PHOSPHORUS AND MOLYBDENUM NUTRITION IN COWPEA
(*Vigna unguiculata* L.)

By

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THESIS
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DECLARATION

I hereby declare that this thesis entitled "Phosphorus and molybdenum nutrition in cowpea (Vigna unguiculata L.)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me any degree, diploma, associateship, fellowship or other similar title at any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Phosphorus and molybdenum in cowpea (Vigna unguiculata L.)" is a record of research work done independently by Smt. Annie Philip under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

cm	-	Centimetre
g	-	gram
kg	-	kilogram
t	-	tonne
ha	-	hectare
^0C	-	degree Celsius
Cv	-	Cultivar
var	-	variety
DAS	-	days after sowing
DMP	-	drymatter production
TDMP	-	total drymatter production
LAI	-	leaf area index
HI.	-	harvest index
Fig.	-	Figure
KAU	-	Kerala Agricultural University

INTRODUCTION

INTRODUCTION

The respectable self sufficiency in food grains had been accomplished through utilization of high yielding varieties and better agronomic practices. But these achievements have promoted the nation to open still another war front to fight against under nourishment and malnutrition. The most important problem we are facing today is how to solve the problem of protein deficiency in our daily diet.

Pulses being a rich and inexpensive source of protein can do a lot to combat this situation. Pulses play a significant role in Indian agriculture, because they provide protein-rich components in average human diet. They contain 20 to 24 percent i.e. about 2.5 times the amount of protein found in cereal grain and offer the most practical means of erradication of malnutrition. But the production pattern of pulses during the past decades is perplexing due to a conglomeration of reasons, both biotic and abiotic.

Even in terms of the recent downward revision by the Indian Council of Medical Research (ICMR) of the minimum per capita daily requirement of pulses from 70 g in 1968 to 40 g in 1980, availability falls short of the requirement. If the present trend continues into the future also, then there is no doubt that even the lower new ICMR norm may face possible threat. There exists thus a timely need to examine the possibilities of averting this potential threat of malnutrition.

Pulses are protective crops not only for mankind but also for soil by virtue of the built-in mechanism of these crops for directly using the inexhaustible stock of nitrogen in the atmosphere.

Nearly 75 per cent of the total area under pulses is occupied by cowpea. The yield of cowpea per unit area is rather low in kerala state when compared to other states, the per hectare yield being 411 kg. This low yield is mainly due to inadequate manuring.

The mineral nutrition of legumes is somewhat more complex than that of the other plant species, because of the special symbiotic relationship existing between the legume host and the associated rhizobial bacteria. Particular nutritional requirements are necessary for this extra physiological process to operate efficiently. It has been universally recognised that yield of legumes can be increased by judicious manuring especially with phosphorus.

Even though the requirement of micronutrients is low, in many instances sufficient quantities may not be available to plants because soils are inherently deficient in them. More over, intensive agricultural practices adopted in recent years have resulted in large scale exhaustion of micronutrients reserves in soil.

Among the micronutrients, molybdenum plays a great role in improving the pulse yield mainly by promoting nitrogen metabolism as it is an essential component of one of the nitrogen fixing enzyme complex, nitrogenase, and a component of nitrogen assimilating enzyme, nitrate reductase. It has an important role to play in N_2 fixation. Increased nodulation and leghaemoglobin content are related to the adequate nutritional role of molybdenum which in turn is responsible for higher nitrogenase activity. The chlorophyll and nitrogen contents of plants are also partially monitored by molybdenum leading to higher yields of cowpea.

In addition, the method of application of nutrients has become important, in improving the efficiency in production with low cost technology especially for micronutrients being the requirement is very low.

The requirement of molybdenum for crops being low, seed treatment will be the ideal method of application. The response of cowpea, to seed treatment of molybdenum was not much studied, under Kerala conditions. Hence standardization of procedure to seed treatment of cowpea with molybdenum forms an important aim of this study.

In the supply of any nutrient either from native soil source and/or from applied fertilizers, its availability and mobility in the soil, absorption and uptake by the plant for distribution in different functional plant parts are important considerations affecting over all efficiency of the nutrient. Change in any factor which either decreases or increases the supply and availability of nutrient shall determine its efficiency and finally the crop yield. Thus in fertilizer management a good knowledge of the nature of nutrient interactions is essential.

Phosphorus is known to interact with other nutrients and there by influence the availability of nutrients which in turn affects crop yields and production. Both excess and deficiency of phosphorus may affect the availability of other nutrients. Interaction of phosphorus with nutrients like nitrogen and zinc were much studied but not with molybdenum.

Phosphorus is known to enhance the uptake of molybdenum and thus help in improving N_2 fixation. Besides, synergestic effect of phosphorus and molybdenum in enhancing productivity of pulse crops was also reported. Better response of cowpea to phosphorus and molybdenum was reported by many workers. But the effect of phosphorus in combination with molybdenum was not studied in detail in cowpea.

With all these views in front, the present study was undertaken with the following objectives:-

(1) To estimate the optimum dose and mode of seed treatment of molybdenum for cowpea,

(2) To assess the interaction effects between phosphorus and molybdenum on the growth and yield of cowpea, and

(3) To work out the economics of phosphorus and molybdenum nutrition for cowpea.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The result of the experiment conducted in India and elsewhere, on the growth, yield and quality of cowpea and related crops as influenced by phosphorus and molybdenum fertilization are reviewed here.

2.1 Dynamics of phosphorus nutrition in legumes.

It has been universally recognised that yield of legumes can be increased by judicious manuring especially with phosphorus. Application of phosphorus to pulses has improved yield and quality of legumes, fixed varying quantities of atmospheric nitrogen resulting in restoration of soil fertility.

2.1.1 Growth

Tarila et al. (1977) observed that in cowpea (<u>Vigna unguiculata</u>) increasing levels of applied phosphorus enhanced growth, flower and fruit number as well as leaf number and leaf area.

Sachidanand et al. (1980) reported that application of P (80,160 or240 ppm) significantly increased the overall dry matter yield in soybean and maximum yield was given by the lowest level of P application (80 ppm). Field experiments with field pea showed that height, leaf number, branch number, pod number, and plant dry weight were significantly affected by increasing P levels from 0 to 100 kg ha^{-1} (Singh et al., 1980).

Shrivastava et al. (1980) reported that in blackgram (<u>Vigna mungo var. radiata</u> Hepper) plant height increased with increasing P upto 75 kg P_2O_5 ha^{-1}. In redgram, Vasimalai and Subramonian (1980) found that applied P had pronounced effect on plant height and leaf area index. Application of 50 kg P_2O_5 ha^{-1} was beneficial or economical. Phosphorus application did not exert significant influence on branching.

Singh et al. (1981) found that in pigeon pea (<u>Cajanus cajan</u> (L) Millsp.) application of 13 kg P ha^{-1} significantly increased plant height and number of branches compared with no application at all stages of crop growth, except at 30 days after planting in the case of number of branches. Moreover, no significant additional increase in plant characters and grain yield was observed when phosphate dose increased to 26 kg P ha^{-1}

Ahlawat and Saraf (1982) noticed that phosphate application promoted root growth (dry root weight) and shoot growth in pigeon pea. Phosphorus at 34 kg P ha^{-1} recorded higher root weight than 17 kg ha^{-1}. Phosphorus application resulted in widening the root:Shoot ratio. Subbian and Ramiah

(1982) opined that in redgram P fertilization significantly increased plant height, number of primary branches and dry matter production.

Ahlawat and Sharma (1989) found that phosphate application increased the height of the plant significantly in french bean. Differences between 17.2 and 34.4 kg P ha^{-1} were not marked in any of the plant characters studied.

Reddy and GajendraGiri (1989) reported that in groundnut application of 40 kg P_2O_5 ha^{-1} significantly increased the root biomass and leaf area index. Tamar et al. (1990) opined that application of phosphorus significantly increased the plant height and dry weight per plant, but the effect on branches per plant was not significant.

Higher doses of phosphorus (120 kg P_2O_5 ha^{-1}) increased leaf area index and dry matter production of soybean (Durai Singh and Gopalaswamy, 1991). Pal and Jana (1991) reported that application of 30 kg P_2O_5 ha^{-1} increased significantly growth parameters like number of branches and dry matter production in summer green gram. No response beyond 30 kg P_2O_5 ha^{-1} was observed. Prabhakar and Saraf (1991) found that application of phosphorus (40 kg P_2O_5 ha^{-1}) significantly increased the plant height, number of branches per plant and leaf area in chickpea. Jat and Mali (1992) reported that application of phosphorus at 40 kg P_2O_5 ha^{-1} improved branching in chickpea.

2.1.2 Yield and yield attributes

Jayaram and Ramiah (1980) reported that application of phosphorus in cowpea increased the number of pods per plant, number of seeds per plant and the grain yield significantly in both summer and Kharif seasons. Linear increase in grain yield was observed upto 37.5 kg P_2O_5 ha^{-1} in summer and 25.0 kg P_2O_5 ha^{-1} in Kharif and beyond that the yield levelled off.

Shrivastava et al. (1980) noticed that in blackgram (*Vigna mungo* var *radiata* Hepper) yield and yield attributing characters like number of pods per plant and test weight were favourably influenced by higher P level. The grain yield was maximum at 50 kg P_2O_5 ha^{-1} beyond which it decreased.

The application of phosphorus increased the yield of chickpea (*Cicer arietinum* L.) significantly over control and the highest yield was obtained at 13.5 kg P ha^{-1}. Application of P increased dry matter accumulation significantly at all stages of growth (Singh and Sharma, 1980). Vasimalai and Subramonian (1980) obtained 50 kg P_2O_5 ha^{-1} as economic dose of P for greengram. Phosphorus application had pronounced effect on number of pods per plant and 1000 grain weight where as number of grain per pod and length were unaffected by P application.

In a field trail with greengram (Phaseolus aureus) Srivastava and Verma (1981) indicated that phosphorus application increased grain and straw yields and harvest index.

Singh et al. (1981) noticed that in pigeon pea (Cajanus cajan (L) Mills p.) application of 13 kg P ha^{-1} significantly increased number of pods per plant, grains per pod, 1000 grain weight and finally grain and stalk yield. However no significant additional increase in grain yield was observed when phosphate application increased to 26.0 kg P ha^{-1}. Sharma and Arora (1982) obtained significantly more yield of green pods and grain yield of cowpea by P application over no P; but the difference in yield between 40 and 80 kg P_2O_5 ha^{-1} was not significant.

According to Gupta and Singh (1983) application of P in graded doses significantly increased the yield of bengalgram (Cicer arietinum L.). Highest yield was obtained at 40 kg P_2O_5 and thereafter the yield of the crop declined slightly at 80 kg P_2O_5 ha^{-1}.

It was shown by Singh et al. (1983) that application of 17 kg P ha^{-1} increased grain and straw yields, number of pods per plant and 1000 grain weight in pigeon pea. However no significant additional increase in grain and straw yield and yield attributes were observed when P was increased to 34 kg. ha^{-1}. Kushwaha and Bhaduria (1984) opined that phosphorus application from 0 to 60 kg P_2O_5 ha^{-1} increased the yield of urd significantly. Negi and Thakur (1985) reported that seed yield of *Vigna mungo* was increased significantly by the increased application of P_2O_5 from 0 to 60 kg ha^{-1}. Arthamwar et al. (1986) observed that yield of blackgram increased significantly upto 50 kg P_2O_5 ha^{-1}.

Kumpawat et al. (1988) found that application of phosphorus upto 60 kg P_2O_5 ha^{-1} increased the grain yield of chickpea. The difference between 40 and 60 kg P_2O_5 ha^{-1} was not significant. In soybean application of 40 kg P_2O_5 ha^{-1} produced significantly higher yield than higher levels. Yield was reduced at higher doses. Phosphorus application increased the number of pods per plant, number of seeds per pod and thousand grain weight (Paikera et al., 1988). Puste and Jana (1988) reported that maximum value of the yield attributes of pigeon pea like number of pods and seeds and weight of 1000 seeds were observed at 70 kg P_2O_5 ha^{-1} which was at par with 35 kg P_2O_5 ha^{-1}.

Shaktawat (1988) found that in cowpea application of 60 kg P_2O_5 ha^{-1} increased the grain yield by

6.9 and 49.4 percent over 30 kg P_2O_5 ha^{-1} and no phosphorus respectively. There was no marked response in yield beyond 30 kg P_2O_5 ha^{-1}.

Phosphate application improved the yield attributes like pods per plant, seeds per pod and 100 seed weight and seed yield in french bean and the difference between 17.2 and 34.4 kg P ha^{-1} were not marked in any of the plant characters studied (Ahlawat and Sharma 1989). Patel et al. (1989) have reported that in Chickpea phosphorus levels did not exert marked influence on yield.

Kushwaha (1990) found that application of phosphorus at higher level (60 kg P_2O_5 ha^{-1}) significantly increased the grain yield over 20 kg P_2O_5 ha^{-1} in soybean.

Setty et al. (1990) observed that 50 kg P_2O_5 ha^{-1} is optimum for bengalgram even under irrigated conditions. Thakuria and Saharia (1990) reported that in greengram highest grain yield was obtained with 20 kg P_2O_5 ha^{-1} which was at par with 40 and 60 kg P_2O_5 ha^{-1}.

Ahlawat and Singh (1991) observed that the grain yield increased markedly by 17.2 and 34.4 kg P ha^{-1} in chickpea. Budhar et al. (1991) found that number of pods and grain weight per plant and grain yield were significantly influenced by higher level of phosphorus (100 kg ha^{-1}).

Dubey and Upadhayaga (1991) noticed that phosphorus fertilization increased both grain and stalk yields significantly in pigeon pea. The response in grain yield was significant upto 30 kg P_2O_5 ha^{-1}. DuraiSingh and Gopala§wamy (1991) in trials with soybean reported that higher doses of phosphorus (120 kg P_2O_5 ha^{-1}) produced higher yield and yield attributes like pods per plant, seeds per pod and test weight of grain.

Grain yield was increased significantly by the application of 40 kg P_2O_5 ha^{-1} in chickpea (Prabhakar and Saraf, 1991). According to Rajput et al. (1991) yield of grain and straw and hundred seed weight increased significantly with an increase in level of phosphorus from 0-40-80 kg ha^{-1}.

Thakuria and Ioikham (1991) reported that application of phosphorus significantly increased the green fodder yield in cowpea and the increase was consistent upto 50 kg P_2O_5 ha^{-1}. Dharam Singh and Singh (1992) observed that phosphorus application improved the yield attributes and grain yield significantly upto 40 kg P_2O_5 ha^{-1} in greengram and cowpea.

Kalita and kalita (1992) reported that application of phosphorus at 40 kg P_2O_5 ha^{-1} recorded maximum and significant value for number of pods per plant, grains per pod, thousand grain weight and grain yield in greengram.

Sarkar (1992) noticed that phosphorus fertilization in green gram upto 80 kg ha^{-1} increased pods per plant, pod length, grainsper pod, 100 grain weight and grain yield.

Singh et al. (1992) found that yield and yield attributes of blackgram were significantly improved due to application of diammonium phosphate @ 100 kg ha^{-1} compared with unfertilized and the plots fertilized with diammonium phosphate @ 50 kg ha^{-1}.

2.1.3 Nodulation and nitrogen fixation

George (1980) reported that phosphorus had significant effect in increasing the number of nodules per plant recording the maximum number of 46.97 nodules with 60 kg P_2O_5 ha^{-1} in blackgram. Haque and Gbla (1980) observed a moderate positive linear effect of rates of P on number of nodules and a highly significant linear effect of P upon nodule weight in soybean. Carsman et al. (1980) reported that phosphorus fertilization increased the number of nodules significantly in soybean. Similar increase in number of nodules per plant in blackgram was observed by Shrivastava et al. (1980) upto 75 kg P_2O_5 ha^{-1}.

Application of 13 kg P ha^{-1} to pigeon pea (*Cajanus cajan* (L) Millsp) significantly increased nodules per plant compared with no P application at all stages of crop growth except at 30 days after planting (Singh et al., 1981).

According to Ahlawat and Saraf (1982) application of phosphorus at 34 kg P ha^{-1} recorded maximum number of nodules and nodule weight than 17 kg P ha^{-1} at 60 and 100 day stages in pigeonpea. Nitrogen yield per plant increased with P application at all growth stages recording higher values with 34 kg compared to 17 kg P ha^{-1}.

Dadson and Acquaah (1984) reported that P application increased the number of nodules significantly in soybean. Vyas et al. (1986) reported that application of 40 kg P_2O_5 ha^{-1} in soybean recorded marked increase in grain yield over control. No further increase in grain and plant characters except nodule weight was observed with P rates in excess of 40 kg ha^{-1}.

Pal and Jana (1991) reported that nodulation was increased significantly upto 30 kg P_2O_5 ha^{-1} in summer greengram. No response was observed beyond 30 kg P_2O_5 ha^{-1}.

Raut and Kohine (1991) observed that phosphorus application with rhizobium inoculation significantly increased the number of nodules by 54 percent and the weight of nodules by 66 percent in chickpea. Thakuria and Ioikham

(1991) reported that application of phosphorus significantly increased the number and dry weight of nodules per plant in cowpea and the increase was consistent upto 50 kg P_2O_5 ha^{-1}.

Kalita and Kalita (1992) observed that application of 40 kg P_2O_5 ha^{-1} produced maximum and significant number of nodules in greengram. According to Jat and Mali (1992) application of phosphorus at 40 kg ha^{-1} increased the nodule dry weight significantly in chickpea.

2.1.4 Chlorophyll and protein content

Singh and Lalhal (1980) showed that chlorophyll content of soybean increased by the increase in the rate of P_2O_5 application.

Application of phosphorus increased the chlorophyll content in summer groundnut upto 60 kg ha^{-1}. However statistical significance was noted only upto 40 kg ha^{-1} (Kaushik and Jain, 1991).

Prasad and Sanoria (1981) obtained highest seed protein content (26.32 percent) in blackgram with nodulation and 150 kg P_2O_5 and lowest 22.93 percent with 50 kg P_2O_5 ha^{-1}.

According to Dwivedi and Singh (1982) the effect of varying doses of P (0,20,40 and 60 kg ha^{-1}) on the percent of protein content was in the increasing order and was significant in bengalgram.

Negi and Thakur (1985) observed that protein content in of seeds of <u>Vigna mungo</u> was increased with increasing phosphorus rates. Roshanlal and Gangasaran (1988) reported that the percent of protein content in groundnut was increased significantly by the application of phosphorus at the rate of 40 kg P_2O_5 ha^{-1}. Rajput etal. (1991) found that protein content of grain increased markedly by phosphorus upto 80 kg P_2O_5 ha^{-1} in soybean.

2.1.5 Nutrient uptake and contents

In redgram, greengram and blackgram application of P increased the P content in grain and straw (Devarajan et al., 1980). Sachidanand et al. (1980) reported that application of phosphorus to soybeans (80, 160, or 240 ppm P_2O_5) significantly increased the P content in plants. Singh and Sharma (1980) found that higher doses of P were effective in increasing uptake of nitrogen, phosphorus and potassium in chickpea (<u>Cicer arietinum</u>) plants at maturity.

A trial conducted by Carsman et al. (1981) to find out the phosphorus requirement of soybean and cowpea as affected by the mode of N nutrition showed that the P concentration of N fixing soybean plants was significantly lower than that of N supplied plants at all levels of applied P fertilizer.

Singh et al. (1981) reported that in field pea (Pisum arvense L. var. Arvense poir) P applied at 60 kg P_2O_5 ha^{-1} gave the maximum uptake of nitrogen. It was shown by Subbian and Ramiah (1981 a) that application of P increased the phosphorus transfer efficiency markedly in redgram and there was not much variation between the two levels of P tested, namely 25 and 50 kg P_2O_5 ha^{-1}. Phosphorus application increased phosphorus uptake at all growth stages of crop and maximum during pod development stage. The rate of P uptake during the pod development stage showed greater need of phosphorus for grain development. Phosphorus application increased nitrogen and potassium uptake also (Subbian and Ramiah, 1981 b).

In pigeon pea, phosphatic fertilizer significantly increased nitrogen and phosphorus concentration and uptake of all nutrients (Hegde and Saraf, 1982). Singh et al. (1983) reported that in pigeon pea application of 17 kg P ha^{-1} increased N and P uptake. However no significant additional increase in N uptake was observed when P was increased to 34 kg ha^{-1}.

Hoque et al. (1984) found that application of phosphorus at increasing rates increased the uptake of phosphorus in soybean.

Negi and Thakur (1985) found that uptake of nitrogen and phosphorus by <u>Vigna mungo</u> increased significantly with increased application of P_2O_5 rates from 0 to 60 kg ha^{-1}. Singh et al.(1986) observed that Mo concentration in mustard increased with phosphorus application.

An increase in molybdenum content by phosphorus application in soybean has been reported by Geethakumari (1989). Mishra and Anand (1989) reported that significant increase in P uptake was observed upto 50 kg ha^{-1} in groundnut.

Tripathi et al. (1989) in their study on the effect of Mo and P_2O_5 in berseem and residual effect in fodder maize in acid soil found that applied phosphorus increased the uptake of molybdenum in the first crop only.

Both nitrogen and phosphorus uptake was increased with phosphorus application in field pea (Srivastava and Verma, 1990). Jana et al. (1990) opined that application of phosphorus increased uptake of nitrogen, phosphorus and potassium in kernel of groundnut.

According to Kaushik and Jain (1991) application of phosphorus increased nitrogen and phosphorus uptake in groundnut upto 60 kg ha^{-1}. However statistical significance was noted only upto 40 kg P_2O_5 ha^{-1}.

Rajput et al. (1991) found that there was a significant increase in NPK contents and their uptake by both grain and straw with every increase in level of phosphorus from 0-40-80 kg. The highest level of phosphorus resulted in the maximum uptake of NPK.

Thakuria and Ioikam (1991) in trails with cowpea found that residual available phosphorus was significant and consistent upto 50 kg P_2O_5 ha^{-1}, but available molybdenum was not affected due to the application of phosphorus. Molybdenum application upto 2 kg ha^{-1} did not influence the residual available phosphorus and molybdenum significantly.

Jat and Mali (1992) observed that application of 40 kg P_2O_5 ha^{-1} to chickpea increased the uptake of nitrogen and phosphorus.

2.2 Dynamics of molybdenum nutrition in legumes

Molybdenum was isolated for the first time by Peter Jacob Hjelm in 1790 and its presence in plants was reported by Demarcay in 1900, as reported by Hopkins (1951). The essentiality of molybdenum for higher plants was established by Arnon and Stout (1939). Plants differ in their ability to extract molybdenum from soils and their requirements of molybdenum. It has been observed that molybdenum is particularly beneficial to legumes and pastures.

2.2.1 Growth and yield

Molybdenum affects several bio-chemical phenomena in plants. Many research workers have reported that molybdenum has an effect on the growth and yield of pulse crops.

In peas (Pisum sativum L) Sharga and Jauhari (1970) reported that application of 0.1 percent molybdenum significantly increased growth and grain yield. Muralidharan and George (1971) opined that height of plants, number of branches, number of leaves per plant and dry matter production was significantly increased by soil application of molybdenum at the rate of 1 kg sodium molybdate ha^{-1} in groundnut.

Shivashankar (1976) observed a favourable effect of doubling the number of pods because of molybdenum nutrition in soybean. Shivashankar (1977) observed that seed treatment of molybdenum increased number and weight of pods of soybean over control.

Haque and Amara (1978) reported that dry matter yield increased from 74 g/m^2 with control to 87.3 g/m^2 with inoculation +0.2 g sodium molybdate /100 g seed and treatment with 0.2 and 0.4 g sodium molybdate /100 g seed gave highest yields.

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The effect of combination of rhizobium inoculation and seed treatment with 0, 200 or 400 g. Mo ha^{-1} on Bragg was studied by Barthakur in 1980 who observed that molybdenum increased plant dry weight. Seed yield of inoculated soybean was increased by 360 percent by the combined application of nitrogen and molybdenum (Haque and Bundu, 1980).

Soybean grain yield and plant dry weight were increased significantly with two and five percent ammonium molybdate solution applied to seeds (Weeraratna, 1980). Boswell (1981) reported that the effective dose of molybdenum for seed treatment of seeds of soybean is 17 g ha^{-1}.

Sodium molybdate @ 217 g ha^{-1} dissolved in 800 litres of water applied during vegetative phase and particularly at pod formation stage increased soybean yield (Hurduc and Savureseu, 1981).

Kormilitsyn (1981) reported that the molybdenum fertilization either by pre sowing treatment of seeds with ammonium molybdate solution or by molybdenum fertilization considerably increased the soybean yields upto 23 percent.

Subbian and Ramiah (1982) in their field experiments with seed and soil application of sodium molybdate in redgram found that molybdenum nutrition did not show any significant increase in growth and yield characters.

Ben et al. (1983) reported that seed yield of soybean increased but not significantly following seed treatment with 18 g molybdenum. Paricha and Kar (1983) observed that seed treatment with molybdenum in blackgram increased the seed yield.

Paricha et al. (1983) found that number of pods per plant was increased significantly by molybdenum treatment in <u>Vigna radiata</u> and the grain yield was increased by 26.4 percent.

Velu and Savithri (1983) reported that the foliar spray of 0.1 percent sodium molybdate thrice at 20th, 30th and 40th day increased the grain yield by 303 kg in blackgram Co-4 variety and the application at the rate of 1.00 kg ha^{-1} increased the grain yield by 459 kg ha^{-1} in Co-4 greengram variety.

Shivashankar (1984) observed that seed treatment of soybean with sodium molybdate was highly toxic in burning away the root morphology by evoking a good response with the emergence of three to four fresh lateral roots where a single tap root existed originally. The number of pods per plant more than doubled with molybdenum treatment.

In pot trials application of molybdenum to soil at the rate of 100 g ha^{-1} increased the dry weight of stems, leaves and number of pods per plant significantly in horse gram (Pradhan and Sarkar, 1985).

Sherell (1985) observed that application of molybdenum in white clover, red clover and leucerne by seed soaking was more than two times as effective as soil application in increasing yield.

Shivashankar (1985) reported significant increase in yield of Vigna radiata and Vigna mungo by treating with 8 g sodium molybdate per kg of seed.

Sukhada Mohandas (1985) opined that bean seeds treated at a concentration of 2ppm showed statistically significant improvement in leaf area and shoot dry weight and caused 56 percent improvement in yield.

Anwarulla and Shivashankar (1987) found that both seed treatment and foliar nutrition of molybdenum favourably influenced the growth of greengram and blackgram by increasing the number of branches and leaves and by nearly doubling the leaf area index. This resulted in increased dry matter, hundred grain weight and yield of pods and grain yield.

In an experiment to study the effect of micro nutrients on yield of soybean, Khalia and Sharma (1988) found that only molybdenum application which is required in higher amount by legumes did result in significant increase in grain yield. This increase in yield may be explained from the yield attributes such as pods per plant, yield per plant and hundred seed weight which were found to be maximum in Mo-treated plants.

Nayak et al. (1989) reported that seed treatment with molybdenum at the rate of 30 g ha^{-1} exerted a significant influence on growth, yield and yield attributes like pods per plant, seeds per pod and hundred seed weight in soybean.

Lapinskar (1990) observed that seed inoculation with rhizobium and seed treatments with 2.5 percent ammonium molybdate increased the average dry matter yields significantly in Trifolium pratense and Medicago sativa.

2.2.2. Nodulation, nitrogen fixation and metabolism

Bortels (1930) was the first man who showed that molybdenum was highly beneficial in N_2 fixation by the nitrogen fixing bacterium Azotobacter chroococcum. Later several workers observed the importance of molybdenum in N_2 fixation (Mulder, 1950; Evans, 1954; Nicholas, 1957; Pandey, 1969).

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Sharga and Jauhari (1970) showed significant increase in nodulation of pea by foliar application of 0.1 percent molybdenum.

Singh (1971) reported similar increase in N content in leaves of daincha by molybdenum application. He also observed that molybdenum supply improved the nitrogen content of stem also. Increase in the number of nodulation and their dry weight per plant of cluster bean with molybdenum treatment had been reported by Ghonsikar and Saxena (1973).

Increased nitrogen content in leaves and stem was reported by application of molybdenum by Kadwe and Budhe (1973) in blackgram. Shivashankar (1977) reported that molybdenum promoted yield of pulse crops like soybean by way of increasing nitrogen fixing ability, nitrogenase activity, uptake of nutrients and thereby general vigour of the crop.

Huang (1979) opined that application of 100to300 g MoO_3 ha^{-1} to soybean increased the number and dry weight of root nodules significantly. Santos and Das (1979) reported positive response of legumes to molybdenum with increasd symbiotic N_2 fixation and effectiveness of nitrate reductase. Significant increase in nodulation of soybean by treating seeds with molybdenum at the rate of 200 and 400 g Mo ha^{-1} was observed by Barthakur (1980).

Weeraratna (1980) suggested that treating seeds of soybean with two percent ammonium molybdate increased the nitrogen content and N_2 fixation. An increase in nodulation in legumes by treating seeds of soybean with sodium molybdate @ 11g Mo ha^{-1} was reported by Kolling et al. (1981).

Srivastava and Verma (1982) observed that soil application of molybdenum at 0.5 kg sodium molybdate ha^{-1} gave higher number of nodules and weight in greengram.

Paricha and Kar (1983) found that the number of nodules and their dry weight and leaf nitrogen content were significantly increased by molybdenum seed treatment in <u>Vigna mungo</u>. Paricha et al. (1983) reported that in <u>Vigna radiata</u> seed treatment with molybdenum increased the number of nodules and the nodules in Mo - treated plants were larger in size.

Lyashko (1984) found that molybdenum application with seed inoculation with rhizobium increased the nitrogen content in soybean plants.

Sherell (1985) observed that application of molybdenum in white clover, red clover and lucerne by seed soaking was more than two times as effective as soil application in increasing N_2 fixation.

Shivashankar (1984; 1985) also got an increase in nodulation and N_2 fixation by treating seeds of soybean with sodium molybdate.

Pradhan and Sarkar (1985) observed that application of molybdenum to soil at the rate of 100 g ha^{-1} increased the dry weight of nodules of horsegram significantly.

Sukhada Mohandas (1985) opined that bean seeds treated with molybdenum at a concentration of two ppm showed significant improvement in nodule number, fresh weight and 50 per cent increase in nitrogen content.

Anwarulla and Shivashankar (1987) reported that both seed treatment and foliar application of sodium molybdate in greengram and blackgram were found to be superior to control in respect of the number of nodules and dry weight of nodules per plant.

Sharma and Minhas (1990) reported that both seed and soil application of molybdenum at the rate of 70 g ha^{-1} produced the maximum mean nitrogen content in soybean.

2.2.3. Chlorophyll content and seed quality

Jha (1964) reported an increase in chlorophyll content in molybdenum treated blackgram and greengram plants. In vetch varieties Orlova and Bazhanova (1975) got a similar increase in chlorophyll content in leaves with molybdenum application.

Shivashankar (1977) also reported a favourable influence of molybdenum on chlorophyll content of soybean. This result was confirmed by Anwarulla and Shivashankar (1987) who observed an increase in chlorophyll content by seed treatment as well as foliar application in greengram and blackgram.

Huang (1979) found that soil application of molybdenum increased chlorophyll content in soybean. Molybdenum seed treatment in soybean with 4g sodium molybdate per kg of seed gave significantly higher chlorophyll content than control (Geethakumari, 1989).

Haque and Bundu (1980) reported that protein content in seeds of soybean was increased significantly by the application of molybdenum with rhizobial inoculation.

Molybdenum was reported as an essential element for protein synthesis by Boswell (1981). Kormilitsyn (1981) opined that molybdenum fertilization increased the crude protein content by 2.7 percent and pure protein by 5.8 percent in soybean.

Ermolaev (1983) observed that pre-sowing treatment of seeds of Phaseolus vulgaris with ammonium molybdate increased the protein content of grain.

Lyashko (1984) found that molybdenum application with rhizobium inoculation increased the protein content in seeds of soybean.

Anwarulla and Shivashankar (1987) observed increase in protein content of greengram and blackgram by seed treatment and foliar application of sodium molybdate.

Sharma and Minhas (1990) also reported an increase in protein content in soybean grains by both seed and soil application of molybdenum.

2.2.4. Nutrient uptake

Jensen and Lesperance (1971) reported that molybdenum added to soil increased molybdenum accumulation in Medicago sativa to 5.2 ppm.

Haque and Amara (1978) found that seed treatment of groundnut with sodium molybdate at the rate of 0.4 or 0.8 g per 100 g of seed increased the uptake of nitrogen significantly.

Martvedt (1981) observed that application of two ppm molybdenum to soil on soybean, lucerne, arrow leaf, red and subterranean clovers increased the uptake of nitrogen and molybdenum.

Both seed and soil application of sodium molybdate on redgram did not show any marked increase in NPK and molybdenum uptake (Subbian and Ramiah, 1981 b).

Lyashko (1984) found that soil application of molybdenum with rhizobium seed inoculation increased the nitrogen content in soybean.

Sundararajan et al. (1984) in field experiment with rainfed spanish groundnut observed that fertilization of molybdenum neither increased the uptake of nutrients nor yield of unshelled nuts. An increase in phosphorus content by the application of molybdenum in soybean had been reported by Geethakumri (1989). Tripathi et al. (1989) found that increasing rates of molybdenum increased the uptake of molybdenum in berseem.

2.3. Interaction effects of phosphorus and molybdenum on legumes

Interaction effects of phosphorus and molybdenum on growth and yield of legumes, uptake of nutrients was reported by many workers. Synergestic effect on crops had been observed between phosphorus and molybdenum by different workers.

2.3.1. **Growth and yield**

Crafts (1954) found that in peas application of super phosphate alone increased yield by 74 percent and application of super phosphate and crude sodium molybdate together increased yield by 91 percent.

Combined application of phosphorus and sodium molybdate significantly increased leaf number, and dry matter production in groundnut. (Muralidharan and George, 1971).

Field experiments conducted on calcareous sandy loam soils at IARI revealed that application of phosphorus and molybdenum improved plant productivity and enhanced grain yield of bengalgram significantly (Mudholkar and Ahlawat, 1979). Kormilitsyn (1981) reported that molybdenum fertilization in conjunction with basal phosphorus either by presowing treatment of seeds with ammonium molybdate solution or by molybdenum fertilization increased soybean yield upto 23 percent.

Kukresh (1981) found that seed treatment with molybdenum significantly increased fodder and seed yields of spring vetch supplied with phosphorus. Basak et al. (1982) observed that application of phosphorus in combination with molybdenum increased shoot dry matter yields of rice.

Shivashankar (1985) observed that yield realised from groundnut by the application of 75 kg P_2O_5 ha^{-1} and that obtained by the combined application of six g sodium molybdate and 37.5 kg P_2O_5 were on par.

Rhizobium inoculation of blackgram, bengalgram, pea and berseem along with phosphate and molybdate application increased the yield under pot culture conditions and of pigeon pea and groundnut under field conditions (Tiwari et al., 1989).

2.3.2. Nodulation

Application of P_2O_5 and sodium molybdate at 75 and 1 kg ha^{-1} respectively increased significantly the weight of nodular tissue per plant in groundnut (Muralidharan and George, 1971).

Tang (1979) opined that application of phosphorus in conjunction with molybdenum increased the nodulation of soybean.

Improved nodulation in soybean by the combined application of phosphorus and molybdenum was reported by Kormilitsyn (1981).

Tiwari et al. (1989) reported that rhizobium inoculation of blackgram, bengalgram, pea and berseem along with phosphate and molybdate application increased the nodulation under pot culture conditions.

2.3.3. Uptake of nutrients

Shukla and Pathak (1973) in a pot culture experiment showed that application of 50 kg P_2O_5 and 0.5 kg Mo together increased the content of phosphorus and molybdenum in berseem, than application of either of them alone.

Singh and Kumar (1979) reported that phosphorus interacted significantly to increase the uptake of molybdenum in soybean.

The addition of molybdenum in the absence of phosphorus decreased the concentration and uptake of sulphur. But when phosphorus was applied the antagonistic effect of molybdenum was overcome (Vinodkumar and Singh, 1981).

Application of phosphorus and molybdenum resulted in increased concentration of molybdenum in clover– grass mixture from one to five ppm Mo (Petric and Jackson, 1982).

Singh et al. (1986) observed that molybdenum concentration in mustard increased with phosphorus application.

Tripathi et al. (1989) in their study on the effect of molybdenum and phosphate in berseem and residual effect on fodder maize in acid soil found that increasing molybdenum rates increased molybdenum and phosphorus uptake in both crops. Applied phosphorus increased phosphorus uptake in both crops and molybdenum uptake in the first crop only.

Results of the research works conducted in different parts of the country revealed favourable response of cowpea for increased application of phosphorus upto about 40 kg P_2O_5 ha^{-1}. Leguminous crops like groundnut, soybean, blackgram and green gram responded well to molybdenum. Seed treatment with molybdenum promoted nitrogen fixation in pea, soybean and blackgram, chlorophyll content in blackgram, green gram and soybean, dry matter production and growth characters in groundnut, beans green gram and blackgram and grain yield in peas, blackgram, soybean, blackgram, greengram and horsegram. But work on molybdenum on cowpea under Kerala conditions is meagre.

Positive interaction between phosphorus and molybdenum with respect to growth and yield attributes were observed in crops like peas, groundnut, bengal gram, soybean and pigeon pea. About 20 per cent increase in yield in peas and soybean were observed by the combined application of phosphorus and molybdenum.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was undertaken with the objective of assessing the interaction effect between phosphorus and molybdenum on the growth and yield of cowpea. The investigation comprised of an initial pot culture study followed by a field experiment. The materials used and the methods adopted for the study are briefly described in this chapter.

3.1 POT CULTURE STUDY

This study was conducted for estimating the optimum dose and mode of seed treatment of molybdenum for grain type of cowpea.

3.1.1 Experimental site

The pot culture study was carried out in the crop museum, attached to the Department of Agronomy, College of Agriculture, Vellayani.

3.1.2 Soil

The soil used for the study was red sandy clay loam. The data on the physico chemical properties of the soil used for the pot culture study are furnished in Table 1.

Table 1. Physico chemical properties of the soil.

Constituent	Content in soil	Rating	Method used
A. Mechanical composition			
Coarse sand	14.50 percent		Bouyoucos
Fine sand	32.40 percent		Hydrometer method
Silt	29.00 percent		(Bouyoucos, 1962)
Clay	24.10 percent		
Textural class	sandy clayloam		
B. Chemical composition			
Organic carbon	0.72 percent	High	Walkley and Black Rapid Titration method (Jackson, 1973)
Available Nitrogen	225 kg/ha	Low	Alkaline Potassium permanganate method (Subbiah and Asija 1956)
Available P_2O_5	38 kg/ha	Medium	Bray Colorimetric method (Jackson, 1973)
Available K_2O	138 kg/ha	Medium	Ammonium acetate method (Jackson, 1973)
Available Molybdenum	0.03 ppm	Low	Hot water soluble method
pH	5.2	Acidic	1:2 Soil solution using pH meter (Jackson, 1973)

3.1.3 Season

The study was conducted during the period from 21st April to 26th July 1990.

3.1.4 Weather data

The meteorological data during the cropping period was collected from the meteorological observatory attached to the Department of Agronomy, College Agriculture, Vellayani and are presented in Appendix 1 and Fig. 1a.

3.1.5 Crop and variety

The cowpea variety used for the study was C-152. This variety was evolved at IARI and is recommended for cultivation in the red sandy clay loam soils of Kerala. It is an erect, tall variety with a duration of about 90 to 100 days.

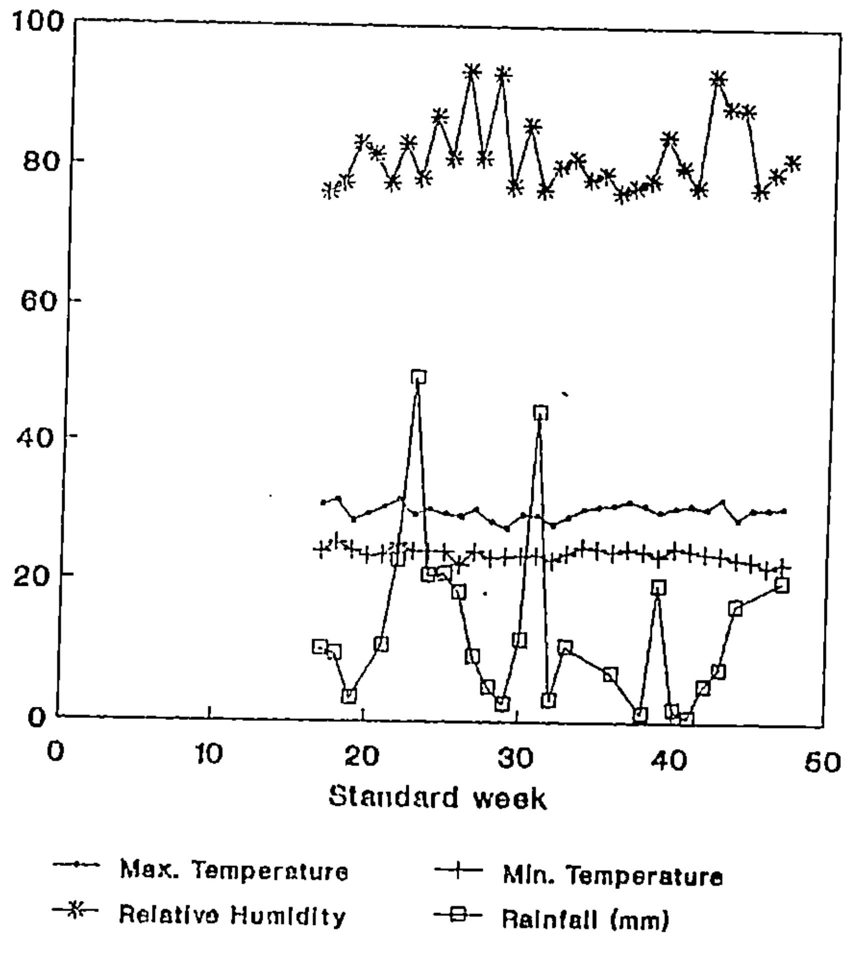
3.1.6 Source of the seed mateiral

The seeds were obtained from the National Seeds Corporation, Karamana.

3.1.7 Fertilizers

Fertilizers with the following analysis were used for the study.

Fig. 1a. Weather conditions during the cropping period (21-4-1990 to 24-11-1990)



Urea - 46 percent N

Mussoriephos - 22 percent P_2O_5

Muriate of Potash = 60 percent K_2O

3.1.8 Design

A pot culture experiment was conducted in CRD with six replications with the following treatments. The treatments comprised of nine levels of molybdenum as sodium molybdate and two methods of seed treatment.

Levels of molybdenum

M_1 = 0.5 g sodium molybdate per kg of seed

M_2 = 1.5 g ,,

M_3 = 2.5 g ,,

M_4 = 3.5 g ,,

M_5 = 4.5 g ,,

M_6 = 5.5 g ,,

M_7 = 6.5 g ,,

M_8 = 7.5 g ,,

M_9 = 8.5 g ,,

Method of seed treatment

S1 Seed coating (Sc)

S2 Seed imbibition (Si)

Treatment combinations

T_0 = Control

T_1 = M_1Sc	T_7 = M_4Sc	T_{13} = M_7Sc
T_2 = M_1Si	T_8 = M_4Si	T_{14} = M_7Si
T_3 = M_2Sc	T_9 = M_5Sc	T_{15} = M_8Sc
T_4 = M_2Si	T_{10} = M_5Si	T_{16} = M_8Si
T_5 = M_3Sc	T_{11} = M_6Sc	T_{17} = M_9Sc
T_6 = M_3Si	T_{12} = M_6Si	T_{18} = M_9Si

3.1.9 Seeds and sowing

3.1.9.1 Seed Treatment

In seed coating method of seed treatment cowpea seeds were dressed with sodium molybdate at rates as per experimental schedule with two percent sugar solution as sticking agent before treating with rhizobium culture and shade dried before sowing.

In seed imbibition method seeds were soaked in sodium molybdate solution for complete imbibition and shade dried before sowing (Shivashankar, 1984). 11.6 kg air dry soil from the proposed experimental site was collected and mixed with FYM and filled in each pot. Two bold disease free seeds of cowpea were sown in each pot. Fertilizers were added as recommended in the package of practices of KAU (N:P:K @ 20:30:10 kg ha^{-1}). Sowing was done on 21.4.90.

3.1.10 After cultivation

Gap filling and thinning were done seven days after sowing so that one healthy plant was retained in each pot. All the weeds were removed by hand weeding and the pots were kept completely weed free.

3.1.11 Plant protection

Two sprayings were given with Ekalux against pests. (0.03 per cent)

3.1.12 Harvest

The dry pods from each pot were picked thrice, sundried, threshed pot wise and the yield of grain and bhusa were recorded separately. The plants were then pulled out from each pot and sundried.

3.1.13 Observations

a. Growth characters

3.1.13.1 Number of leaves per plant

The number of leaves per plant in each pot was counted, and the mean value of the six replications were computed at flowering stage.

3.1.13.2 Number of branches per plant

The number of branches per plant in each pot was counted, and the mean value of the six replications were computed at flowering stage.

3.1.13.3 Number of nodules per plant

One plant each from two replications was dug out carefully. The roots of the plants were washed free of soil particles. The nodules were removed from roots and counted and the average number of nodules per plant was recorded at flowering stage.

b. Yield and yield attributes

3.1.13.4 Grain yield

Yield of grain obtained from each pot was recorded separately and furnished as yield per plant.

3.1.13.5 Number of pods per plant

The number of pods per plant in each pot was counted at the time of harvest and the mean value was computed.

3.1.13.6 Number of seeds per pod

Five pods from each pot was threshed separately and the number of seeds in each pod was counted and the average was worked out.

3.1.13.7 Hundred seed weight

Hundred seeds were selected randomly from each pot, weighed and recorded in g.

3.1.14 Statistical Analysis

The statistical analysis of the data on the above mentioned biometric observations and yield attributes was done and the significance was tested by F test (Snedecor and Cochran, 1967). Based on the results, three levels of Sodium molybdate (0.5, 1.5 and 2.5 g of sodium molybdate kg^{-1} of seed) were selected for the field experiment.

3.2 FIELD EXPERIMENT

A field experiment was conducted for assessing the interaction effect between phosphorus and molybdenum on the growth and yield of cowpea var. C-152.

The materials and methods used for the study are briefly described below.

3.2.1 Experimental site

The experiment was conducted at the Instructional farm attached to the College of Agriculture, Vellayani. The site selected was an open terraced land with good sunlight. The land was lying fallow during the preceeding eleven months of the present investigation.

3.2.2 Soil

The data on the physico - chemical properties of the soil are the same as that of the soil used for pot culture study as presented in para 3.1.2.

3.2.3 Season

The experiment was conducted during the period from 16th August 1990 to 30th November 1990.

3.2.4 Weather conditions

The weather data during the entire crop season were collected from the meteorological observatory, attached to the Department of Agronomy, College of Agriculture, Vellayani and are presented as standard week averages in Appendix 1 and Fig. 1a.

3.2.5 Crop and Variety

Cowpea variety C-152 was used for the study. The seed material was supplied by the National Seeds Corporation, Karamana.

3.2.6 Fertilizers

Fertilizers with the following analysis were used for the study.

Urea = 46 percent N

Mussoriephos = 22 percent P_2O_5

Muriate potash = 60 percent K_2O

3.2.7 Land preparation

The experimental site was tilled with a power tiller. The weeds and stubbles were removed and the soil was mixed with cowdung (2t ha^{-1}). The field was laid out into plots and blocks as per experimental design.

3.2.8 Seeds and Sowing

Cowpea seeds were dressed with sodium molybdate at rates as per experimental shedule with two percent sugar solution as sticking agent before treating with rhizobium culture (Shivashankar, 1984). Treated seeds were dibbled into the soil at a spacing of 25x15 cm.

3.2.9 Fertilizer application

Lime at the rate of 250kg ha^{-1} was applied at the time of first ploughing. Half the quantity of nitrogen and whole of potash were applied as basal as per package of practices recommendation at the rate of 20 kg N and 10 kg K_2O per hectare. Remaining N was applied 20 days after sowing. phosphorus was given as per experimental schedule.

3.2.10 After cultivation

Germination was good. One week after emergence, the crop was thinned. The crop was given two weedings and three hoeings. Irrigation was done twice. First irrigation was given 15 days after sowing and the second at the flowering stage. Thirty days after sowing, ten plants were selected randomly from the net plot area and tagged as observational plants.

3.2.11 Plant Protection

Two sprayings were given with Ekalux against pests as prophyllatic measure(0.03 per cent)

3.2.12 Harvest

The dry pods from the net plot were picked thrice, sun dried, threshed plot-wise and the yield of grain and bhusa were recorded separately. The plants were then pulled out from the net area of each plot and sun dried. A day prior to harvest, the observational plants were pulled out and necessary observations were recorded.

3.2.13 Design and layout

The experiment was laid out in RBD with three replications. The layout plan is shown in Fig.1b.

Gross plot size	= 3 x 3.45 m
Net plot size	= 2.5 x 2.85 m
Spacing	= 25 x 15 cm
Net area of one plot	= 7.125 sq cm

Fig. 1b. LAY OUT PLAN

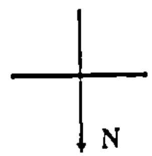
<----- Replication I ----->				<----- Replication II ----->				<----- Replication III ----->			
P_1M_2	P_3M_1	P_4M_3	P_4M_2	P_2M_3	P_1M_0	P_1M_2	P_3M_3	P_2M_0	P_2M_2	P_3M_3	P_1M_0
P_2M_0	P_2M_1	P_4M_1	P_3M_0	P_3M_0	P_4M_0	P_1M_1	P_4M_2	P_1M_3	P_3M_0	P_3M_2	P_4M_0
P_2M_3	P_2M_2	P_3M_2	P_1M_1	P_3M_1	P_2M_2	P_2M_0	P_4M_3	P_4M_1	P_1M_1	P_2M_3	P_4M_2
P_1M_0	P_1M_3	P_3M_3	P_4M_0	P_4M_1	P_3M_2	P_2M_1	P_1M_3	P_3M_1	P_1M_2	P_2M_1	P_4M_3

Design - R.B.D.

Plot size - 3.0 x 3.45 m

Levels of phosphorus
P_1 = 15 kg P_2O_5 ha^{-1}
P_2 = 22.5 kg P_2O_5 ha^{-1}
P_3 = 30 kg P_2O_5 ha^{-1}
P_4 = 37.5 kg P_2O_5 ha^{-1}

Levels of molybdenum
M_0 = 0 g sodium molybdate kg^{-1} of seed
M_1 = 0.5 g sodium molybdate kg^{-1} of seed
M_2 = 1.5 g sodium molybdate kg^{-1} of seed
M_3 = 2.5 g sodium molybdate kg^{-1} of seed



3.2.13.1 Treatments

The treatments comprised of four levels of phosphorus and four levels of molybdenum as shown below.

Levels of Phosphorus	Levels of molybdenum
P_1=15.0kg P_2O_5 ha^{-1}	M_0=0 g Sodium molybdate kg^{-1} of seed
P_2=22.5 kg P_2O_5 ha^{-1}	M_1=0.5 g Sodium molybdate kg^{-1} of seed
P_3=30.0kg P_2O_5 ha^{-1}	M_2=1.5 g Sodium molybdate kg^{-1} of seed
P_4=37.5 kg P_2O_5 ha^{-1}	M_3=2.5 g Sodium molybdate kg^{-1} of seed

N and K_2O @ 20;10 kg ha^{-1} and lime @ 250 kg ha^{-1} were applied uniformly to all the treatments.

Treatment Combinations

P_1 M_0	P_2 M_0	P_3 M_0	P_4 M_0
P_1 M_1	P_2 M_1	P_3 M_1	P_4 M_1
P_1 M_2	P_2 M_2	P_3 M_2	P_4 M_2
P_1 M_3	P_2 M_3	P_3 M_3	P_4 M_3

Number of replications = Three

3.2.14 Observations

a. Growth characters

3.2.14.1 Height of the plant

The mean values of the heights of 10 sample plants were computed at vegetative, flowering and harvest stages and recorded. The height was taken from the base of the plant to the terminal node and expressed in centimetres.

3.2.14.2 Number of branches per plant

The mean values for the number of branches per plant were computed from ten observational plants at vegetative, flowering and harvest stages and were recorded.

3.2.14.3 Leaf area index (LAI)

The leaf area of ten observational plants in each plot was measured with the help of a leafarea meter, at vegetative, flowering and harvest stages. The LAI was worked out from the data on leaf area and corresponding ground area as follows:

$$LAI = \frac{\text{Leaf Area}}{\text{Ground area}}$$

3.2.14.4 Number and weight of root nodules per plant

This was recorded at vegetative and flowering stages. Three plants were dug at uniform depth of approximately 40 cm from the rows set a part for this observation. The roots of the plants were washed free of soil particles. The nodules were removed from the roots and counted and the average number of nodules per plant was recorded. The nodules were then ovendried to a constant weight and the weight of the nodules per plant was recorded.

3.2.14.5 Chlorophyll content at 50% flowering

Total chlorophyll content of fresh leaves were estimated at flowering stage by Spectrophotometric method as described by Starnes and Hadley (1963). The content of total chlorophyll (mg g^{-1} fresh weight) was then estimated using the following relationship.

$$\text{Total chlorophyll } (mg\, g^{-1}) = \frac{(20.2\, A_{645} + 8.02 A_{663})}{a \times 1000 \times W} \times V$$

Where a = length of path light in the cell (usually 1cm)

V = volume of extract in ml

W = fresh weight of the sample in g

3.2.14.6 Dry matter partitioning

The observation was taken at three stages, i.e. vegetative, flowering and at harvest. Five plants were uprooted carefully, sun dried and then oven dried at 80°C for 48 hours and the weight of leaf and stem were recorded separately.

3.2.14.7 Days to 50 percent flowering

The date of flowering of 50 percent of the net population was recorded for each treatment and the period taken was recorded as number of days.

b. Yield and yield attributes

3.2.14.8 Number of pods per plant

Pods collected from the observational plants were counted separately and the averages were worked out.

3.2.14.9 Length of pod

Lengths of 10 pods selected randomly from the net plot of each treatment were measured in cm and the averages were worked out.

3.2.14.10 Number of seeds per pod

Pods used for measuring the length were threshed separately and the number of seeds in each pod were counted and the averages were worked out.

3.2.14.11 Hundred seed weight

Hundred seeds selected randomly from the bulk in each net plot, were weighed and recorded in g.

3.2.14.12 Grain yield

Yield of grain obtained from each net plot was recorded separately and expressed in kg ha^{-1} adjusted to 12 percent moisture.

3.2.14.13 Bhusa yield

After the pods were picked from each net plot, the plants were uprooted, sundried uniformly and weighed. The weight was expressed in kg ha^{-1}.

3.2.14.14 Total dry matter production

The sample plants were sundried and then dried to a constant weight in an air oven kept at 80°C for 48 hours. Dry matter production was worked out for each treatment and expressed in kg ha^{-1}.

3.2.14.15 Harvest index

The harvest index was worked out based on the grain, husk and bhusa yield obtained from the net plot using the following formula and expressed in percent as suggested by Nichiporovich (1960)

$$\text{HI percent} = \frac{\text{Economic Yield}}{\text{Biological Yield}} \times 100$$

3.2.15 Chemical Analysis

3.2.15.1 Plant analysis

The sun dried plant samples were chopped and dried in an air oven at 80°C till constant weight was obtained.

The samples were then ground to 0.5 mm size. The plant and grain samples were separately analysed for nitrogen, phosphorus, potassium and molybdenum contents at harvest.

3.2.15.1.1 Nitrogen

Total nitrogen content of the plant sample was estimated by the modified Microkjeldahl method (Jackson, 1973).

3.2.15.1.2 Phosphorus

The Phosphorus content of the plant samples were estimated colorimetrically, after wet digestion of the sample and developing colour by Vanadomolybdo phosphoric yellow colour method and the colour intensity was read in a Klett summerson photo electric colorimeter (Jackson, 1973).

3.2.15.1.3 Potassium

Total potassium content in plant sample was estimated by the flame photometric method in the Perkin-Elmer 3030 Atomic Absorption Spectrophotometer, after wet digestion of the sample using di- acid mixture (Cooksey and Barnett, 1979).

3.2.15.1.4 Molybdenum

The molybdenum content in plant samples were determined colorimetrically by the thiocyanate orange-red colour method

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(Jackson, 1973) and the colour intensity was read in a Klett Summerson photo electric colorimeter using a blue filter.

3.2.15.1.5 Protein content of the grain

The percentage of protein in the grain was calculated from the percentage of nitrogen by using the factor 6.25 (Simpson et al., 1965).

3.2.15.1.6 Uptake of nutrients by the crop

The total uptake of N, P, K and Mo by the plant was calculated from the nutrient contents and dry weight of the plant at harvest and expressed as kg ha^{-1}.

3.2.15.2 Soil analysis

The composite soil sample collected prior to the experiment and soil samples collected from individual plots after the experiment were analysed for available N, available P_2O_5 and available K_2O. Available nitrogen was determined by the alkaline potassium permanganate method (Subbiah and Asija, 1956). Available phosphorus was determined by Bray colorimetric method (Jackson, 1973). Available potassium was determined by the ammonium acetate method (Jackson, 1973).

3.2.15.3 Statistical analysis

Data relating to each character were statistically analysed and the significance tested by F - test (Snedecor and Cochran, 1967).

Important correlations were also worked out.

Dose - response relisationship and standardisation of fertilizer response

Dose - response relationship was explained by
$y = b_o + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2$.

The optimum combination of phosphorus and molybdenum (mathematical and economic optimum doses) was estimated by solving the equations.

$$\frac{dy}{dx_1} = 0, \quad \frac{P_p}{P_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\frac{dy}{dx_2} = 0, \quad \frac{P_m}{P_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where P_y = price per kg of grain

P_p = price per kg of P_2 O_5

P_m = price per g of molybdenum .

RESULTS

4. RESULTS

POT CULTURE

The results of the pot culture experiment, to find out the optimum dose and mode of seed treatment of molybdenum for cowpea are presented below.

4.1 GROWTH CHARACTERS

The effect of the methods of seed treatment with molybdenum for cowpea on growth characters viz. number of branches per plant, number of leaves per plant and number of nodules per plant at flowering stage are presented in Tables 2 and 3.

Number of leaves, number of branches and number of nodules per plant at flowering stage increased significantly with increasing levels of molybdenum upto M_3 level (2.5 g sodium molybdate kg^{-1} of seed) for seed coating mode of seed treatment. Highest value for all the growth characters were recorded at M_3 level and a significant reduction was noticed with increasing levels of molybdenum beyond M_3 level.

Significant interaction for number of leaves was observed between treatments and seed coating. No significant difference in number of leaves was observed at M_2 and M_3 levels of molybdenum in seed coating and then a significant

Table 2. Growth and yield of cowpea as influenced by different levels of molybdenum

Levels of molybdenum (g sodium molybdate kg^{-1} of seed)	Leaves $plant^{-1}$ (No.)	Branches $plant^{-1}$ (No.)	Root nodules $plant^{-1}$ (No.)	Pods $plant^{-1}$ (No.)	Seeds pod^{-1} (No.)	Hundred seed weight (g)	Grain yield $plant^{-1}$ (g)
0.5	36.0	13.3	107	14.3	15.2	9.7	5.3
1.5	38.0	13.3	149	15.6	15.7	9.9	5.6
2.5	37.3	13.5	165	16.0	15.7	10	5.9
3.5	33.5	10.7	107	13.3	13.8	9.6	5.1
4.5	27.2	9.4	95	12.4	13.2	9.3	4.8
5.5	27.5	9.8	75	12.0	13.1	8.9	4.1
6.5	22.0	9.3	56	11.8	12.0	8.7	4.0
7.5	20.2	8.8	51	11.3	11.6	8.5	4.0
8.5	18.5	8.5	42	10.8	11.0	8.3	3.6
F (8, 38)	420.60**	92.48**	358.90**	100.02**	146.73**	75.94**	11.57**
SEm ±	0.37	0.22	2.26	0.19	0.15	0.10	0.01
C.D. (0.05)	1.06	0.62	6.5	0.54	0.43	00.29	0.04
Control	41.3	12.3	101	15.0	14.3	9.8	4.5
Trd. Vs. control F (1, 38)	532.2**	25.89**	4.15**	69.18**	15.58**	33.14**	8.43**

** Significant at 0.01 level

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Table 3. Interaction effects of levels and mode of seed treatment of molybdenum on growth and yield of cowpea

Treatment	Leaves $plant^{-1}$ (No.)	Branches $plant^{-1}$ (No.)	Root nodules $plant^{-1}$ (No.)	Pods $plant^{-1}$ (No.)	Seeds pod^{-1} (No.)	Hundred seed weight (g)	Grain yield $plant^{-1}$ (g)
Sc M_1	44.3	16.3	135	17.7	16.1	10.2	6.8
Sc M_2	45.6	16.3	206	20.7	17.3	10.6	7.4
Sc M_3	46.3	17.3	245	21.3	17.0	11.0	8.0
Sc M_4	40.3	12.3	111	17.0	16.4	10.7	6.4
Sc M_5	30.3	10.7	105	15.3	15.3	10.2	5.8
Sc M_6	33.6	11.3	95	14.7	15.6	9.6	4.6
Sc M_7	22.7	9.7	88	14.3	13.7	9.5	4.5
Sc M_8	21.3	9.7	76	13.7	13.6	9.4	4.4
Sc M_9	20.6	9.7	61	13.0	12.7	9.1	4.0
Mean	33.9	12.7	125	16.4	15.3	10.0	5.8
Si M_1	27.7	10.3	78	10.9	14.4	9.2	3.8
Si M_2	30.3	10.3	92	10.6	14.2	9.1	3.8
Si M_3	28.3	9.6	84	10.6	14.4	8.9	3.8
Si M_4	26.6	9.1	102	9.6	11.2	8.5	3.7
Si M_5	24.0	8.1	84	9.5	11.1	8.4	3.7
Si M_6	21.3	8.2	56	9.3	10.5	8.1	3.5
Si M_7	21.3	8.2	25	9.2	10.1	7.8	3.5
Si M_8	19.0	8.1	25	8.9	9.5	7.7	3.5
Si M_9	16.3	7.3	23	8.3	9.2	7.5	3.2
Mean	23.9	8.8	63	9.7	11.6	8.4	3.6
Control	41.3	12.3	101	15.0	14.3	9.8	4.5
F (8, 38)	76.21**	25.33**	111.39**	34.99**	14.25**	5.05**	7.2**
SEm±	0.52	0.30	3.2	0.27	0.21	0.10	0.05
C.D. (0.05)	1.5	0.87	9.2	0.77	0.60	0.29	0.02

** Significant at 0.01 level Sc - Seed coating Si - Seed imbibition decrease was seen. In the case of seed imbibition leaves increased at M_2 level (1.5 g sodium molybdate-1kg of seed) and a decrease from M_2 onwards.

Number of branches increased upto M_3 at seed coating (Sc), and upto M_2 for seed imbibition (Si). No significant difference was seen at the first two levels of molybdenum for both seed coating and seed imbibition. Thirteen branches on an average was recorded for Sc, in comparison with nine for Si.

Seed imbibition mode of seed treatment was found to be significantly inferior to the seed coating mode of seed treatment at all levels of molybdenum.

4.2 YIELD ATTRIBUTES

The influence of mode of seed treatment with molybdenum for cowpea on various yield attributes viz. number of pods per plant, number of seeds per pod, hundred seed weight and grain yield are presented in Tables 2 and 3.

The number of pods per plant was significantly influenced by mode of seed treatment with molybdenum and levels of molybdenum. Highest number of pods was recorded by M_3 (21.3) which was on par with M_2 and were significantly superior to the control. It was also noted that there was an increasing trend in the number of pods per plant, as the molybdenum level increased with seed coating method of seed treatment upto M_3 level. Higher levels of molybdenum beyond M_3 recorded significantly lower number of pods per plant.

Hundred seed weight followed the same trend as the number of pods per plant. Maximum weight of seeds was recorded by M_3 which was significantly superior to the control. Here also higher levels of molybdenum beyond M_3 recorded significantly lower number of pods per plant in comparison with M_1,M_2 and M_3.

Seeds per pod increased significantly with increasing levels of molybdenum for seed coating method of seed treatment. Maximum number of seeds per pod was obtained at M_2 Which was on par with M_3 and M_4 and was significantly superior to the control.

Grain yield was also significantly influenced by the method of seed treatment and also levels of molybdenum. M_3 level recorded maximum and significant grain yield in comparison with all other levels of molybdenum and control Grain yield increased significantly with increasing level of molybdenum upto M_3 level but with higher levels of molybdenum a significant reduction in grain yield was noted.

Result showed that seed imbibition mode of seed treatment was significantly inferior to the seed coating mode of seed treatment at all levels of molybdenum. The above result showed that seed coating method of seed treatment with molybdenum levels M_1, M_2 and M_3 were found to be significantly superior to the rest of the treatments, and hence they were selected and tested in the field along with four levels of P_2O_5.

FIELD EXPERIMENT

The results of the study on phosphorus and molybdenum nutrition of cowpea var C 152 are presented below:

4.3 GROWTH CHARACTERS

4.3.1 Height of the plant

The effect of phosphorus and molybdenum and their interactions on the height of the plant at various stages of growth and at harvest are presented in Tables 4,5,6and 7.

Height of the plant was found to increase with incremental levels of phosphorus upto P_2 (22.5 Kg $P_2O_5ha^{-1}$) and then gradually decreased. Height difference was not seen at P_2 and P_3. Highest level of phosphorus (37.5 kg P_2O_5 ha^{-1}) recorded a significant reduction in plant height (29.33 cm) compared to P_2 and P_3 levels which were on par (31.31 and 30.25 cm respectively).

Table 4. Growth characters of cowpea as infuenced by different levels of phosphorus and molybdenum.

Treatments	Height of plants (cm)	Branches plant^{-1} (no.)	Leaf Area Index	Root nodules plant^{-1} (no.)	Dry weight of root nodules plant^{-1} (mg)	Days for 50% flowering	Chlorophyll content at flowering (mg g^{-1})
P_1	24.00	9.57	4.06	26.21	84.88	49.58	2.95
P_2	31.31	11.14	4.60	35.05	106.06	48.08	3.67
P_3	30.25	11.22	4.65	37.40	119.28	47.42	3.78
P_4	29.33	10.24	4.50	34.8	108.03	48.33	2.91
F (3,30)	240.84**	231.86**	563.35**	127.32**	234.73**	31.25**	341.27**
SEm ±	0.19	0.05	.01	0.44	.94	0.16	0.03
C.D. (0.05)	0.56	0.15	0.03	1.26	2.71	0.47	0.07
M_0	26.23	9.67	4.18	25.15	77.84	50.42	2.53
M_1	28.83	10.46	4.45	33.80	101.06	48.33	3.31
M_2	29.05	11.03	4.60	33.99	114.98	47.00	3.74
M_3	29.78	11.01	4.58	40.54	124.37	47.67	3.72
F (3, 30)	63.82**	154.21**	309.00**	210.32**	466.12**	83.21**	503.65**
SEm ±	0.19	0.05	0.01	0.44	0.94	0.16	0.03
C.D. (0.05)	0.56	0.15	0.03	1.26	2.71	0.47	0.07

** Significant at 0.01 level

Table 5. Interaction effects of phosphorus and molybdenum on growth characters of cowpea.

Characters	P_1				P_2				P_3				P_4			
	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3
Height of plants(cm)	21.86	23.17	25.01	25.97	27.55	30.37	31.22	32.11	28.04	32.17	29.79	30.99	27.46	29.61	30.19	30.07
F (9, 30)	5.25**															
SEm±	0.39															
C.D(0.05)	1.12															
Branches (no plant^{-1})	8.87	9.44	9.91	10.07	9.47	11.00	12.23	11.86	10.10	11.07	11.83	11.86	10.23	10.33	10.14	10.25
F (9, 30-)	26.84**															
SEm±	0.10															
C.D. (0.05)	0.30															
Leaf Area Index	3.85	3.98	4.15	4.27	4.09	4.61	4.91	4.76	4.32	4.67	4.83	4.76	4.43	4.51	4.51	4.52
F (9, 30)	39.58															
SEm±	0.02															
C.D. (0.05)	0.06															
Root nodules (no. plant^{-1})	19.42	25.40	28.22	31.82	23.33	39.05	37.33	40.50	27.28	35.45	38.05	48.83	30.55	35.28	32.57	41.00
F (9, 30)	13.50**															
SEm±	0.87															
C.D. (0.05)	2.51															
Dry Weight of Root nodules (mg plant^{-1})	64.60	80.67	101.83	92.43	76.13	93.12	120.93	134.05	92.03	116.25	119.50	149.33	78.58	114.21	117.67	121.67
F (9, 30)	24.38**															
SEm±	1.87															
C.D. (0.05)	5.41															
Days for 50% flowering	51.33	50.33	48.00	48.67	51.33	47.33	46.33	47.33	49.67	47.33	46.33	46.33	49.33	48.33	47.33	48.33
F (9, 30)	37.11**															
SEm±	0.32															
C.D. (0.05)	0.94															
Chlorophyll content at flowering (mg g^{-1})	2.14	2.76	3.27	3.61	2.63	3.79	4.47	3.79	2.79	3.92	4.28	4.14	2.57	2.79	2.94	3.33
F (9, 30)	5.17**															
SEm±	0.05															
C.D. (0.05)	0.15															

** Significant at 0.01 level

Table 6. Growth characters of cowpea at various growth stages as influnced by different levels of phosphorus and molybdenum

Character	P_1	P_2	P_3	P_4	M_0	M_1	M_2	M_3
Height of plants (cm)								
S_1	11.22	11.95	12.45	11.78	11.17	11.97	12.11	12.14
S_2	27.81	34.24	34.11	32.42	28.91	32.44	33.17	34.06
S_3	32.98	47.75	44.19	43.80	38.60	42.09	41.88	43.16
F (6, 64)	66.74**				9.32**			
SEm ±	0.32				0.32			
C.D. (0.05)	0.91				0.91			
Branches (no $plant^{-1}$)								
S_1	6.5	8.05	7.94	7.5	7.06	7.52	7.65	7.75
S_2	12.48	13.56	13.55	12.64	11.85	12.93	13.73	13.72
S_3	9.73	11.81	12.15	10.58	10.09	10.93	11.7	11.55
F (6, 64)	18.23**				14.77**			
SEm ±	0.08				0.08			
C.D. (0.05)	0.23				0.23			
Leaf Area Index								
S_1	1.42	1.68	1.83	1.80	1.23	1.87	1.90	1.73
S_2	6.55	6.90	7.06	7.06	6.59	7.01	7.07	6.89
S_3	4.56	4.75	4.91	4.88	4.36	4.9	5.00	4.82
F (6, 64)	13.93**				6.80**			
SEm ±	0.02				0.02			
C.D. (0.05)	0.05				0.05			
Root nodules (no $plant^{-1}$)								
S_1	14.84	19.11	21.39	19.27	14.29	19.09	19.23	21.99
S_2	37.58	51.00	53.42	50.33	36.00	48.50	48.75	59.08
F (3,32)	32.04**				62.98**			
SEm ±	0.56				0.56			
C.D. (0.05)	1.61				1.61			
Dry weight of root nodules (mg $plant^{-1}$)								
S_1	54.52	78.78	88.33	82.50	51.53	74.68	84.88	93.03
S_2	115.25	133.33	150.23	133.57	104.14	127.44	145.68	155.71
F (3, 32)	5.50**				5.55**			
SEm ±	1.54				1.54			
C.D. (0.05)	4.46				4.46			

** Significant at 0.01 level

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Table 7. Interaction effects of phosphorus and molybdenum on growth characters of cowpea at various growth stages.

Characters	P_1				P_2				P_3				P_4			
	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3
Height of plants(cm)																
S_1	10.58	10.92	11.53	11.83	11.12	12.07	12.33	12.27	11.53	13.08	12.55	12.65	11.47	11.80	12.03	11.80
S_2	24.93	27.18	29.35	29.78	29.40	34.00	34.97	38.58	31.27	35.97	34.00	35.20	30.03	32.60	34.37	32.67
S_3	30.07	31.14	34.10	36.30	42.13	45.05	46.37	45.47	41.33	47.47	42.83	45.10	40.87	44.40	44.17	45.73
F (18,64)	2.65**															
SEm±	0.63															
C.D. (0.05)	1.83															
Branches (no plant⁻¹)																
S_1	6.08	6.45	6.6	6.87	7.13	8.33	8.47	8.25	7.37	7.77	8.27	8.38	7.67	7.53	7.28	7.52
S_2	11.20	12.27	13.27	13.20	11.62	13.33	14.70	14.60	12.27	13.40	14.27	14.27	12.33	12.73	12.70	12.80
S_3	9.33	9.62	9.87	10.13	9.67	11.33	13.52	12.72	10.67	12.03	12.97	12.93	10.70	10.73	10.45	10.00
F (18,64)	4.06**															
SEm±	0.16															
C.D. (0.05)	0.46															
Leaf Area Index																
S_1	1.11	1.19	1.23	1.36	1.35	1.86	2.23	2.04	1.57	1.96	2.10	1.99	1.62	1.72	1.77	1.81
S_2	6.24	6.45	6.80	6.89	6.48	7.06	7.29	7.21	6.65	7.14	7.26	7.21	6.82	6.94	6.88	6.91
S_3	4.16	4.30	4.42	4.56	4.46	4.91	5.20	5.05	4.75	4.93	5.12	5.08	4.86	4.88	4.89	4.85
F (18, 64)	4.89**															
SEm±	0.03															
C.D.(0.05)	0.09															
Root nodules(no plant⁻¹)																
S_1	8.83	14.80	16.43	19.30	14.00	21.43	19.33	21.67	15.57	20.57	21.10	28.33	18.77	19.57	20.07	18.67
S_2	30.00	36.00	40.00	44.30	32.61	56.67	55.33	59.33	39.00	50.33	55.00	69.33	42.33	51.00	44.67	63.33
S_3																
F (9, 32)	9.75**															
SEm±	1.09															
C.D(0.05)	3.17															
Dry weight of Root nodules (mg plant⁻¹)																
S_1	39.53	53.67	58.67	66.20	48.93	63.73	95.20	107.27	64.67	86.67	93.33	108.67	53.00	94.67	92.33	90.00
S_2	89.67	107.67	145.00	118.67	103.30	122.50	146.67	160.83	119.40	145.83	145.67	190.00	104.17	133.17	143.00	153.33
S_3																
F (9, 32)	8.19**															
SEm±	3.03															
C.D(0.05)	8.75															

** Significant at 0.01 level

Application of molybdenum also recorded a favourable effect on the height of the plant. Maximum and significant height (29.78 cm) was recorded at M_3 level (2.5 g sodium molybdate kg^{-1} of seed), but the effect due to M_1 and M_2 levels were on par, which were significantly superior to the control (M_0).

Significant interaction was observed between molybdenum and phosphorus. At P_1 level, height of the plant increased significantly with molybdenum. But the effect due to M_2 and M_3 levels were on par and was significantly superior to the other two levels. At P_2 and P_4 levels, M_1, M_2 and M_3 behaved similarly. But at P_3 level maximum and significant height (32.17 cm) was recorded at M_1 level, but the effect due to M_2 and M_3 were on par which were significantly superior to the control (M_0).

In the absence of molybdenum, phosphorus application increased the height of the plant significantly, but the effect due to the higher three levels were on par. At M_1 level, maximum and significant height was recorded at P_3 level. At M_2 level, P_2 and P_4 behaved similarly. But the effect due to P_3 and P_4 levels were on par. At M_3 level maximum plant height was recorded at P_2 level which was on par with P_3 level and significantly superior to the other two levels.

An increase in phosphorus and molybdenum was found to increase the height of the plant, however a dose of P higher than P_2 was not found to produce a positive significant height increase. Higher dose of P in combination with doses M_2 and M_3 did not exhibit marked increase in plant height. Maximum height was observed at P_3M_1 level(32.17 cm) which was on par with P_2 $M_2$and P_2M_3.

At vegetative stage a significant increase in plant height was observed only at P_3 level, which was on par with P_2 and P_4 levels and significantly superior to P_1 level. At flowering and harvesting stages, plant height increased significantly with increased application of phosphorus. The effect due to P_2 and P_3 levels were on par and were significantly superior to the other two levels at flowering stage. But at harvest stage the effect due to P_2 and P_3 were on par and P_3 was again on par with P_4. All these higher levels of P were superior to the lowest level.

At vegetative stage, the addition of molybdenum increased the height. Same trend was observed in other two stages also. At all stages maximum plant height was recorded at M_3 level. At vegetative and flowering stages effect due to M_2 and M_3 were on par and were significantly superior to all other levels, while at harvest stage maximum and significant height of the plant (43.16 cm) was recorded at M_3 level.

The. P x Mo interaction was significant at all stages. Maximum height of the plant was produced by P_3M_1 combination at vegetative stage which was on par with P_3M_2 and P_3M_3. At flowering stage maximum height of the plant was produced at P_2M_3 where as at harvest stage P_3M_1 recorded the maximum height of the plant. However, this was on par with P_2M_2 and P_4M_3.

4.3.2 Number of branches per plant

The effect of phosphorus and molybdenum and their interactions on number of branches per plant at various stages of growth and at harvest are presented in Tables 4,5,6 and 7.

The branching character of cowpea was significantly influenced by phosphorus application. Application of phosphorus at P_2 and P_3 levels reported significantly higher values compared to the other two levels, but they themselves were on par. Higher levels of molybdenum (M_2 and M_3) behaved similarly with respect to branching character and were significantly superior to the other two levels.

The interaction between phosphorus and molybdenum was also found to be significant. The P_2 M_2 treatment produced the maximum and significant value (12.2 branches per plant). Higher combinations of the doses of P and Mo above P_2M_2 did not produce a significant increase in the number of branches.

An increase in P higher than P_2 is not found to be favourable for the increase in the number of branches at all growth stages of the crop. At vegetative stage P_2 and P_3 levels were on par and recorded significantly higher number of branches compared to the other two levels. At flowering stage also with respect to P_2 and P_3 levels same trend was observed. At harvest stage number of branches increased significantly with increasing levels of phosphorus. Maximum value of 12.15 was recorded at P_3 level, but at P_4 level, a significant reduction (10.58) was observed compared to P_2 and P_3 levels.

At vegetative stage molybdenum responded upto M_1 level, a further increase was not found to produce positive response. At flowering and harvest stages effects due to M_2 and M_3 levels were on par and were significantly superior to the other two levels. Compared to control which recorded 11.85 branches, all levels of molybdenum increased the number of branches significantly at flowering stage.

Significant interaction was observed between phosphorus and molybdenum from vegetative stage onwards. Maximum number of branches was recorded by P_2 M_2 at all stages. An increase of P or Mo higher than P_2 M_2 was found to reduce the number of branches at all stages.

4.3.3 Leaf Area Index

The effect of phosphorus and molybdenum and their interaction on LAI of the plant at various stages of growth and at harvest are presented in Tables 4,5,6 and 7.

Leaf Area Index was also significantly influenced by phosphorus application. LAI value of 4.65 was observed at P_3 level, which was significantly superior to all other three levels. Addition of molybdenum also significantly influenced Leaf Area Index. Maximum values were obtained at M_2 and M_3 levels which were on par, but were significantly superior to M_0 and M_1 levels.

In the absence of molybdenum application of phosphorus significantly influenced LAI and maximum Leaf Area Index was obtained at P_4 level (4.43). At M_1 and M_3 levels phosphorus application at $P_2$and P_3 levels recorded a similar effect on Leaf Area Index and was significantly superior to other two levels. At M_2 level maximum LAI of 4.91 was obtained at P_2 level.

At P_1 level with incremental doses of molybdenum LAI increased significantly. At P_2 and P_3 levels maximum LAI was obtained at M_2 where as at P_4 level all the higher three levels of molybdenum had a similar effect on LAI and were significantly superior to the control. Maximum LAI was recorded for P_2 M_2. An increase in P and Mohigher than P_2 M_2 was found to reduce the LAI. At vegetative stage P_3 and P_4 levels recorded higher values of LAI which was significantly superior to the other two levels of phosphorus. But at flowering stage maximum and significant LAI of 7.06 was obtained at P_3 and P_4 levels. But at harvest stage, the effect due to higher three levels of phosphorus were significantly superior to the lowest level of P.

At all the three stages the maximum and significant value for LAI was recorded at M_2 level. Application of molybdenum at M_1 level also recorded significantly higher values compared to the control.

Significant interaction was observed between phosphorus and molybdenum on LAI from vegetative stage onwards. Maximum LAI was recorded at P_2 M_2 at all stages, which was significantly superior to all other levels at vegetative and harvest stages. At flowering stage this was on par with P_2 M_3 and P_3 M_3.

4.3.4 Number of nodules

The effect of phosphorus,molybdenum and their interaction effect on number of nodules are presented in Tables 4,5,6 and 7.

Nodulation was significantly influenced by phosphorus application. Maximum and significant number of nodules (37.40) was obtained at P_3 level, but the effect due to P_2 and P_4 levels were similar and were significantly superior to lowest level of P (26.21). Application of molybdenum also highly influenced the number of nodules per plant. Highest level of molybdenum recorded the maximum number of nodules (40.54) which were significantly superior to all three levels, but M_1 and M_2 levels behaved similarly with respect to nodulation.

Interaction between phosphorus and molybdenum also found to have a significant increase on nodulation. Number of nodules increased with an increase in P upto P_3 and this was seen at higher doses of Mo(M_2 and M_3) with P. P_3 M_3 recorded the maximum number of nodules (48.83) though the response of Mowas linear upto M_3.

At all levels of phosphorus, application of molybdenum increased the number of nodules significantly compared to the control. Both in the absence and presence of molybdenum addition of phosphorus at higher levels increased the number of nodules significantly compared to the lowest level of phosphorus.

At vegetative stage maximum number of nodules was obtained at P_3 level (21.39) which was significantly superior to other three levels of phosphorus . Effect of phosphorus at P_2&P_4 were similar on nodulation. Same trend was observed at flowering stage. Application of molybdenum both at vegetative and flowering stages significantly increased the number of nodules. Maximum number of nodules at both stages were observed at M_3 level, which were significantly superior to other two levels. Application of molybdenum at M_1 and M_2 levels produced similar effect on nodulation.

Significant interaction was observed between phosphorus and molybdenum on number of nodules at vegetative and flowering stages. At both stages P_3 M_3 recorded the maximum number of nodules which was significantly superior to all other levels.

4.3.5 Weight of nodules

The effect of phosphorus and molybdenum and their interactions on weight of nodules at vegetative and flowering stages of growth are presented in Tables 4,5,6 and 7.

Significant increase on weight of nodules by application of phosphorus was observed. Maximum weight of nodules (119.28 mg $plant^{-1}$) was recorded at P_3 level which was significantly superior to all other levels. Application of molybdenum also significantly increased the weight of nodules. The highest value (124.37 mg $plant^{-1}$) was recorded at M_3 level.

Interaction between phosphorus and molybdenum significantly influenced the weight of nodules, $P_3 M_3$ level recorded the maximum and significant value for weight of nodules (149.33 mg plant^{-1}) and $P_1 M_0$ level recorded the lowest weight of nodules (64.6mg plant $^{-1}$). Doses higher than $P_3 M_3$ is not found to produce a favourable effect on nodule weight. At all levels of phosphorus, addition of molybdenum increased the weight of nodules significantly. But at P_1 level, addition of molybdenum at M_3 level reduced the weight of nodules significantly compared to M_2 level. At P_2 and P_3 levels maximum number of nodules was obtained at M_3 level, where as at P_4 level effect due to M_2 and M_3 levels were on par, and that due to M_1 and M_2 were on par. All these three levels were significantly superior to the control.

In the absence of molybdenum and at the highest level of molybdenum maximum weight of nodules was obtained at P_3 level. But at M_1 and M_2 levels P_3 and P_4 levels behaved similarly, but at M_1 level these two levels were significantly superior to P_1 and P_2 levels.

In both stages compared to the lowest level of phosphorus addition of phosphorus increased the weight of nodules significantly. Maximum weight of nodules was obtained at P_3 level which were significantly superior to all other levels.

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Influence of molybdenum on weight of nodules was also significant at both stages. Maximum weight of nodules was observed at M_3 level at both stages (93.03 and and 155.71 mg plant^{-1} respectively) which were significantly superior to other levels.

Significant interaction between phosphorus and molybdenum on weight of nodules was noticed at vegetative and flowering stages. At vegetative stage maximum value for weight of nodules was noticed at P_3 M_3 which was on par with P_3 M_3 and both were significantly superior to all other levels.

4.3.6 Chlorophyll content at 50% flowering

The effect of phosphorus and molybdenum and their interaction effect on the content of chlorophyll at 50% flowering stage are presented in Tables 4 and 5.

On a perusal of the data it was observed that the content of chlorophyll increased significantly with increasing levels of phosphorus upto P_3 level(30 kg $P_2O_5ha^{-1}$) Maximum content of chlorophyll of 3.78 mg g^{-1} was obtained at P_3 level, but at P_4 level (37.5 kg $P_2O_5ha^{-1}$) a significant reduction in the content of chlorophyll was observed compared to P_2 and P_3 levels.

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A significant increase in the content of chlorophyll was also observed with higher levels of molybdenum but the effect due to M_2 (1.5 g sodium molybdate kg^{-1} of seed) was on par with M_3 (2.5 g sodium molybdate kg^{-1} of seed).

The interaction between phosphorus and molybdenum also influenced the content of chlorophyll significantly. Maximum content of chlorophyll (4.47 mg g^{-1}) was observed with the application of 22.5 kg P_2O_5 ha^{-1} (P_2 level) along with the application of molybdenum at the rate of 1.5 g sodium molybdate kg^{-1} of seed (M_2 level) followed by the application of 30 kg P_2O_5 ha^{-1} at the same level of molybdenum but it was on par with the highest level of molybdenum at the same level of phosphorus. At P_1 and P_4 levels (15 kg P_2O_5 and 37 kg P_2O_5 ha^{-1} respectively) a significant increase in the content of chlorophyll was observed with higher levels of molybdenum but at P_2 and P_3 levels application of molybdenum at the rate of 1.5 g sodium molybdate kg^{-1} of seed gave the highest value.

4.3.7 Days for 50% flowering

The effect of phosphorus and molybdenum and their interaction effects on days for 50% flowering are presented in Tables 4 and 5.

The data presented in the Table revealed that levels of phosphorus had a significant influence on the days for 50% flowering. Plants receiving phosphorus at the lowest level took maximum days for 50% flowering, but at higher levels of phosphorus a significant reduction in flowering period was observed.

With higher levels of molybdenum a significant reduction in the number of days for 50% flowering was noticed. At all other levels of molybdenum except at M_3 level plants flowered earlier with higher levels of phosphorus, but at M_3 level this effect was noticed only upto P_3 level.

4.4 YIELD ATTRIBUTES

4.4.1 Number of Pods per Plant

The effect of phosphorus and molybdenum and their interaction effects on the number of pods per plant are presented in Tables 8 and 9.

On a perusal of the data it was observed that the number of pods per plant increased significantly with increasing levels of phosphorus. Maximum number of pods per plant (13.26) was obtained at P_3 level which was on par with P_2 level (13.18) but at P_4 level a significant reduction in the number of pods per plant was observed compared to P_2 and P_3 levels.

Table 8. Yield and yield attributes of cowpea as in influnced by different levels of phosphorus and molybdenum

Treatment	Number of pods plant^{-1}	Length of pod (cm)	Number of seeds pod^{-1} [redacted]	Hundred seed weight (g)	Grain yield kg ha^{-1}	Total dry matter production kg ha^{-1}	Harvest Index
P_1	10.12	12.99	13.26	8.82	685.00	2637.92	26.06
P_2	13.18	14.73	15.20	10.13	1147.00	3254.25	35.14
P_3	13.26	15.09	14.93	10.39	1152.67	3264.83	35.23
P_4	11.63	14.22	14.71	9.65	965.17	2888.83	33.41
F (3, 30)	201.72**	629.70**	53.23**	102.65**	2349**	261.66**	313.65**
SEm±	0.10	0.03	0.12	0.07	4.53	18.81	00.25
C.D. (0.05)	0.30	0.11	0.34	0.20	13.09	54.32	0.71
M_0	9.90	13.23	13.60	9.18	821.75	2787.83	29.42
M_1	12.62	14.54	14.59	10.03	1028.00	3011.83	33.71
M_2	12.93	14.63	14.96	9.93	1065.75	3150.25	33.45
M_3	12.75	14.63	14.95	9.84	1034.33	3095.92	33.26
F (3, 30)	187.88**	356.27**	28.74**	31.84**	607**	71.99**	68.78**
SEm±	0.10	0.03	0.12	0.07	4.53	18.81	0.25
C.D. (0.05)	0.30	0.11	0.34	0.20	13.09	54.32	0.71

** Significant at 0.01 level

Table 9. Interaction effects of phosphorus and molybdenum on yield and yield attributs of cowpea

Characters	P_1				P_2				P_3				P_4			
	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3
Number of pods plant^{-1}	9.10	9.93	10.67	10.77	9.70	14.33	14.50	14.20	10.00	14.20	14.50	14.33	10.80	12.00	12.03	11.70
$F_{(9, 30)}$	21.25**															
SEm±	0.21															
C.D. (0.05)	0.61															
Length of pod(cm)	12.67	12.93	13.13	13.23	12.73	15.13	15.70	15.37	13.73	15.43	15.67	15.53	13.77	14.67	14.03	14.40
$F_{(9, 30)}$	60.76**															
SEm±	0.07															
C.D. (0.05)	0.21															
Number of seeds per pod^{-1}	12.60	12.93	13.80	13.70	13.35	15.88	15.73	15.83	14.00	15.10	15.40	15.23	14.47	14.43	14.90	15.03
$F_{(9, 30)}$	4.32**															
SEm±	0.24															
C.D. (0.05)	0.69															
Hundred seed weight (g)	8.50	8.82	8.94	9.02	8.76	10.58	10.80	10.37	9.67	10.57	10.77	10.53	9.80	10.17	9.20	9.43
$F_{(9, 30)}$	13.42**															
SEm±	0.14															
C.D. (0.05)	0.39															
Grain yield (kg ha^{-1})	625.00	676.00	721.00	718.00	880.00	1242.00	1287.00	1179.00	935.00	1208.00	1248.00	1219.67	847.00	986.00	1007.00	1020.67
$F_{(9, 30)}$	54.83**															
SEm±	9.06															
C.D. (0.05)	26.17															
Total dry matter production (kg ha^{-1})	2471.67	2507.00	2751.61	2821.33	2880.33	3385.33	3455.00	3296.33	3001.00	3323.00	3396.00	3339.33	2798.33	2832.00	2998.33	2926.67
$F_{(9, 30)}$	8.28**															
SEm±	37.62															
C.D(0.05)	108.63															
Harvest Index	25.33	26.97	26.17	25.77	30.83	36.7	37.27	35.77	31.17	36.33	36.77	36.63	30.33	34.83	33.60	34.87
$F_{(9, 30)}$	6.13**															
SEm±	0.49															
C.D. (0.05)	1.42															

** Significant at 0.01 level

A significant increase in the number of pods per plant was observed with higher levels of molybdenum, but the effect due to M_1, M_2 and M_3 were on par which were significantly superior to the control. Maximum number of pods per plant was observed at M_2 and M_3 levels but M_3 was on par with M_1.

The interaction between phosphorus and molybdenum also influenced the number of pods per plant. At all levels of phosphorous addition of molybdenum increased the number of pods plant $^{-1}$ significantly. At P_1 level the effect due to M_2 and M_3 were on par which were significantly superior to M_0 and M_1 levels. At P_2, P_3 and P_4 levels the effect due to M_1, M_2 and M_3 were on par which were significantly superior to the control.

In the absence of molybdenum P_3 and P_4 levels increased the number of pods per plant significantly compared to the lower two levels of phosphorus which were on par. In the presence of molybdenum P_2 and P_3 levels behaved similarly but were significantly superior to the lowest and highest levels of phosphorus. In this case also P_2 M_2 was found to be sufficient for producing maximum number of pods per plant.

4.4.2 Length of pod

The effect of phosphorus and molybdenum and their interaction effects on length of pod are presented in Tables 8 and 9.

Length of pod was significantly increased with increasing levels of phosphorus. Maximum length of pod (15.09 cm) was obtained at P_3 level but at P_4 level a significant reduction in length of pod was observed compared to P_2 and P_3 levels.

Significant increase in the length of pod was also observed with higher levels of molybdenum while M_1, M_2 and M_3 levels were on par with each other but significantly superior to M_0 level (13.23 cm).

Significant phosphorus and molybdenum interaction was noticed with respect to length of pod. At all levels of phosphorus significant increase in the length of pod was noticed with increasing levels of molybdenum. But at P_2 and P_3 levels with the highest level of molybdenum a significant reduction in length of pod was observed. But at P_4 level maximum length of pod was observed at M_1 level which was significantly superior to all other levels of molybdenum. At all levels of molybdenum length of pod increased significantly with higher levels of phosphorus upto P_3 level, but at P_4 level a significant reduction in length of pod was observed.

An increase in P higher than P_2 and an increase in Mo higher than M_2 was found to result in a reduction in pod length. Maximum pod length was seen at P_2 M_2 (15.70cm) though the average effect of P gave a positive response upto P_3.

4.4.3 Number of seeds per pod

The effect of phosphorus and molybdenum and their interaction effect on number of seeds per pod are given in Tables 8 & 9. Significant increase in the number of seeds per pod was noticed with increasing levels of phosphorus. Maximum number of seeds pod^{-1} (15.2) was obtained at P_2 level, with P_3 level on par with it producing 14.93 seeds pod^{-1}. P_3 was again found to be on par with P_4 (14.71).

Number of seeds per pod was significantly increased by the application of higher levels of molybdenum. Maximum number of seeds pod^{-1} was obtained at M_2 and M_3 levels which were on por with each other.

The interaction between phosphorus and molybdenum also influenced the number of seeds per pod significantly. At P_1 level the effect due to M_2 and M_3 were on par which were significantly superior to M_1 and the control level of molybdenum but the effect due to M_0 and M_1 were on par. At P_2 and P_3 levels number of seeds per pod produced at M_1, M_2 and M_3 levels were similar and were significantly superior to the control. At P_4 level lower two levels and higher two levels of molybdenum behaved similarly, where as the higher two levels were significantly superior to the lower two levels.

4.4.4. Hundred seed weight

The effect of phosphorus and molybdenum and their interaction effects on hundred seed weight are presented in Tables 8 and 9.

Both phosphorus and molybdenum influenced hundred seed weight significantly. Maximum hundred seed weight (10.39 g) was observed at P_3 level which was significantly superior to other levels of phosphorus. All levels of molybdenum behaved similarly and recorded significantly higher value for hundred seed weight than the control.

Interaction between phosphorus and molybdenum also influenced hundred seed weight significantly. At P_1 level the effect due to M_2 and M_3 were on par which were significantly superior to the control. At P_2 and P_3 levels, M_1 and M_2 behaved similarly but at P_3 level M_2 was again on par with M_3 which were significantly superior to the control. At P_4 level maximum hundred seed weight was recorded at M_1 level.

In the absence of molybdenum P_3 and P_4 levels increased the hundred seed weight significantly compared to the lower two levels of phosphorus which were on par. In the presence of molybdenum, P_2 and P_3 levels behaved similarly but were significantly superior to the lowest and highest level of phosphorus. Maximum 100 seed weight was recorded at P_2 M_2 (10.80 g). A further increase in either P or Mo was not necessary to increase the 100 seed weight.

4.4.5 Grain yield

The effect of phosphorus and molybdenum and their interaction effects on grain yield are presented in Tables 8 and 9.

Grain yield of cowpea was significantly influenced by the application of phosphorus. Highest yield (1152.67 kg ha^{-1}) was observed at P_3 level which was on par with that obtained at P_2 level (1147 kg ha^{-1}) and was significantly superior to the other two levels of phosphorus.

Effect of molybdenum on the yield of grain was also significant. Maximum and significant yield of 1065.75 kg ha^{-1} was noticed at M_2 level. Significant reduction in the yield of grain was observed at the highest level of molybdenum compared to the M_3 level.

The interaction between phosphorus and molybdenum was also significant. At all levels of phosphorus application of molybdenum at the rate of 0.5 kg^{-1} of seed (M_1) significantly increased the grain yield compared to the control. But at P_4 level the effect due to M_1 and M_2 were on par. But at P_1 and P_4 levels application of molybdenum at M_2

and M_3 levels did not indicate any significant difference. At P_2 and P_3 levels application of molybdenum at M_2 level recorded maximum yield which were significantly superior to lower levels of molybdenum and significantly inferior to the highest level of molybdenum. The best interaction with respect to grain yield was for $P_2 M_2$ (1287 kg ha^{-1}).

Both in the absence and presence of molybdenum, application of phosphorus at the highest level recorded a significant reduction in the yield of grain compared to P_2 and P_3 levels. In the absence of molybdenum, application of phosphorus at P_3 level recorded maximum grain yield which was significantly superior to the lower two levels of phosphorus. But at M_1 and M_2 levels application of phosphorus, at P_2 level recorded maximum yield which were significantly superior to all other levels of phosphorus. Behaviour of phosphorus in the absence of molybdenum and at the highest level of molybdenum was similar. With the application of molybdenum at the highest level (M_3), P_3 level of phosphorus recorded maximum and significant yield. The same trend was observed with the absence of molybdenum.

4.4.6 Total Dry Matter Production (TDMP)

The effect of phosphorus and molybdenum and their interaction effects on total dry matter production are presented in Tables 8 and 9.

A significant increase in dry matter production was noticed with increasing levels of phosphorus. Maximum production of dry matter of 3264.83 kg ha^{-1} was observed at P_3 level but at P_4 level dry matter production decreased by 12 percent. But the effect due to P_2 and P_3 levels were on par.

With increasing levels of molybdenum dry matter production increased significantly. Maximum and significant value of 3150.25 kg ha^{-1} was obtained at M_2 level.

The interaction between phosphorus and molybdenum also influenced the total dry matter production. At P_1 and P_4 levels, the effect due to M_2 and M_3 levels were on par which were significantly superior to M_0 and M_1 levels at corresponding levels of phosphorus, but at both levels of phosphorus the effect due to lower two levels of molybdenum were on par where as at P_2 and P_3 levels dry matter produced at M_1 and M_2 levels were similar and were significantly superior to the control level of molybdenum, but at P_2 level a significant reduction in dry matter production was observed at highest level of molybdenum compared to P_3 level. At all levels of molybdenum, dry matter production increased significantly with increasing levels of phosphorus. But a significant reduction was noticed in dry matter production at all levels of molybdenum with the addition of highest level of phosphorus compared to the P_3 level. Maximum dry matter was produced at P_2 M_2 level (3455.00 kg ha^{-1}) which was on par with P_2 M_1 (3385.33 kg ha^{-1}) and P_3 M_2 (3396.00 kg ha^{-1}).

4.4.7 Harvest Index

The effect of phosphorus and molybdenum and their interaction effects on harvest index are presented in Tables 8 and 9.

Both phosphorus and molybdenum influenced the harvest index significantly. Maximum harvest index of 35.23 was observed at P_3 level which was significantly superior to other levels of phosphorus except P_2 level. All levels of molybdenum behaved similarly and recorded higher values compared to control. The average effect of molybdenum showed a slight decrease in H.I at M_2 (33.45) which was on par with M_1 (33.71)

Phosphorus x molybdenum interaction effect was also significant. Maximum harvest index was observed at P_2 M_2 level which was on par with M_1 level at the same level of phosphorus and also with all levels of molybdenum at P_3 level. At all levels of molybdenum phosphorus application increased the harvest index significantly. But in the presdence of molybdenum, phosphorus at highest level recorded a significant reduction in harvest index. But in the absence

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of molybdenum though a reduction was observed it was not significant.

4.5 QUALITY ATTRIBUTES

4.5.1 Crude Protein Content of Grain

The effects of phosphorus and molybdenum and their interaction effects on crude protein content of grain are presented in Tables 10 and 11.

Addition of phosphorus increased the protein content of grain significantly. Maximum value was recorded at P_3 level (25.09%) which was on per with P_2 level (24.68%) which were significantly superior to the other two levels. The protein content of grain of cowpea increased significantly with higher levels of molybdenum. Application of molybdenum at the highest level recorded maximum content of protein of 25.58 percent.

At P_1 and P_4 levels maximum content of protein was recorded at the highest level of molybdenum. At $P_2$and P_3 levels content of protein obtained at M_2 and M_3 levels were on par and were significantly superior to the lower two levels of molybdenum.

In the absence of molybdenum the higher three levels of phosphorus had a similar effect on the content of protein and were significantly superior to the lowest level of phosphorus. At M_1 level application of phosphorus at the highest level recorded a significant reduction in the content of protein compared to the P_3 level but the effects were on par with that obtained at P_2 level. But the lowest level of phosphorus reduced the content of protein significantly compared to the higher levels of phosphorus in the presence of molybdenum. At M_2 and M_3 levels, P_2 and P_3 levels behaved similarly and were significantly superior to the lowest and highest levels of phosphorus. Maximum crude protein was recorded at P_2 M_3 but it was on par with P_2 M_2.

4.6 NUTRIENT UPTAKE BY THE CROP

4.6.1 Nitrogen uptake

The effect of phosphorus and molybdenum and their interaction effects on uptake of nitrogen by the crop are presented in Tables 10 and 11.

Compared to the lowest level of phosphorus all other levels of phosphorus increased the uptake of nitrogen significantly. But the effect due to P_2 and P_3 were on par and were significantly superior to the other two levels and it showed that an increase in P beyond P_2 was not favourable to increase N uptake capaciy of the crop. Uptake of nitrogen was also significantly increased with increasing doses of

Table 10. Nutrient uptake and protein content of cowpea as inflnced by different levels of phosphorus and molybdenum

Treatment	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	Potassium uptake (kg ha^{-1})	Molybdenum uptake (kg ha^{-1})	Protein content of grain (%)
P_1	95.06	9.33	33.64	0.168	20.0
P_2	137.95	14.22	45.02	0.238	24.68
P_3	138.93	14.97	43.55	0.341	25.09
P_4	119.51	14.72	35.73	0.301	23.69
F (3, 30)	1158.7**	819.20**	569.44**	831.44**	229.63**
SEm±	0.60	0.09	0.23	0.002	0.15
C.D. (0.05)	1.74	0.27	0.68	.008	0.44
M_0	98.94	10.97	31.53	0.143	20.17
M_1	123.66	14.19	39.30	0.223	23.08
M_2	132.40	14.22	43.70	0.327	24.65
M_3	136.45	13.86	43.20	0.353	25.58
F (3, 30)	773.80**	283.48**	576.13**	1362.56**	239.57**
SEm±	0.60	0.09	0.23	0.002	0.15
C.D. (0.05)	1.74	0.27	0.68	0.008	0.44

** Significant at 0.01 level

Table 11. Interaction effects of phosphorus and molybdenum on nutrient uptake and protein content of cowpea

Characters	P_1				P_2				P_3				P_4			
	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3
Nitrogen uptake (kg ha^{-1})	69.96	90.87	106.90	112.50	102.50	145.66	149.08	154.30	116.21	142.57	147.37	149.57	106.93	115.53	126.17	129.41
F (9, 30)	32.43**															
SEm±	1.21															
C.D. (0.05	3.49															
Phosphorus uptake (kg ha^{-1})	7.93	9.00	10.07	10.32	10.13	15.26	16.22	15.25	11.58	16.10	15.95	16.23	14.22	16.39	14.65	13.62
F(9,30)	32.52**															
Sem±	0.19															
C.D. (0.05)	0.54															
Potassium uptake (kg ha^{-1})	26.87	35.93	33.12	38.63	31.66	47.05	55.39	45.99	36.47	40.75	49.80	46.36	31.11	33.47	36.50	41.83
F (9, 30)	79.21**															
SEm±	0.47															
C.D. (0.05)	1.35															
Molybdenum uptake (kg ha^{-1})	0.093	0.103	0.190	0.283	0.133	0.170	0.320	0.330	0.177	0.333	0.407	0.447	0.170	0.287	0.393	0.353
F (9, 30)	50.90**															
SEm±	0.005															
C.D. (0.05)	0.015															
Protein content(%)	16.80	18.5	21.23	23.47	20.73	24.43	26.73	26.83	21.37	25.73	26.67	26.60	21.77	23.63	23.97	25.40
F (9, 30)	10.51**															
SEm±	0.31															
C D. (0.05)	0.88															

** Significant at 0.01 level

molybdenum. Maximum value was recorded at the M_3 level (136.45 kg ha^{-1}).

Among phosphorus and molybdenum interactions maximum value was recorded at P_2 M_3 level (154.3 kg ha^{-1}) which was significantly superior to all other interactions. At P_1 and P_2 levels uptake of nitrogen increased significantly with increasing levels of molybdenum while at P_3 and P_4 levels the effect due to M_2 and M_3 levels were on par and were significantly superior to the other two levels. But compared to control level of molybdenum, the M_1 level was superior both at P_3 and P_4 levels. Both in the absence and presence of molybdenum phosphorus at the highest level recorded a significant reduction compared to the P_3 levels, but in the presence of molybdenum the effect due to P_4 levels were significantly inferior to P_2 levels also.

4.6.2 Phosphorus uptake

The effect of phosphorus and molybdenum and their interaction effect on uptake of phosphorus by the crop are presented in Tables 10 and 11.

Uptake of phosphorus increased significantly with increasing levels of phosphorus but the effect due to higher two levels of phosphorus were similar. Addition of molybdenum also significantly influenced the uptake of phosphorus but the effect due to M_1 and M_2 levels were on par and were significantly superior to the other two levels. The average effect of P showed that maximum P uptake by the crop is at P_3 and that of Mo at M_2.

In the absence of molybdenum uptake of phosphorus increased significantly with increasing levels of phosphorus. Maximum value was obtained at P_4 level. At M_1 level higher uptake was observed at P_3 and P_4 levels which were on par and were significantly superior to the other two levels. At M_2 and M_3 levels uptake of phosphorus at P_4 levels was significantly reduced compared to the respective P_2 and P_3 levels. But the effect due to P_2 and P_3 levels were on par at M_2 levels. Where as at M_3, maximum uptake was obtained at P_3 level, but at all levels of molybdenum compared to the lowest level of phosphorus, uptake was significantly influenced by the other two levels. The P uptake at P_2 M_2, P_3 M_2 and P_3 M_3 were on par. P_3 M_3 was found to be the most favourable treatment combination for P uptake, which was on par with P_2 M_2.

4.6.3 Potassium Uptake

The effect of phosphorus and molybdenum and their interaction effect on uptake of potassium by the crop are presented in Tables 10 and 11.

Maximum uptake (45.02 kg ha^{-1}) was obtained at P_2 level which was significantly superior to the other two levels. Application of phosphorus at the highest level recorded a significant reduction in the uptake of potassium compared to the P_2 and P_3 levels.

Compared to the M_0 level the uptake of potassium increased significantly with molybdenum application. But the effect due to higher two levels of molybdenum were on par and was significantly superior to the other two levels of molybdenum . Maximum uptake of potassium was observed at P_2 M_2 level which was significantly superior to all other levels. At all levels of phosphorus addition of molybdenum significantly increased the uptake of potassium. At $P_1$and P_4 levels maximum uptake was observed at M_3 level, where as at P_2 and P_3 levels M_2 level recorded maximum uptake. Maximum K uptake was recorded at P_2 M_2.

4.6.4 Molybdenum uptake

The effect of phosphorus and molybdenum and their interaction effect on uptake of molybdenum are presented in Tables 10 and 11.

Compared to the lowest level of phosphorus, all levels of phosphorus recorded a significant increase in the uptake of molybdenum. Maximum uptake (0.34 kg ha^{-1}) was observed at P_3 which was significantly superior to all other levels followed by P_4 and P_2. Uptake of molybdenum by the plant increased significantly with increasing doses of molybdenum. Maximum and significant uptake was observed at M_3 level (0.35 kg ha^{-1}) followed by M_2 (0.33 kg ha^{-1}) and M_1 (0.22kg ha^{-1}).

In the absence of molybdenum,the increasing levels of phosphorus increased the uptake of molybdenum but the highest two levels were on par. In the presence of molybdenum the highest value was obtained at P_3 level which was significantly superior to all other levels. But the application of phosphorus at the highest level was significantly inferior to that obtained at the corresponding P_3 level but superior to the corresponding P_1 and P_2 levels and P_2 level at all levels of molybdenum was significantly higher than the corresponding P_1 level. Among P*Mo interaction,maximum and significant uptake of molybdenum was obtained at P_3 M_3 (0.447kg ha^{-1}).

4.7 NUTRIENT CONTENT IN THE SOIL AFTER THE EXPERIMENT

4.7.1 Nitrogen content

The effect of phosphorus and molybdenum and their interaction effects on nitrogen content in the soil after the experiment are presented in Tables 12 and 13.

Application of phosphorus increased in the content of nitrogen in the soil significantly. But at the highest level of phosphorus a significant reduction in the content of nitrogen in the soil was observed compared to the P_2 and P_3 levels.

Increasing level of molybdenum increased the available nitrogen status of the soil significantly but the effect due to the highest two levels of molybdenum were on par.

The interaction between phosphorus and molybdenum influenced the nitrogen content in the soil significantly. Except at M_3 level, increasing levels of phosphorus increased the available nitrogen content of the soil significantly but the nitrogen status obtained at the highest level of phosphorus was significantly inferior to the corresponding P_2 and P_3 levels. But at M_3 level the behaviour of the lowest and highest levels of phosphorus was similar, and were significantly inferior to the effect due to P_2 and P_3 levels which were on par with each other. Maximum and significant content of nitrogen of the soil was obtained at P_3 M_2 level (366 kg ha^{-1}).

4.7.2 Phosphorus content

The effect of phosphorus and molybdenum and their interaction effects on phosphorus content of the soil after

Table 12. Available soil nutrient status after the experiment as influnced by different levels of phosphorus and molybdenum

Treatment	Available nitrogen (kg.ha^{-1})	Available phosphorus (kg.ha^{-1})	Available potassium (kg.ha^{-1})
P_1	201.75	33.93	56
P_2	272.58	43.13	71
P_3	310.50	44.60	77
P_4	224.08	40.06	69
F (3, 30)	407.51**	215.70**	205.25**
SEm±	2.42	0.32	0.62
C.D. (0.05)	6.98	1.00	1.79
M_0	198.08	32.96	50
M_1	246.58	41.70	70
M_2	279.00	43.94	76
M_3	285.25	43.13	77
F (3, 30)	271.90**	247.85**	392.19**
SEm±	2.42	0.32	0.62
C.D. (0.05)	6.98	1.00	1.79

** Significant at 0.01 level

Table 13. Interaction effects of phosphorus and molybdenum on available soil nutrient status after the experiment.

Characters	P_1				P_2				P_3				P_4			
	M0	M1	M2	M3	M0	M1	M2	M3	M0	M1	M2	M3	M0	M1	M2	M3
Available nitrogen ($kg\,ha^{-1}$)	163.67	192.67	212.00	238.67	210.67	243.67	295.33	340.67	218.33	326.67	366.00	331.00	199.67	223.33	242.67	230.67
$F_{(9, 30)}$	33.16**															
SEm±	4.84															
C.D. (0.05)	13.97															
Available phosphorus ($kg\,ha^{-1}$)	27.50	33.40	35.43	39.40	32.67	44.17	49.20	46.20	35.27	47.00	47.80	48.33	36.40	42.23	43.33	38.28
$F_{(9, 30)}$	19.71**															
SEm±	0.64															
C.D. (0.05)	1.85															
Available potassium ($kg\,ha^{-1}$)	45.00	54.00	60.00	65.00	47.00	74.00	82.00	80.00	55.00	80.00	87.00	86.00	54.00	69.00	75.00	76.00
$F_{(9, 30)}$	10.95**															
SEm±	1.24															
C.D. (0.05)	3.58															

** Significant at 0.01 level

the experiment are presented in Tables 12 and 13.

The P content of the soil was significantly influenced by the addition of phosphorus. Maximum value was recorded at P_3 level which was significantly superior to all other levels. Compared to P_1 level phosphorus status was significantly increased by all levels of phosphorus.

Compared to the M_0 level, addition of molybdenum significantly increased the content of phosphorus in the soil. Effect due to M_2 and M_3 levels were on par. But M_2 level (43.94 kg ha^{-1}) was significantly superior to the lower two levels.

At P_1 level P status of the soil increased significantly with increasing levels of molybdenum. Maximum value of 39.40kg ha^{-1} was obtained at M_3 level compared to M_1 and M_2 levels. Among PxMo interactions P_2M_2 recorded maximum value for phosphorus status of soil (49.20 kg ha^{-1}).

4.7.3 Potassium content

The effect of phosphorus and molybdenum and their interaction effects on potassium content of the soil after the experiment are presented in Tables 12 and 13.

The K content of the soil was significantly influenced by the addition of phosphorus. Maximum value was recorded at P_3 level. The effect due to P_2 and P_4 were on par.

Addition of molybdenum also significantly increased the potassium content in the soil. Effect due to M_2 and M_3 levels were on par.

At all levels of phosphorus, K status of the soil increased significantly with increasing levels of molybdenum. At P_1 and P_4 levels, maximum value was obtained at M_3 level where as at P_2 and P_3 levels maximum value was obtained at M_2 level.

4.8 CORRELATION STUDIES

Correlation study was conducted between grain yield and growth characters viz. number of nodules, weight of nodules, and Leaf Area Index at flowering stage, grain yield and yield attributes and also between grain yield and uptake of nutrients. The correlation coefficients are given in Table 14.

Maximum correlation was obtained by grain yield and Harvest Index followed by grain yield and length of pod and grain yield and number of pods per plant and the correlation coefficients were 0.9626, 0.9438 and 0.9144 respectively.

Table 14. Values of simple correlation coefficients

Sl. No.	Characters correlated	Correlation coefficients
1	Grain yield x Leaf Area Index	0.8398**
2	Grain yield x Number of nodules	0.7809**
3	Grain yield x Weight of nodules	0.6647**
4	Grain yield x Chlorophyll content	0.7825**
5	Grain yield x Number of pods per plant	0.9144**
6	Grain yield x Number of seeds per pod	0.8698**
7	Grain yield x Length of pod	0.9438**
8	Grain yield x Hundred seed weight	0.8779**
9	Grain yield x Harvest Index	0.9626**
10	Grain yield x Nitrogen uptake	0.9391**
11	Grain yield x Phosphorus uptake	0.8930**
12	Grain yield x Potassium uptake	0.8389**
13	Grain yield x Molybdenum uptake	0.6807**

** Significant at 0.01 level

Table 15. Optimum doses of phosphorus and molybdenum

Item	Price Rs. kg^{-1}	Mathematical optimum dose $kg.ha^{-1}$	Economic optimum dose $kg.ha^{-1}$
Grain	6.00	–	–
P_2O_5	6.25	28.24	28.06
Molybdenum (Rs g^{-1})	3.96	0.082	0.082

4.9 RESPONSE SURFACE AND ECONOMICS OF PHOSPHORUS AND MOLYBDENUM APPLICATION

4.9.1 Dose - response relationship and standardisation of fertilizer response

The fitted quadratic response surface is as follows.

$$\hat{Y} = -1208.84 + 161.8489P + 288.5321M - 2.8866 P^2 - 96.2379M^2 + 0.8693 PM$$

(R^2 =0.90 or 90%)

Ninety percent of the variation in yield is explained by the regression relationship of phosphorus and molybdenum with yield.

The mathematical and economic optimum doses worked out are given in Table 15. Mathematical optimum dose for phosphorus and molybdenum was found to be 28.24 and 0.082 kg ha^{-1} (1.37 g sodium molybdate kg^{-1} of seed) respectively. Economic optimum dose of phosphorus and molybdenum was found to be 28.06 and 0.082 kg ha^{-1} (1.37 g sodium molybdate kg^{-1} of seed) respectively.

Economics of phosphorus and molybdenum application

The economics of phosphorus and molybdenum application presented in Table 16. revealed that the treatment P_2 M_2 (22.5 kg P_2O_5 ha^{-1} in conjunction with 1.5 g

Table 16. Economics of fertilizer application per hectare

Treatments	Cost of production Rs. ha-[1]	Yield of grain kg-ha^{-1}	Value of grain Rs ha^{-1}	Net profit Rs ha^{-1}	Benefit : cost ratio
P_1M_0	4700	625.00	3750	-950	0.20
P_1M_1	4730	676.00	4056	-674	0.14
P_1M_2	4790	721.00	4326	-464	0.10
P_1M_3	4850	718.00	4308	-542	0.11
P_2M_0	4750	880.00	5280	+530	0.11
P_2M_1	4780	1242.00	7452	+2672	0.56
P_2M_2	4840	1287.00	7722	+2982	0.62
P_2M_3	4900	1179.00	7074	+2174	0.44
P_3M_0	4800	935.00	5610	+810	0.17
P_3M_1	4830	1208.00	7248	2418	0.51
P_3M_2	4890	1248.00	7488	2598	0.53
P_3M_3	4950	1219.00	7318	2368	0.48
P_4M_0	4850	847.00	5082	232	0.05
P_4M_1	4880	986.00	5916	1036	0.21
P_4M_2	4940	1007.00	6042	1102	0.22
P_4M_3	5000	1020.70	6126	1126	0.23

Cost of 1 kg N = Rs.5.33
Cost of 1 kg P_2O_5 = Rs. 6.25
Cost of 1 kg K_2O = Rs. 2.91
Cost of 1 kg molybdenum = Rs. 3960/-

Price of 1 kg grain = Rs. 6.00

sodium molybdate kg^{-1} of seed) was the most economically viable treatment with a net profit of Rs 2982 and a benefit: cost ratio of 0.62. The second best treatment was found to be P_2M_1 (22.5 kg P_2O_5 ha^{-1} in conjunction with 0.5 g sodium molybdate kg^{-1} of seed) followed by P_3 M_2 (30.0 kg P_2O_5 ha^{-1} in combination with 1.5 g sodium molybdate kg^{-1} of seed) which recorded net profit of Rs. 2672 and Rs. 2598 respectively. Benefit: cost ratio of these two treatments were 0.56 and 0.53 respectively.

DISCUSSION

5. DISCUSSION

POT CULTURE EXPERIMENT

An investigation was undertaken for estimating the optimum dose and mode of seed treatment of molybdenum for cowpea. The results obtained are discussed below.

5.1. Growth and yield of cowpea

The results of this experiment revealed that application of molybdenum at M_3 level (2.5 g sodium molybdate kg^{-1} of seed) recorded positive and significant influence on number of branches and nodules $plant^{-1}$ compared to the other levels tried. Number of branches and number of nodules $plant^{-1}$ increased by 17 percent and 63 percent respectively compared to the control (Fig. 2). This profused branching and higher nodulation might have resulted in better tapping of solar radiation and higher nitrogen fixation. Similar increase in number of branches and nodulation had been reported by Muralidharan and George (1971) in groundnut and Anwarulla and Shivashankar (1987) in greengram and blackgram by molybdenum application.

This better fixation of nitrogen and tapping of solar radiation at M_3 level resulted in better expression of yield contributing characters like number of pods $plant^{-1}$,

Fig.2. Growth characters of cowpea (plant^{-1}) as influenced by different levels of molybdenum

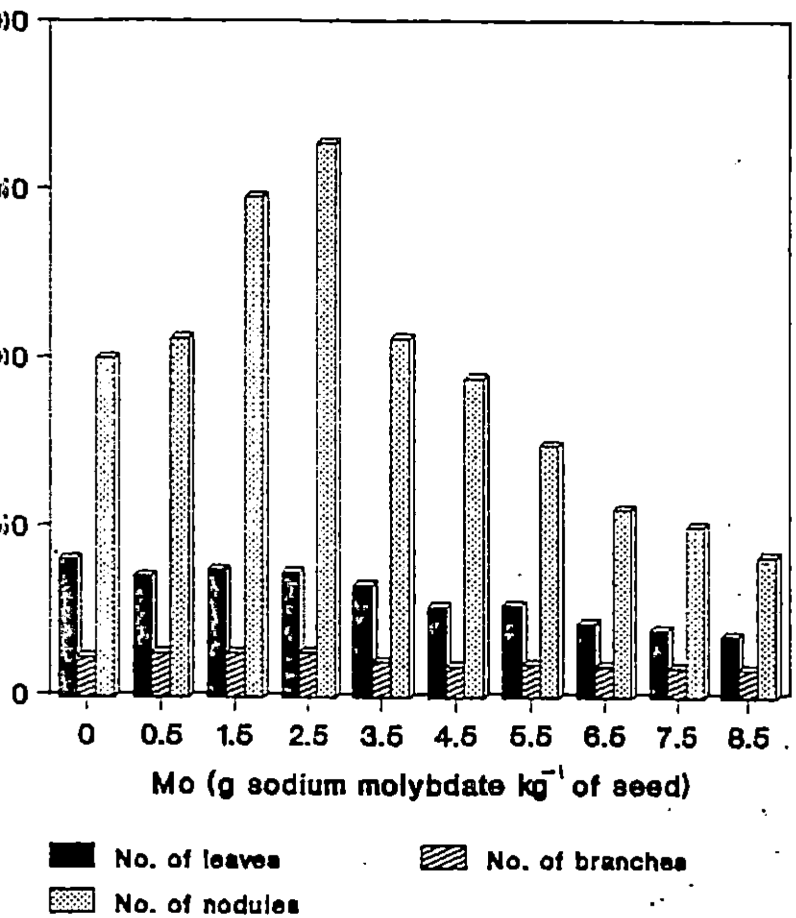
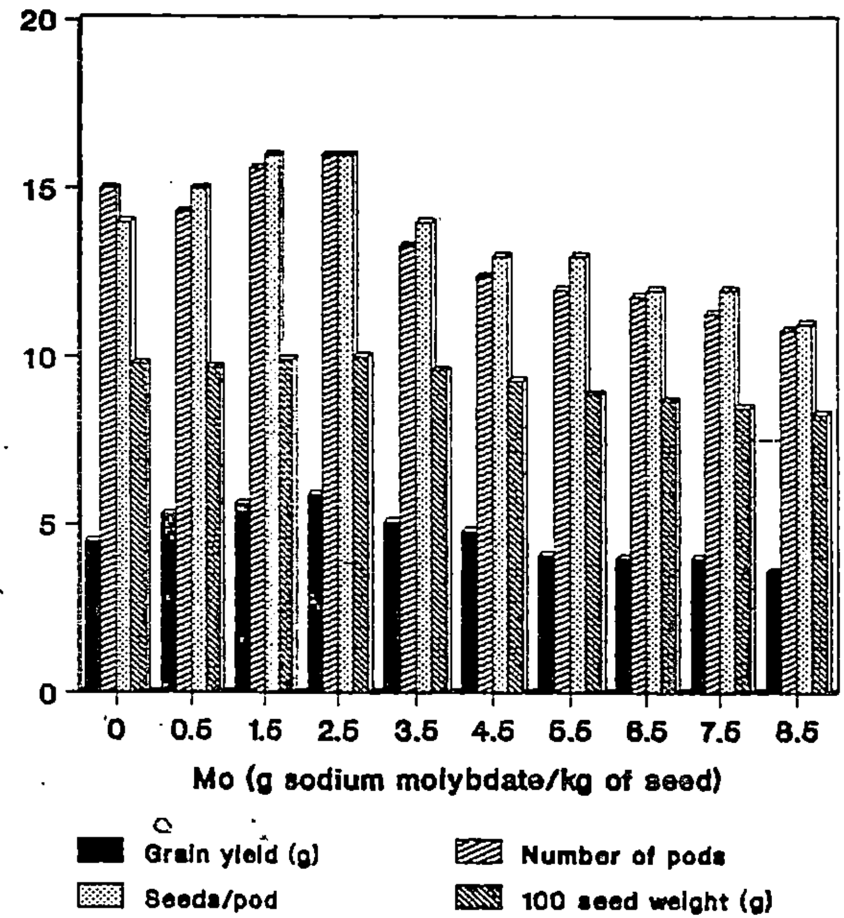


Fig. 3. Yield attributes of cowpea (plant^{-1}) as influnced by different levels of molybdenum



number of seeds pod^{-1} and hundred seed weight (Fig. 3). Number of pods $plant^{-1}$ increased by 7 percent, seeds pod^{-1} by 14 percent and hundred seed weight by 2 percent compared to the control. All these cumulatively resulted in maximum and significant yield of 5.9 g $plant^{-1}$ at this level of molybdenum which was 31 percent higher than the control. Appreciable increase in grain yield by molybdenum fertilization explained from the yield attributes such as number of pods $plant^{-1}$, number of seeds Pod^{-1} and hundred seed weight had been reported by Paricha et al. (1983) in greengram, Anwarulla and Shivashankar (1987) in greengram and blackgram and Khalia and Sharma (1988) in soybean. Though M_O level recorded maximum number of leaves no other parameters was found to be significantly superior. This may be due to the shading effect and higher number of parasitic leaves.

Among the methods of seed treatment coating was found to be better for cowpea. It resulted in 66 percent increase in yield over that of seed imbibition. By seed imbibition, molybdenum that has been absorbed into the tissues might have adversely affected the germinating tissues and might have resulted in poor initial root growth as evidenced from data presented on Appendix 2.

This better influence of seed coating method on yield is the cumulative result of growth and yield contributing characters. Figure 4 gives the growth and yield components and indicates that seed coating significantly increased the growth characters like number of leaves, branches and nodules plant^{-1} by 42, 44, and 100 percent respectively over seed imbibition. This increase in the number of leaves and branches plant^{-1} by seed coating may be due to better nodulation.

Yield components like number of pods plant^{-1}, number of seeds pod^{-1} and hundred seed weight increased by 60, 25 and 19percent respectively. Shivashankar (1984) observed that seed treatment of soybean with sodium molybdate is highly toxic in burning away the root tip and in changing the very root morphology by evoking a good response with the emergence of three to four fresh lateral roots where a single top root existed originally. Nodulation characteristics were consequently influenced favourably. The number of pods plant^{-1} was more than doubled with molybdenum seed treatment.

All these parameters discussed above made the treatment which received coating of molybdenum at the rate of 2.5 g sodium molybdate kg^{-1} of seed significantly superior to the other treatments.

Fig. 4. Growth and yield of cowpea ($plant^{-1}$) as influenced by mode of seed treatment with molybdenum

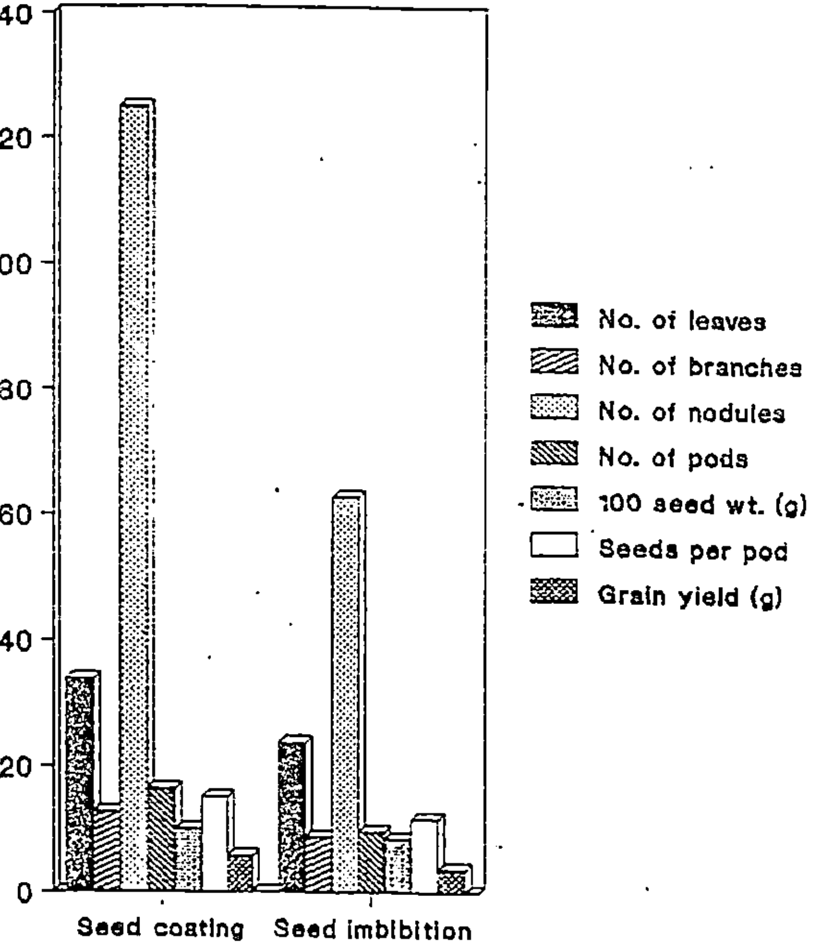
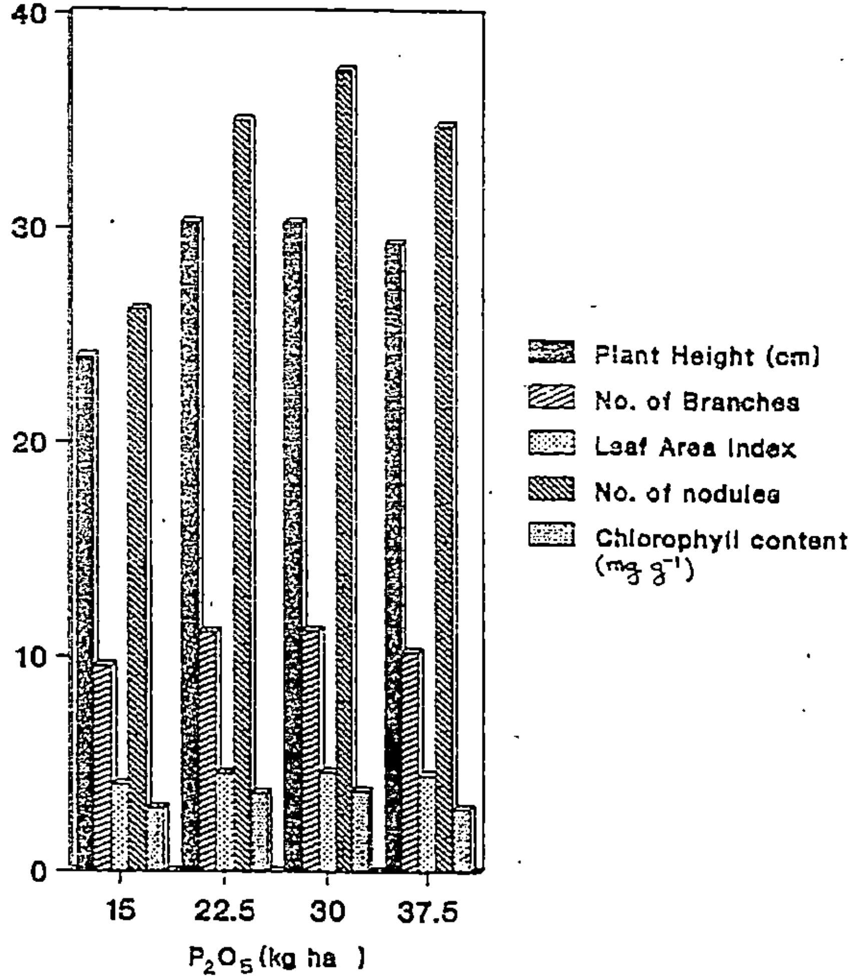


Fig. 5. Growth characters of cowpea ($plant^{-1}$) as inluenced by different levels of phosphorus



FIELD EXPERIMENT

An experiment was conducted for assessing the interaction effect between phosphorus and molybdenum on the growth and yield of cowpea var.C.152. The results of the study are discussed below.

5.2. Phosphorus

5.2.1. Growth and yield

The data revealed that application of phosphorus significantly increased the height, number of branches and LAI of cowpea. Height of the plant increased from 24.0cm to 30.25cm, number of branches from 9.57 to 11.22 and LAI from 4.06 to 4.65 as the level of P_2O_5 increased from 15 to 30 kg ha^{-1} (Fig.5).

This favourable effect of phosphorus may be due to the better nodulation and higher content of chlorophyll by the application of higher doses of phosphorus. Maximum number and weight of nodules (37.40, 119.28 mg $plant^{-1}$) and chlorophyll content (3.78 mg g^{-1}) were recorded by the application of 30.0 kg P_2O_5 ha^{-1} (Fig.5).

Phosphorus being an essential constituent of cellular proteins and nucleic acid, it encourages the meristematic activity in plants (Black, 1969). The increase in the height, number of branches and LAI might be due to hastened meristematic activity, better root growth and better absorption of nutrients by increased application of phosphorus. Similar increase in height by the increased levels of phosphorus was reported by Tarila et al. (1977) in cowpea, Rollin Bhaskar (1979) in greengram and Subbian and Ramiah (1982) in redgram. Subbian and Ramiah (1982)in redgram had observed that P fertilization significantly increased the number of branches. Improvement in LAI had been reported by Nogueira et al. (1971) in soybean and Tarila et al. (1977) in cowpea.

In promoting the activity of nitrogen fixing bacteria, phosphorus is the most important limiting factor. Such significant increase in nodulation by the application of phosphorus had been reported by Sharma and Garg (1973) in cowpea, Tang (1979), Dadson and Acquaah (1984) and Carsman et al. (1980) in soybean and Raut and Kohine (1991) in Chickpea.

The effect of phosphorus on the content of chlorophyll may be due to the availability of higher energy in the form of ATP which might have favoured the multiplication of cells and increased the chlorophyll pigment in leaf tissues. Such increase in chlorophyll content by phosphorus nutrition had been observed by Singh and Lalhal (1980) in soybean.

Earliness in flowering was noticed in plants supplied with more phosphorus. Phosphorus might have stimulated rapid cell division and growth of plant which in turn caused early flowering. The result obtained in this investigation (Fig.5) is in agreement with the finding of Tarila et al. (1977) in cowpea. Because of these reasons flowering was considerably delayed in those plants, deficient in phosphorus when compared with others which were adequately supplied with it. The influence of phosphorus in inducing earliness in flowering is well known (Black 1969).

These favourable effects on growth parameters have resulted in better expression of yield contributing characters like number of pods plant^{-1}, length of pod, number of seeds pod $^{-1}$ 100 seed weight and there by yield (Fig.6). Number of pods plant^{-1} increased by 31 percent, length of pod by 16 percent, number of seeds by 13 percent 100 seed weight by 18 percent as the level of phosphorus increased from 15 to 30kg P_2O_5 ha^{-1}.

An adequate supply of phosphorus is important in laying down the primordia for the reproductive parts of plants. Phosphorus is considered essential in the formation of fruits and seeds. The presence of easily available phosphorus seemed to have stimulated plants to produce more pods. Similar increase in pod number by phosphorus application was reported by Subramanian et al. (1977) in cowpea , Subbian and Ramiah (1982) in redgram. Phosphorus is an essential part of the nucleoprotein which hastened mitotic cell division (Black 1969). The increase in pod length noticed by phosphorus application is due to its role in cell division. Similar findings were reported by Panda (1972) in greengram.The significant effect of phosphorus on number of seeds pod^{-1} was mainly due to the favourable effect on pod length. Ahmed and Shafi (1975) recorded an increase in grains pod^{-1} by phosphorus application in peas, Singh et al. (1975) in greengram and Subramanian et al. (1977) in cowpea. Increase in 100 grain weight by phosphorus fertilization may be due to its effect on efficient seed development and grain filling. Similar increase in 100 seed weight with increasing levels of phosphorus was reported by Rollin Bhaskar (1979) in greengram.

Highest dry matter production (3264.83 kg ha $^{-1}$) and grain yield (1152.67 kg ha^{-1}) was obtained at P_3 level(30.0 kg P_2O_5 ha^{-1}) which were on par with that obtained at P_2 level (22.5 kg ha^{-1}) (Fig. 7). Increase in grain yield by phosphorus application was also evident from the results of experiments conducted in pulse crop by several workers like Subbian and Ramiah (1982) in redgram, Kushwaha and Bhaduria (1984), Negi and Thakur (1985) and Arthamwar et al. (1986) in blackgram.

g. 6. Yield attributes of cowpea (plant^{-1}) as influenced by different levels of phosphorus

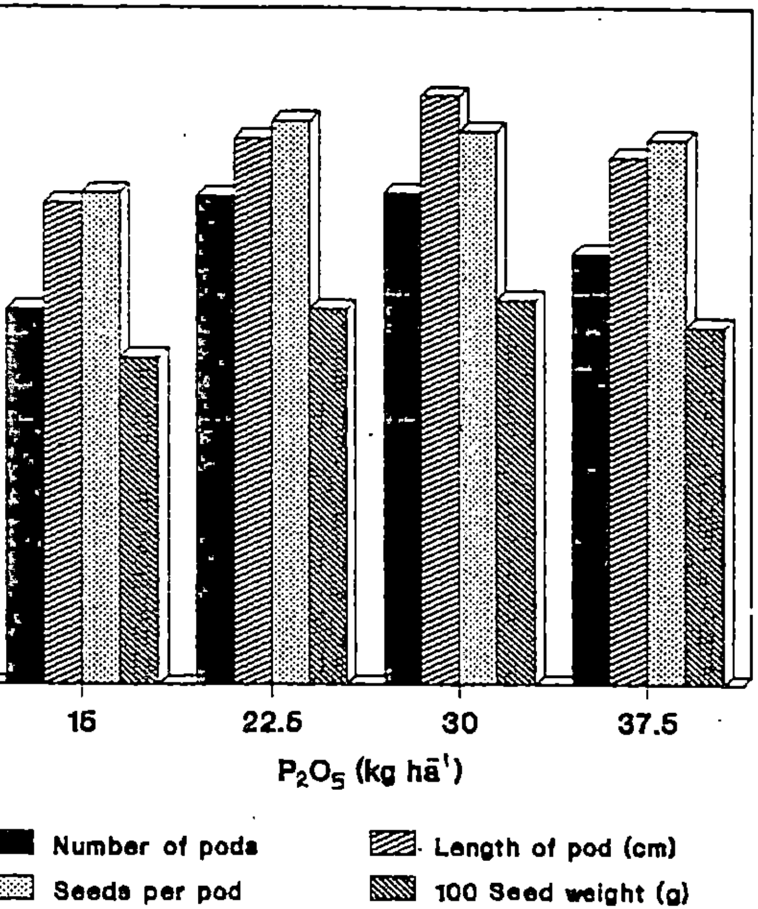
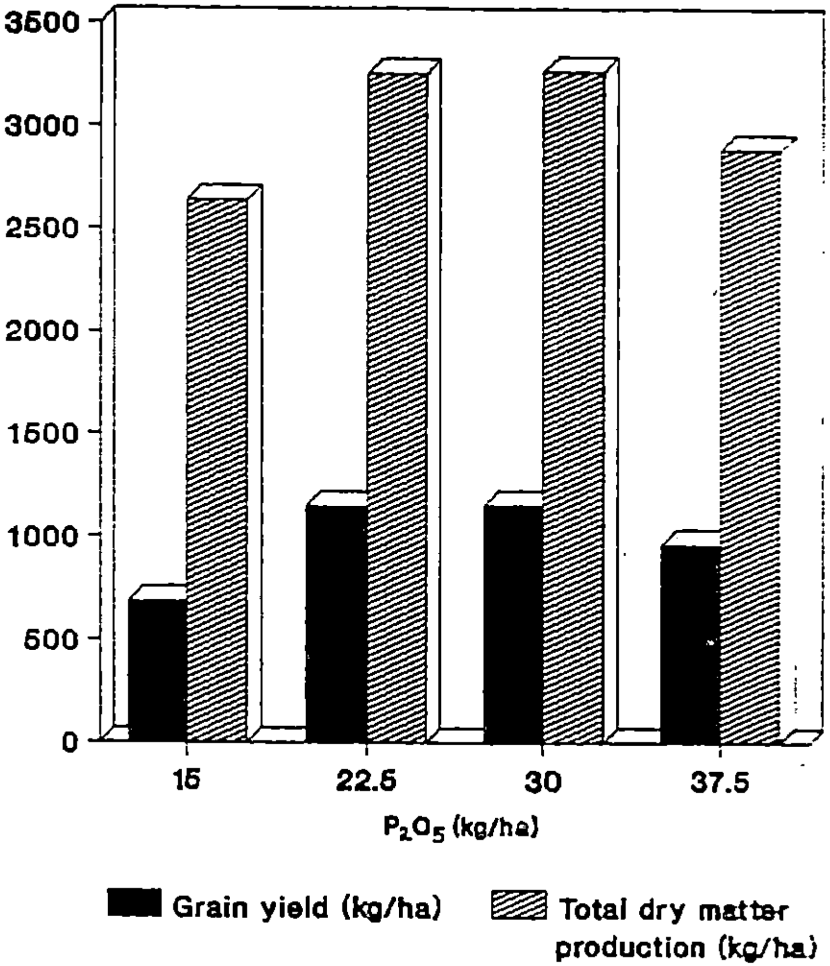


Fig.7. Yield and total dry matter production of cowpea (kg/ha) as influenced by different levels of phosphorus



At the highest level of phosphorus (37.5 kg P_2O_5 ha^{-1}) decrease in various growth and yield parameters and yield was observed. This lack of response at a rate above 22.5 kg P_2O_5 ha^{-1} may be due to the medium status of phosphorus of the soil used for this investigation. Application of phosphorus at highest level might have upset the nutrient balance and might have resulted in lower yield. Similar decrease in grain yield beyond a certain limit of phosphorus application was earlier recorded by many scientists. Ahlawat et al. (1979) reported that higher level of phosphorus (60.0 kg P_2O_5 ha^{-1}) did not cause any additional increase in grain yield of cowpea over 30 kg P_2O_5 ha^{-1}. Jayaram and Ramiah (1980) reported a linear increase in the grain yield of cowpea by phosphorus application, upto 37.5 kg P_2O_5 ha^{-1} and above this level the yield was leveled off. As evidenced from the data presented in (Fig.8) the uptake of all the four nutrients were reduced by the application of highest level of phosphorus which resulted in lower yield.

5.2.2. Nutrient status of plant and soil

With the increasing doses of phosphorus, uptake of nitrogen, phosphorus and potassium increased (Fig. 8). Uptake of nitrogen increased from 95.06 to 138.93 kg ha^{-1}. Uptake of phosphorus increased from 9.30 to 14.97 kg ha^{-1} and uptake of potassium increased from 33.60 to 43.55 kg ha^{-1}

as the level of phosphorus increased from 15 to 30 kg ha^{-1}. But the uptake of nitrogen by the application of 22.5 and 30.0 kg P_2O_5 ha^{-1} were on par, while that of phosphorus and molybdenum increased significantly and uptake of potassium decreased significantly.

The significant increase in the uptake of nitrogen with increasing levels of phosphorus may be due to significant influence on root development, nitrogen fixation and meristematic activity of the plant which resulted in an increase in the total dry matter production. This increase in drymatter production resulted in an increase in uptake of nitrogen. Here pattern of influence was the same as that obtained for dry matter production. This finding is in conformity with that reported by Sahu and Behera (1972) in cowpea, Subbian and Ramiah (1981 b) in redgram and Negi and Thakur (1985) in blackgram.

Better absorption of phosphorus and molybdenum may be due to better root growth by the application of phosphorus. Similar increase in the uptake of phosphorus by P fertilization had been reported by Subbian and Ramiah (1981 b) in redgram, Negi and Thakur (1985) in blackgram and Tripathi et al. (1989) in berseem. Phosphorus enhance the absorption and translocation of molybdenum by plants due to the release of adsorbed MoO_4^{2-} thus making it more available to plants (Tisdale et al., 1985). Increase in the uptake of molybdenum by the application of phosphorus had also reported by Singh et al. (1986) in mustard, Geetha kumari (1989) in Soybean and Tripathi et al. (1989) in berseem.

Reduction in the uptake of potassium may be due to the reduction in total dry matter production at highest level of phosphorus.

Protein content of grain was found to be increased by increased application of phosphorus. Under phosphorus deficiency protein synthesis is adversely affected because of the accumulation of arginine, asparagine and glutamine in the tissues of leguminous plants. Phosphorus is an important constituent of nucleic acid which forms protein (Kanwar, 1976). Kurdikeri et al. (1973) found that protein content of cowpea was increased by 5 percent due to the application of 22.0 kg P_2O_5 ha^{-1}. Negi and Thakur (1985) also observed that protein content in seeds of _Vigna mungo_ increased with increasing phosphorus rates.

As the level of application of phosphorus increased from 15 to 30 kg ha^{-1}, content of nitrogen, phosphorus and potassium of the soil increased significantly, but at the highest level a significant reduction in all the three nutrient content of soil was noticed - Table. 12.

Fig. 8. Nutrient uptake of cowpea (kg/ha) as influenced by different levels of phosphorus

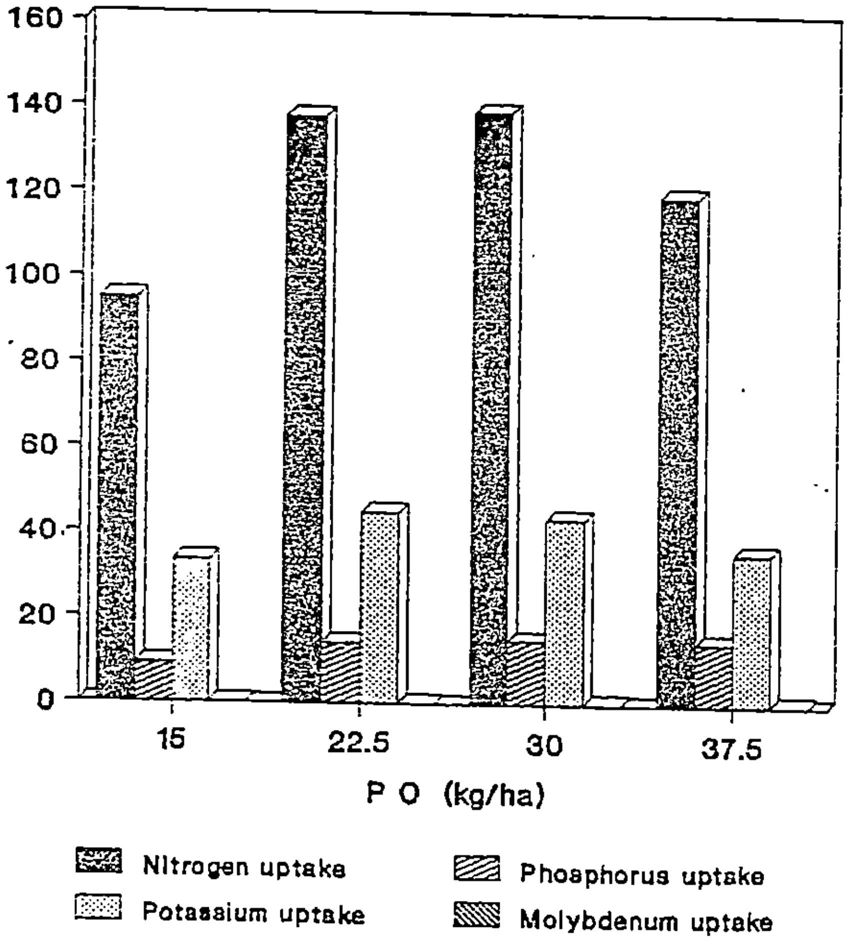
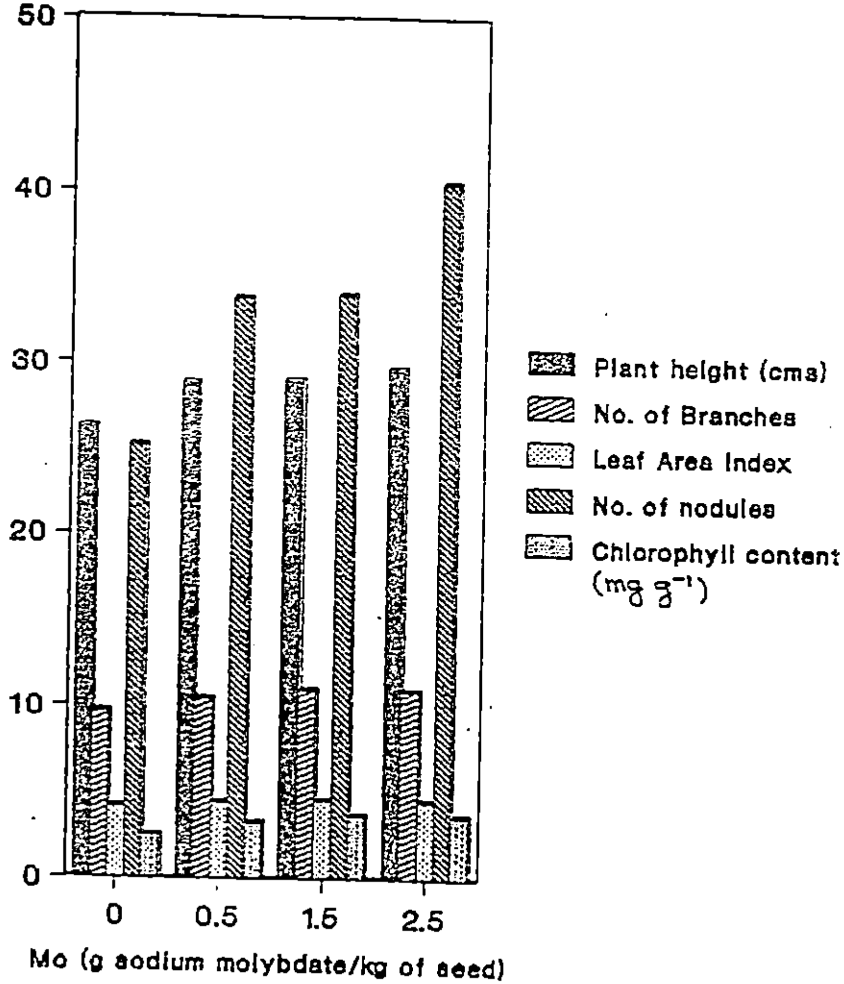


Fig. 9. Growth characters of cowpea (plant) as influenced by different levels of molybdenum



This increase in the content of N, P and K by the application of P at P_3 level (30.0 kg ha $^{-1}$) may be due to its favourable effect on canopy development and the leaf shedding might have helped to increase the nutrient content of soil .Phosphorus might have played an important role in the decomposition of organic matter which also might have a role in increasing the content of nutrient. Increase in the amount of nitrogen fixed at higher levels of P also might have resulted in more soil nitrogen. Similar increase in the nitrogen content of soil by phosphorus application was reported by Garg etal. (1970), Khara and Rai (1968) and Sahu and Behera (1972) in cowpea. Increase in the availability of phosphorus by the application of incremental doses of phosphatic fertilizers was reported by many workers (Garg et al., 1970; Sharma and Yadav, 1976).

5.3 MOLYBDENUM

5.3.1 Growth and Yield

Treating cowpea seeds with molybdenum increased the height of the plant, number of branches and LAI significantly (Fig.9). Treatments receiving highest level of molybdenum (2.5 g sodium molybdate kg $^{-1}$ of seed) recorded the maximum and significant height ~~increase~~ (29.78 cm).

The two higher levels of molybdenum seemed to have similar effect on number of branches. Number of branches increased by 14 percent and LAI by 10 percent over non treatment. Maximum LAI (4.60) was recorded at M_2 level (1.5 g sodium molybdate kg^{-1} of seed) which was on par with M_3 level (2.5 g sodium molybdate kg^{-1} of seed).

This higher rate of growth resulted from the application of molybdenum might be due to an increased rate of symbiotic N_2 fixation and higher chlorophyll content. This might be in turn due to the better root development and nodulation in Mo treated plants. Number of nodules increased from 25 to 41, weight of nodules from 77.8 to 124.4 mg $plant^{-1}$ and chlorophyll content from 2.53 to 3.72 mg g^{-1} as the level of molybdenum increased from 0 to 2.5 g sodium molybdate kg^{-1} of seed (Fig.9).

Increase in the height of the plant in Mo treated plants is similar to the results obtained by Muralidharan and George (1971) in groundnut and Huang (1979) in soybean. Also significant increase in the number of branches by molybdenum treatment had been reported by Muralidharan and George (1971) in groundnut and Anwarulla and Shivashankar (1987) in greengram and blackgram.

Increase in the number of leaves and LAI in Mo treated plants is similar to the results obtained by Sukhada Mohandas (1985) and Anwarulla and Shivashankar (1987). Increase in LAI brought about by molybdenum may be due to increased plant growth and number of expanded leaves with a larger leaf area. This can also be attributed to the additional photosynthetic area made available in these plants due to increased number of branches, increased leaf area and higher chlorophyll content.

Molybdenum is an essential micro nutrient in the symbiotic nitrogen fixation and hence to legumes. It is an essential component of one of the nitrogen fixing enzyme complex, nitrogenase.

The nodules in molybdenum treated plants were bigger and this may be due to molybdenum having an indirect role in inducing early infection of the roots when the proportion of young and tender rootlets is higher. Shivashankar (1984) had reported that seed treatment with molybdenum in soybean resulted in an increase in root density and mass particularly with tender root hairs and rootlets thereby the chances of root infection by rhizobium must have been greatly augmented as evidenced by 50 to 100 percent increase in nodule number and weight.

The nodule dry weight per plant increased as a result of molybdenum application since effective nodules were bigger and heavier. This again may be related to earlier development of nodules and their dry weight per plant due to the application of molybdenum. Such improvements in nodulation and growth characteristics had been observed by Sharga and Jauhari (1970) in peas, Shivashankar (1977 and 1985) in soybean, groundnut and cowpea, Paricha and Kar (1983), and Anwarulla and Shivasankar (1987) in blackgram and greengram.

The treatments M_2 and M_3 (1.5 and 2.5 g sodium molybdate kg^{-1} of seed) recorded higher values for all the growth and yield attributes except hundred seed weight (Fig.9 and 10). But maximum yield (1066 kg ha^{-1}) was recorded by M_2 level (1.5 g sodium molybdate kg^{-1} of seed) which was three percent higher than that at M_3 level (2.5 g sodium molybdate kg^{-1} of seed) (Fig. 11). This slight superiority of M_2 level could be attributed to the slight increase in growth characters like LAI and chlorophyll content and yield contributing characters like number of seeds per pod, number of pods per plant and uptake of phosphorus.

Fig.11 indicates that dry matter production was also higher for M_2 (3150 kg ha^{-1}) which was 2 percent higher than that at M_3. Higher dry matter production with molybdenum fertilization was reported by Muralidharan and George (1971) and Haque and Amara (1978) in groundnut, Barthakur (1980) and Anwarulla and Shivashankar (1987) in soybean. Improvements in yield attributes, in number of seeds $plant^{-1}$ (Huang 1979), number of pods $plant^{-1}$ (Shivashankar

Fig.10. Yield attributes of cowpea ($plant^{-1}$) as influenced by different levels of molybdenum

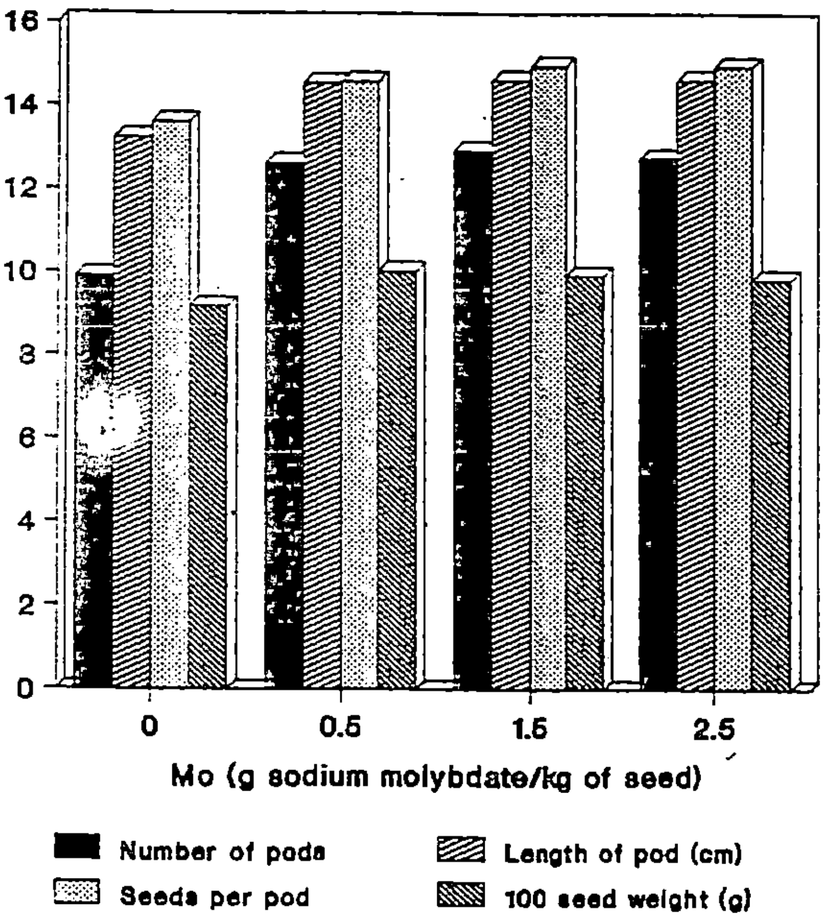
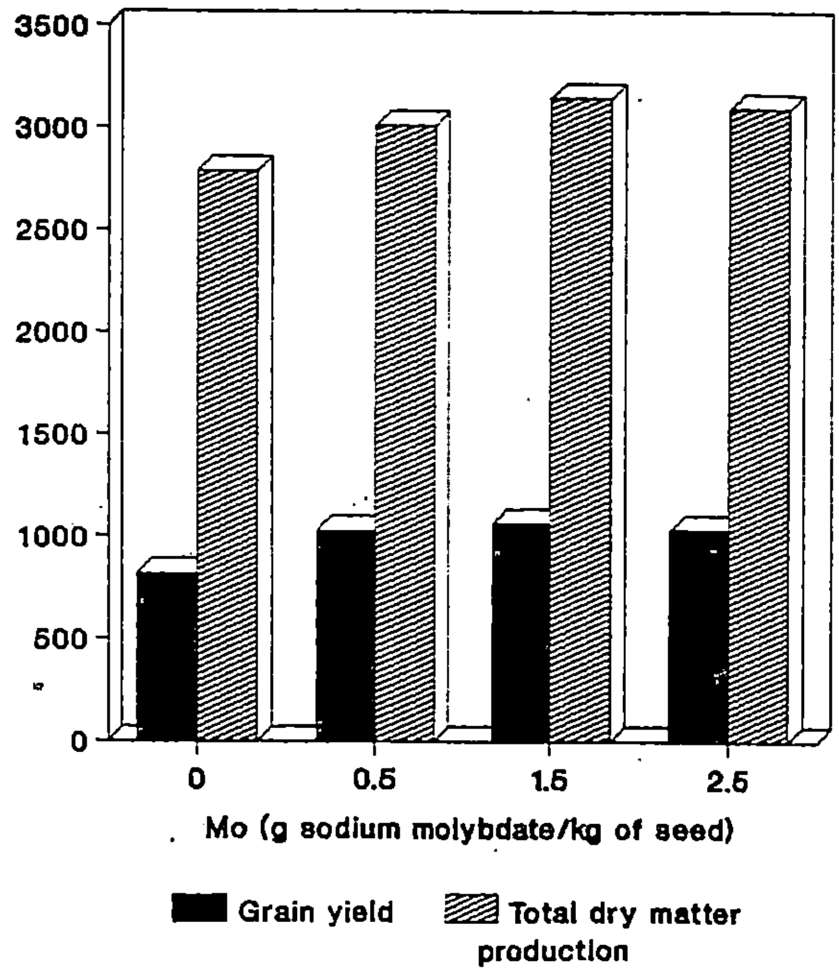


Fig. 11. Yield and Total dry matter production of cowpea (kg/ha) as influenced by different levels of molybdenum



1984 and Khalia and Sharma 1988), length of pod (Shivashankar 1984) and hundred seed weight (Khalia and Sharma 1988) by molybdenum treatment in soybean were found to enhance the yield.

Higher content of crude protein (25.58 percent) was observed at M_3 level (2.5 g sodium molybdate kg^{-1} of seed) and that may be due to the higher uptake of nitrogen.

Molybdenum is known to participate in the nitrate reduction system of nitrogen metabolism in higher plants (Nicholas 1961). The enzyme nitrate reductase catalyses the induction of nitrate and molybdenum is the prosthetic group of the enzyme; its place cannot be substituted by any other element. As molybdenum is involved in the nitrate reductase enzyme which controls the reduction of inorganic nitrate to a form the plant can utilize in building protein, molybdenum may be considered a key element in nitrogen metabolism. Increase in protein content was reported by Haque and Bundu (1980), Kormilitsyn (1981) and Lyashko (1984) in soybean.

5.3.2. Nutrient status of plant and soil

Higher uptake of nutrients was observed in molybdenum treated plots. Fig. 12 indicates that N uptake increased by 38 percent as molybdenum level increased from 0 to 2.5 g sodium molybdate kg^{-1} of seed and P uptake by 30 percent as level of molybdenum increased from 0 to 1.5 g sodium molybdate kg^{-1} of seed. These were because of improvements on root growth. Consequent to these improvements in rooting, nodulation and growth attributes, the yield attributes were also improved.

Uptake of phosphorus and potassium were higher at M_2 level (1.5 g sodium molybdate kg^{-1} of seed) whereas uptake of nitrogen and molybdenum were higher at M_3 level (2.5 g sodium molybdate kg^{-1} of seed). This better uptake of nitrogen at higher levels of molybdenum may be the result of the better activity of nitrate reductase, as molybdenum being a component of this nitrogen assimilating enzyme, which enhance the nitrogen content of the crop. Higher values of molybdenum uptake may be due to the increased availability of molybdenum. Reduction in the uptake of phosphorus and potassium may be due to the reduction in the dry matter production at M_3 level. Increase in N uptake by molybdenum treatment had been reported by Martvedt (1981) and Lyashko (1984) in soybean. An increase in phosphorus uptake by molybdenum treatment had also been reported by Tripathi et al. (1989) in berseem. Trumble and Ferreus (1946) noted a positive interaction of K and Mo in pot experiment. Lyashko (1984) had reported that applied molybdenum increased the molybdenum content in leaves and seeds of soybean.

With the increasing levels of molybdenum, the

Fig. 12. Nutrient uptake of cowpea (kg/ha) as influenced by different levels of molybdenum

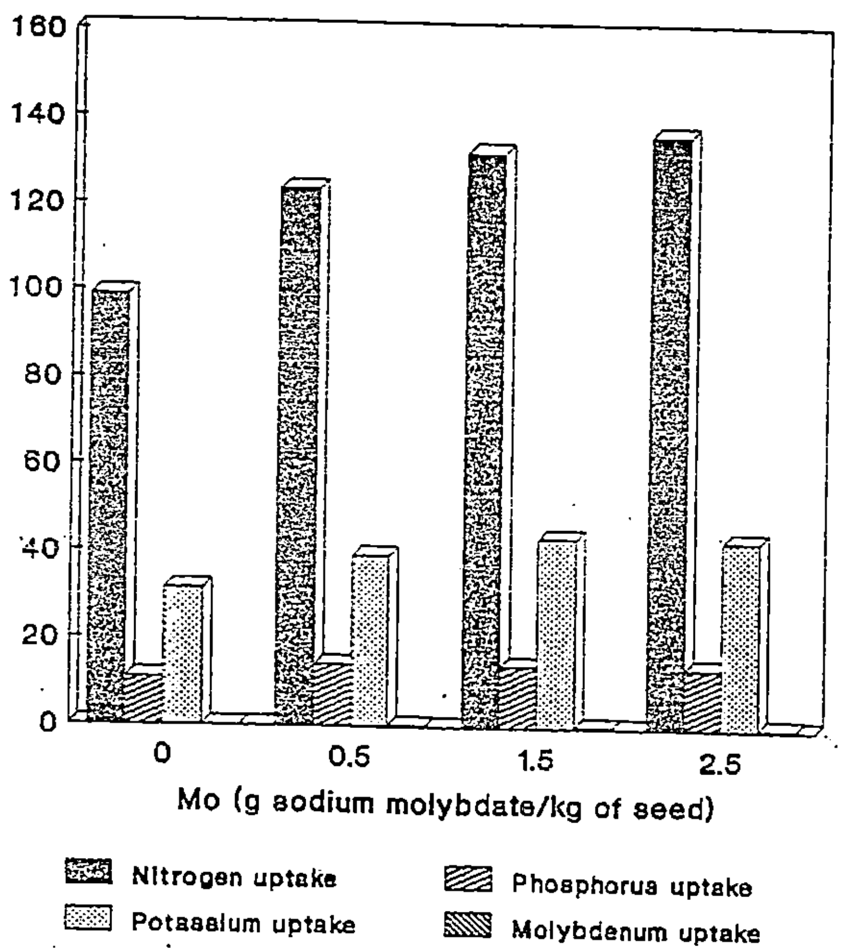
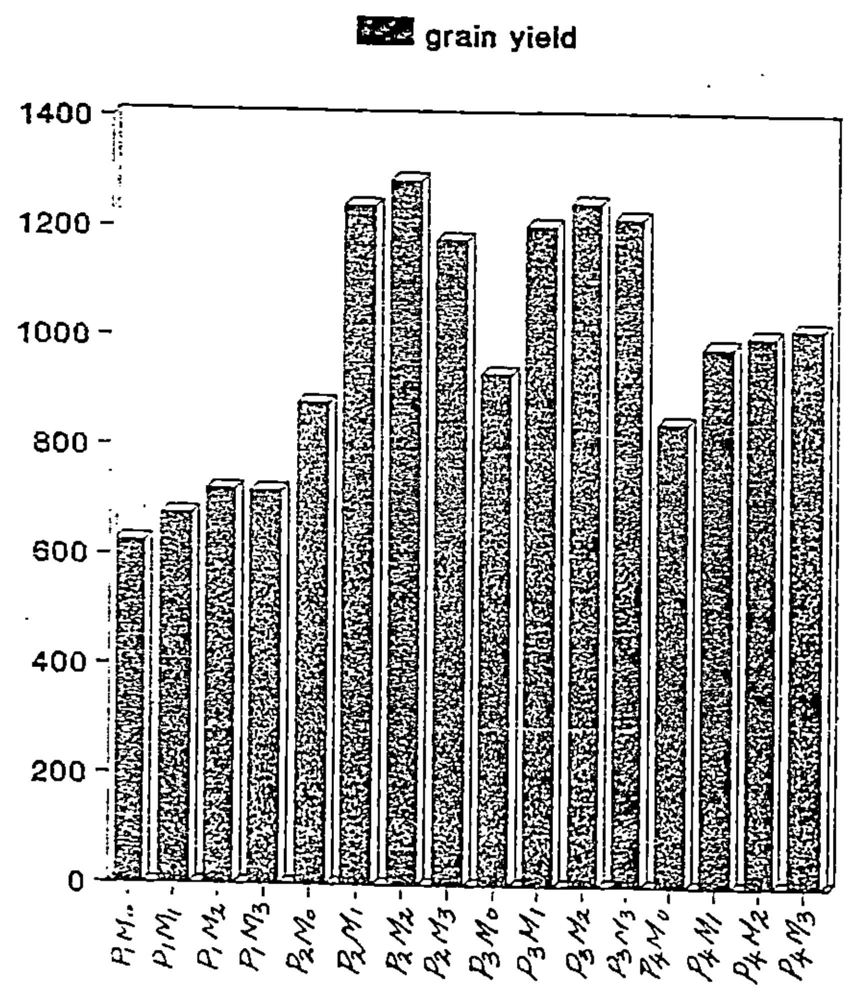


Fig. 13 Interaction effects of phosphorus and molybdenum on grain yield of cowpea (kg/ha)



content of N, P and K increased but the effect due to M_2 and M_3 were on par with respect to the content of these nutrients in soil. Molybdenum treated plants were more vigorous and recorded better biomass production and nodulation. During senescence stage by shedding of leaves, sloughing of roots, a large portion of biomass was returned in the soil. This might have improved the fertility status of soil.

5.4 PHOSPHORUS AND MOLYBDENUM

5.4.1 Growth and Yield

The combined effect of phosphorus and molybdenum was beneficial in increasing the grain yield of cowpea (Fig.13). Highest yield (1287 kg ha^{-1}) was obtained at P_2 M_2 level (22.5 kg P_2 $O_5 ha^{-1}$ in conjunction with 1.5 g sodium molybdate kg^{-1} of seed) (Fig. 13). This may be due to the better influence of this treatment on growth characters viz. number of branches per plant (12.23), LAI (4.91) and Chlorophyll content (4.47 mg g^{-1}) and Yield attributes viz. pod length (15.70 cm), number of pods per plant (14.50), hundred seed weight (10.80 g) and harvest index (37.27) as evidenced from Tables 5 and 9. Better uptake of phosphorus and potassium at this level also played a role in promoting the growth of the plant (Table 11).

Highest dry matter production (3455 kg ha^{-1}) was also recorded at this level of phosphorus and molybdenum.

Though the yield recorded by P_2(22.5 kg P_2O_5 ha^{-1}) and P_3(30 kg P_2O_5 ha^{-1}) levels were on par, at P_2 level application of molybdenum at M_2 level (1.5 g sodium molybdate kg^{-1} of seed) recorded the maximum yield. In the absence of molybdenum yield obtained by the application of 30.0kg P_2O_5 ha^{-1} (935.00 kg ha^{-1}) was significantly superior to the other levels of phosphorus, but in the presence of molybdenum, even at the lowest level of molybdenum (0.5 g sodium molybdate kg^{-1} of seed) application of 22.5kg P_2O_5 ha^{-1} has recorded an yield (1242.00 kg ha^{-1}) significantly superior to that obtained by the application of 30.0 kg P_2O_5 ha^{-1} alone. This marked increase in yield of crop with combined application of phosphorus and molybdenum was due to improvement in growth and yield attributes which is clear from the correlation data presented in Table 14.

At higher levels of phosphorus favourable effect of molybdenum was not seen. One reason may be due to the poor response to higher levels of phosphorus in this particular experiment. Addition of molybdenum might have enhanced the uptake of phosphorus by promoting root growth and the requirement of phosphorus at P_2 level might have been sufficient.

Such synergestic effect between molybdenum and phosphorus was documented by other workers also. Crafts (1954)found that in peas application of superphosphate alone increased the yield by 74 percent and combined application of superphosphate and sodium molybdate increased the yield by 91 percent. Mudholkar and Ahlawat (1979) reported that application of phosphorus and molybdenum together improved plant productivity and enhanced grain yield of bengalgram significantly. Basak et al. (1982) observed that combined application of phosphorus and molybdenum increased shoot dry matter yields of rice.

Shivashankar (1985) observed that yield realised from groundnut by the application of 75 kg $P_2 O_5$ ha^{-1} and that obtained by the combined application of 6 g sodium molybdate and 37.5kg $P_2 O_5$ ha^{-1} were on par. Rhizobium inoculation of blackgram, bengalgram,pea and berseem along with phosphate and molybdate application increased the yield under pot culture conditions and of pigeonpea, and groundnut under field conditions (Tiwari et al. 1989)

At P_1 level (15.0 kg $P_2 O_5$ ha^{-1}) increasing dose of molybdenum increased the grain yield, but the effect due to the higher two levels were on par (Fig.13). Silmilar trend was observed in the height of the plant, number of branches (Table 5). Length of pod, number of pods per plant, number of seeds per plant, harvest index and hundred seed weight also followed the same pattern (Table 9).

At P_2 and P_3 levels (22.5 and 30.0kg P_2O_5 ha^{-1}) response was seen only upto M_2 level (1.5 g sodium molybdate kg^{-1} of seed), there after a slight reduction was noticed. Similar trend was observed with dry matter production also. This may be due to the slight reduction in growth characters like LAI and content of Chlorophyll (Table 5) and yield attributes like length of pod, number of pods $plant^{-1}$, harvest index and hundred seed weight at P_2 and P_3 levels (Table 9). Crude protein content also followed the same pattern. The positive influence of molybdenum at lower levels of phosphorus may be due to the better availability of phosphorus by treating with molybdenum . But at P_2 and P_3 levels at M_2 level itself, requirement must have got satisfied. Phosphorus is also known to enhance the uptake of molybdenum and thus help in improving N_2 fixation there by increasing the yield (Tisdale et al. 1985).

At P_4 level (37.5 kg P_2 O_5 ha^{-1}) effect due M_2 and M_3 were on par with respect to growth characters like height of the plant, number of branches, LAI and nodule weight (Table 5). Dry matter production and yield attributes viz. number of pods, number of seeds pod^{-1}, harvest index and hundred seed weight also followed the same pattern (Table 9).

At the highest level of phosphorus, molybdenum content was found to be higher and that may be the reason for similar effect of M_2 and M_3.

Muralidharan and George (1971) observed that dry matter production increased significantly by the combined application of P_2O_5 and sodium molybdate in groundnut. Increase in crude protein content of soybean seeds by the combined application of molybdenum and phosphorus had been reported by Kormilitsyn (1981).

5.4.2. **Nutrient Status of plant and soil**

Higher uptake of nutrients was also observed by the combined effect of molybdenum and phosphorus. Highest value for the uptake of all nutrients was observed when molybdenum was applied in conjunction with phosphorus at P_3 level (30.0 kg P_2O_5 ha^{-1}). At P_4 level (37.0 kg. P_2O_5 ha^{-1}) a slight reduction was noticed (Table 11). Similar increase in uptake of nutrients had been reported by other workers also. Shukla and Pathak (1973) found that application of 50 kg P_2O_5 and 0.5 g Mo together increased the content of phosphorus and molybdenum in berseem than application of either of them alone. Combined application of phosphorus and molybdenum resulted in increased concentration of molybdenum in clover-grass mixture from 1 to 5ppm Mo (Petric and Jackson, 1982).

In general nutrient status of the soil increased with the combined application of phosphorus and molybdenum (Table 13). Increased application of molybdenum increased the nitrogen content of soil. This may be due to the effect on nodulation. With respect to P and K uptake no definite trend was observed. At higher levels of phosphorus response was seen only upto M_2 level, thereafter a reduction was noticed. The dynamism and complexity of the soil might have resulted like this.

5.5 Response surface and economics of phosphorus and molybdenum application

5.5.1 Dose-response relationship and standardisation of fertilizer response

Main effects of P and Mo and their interactions were found to have significant effect on the growth and yield of cowpea. So the changes in the response (Yield) at graded doses of phosphorus and molybdenum are explained by the quadratic response surface fitted. It can be seen from Table 15 that the mathematical and the economic optimum doses worked out are almost equivalent. 28.0 kg P_2O_5 ha^{-1} was found to be the ideal dose of phosphorus and 1.37 g sodium molybdate kg^{-1} of seed for molybdenum in cowpea.

5.5.2 Economics of phosphorus and molybdenum application

Data depicted in Table 16 revealed that optimum and economically viable treatment combination is P_2M_2 (22.5 kg P_2O_5 ha^{-1} in conjunction with 1.5 g sodium molybdate kg^{-1} of seed). This is due to the better yield and higher net profit obtained by the particular treatment.

SUMMARY

6. SUMMARY

An investigation was undertaken at the College of Agriculture, Vellayani with the objective of assessing the interaction effect between phosphorus and molybdenum on the growth and yield of cowpea. The investigation comprised of an initial pot culture study followed by field experiment. Pot culture study was conducted for estimating the optimum dose and mode of seed treatment of molybdenum for cowpea. C-152, a grain type of cowpea, recommended for cultivation in the red sandy clay loam soil of Kerala, was used for this investigation. The soil of the experimental site was sandy clay loam. The available nutrient status of the soil was medium in nitrogen and phosphorus and low in potassium and molybdenum. Pot culture experiment was taken up in C R D with six replications. The treatments comprised of nine levels of molybdenum as sodium molybdate (0.5, 1.5 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 g sodium molybdate kg^{-1} of seed) and two methods of seed treatment (seed coating and seed inbibition). Pot culture experiment was followed with a field investigation which was conducted in R B D with three replications. The treatments included four levels of phosphorus 50 percentage (15.0 kg per ha^{-1}), 75 percentage (22.5 kg ha^{-1}), 100 percentage (30 kg ha^{-1}) and 125 percentage (37.5kg ha^{-1}) of the recommended dose of phosphorus and four levels of molybdenum (0, 0.5, 1.5 and 2.5 g sodium molybdate kg^{-1} of seed).

The effect of various treatments on growth, yield and quality of cowpea was studied by recording observations on various growth and yield attributes. Nutrient status of the soil and plant were also computed. The economics of cultivation and nutrient response were also studied. The result of this study are summarised below.

1. The results of the pot culture experiment showed that seed coating of molybdenum is better than seed imbibition. The molybdenum levels 0.5, 1.5 and 2.5 g sodium molybdate kg^{-1} of seed were significantly superior to the other levels tried (3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 g sodium molybdate kg^{-1} of seed) and the control.

   Results of field experiment are narrated below.

2. Height and branching increased with incremental doses of phosphorus but the effect due to the application of 22.5 and 30.0 kg P_2O_5 ha^{-1} were on par and were significantly superior to other levels of phosphorus. At the maximum level tried (37.5 kg P_2O_5 ha^{-1}) a reduction was noticed in these parameters.

3. Maximum LAI (4.65), nodule number and weight (37.4 and 119.28 mg plant^{-1}) and chlorophyll content (3.78 mg g^{-1}) were obtained by the application of 30.0 kg P_2O_5 ha^{-1}. Plants that received phosphorus at this level flowered earlier.

4. Yield attributes such as number of pods plant^{-1}, length of pod, number of seeds pod^{-1} and hundred seed weight were also influenced significantly by the application of different rates of phosphorus. Application of phosphorus at the rate of 30.0 kg P_2O_5 ha^{-1} recorded the maximum value for length of pod (15.09 cm) and hundred seed weight (10.39g). Application of 22.5 and 30.0 kg P_2O_5 ha^{-1} produced similar effect on number of pods plant^{-1}, and number of seeds pod^{-1} and were significantly superior to other levels of phosphorus.

5. Highest grain yield (1152.67 kg ha^{-1}) was recorded by the application of 30.0 kg P_2O_5 ha^{-1} which was on par with that obtained by the application of 22.5 kg P_2O_5 ha^{-1} (1147.00 kg ha^{-1}). These two treatments were significantly superior to other levels of phosphorus. Similar trend was observed for dry matter production, harvest index and crude protein content of grain.

6. Uptake of nitrogen followed the same pattern as that of grain yield and dry matter production. Effects due

to the application of 30.0 kg and 37.5 kg P_2O_5 ha^{-1} were on par and these levels recorded the maximum and significant uptake for phosphorus (14.97 and 14.72 kg ha^{-1}). Application of 22.5 kg P_2 O_5 ha^{-1} recorded maximum uptake of potassium (45.02 kg ha^{-1}) where as uptake of molybdenum was maximum for the treatment receiving 30.0 kg P_2 O_5 ha^{-1} (0.34 kg ha^{-1})

7. The available nitrogen, phosphorus and potassium content of the soil after the experiment was found to be influenced significantly by the different levels of phosphorus. Maximum value for all the three nutrients - N;P&K (310.50 kg ha^{-1}, 44.60 kg ha^{-1}, 77.0 kg ha^{-1} respectively) was recorded by the application of 30.0 kg P_2 O_5 ha^{-1}

8. Molybdenum favourably influenced the growth of cowpea by increasing the height of the plant, number branches, Leaf Area Index, nodulation and chlorophyll content. Treatments that received the highest level of molybdenum (2.5 g sodium molybdate kg^{-1} of seed) recorded the maximum and significant value for height of the plant, number of nodules and dry weight of nodules. (29.78 cm, 40.54 and 124.37 mg $plant^{-1}$ respectively)

9. Seed treatment with1.5 and2.5 g sodium molybdate kg^{-1} of seed was found to be significantly superior to the

other levels in promoting branching (11.03 and 11.01 respectively) L.A.I. (4.60 and 4.58) and chlorophyll content of cowpea (3.74 and 3.72 mg g^{-1} respectively). Plants that received molybdenum at the rate of 1.50 g sodium molybdate kg^{-1} of seed flowered earlier.

10. Molybdenum treatments increased the yield attributes such as number of pods $plant^{-1}$, pod length, number of seeds $pods^{-1}$ and hundred seed weight significantly. Effect due to the application of 1.5 and 2.5 g sodium molybdate kg^{-1} of seed were on par and these levels recorded the maximum and significant value for number of pods $plant^{-1}$ and number of seeds pod^{-1}. Mo-treated plants recorded higher pod length. Similar trend was seen in harvest index and hundred seed weight. Treatment that received molybdenum at the rate of 2.5 g sodium molybdate kg^{-1} of seed recorded the maximum and significant value for protein content (25.58%).

11. Maximum and significant value for grain yield and dry matter production (1065.75 and 3150.25 kg ha^{-1}) was recorded by the application of molybdenum at the rate of 1.5 g sodium molybdate kg^{-1} of seed.

12. Seed treatment with highest level of molybdenum (2.5 g sodium molybdate kg^{-1} of seed) recorded the highest value for uptake of nitrogen(136.45 kg ha^{-1}) and

molybdenum (0.35 kg ha^{-1}). Application of molybdenum at the rate of 0.5 g and 1.5 g sodium molybdate kg^{-1} of seed produced similar effect on uptake of phosphorus while 1.5 g and 2.5 g sodium molybdate kg^{-1} of seed produced similar effect on uptake of potassium.

13. Available nitrogen, phosphorus and potassium status of the soil after the experiment was found to be significantly influenced by the different levels of molybdenum. Seed treatment with 1.5 and 2.5 g sodium molybdate kg^{-1} of seed produced similar effect for all the three nutrients and were significantly superior to other levels.

14. Combined effect of phosphorus and molybdenum was beneficial in improving the growth and yield of cowpea. Treatment that received 22.5 kg P_2O_5 ha^{-1} (P_2) in conjunction with 1.5 g sodium molybdate kg^{-1} of seed (M_2) recorded the maximum value for branching (12.23) Leaf Area Index (4.91) and chlorophyll content (4.47 mg g^{-1}). Plant height was maximum (32.17 cm) with 30.0 kg P_2O_5 ha^{-1} (p_3) in conjunction with 0.5 g sodium molybdate kg^{-1} of seed which was on par with P_2M_2.

15. Nodulation was influenced significantly by the combined application of phosphorus and molybdenum. Treatment that received 30.0 kg P_2O_5 ha^{-1} (P_3) along with 2.5 g

sodium molybdate kg $^{-1}$ of seed (M_3) recorded the maximum number and weight of nodules (48.83 and 149.33 mg plant^{-1} respectively).

16. Maximum and similar number of pods plant^{-1} was observed by molybdenum application at P_2 and P_3 levels. Same trend was observed for number of seeds pod^{-1}, pod length, hundred seed weight, harvest index and crude protein content. But among these treatments slight superiority was observed for the treatment receiving 22.5 kg P_2O_5 ha^{-1} in conjunction with 1.5 g sodium molybdate kg^{-1} of seed P_2M_2.

17. Maximum and significant grain yield (1287.00 kg ha^{-1}) was recorded by the treatment that received 22.5 kg P_2O_5 ha^{-1} in conjunction with 1.5 g sodium molybdate kg^{-1} of seed P_2M_2. Considering the effect of phosphorus alone grain yield obtained from the application of 22.5 (P_2) and 30.0 kg (P_3) P_2O_5 ha^{-1} were similar (1147.00 and 1152.67 kg ha $^{-1}$ respectively), but in conjunction with molybdenum P_2 level was significantly superior to the higher levelsof phosphorus.

In the absence of molybdenum yield obtained by the application of 30.0 kg P_2O_5 ha^{-1} (935.00 kg ha^{-1}) was significantly superior to the other levels of phosphorus, but in the presence of molybdenum, even at the lowest level of molybdenum (0.5 g) sodium molybdate

kg^{-1} of seed application of 22.5 kg $P_2 O_5$ ha^{-1} had recorded an yield (1242.00 kg ha^{-1}) significantly superior to that obtained by the application of 30.0 kg $P_2 O_5$ ha^{-1} alone.

Highest dry matter production (3455.00 kg ha^{-1}) was also recorded by this treatment. This was on par with that obtained at P_3M_2 and P_2M_1 (3396.00 and 3385.00 kg ha^{-1})

18. Maximum and significant value for uptake of nitrogen (154.30 kg ha^{-1}) was recorded by the application of 22.5 kg $P_2 O_5$ ha^{-1} in combination with the highest level of molybdenum (2.5 g sodium molybdate kg^{-1} of seed). Potassium uptake (55.39 kg ha^{-1}) was maximum at the same level of phosphorus which received a lower dose of molybdenum (1.5 g sodium molybdate kg^{-1} of seed). The uptake of molybdenum was significantly higher in treatments that received 30.0 kg$P_2 O_5$ ha^{-1} and 2.5 g sodium molybdate kg^{-1} of seed (0.45 kg ha^{-1}). Highest phosphorus uptake was recorded at $P_4 M_1$ (16.39 kg ha^{-1})

19. Available nitrogen and potassium content of soil after the experiment was maximum (366.0 and 87.0 kg ha^{-1} respectively) at P_3M_2 and phosphorus content at P_2M_2 (49.20 kg ha^{-1}) which was on par with that obtained at P_3M_3 and P_3M_2.

The present investigation revealed that for the variety C-152 a combination of 22.5 kg P_2O_5 ha^{-1} with 1.5 g sodium molybdate kg^{-1} of seed can give better yield and better profit. Based on the dose response relationship ideal dose for phosphorus was found to be 28.0 kg $P_2O_5ha^{-1}$ and that of molybdenum 1.37 g sodium molybdate kg^{-1} of seed.

Future line of work

(i) Since positive and significant response was obtained by molybdenum application for cowpea, investigations should be taken up for assessing the efficiency of different source of molybdenum and the different methods of application in different legumes.

(ii) To ascertain the interaction effect molybdenum can be tested with different sources of phosphorus

(iii) To assess the exact relationship between phosphorus and molybdenum in plants more detailed studies on plant metabolism is envisaged. Thorough investigation on various soil properties and dynamics should also be carried out for having a better understanding of this synergestic relationship between phosphorus and molybdenum

(iv) The same experiment may be repeated to confirm the trend of results obtained in the present experiment.

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APPENDICES

APPENDIX - I

Weather data during the Cropping Season (weekly averages) (from 21-4-1990 to 24-11-1990)

Standard week	Period From	Period To	Max. temperature °C	Min. temperature °C	Relative humidity (%)	Rainfall (mm)
17	21-4-90	28-4-90	30-80	24.10	76.12	10.40
18	29-4-90	5-5-90	31.60	25.40	77.41	9.70
19	6-5-90	12-5-90	28.50	24.21	83.21	3.43
20	13-5-90	19-5-90	29.60	23.44	81.72	--
21	20-5-90	26-5-90	30.50	23.56	77.41	10.90
22	27-5-90	2-6-90	31.60	25.10	83.28	22.80
23	3-6-90	9-6-90	29.46	24.11	78.20	49.53
24	10-6-90	16-6-90	30.20	24.12	87.13	20.63
25	17-6-90	23-6-90	29.53	24.07	81.07	20.83
26	24-6-90	30-6-90	29.14	22.20	93.64	18.25
27	1-7-90	8-7-90	30.13	24.07	81.14	9.40
28	9-7-90	15-7-90	28.30	23.16	93.28	5.00
29	16-7-90	22-7-90	27.5	23.42	77.00	2.60
30	23-7-90	29-7-90	29.37	23.50	86.00	11.70
31	30-7-90	5-8-90	29.34	23.57	76.60	44.40
32	6-8-90	12-8-90	28.00	22.90	79.90	3.18
33	13-8-90	19-8-90	29.08	23.90	81.10	10.80
34	20-8-90	26-8-90	30.30	24.80	78.00	--
35	27-8-90	2-6-90	30.60	24.60	75.90	--
36	3-9-90	9-9-90	30.80	24.10	76.20	7.10
37	10-9-90	16-9-90	31.40	24.50	77.00	--
38	17-9-90	23-9-90	30.80	24.20	7.90	1.30
39	24-9-90	30-9-90	29.20	23.50	84.50	19.30
40	1-10-90	7-10-90	30.50	24.70	79.90	1.85
41	8-10-90	14-10-90	30.90	24.30	77.07	0.65
42	15-10-90	21-10-90	30.40	24.02	93.20	5.34
43	22-10-90	28-10-90	31.80	23.70	88.69	7.70
44	29-10-90	4-11-90	28.80	23.10	88.50	16.60
45	5-11-90	1-11-90	30.40	22.90	76.50	--
46	12-11-90	18-11-90	30.40	22.08	76.07	--
47	19-11-90	25-11-90	30.60	23.50	81.20	19.90

APPENDIX - II

Effect of mode of seed treatment on number of lateral roots in cowpea. (15 days after emergence)

Levels of molybdenum (g sodium molybdate kg^{-1} of seed)	Mode of seed treatment	
	Seed coating	Seed imbibition
0	7	7
0.5	7	5
1.5	8	5
2.5	10	4
3.5	8	3
4.5	7	2
5.5	3	2
6.5	4	2
7.5	3	1
8.5	3	1

PHOSPHORUS AND MOLYBDENUM NUTRITION IN COWPEA
(*Vigna unguiculata* L.)

By

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ABSTRACT OF A THESIS
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ABSTRACT

An investigation was undertaken at the College of Agriculture, Vellayani during the period from April to November 1990 with the objective of assessing the interaction effect between phosphorus and molybdenum on the growth and yield of cowpea. The investigation comprised of an initial pot culture study followed by field experiment. The results of the study indicated that seed coating of molybdenum was better than ~~seed coating of~~ seed imbibition. Application of phosphorus at the rate of 30.0 kg P_2O_5 ha^{-1} increased the height and branching and resulted in maximum LAI, nodule number and weight, chlorophyll content, maximum length of pod, hundred seed weight and highest grain yield of 1152.67 kg ha^{-1}. Maximum uptake of nitrogen, phosphorus and molybdenum was recorded at this level. The maximum available nitrogen, phosphorus and potassium content of the soil after the experiment was also recorded at this level.

Seed treatment with molybdenum (1.5 and 2.5 kg sodium molybdate kg^{-1} of seed) favourably influenced the growth of cowpea by increasing the height of plant, number of branches, LAI, nodulation and chlorophyll content. Yield attributes such as number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and hundred seed weight increased significantly at these levels. Maximum and significant value for grain yield and dry matter

production was recorded by the application of molybdenum at the rate of 1.5 g sodium molybdate kg^{-1} of seed. Maximum uptake of nitrogen, potassium and molybdenum was noted at the level of 2.5 g sodium molybdate kg^{-1} of seed. Seed treatment with 1.5 and 2.5 g sodium molybdate kg^{-1} of seed, significantly influenced the available nitrogen, phosphorus and potassium status of the soil after experiment.

Combined effect of phosphorus and molybdenum was beneficial in improving the growth and yield of cowpea. Treatment that received 22.5 kg P_2O_5 ha^{-1} in conjunction with 1.5 g sodium molybdate kg^{-1} of seed recorded maximum value for branching, LAI, chlorophyll content, pods $plant^{-1}$, seeds pod^{-1}, pod length, hundred seed weight, harvest index, crude protein content and grain yield of 1287 kg ha^{-1}. Highest dry matter production (3455 kg ha^{-1}) was also recorded at this level of phosphorus and molybdenum. Maximum uptake of nitrogen was recorded by the application of 22.5 kg P_2O_5 ha^{-1} in combination with 2.5 g sodium molybdate kg^{-1} of seed. The uptake of molybdenum was significantly higher in treatments that received 30.0 kg P_2O_5 ha^{-1} and 2.5 g sodium molybdate kg^{-1} of seed. Highest phosphorus uptake was recorded by the treatment that received 37.5 kg P_2O_5 ha^{-1} in conjunction with 0.5 g sodiuum molybdate kg^{-1} of seed.

The present investigation revealed that for the variety C-152 a combination of 22.5 kg P_2O_5/ha^{-1} with 1.5 g sodium molybdate/kg^{-1} of seed gave maximum yield and maximum profit. Based on the dose response relationship economic optimum dose for phosphorus was found to be 28 kg P_2O_5/ha^{-1} and that of molybdenum 1.37 g sodium molybdate/kg^{-1} of seed.