Forestry, Solan (HP) during kharif season of 1993 and 1994. The experiment was laid out in randomized block design with three replications. The treatments comprised of four levels of phosphorus (0, 40, 80 and 120 kg P₂O₅/ha) and potassium (0, 30, 60 and 90 kg K₂O/ha).

The results obtained from the present studies, clearly showed significant effects of phosphorus and potassium on growth, quality and production potential of French bean cv. Contender. The highest doses of P₁₂₀ and K₉₀ significantly influenced the leaf area, plant height, pod length, whereas the lower doses of P₈₀ and K₆₀ had the favorable effects on the days to 50 per cent flowering, days to first picking, number of branches, number of pods, green pod yield, protein, dry matter and NPK content in pods, NPK uptake and total dry matter production by crop. However, both these combinations were at par to each other. Therefore, P₈₀xK₆₀ was the most economical dose where the net returns of Rs.26238.30 per hectare recorded higher than the control. Potassium @ 60 Kg K₂O/ha proved to check the severity of angular leaf spot.

The optimum levels of phosphorus and potassium, worked out by the one factor quadratic function, where 108.98 kg P₂O₅ and 76.93 kg K₂O per hectare. The expected yield potential was 9970.52 kg and 10021.93 kg/ha, respectively. Keeping in view the rising cost of phosphate and potassic fertilizers, the application of phosphorus and potassium beyond 80 kg P₂O₅ and 60 kg K₂O per hectare, seems futile.


 Signature of the Major Advisor


 Signature of the Student

COUNTERSIGNED

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