TRACER STUDIES ON PHOSPHORUS USE EFFICIENCY IN MUSTARD - CHICKPEA PLANTING PATTERNS UNDER RAINFED CONDITIONS

By

ABHAY KUMAR VYAS

A thesis

submitted to the Faculty of Post-Graduate School,
Indian Agricultural Research Institute, New Delhi,
in partial fulfilment of the requirements for
the degree of

DOCTOR OF PHILOSOPHY

IN

AGRONOMY

1989

Approved by: Chairman : (Dr. R.K. Rai)

Members : (Dr. M.N. Sinha)

(Dr. Munshi Singh)

(Dr. P.S. Deshmukh)

(Dr. J.C. Bajaj)

Dr. R.K. Rai,
Scientist
Division of Agronomy,
IARI, New Delhi-110012.

CERTIFICATE

This is to certify that the thesis entitled "Tracer studies on phosphorus use efficiency in mustard-chickpea planting patterns under rainfed conditions" submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agronomy, is a bonafide record of research carried out by Shri Abhay Kumar Vyas, under my supervision. No part of the thesis has been submitted for any other publications, degree or diploma.

The assistance and help received during the course of investigation have been duly acknowledged.

New Delhi
Dated 9/16 January, 1989

(R.K. RAI)
Chairman
Advisory Committee

ACKNOWLEDGEMENT

I take this opportunity to offer my deep sense of gratitude to Dr. R.K. Rai, Chairman of my Advisory Committee and Scientist, Division of Agronomy, Indian Agricultural Research Institute, New Delhi, for valuable guidance, constant encouragement and inspiration in the course of this investigation and preparation of the thesis and for his ever willing help throughout the degree programme.

I express my heartiest gratitude to the members of my Advisory Committee, Dr. M.N. Sinha, Senior Scientist (Agronomy), Dr. Munshi Singh, Senior Scientist and Professor of Genetics, Dr. P.S. Deshmukh, Scientist (Plant Physiology) and Dr. J.C. Bajaj, Senior Scientist (Soil Science and Agricultural Chemistry) for their suggestions and constructive criticism throughout the period of investigation and finalisation of the thesis.

I am grateful to Dr. R.B.L. Bhardwaj, former Head of the Division of Agronomy, Dr. K.N. Singh, present Head of the Division of Agronomy and Dr. Rajendra Prasad, Professor of Agronomy for providing me all necessary facilities to carry out this investigation.

I am also thankful to Dr. P.N. Tiwari, Project Director, Nuclear Research Laboratory, IARI, for providing necessary help to carry out the investigation.

My sincere thanks are due to Shri R.R. Patil, Statistician and Shri Dhaka for their help in statistical analysis.

My thanks are also due to Shri Ram Chander, T-3, Ram Parikshan, T-1 and other field staff of Radiotracer Unit, for their assistance and cooperation.

I wish to express my profound gratitude to my parents Dr. K.K. Vyas and Mrs. S. Vyas who have been a great source of inspiration to me in this work and in my life.

My sincere thanks are also due to Dr. S.K. Pareek, Shri Sudhir Gupta, Shri Bharu Lal Kumawat and Shri Sita Ram Naga from whom I received valuable help. I also acknowledge my thanks to Shri R.A. Sharma, Shri K.K. Mishra, Dr. N.C. Jain, Shri B.L. Soni, Shri L.N. Sharma, Shri J.N. Meena, Shri R. Nagar, Shri M.L. Meena and Shri A.V. Singh for their help. Sincere appreciation goes to Shri K.L. Gauba for his cooperation in neatly and carefully bringing out this manuscript.

Finally, I wish to place on record my gratefulness to the Director, Indian Agricultural Research Institute, New Delhi for awarding me the Senior Fellowship during the tenure of my Ph.D. programme.

New Delhi (ABHAY KUMAR VYAS)

Dated: 9th January, 1989

CONTENTS

...

LIST OF TABLES

List of Tables (contd....)

List of Tables (contd....)

...

LIST OF ILLUSTRATIONS

•••

1. INTRODUCTION

Indian Agriculture could be able to meet the food requirement of ever rising population and nearly self-sufficiency has been achieved in major cereal crops. But stagnation in the production of pulses and oilseeds still remains an issue of primary concern. On the one hand, sizeable import of edible oils is causing heavy drain of foreign exchange while on the other hand, availability of pulses is inadequate to meet the protein requirement of pre-eminently vegetarian population in India. The paradox is that the oilseeds and pulses are energy rich crops but are grown in energy stress conditions resulting in poor productivity. Presently 92% of pulse production and 90% of the oilseeds production are estimated to come from rainfed areas. Even if all the estimated irrigation potential is exploited, not more than 60% of the gross cropped area can be brought under irrigation. Therefore, rainfed areas will stay as main domain for these crops and the country will have to depend on rainfed/dryland farming to sustain the level of production not only to meet the edible oil and pulse requirement but also to minimise the social imbalance between rainfed and irrigated areas.

Mustard is the second most important oilseed crop and covers highest acreage among *rabi* oilseeds, whereas chickpea had the larger share of pulse production and area. These crops are seldom provided with the fertilizers resulting in poor productivity of mustard (714 kg ha^{-1}) and chickpea (658 kg ha^{-1}). Since these crops will stay for a long time to come in rainfed areas therefore, it is necessary to develop the suitable technology by way of changing their planting pattern and use of fertilizers.

In recent years the intercropping of legume and non-legume crop components has received much attention in realising the greater yield advantage in rainfed conditions (Willey and Rao, 1980 and Nikam et al., 1987). Whereas this system not only utilize the growth resources most efficiently but also minimises the risk by way of providing insurance against failure of a crop and often results in higher yield advantages over pure culture. Several studies have evinced advantage of mustard-chickpea intercropping in alternate rows over either of the sole crops (Saxena and Yadav, 1975; Singh and Bajpai, 1982 and Kushwaha, 1985). However, chickpea yield in 1:1 mustard-chickpea system was suppressed to a greater extent by tall growing mustard plants and as the spacing between mustard rows was increased to accomodate more chickpea rows in between, the chickpea yield relatively increased (Meena, 1985). Wider row spacing can be kept either by replacing some of the mustard rows by chickpea without changing the plant spacing within rows or by reducing the plant spacing within rows to maintain the same plant population of main crop as in pure stand. Nevertheless, competition among the component crops in two situations differ to a great extent and hence both these systems could be tried in one study.

Fertilizer is single most important input in modern agriculture to raise crop productivity specially in rainfed/dryland areas because they are not only thirsty but are also hungry. Among the primary nutrient elements phosphorus nutrition is considered very important for oilseeds and pulses. Several researchers have observed favourable response to applied phosphorus by mustard (Mudholkar and Ahlawat, 1981; Archar and Vaidyanathan, 1982 and Dhillon and Vig, 1985) as well as by chickpea (Dixit et al., 1983; Singh et al., 1984 and Borgohain and Agarwal, 1986).

When these crops are grown in an intercropping system with varying row ratio than their total dry matter production will vary considerably to their sole stands. Therefore, the nutrient particularly phosphorus requirement will bound to differ to their sole stand and the fertilizer requirement will have to be different when these crops are put together in an intercropping system. Phosphorus requirement of individual crops have been worked out quite precisely by agronomists for mustard and chickpea, separately. However, some researchers have tried mustard and chickpea in intercropping system either in replacement series or in additive series but comparative information on mustard-chickpea intercropping in both the systems/ patterns was absent, particularly on the aspect of soil and applied phosphorus uptake under different patterns. Thus, to analyse the proportion of native and applied phosphorus, use of radio-isotopes serves as a superior analytical tool, extending the sensitivity, specificity and increasing the case of analysis beyond conventional methods. Its usefulness is based on the concept that an applied radio-active isotope equilibrates with its stable element in the soil.

Keeping these factors in view, it was considered appropriate to carry out an investigation entitled "Tracer studies on phosphorus use efficiency in mustard-chickpea planting patterns under rainfed conditions" with the following objectives:

1. To study the effect of planting patterns on biomass production of mustard and chickpea.
2. To study the response of mustard and chickpea to fertilizer phosphorus under different planting patterns.
3. To assess the relative contribution of native and fertilizer phosphorus in mustard-chickpea planting patterns.

....

2. REVIEW OF LITERATURE

In this chapter an attempt has been made to present a brief review on mustard (Brassica juncea L. Czern and Coss) and chickpea (Cicer arietinum L.) cultivation. It covered the effects of planting patterns of crops and phosphorus fertilization on plant growth, yield and yield attributes, light interception by crop canopy, quality, nutrient content and uptake and yield advantages. Where information on certain aspects of intercropping systems for rainfed conditions was not available or was inadequate similar information on research conducted under irrigated conditions has been reviewed. Before the review is presented, it is considered appropriate that the important aspects of the concepts and practices of intercropping systems are discussed.

Intercropping is the practice of growing two or more crops together on the same area of land, the crops are not always sown or harvested exactly at the same time but usually grew simultaneously for a significant part of their periods. It also implies that the crops are raised in separate rows and not grown mixed (Andrews and Kassam, 1975; Freyman and Venkateswarlu, 1977). The intercropping systems are of two types viz., replacement series and additive series. In former, 50 per cent population of main crop is replaced by intercrop while in latter the plant population of main crop remains unchanged and additional plant population of intercrop or associate crop is adjusted.

When two or more crops are raised as intercrops, one comes across two situations, in one, the intercrop grows better in the presence of another and exceeds in yield advantage over the sole crop (Donald, 1963; Van Den Bergh, 1968 and Willey, 1975), in another, adverse effect of competition between component crops are noted and the yield advantage compared to the sole crop is lowest (Ahlgren and Aamodi, 1939; Donald, 1946 and Harper, 1961).

The yield advantages obtained through intercropping are due to efficient utilization of the available growth resources like water (Kassam, 1973; Baker and Norman, 1975), nutrients (Ibrahim and Kahesh, 1971; Kassam and Stockinger, 1971; Dalal, 1974 and Lakhani, 1976) and light (Nelliet et al., 1974; Baker and Yusuf, 1976). The crops besides utilizing growth resources more efficiently, suppressed weeds and lowered disease and pest incidence, resulting in overall improvement in production over sole cropping (Litsinger and Moody, 1975; Rao and Shetty, 1977). Against the benefits noted, intercropping sometimes produced injurious (allelopathic) effects on one or both the crop components (Risser, 1969 and Rice, 1974). The intercrops also posed problems of crop management in countries/ regions where higher degree of mechanisation is practised (Willey, 1979).

2.1. Sole mustard

Rapeseed-mustard, because of its capacity to flourish well even on poor soils, is seldom fertilized. Experimental evidences reveal that phosphorus in right amount with efficient method of fertilization enhances the yield remarkably. The importance of phosphorus fertilization on Brassicae has been emphasized by many workers (Pathak et al., 1963; Singh et al., 1967 and Bhan, 1977). Its application may have favourable effect on growth, yield and quality attributes which are detailed hereunder:

2.1.1. Plant growth

Bhan and Singh (1976) reported that phosphorus application increased the plant height and number of branches per plant, while working on sandy loam soils at Kanpur. These ancillary characters remained at par with 25 and 50 kg P_2O_5 ha^{-1}. Osborne and Batten (1978) studied the effect of superphosphate on rape (*Brassica napus*) grown on two sites. Site I had low total nitrogen (0.066 to 0.125%) with available P ranging from 11 to 79 ppm. The site II had high total nitrogen (0.124 to 0.146%) with wide range of available P (8 to 50 ppm). Phosphorus application resulted in significant increase in dry matter production. Strong and Barry (1980) in a pot experiment studied the effect of ^{32}P labelled phosphorus under different moisture regimes on growth of tops and roots of rape and wheat. Phosphorus application did not influence the tops growth of rape both under dry (soil water content ranging from 0.25 to 0.33 g g^{-1}) and wet regimes (soil water content ranging from 0.33 to 0.42 g g^{-1}). The relative growth response was greater on soil low in P than one having medium P content. In unfertilized soil, rape produced larger root system in soils having high P content (24-33 ppm). Fertilizer application increased the overall rootmass under dry and wet regimes in P deficit soil. In rapeseed (Brassica campestris var. yellow sarson), Mudholkar and Ahlawat (1981) observed increased plant height with phosphorus application on sandy loam soils at Sirsa. However, differences between 40 and 80 kg P_2O_5 ha^{-1} were not significant. Dry matter accumulation per plant also increased significantly with increasing levels of P_2O_5 upto 80 kg ha^{-1}. While Mondal and Gaffer (1983) did not observe any marked effect of phosphorus on growth of mustard.

2.1.2. Yield and yield attributes

The work done in Canada by Soper (1971) showed that the response to phosphorus application in rape was quadratic. When the soil P content was more than 10 ppm, there was no response to added phosphate. Joshi et al. (1973) obtained higher seed yield upto the application of 50 kg P_2O_5 ha^{-1} on loamy sand soils of Durgapura. There was no difference in stalk yield due to phosphorus application. Bhan and Singh (1974) opined that 20 kg P_2O_5 ha^{-1} was sufficient for Agra region. However, for central tract of Uttar Pradesh, 25 to 50 kg P_2O_5 ha^{-1} is recommended for maximum yield (Bhan and Singh, 1976). In Australia, Osborne and Batten (1978) recorded increased seed in *Brassica napus* with drilled superphosphate on sites with low to medium level of available P. According to Singh (1978), the rate of phosphorus varied from 25 to 50 kg P_2O_5 ha^{-1} for rapeseed-mustard provided organic manures are applied in sufficient quantities under irrigated conditions. In Sweden, Monoz (1979) stated the need of applying 100 kg P ha^{-1} for Spain and Tower varieties of rapeseed. In Canada, Sheppard and Bates (1980) compared the five levels of P ranging from 0 to 100 kg ha^{-1} applied as broadcast with or without 7 kg P ha^{-1} banded below the seed on *Brassica napus*. Though the response was upto 100 kg P ha^{-1}, the apparent yield increase from 50 to 100 kg P ha^{-1} was not significant. Yield response to broadcast P was eliminated when 7 kg P ha^{-1} was banded below the seed whereas 25 kg P ha^{-1} broadcast was required to produce comparable yield in the absence of banded fertilizer. Rape responded upto 25 kg P ha^{-1} when the soil test value was 10 ug cc^{-1}. Working with yellow sarson, Mudholkar and Ahlawat (1981) reported that phosphorus application had favourable effect on dry matter accumulation per plant upto 80 kg P_2O_5 ha^{-1}. However, seed yield response was not significant beyond 40 kg P_2O_5 ha^{-1}. The relationship to seed yield and phosphorus application was quadratic in nature, the optimum economic dose being 68.9 kg P_2O_5 ha^{-1} with a net return of Rs 567 ha^{-1}. Vir and Verma (1981) obtained higher seed yield of rainfed mustard with the application of 30 kg P_2O_5 ha^{-1} and higher dose of 60 kg reduced the seed yield. On the basis of over 10 year trials in the United Kingdom, Archar and Vaidyanathan (1982) recommended 40 kg P_2O_5 ha^{-1} for yield more than 250 kg per hectare with soil P index of 1-2. For fields with higher yield potential, 60 kg P_2O_5 ha^{-1} was recommended. The data from the All India Coordinated Agronomic Research Project experiments on cultivators' fields revealed that application of 40 kg P_2O_5 ha^{-1} gave an additional response of 300 kg ha^{-1} over 60 kg P_2O_5 ha^{-1}. The response to P was more in Manipur, Bihar, Haryana and Gujarat (Pillai et al., 1984). Rana et al. (1984) conducted 62 and 53 single replicated trials for two years in succession (1980-81 and 1981-82) on groundnut and raya, respectively, on cultivators' fields in Ropar and Patiala districts of Punjab. They found the combination of 20 or 40 kg P_2O_5 ha^{-1} with different rates of N (20, 40 and 60 kg ha^{-1}) significantly improved the raya seed yield over their individual applications. Christensen et al. (1985) reported increased yields of mustard in phosphorus deficient soils. Dhillon and Vig (1985) conducted field experiments on raya at cultivators' fields in Ludhiana district of Punjab during rabi 1982-83. The available phosphorus status of soil was ranging between 7.2 - 12.5 kg ha^{-1}. The application of phosphorus increased the seed yield and economic optimum dose found was 40 kg P_2O_5 ha^{-1}.

No response of mustard to phosphorus was reported by many workers (Singh and Tomer, 1971; Patel et al., 1980; Chaniara and Damor, 1982 and Mondal and Gaffer, 1983) probably due to medium available P status of soil. Response to phosphorus varied depending on soil type, variety and locations.

2.1.3. Quality of seed

The oil content of seeds of *Brassica* varies considerably and it depends on nutrition, weather conditions during ripening stage and degree of maturity of seed at harvest. The reports on the effect of phosphorus on oil content are contradictory. Phosphorus application has been found to improve the oil content (Gupta et al., 1972 and Vidyapathiroy et al., 1981). However, application of P did not influence the oil content in many studies (Monoz, 1979 and Sheppard and Bates, 1980). In Australia, Osborne and Batten (1978) recorded increased oil and protein yield in *Brassica napus* with drilled superphosphates on sites with low to medium level of available P. According to Vir and Verma (1981), there was no consistent effect of P on the oil content of mustard.

2.1.4. Nutrient content and uptake

Racz et al. (1965) studied the phosphorus utilization by rape, flax and wheat on fallow and non-fallow sites. They found increased P content by addition of phosphorus fertilizer. Rape contained the highest percentage of P at 21 days after seeding which decreased with advancement of maturity. The P content of the plant material produced on the fallow site was generally higher than in plants growth on the non-fallow site. Phosphorus application also increased P content in seed. In green house studies, Virmani and Gulati (1971) used monocalcium phosphate labelled with ^{32}P to study the uptake and utilization of soil and applied phosphorus by mustard and found that phosphorus application significantly improved the yield and total phosphorus uptake. Mehrotra et al. (1972) reported increased P content and its uptake with addition of phosphorus upto 22 kg P_2O_5 ha^{-1}. They observed increase in P content upto branching stage and it declined thereafter. Bhat and Nye (1973) compared the amount of P taken up by rape on a pretreated sandy loam with that removed from the soil through autoradiograph of depleting zone. The P gradient around the roots indicated intense root activity but the zone of depletion extended well beyond the tips of root hairs. According to Bole (1973), root hair density increased with phosphorus application but soil P uptake was not closely related to root hair length in any of the P regimes. The roots of rape virtually devoid of root hairs took up 2 to 6 times as much soil P per unit length as the wheat roots with root hairs. Joshi et al. (1973) obtained increased P content of plants with increased levels of phosphorus at all growth stages. Available P content of soil increased with phosphorus application both at 30 and

60 days after sowing. The available P values were slightly low at 60 days indicating thereby comparatively higher uptake of P by mustard. Application of phosphorus also resulted in increased P uptake. Sheppard and Bates (1980) reported that phosphorus fertilization did not affect N concentration. Leaf P concentration increased with P fertilization from 0 to 25 kg ha^{-1} but higher rates had little effect. The critical leaf P concentration was as low as 0.2% and P concentration at 10% flowering was not critical to seed yield. While comparing the P uptake of wheat and rape using labelled phosphorus, Strong and Barry (1980) found increased total phosphorus uptake by roots and tops with P fertilization in soils low in P content. The recovery of fertilizer phosphorus was also more in such soils. The higher concentration of rape roots (0.270%) than of wheat roots (0.074%) resulted in the presence of a greater quantity of phosphorus in the root system of rape than that in wheat. Phosphorus in the root system of rape was 15-27% of the total as compared to only 6-16% in wheat. In rainfed mustard, P application had no effect on the N content of the seed and stover. P concentration in both seed and stover increased with P application and this increase was significant upto 30 and 60 kg P_2O_5 ha^{-1} in seed and stover, respectively. Apparently, the translocation of P from stem to seed was poor under the higher dose. The uptake of N and P in seed and stover followed similar trend. Dhillon and Vig (1985) observed that application

of phosphorus improved the efficiency of applied nitrogen. The magnitude of phosphorus absorption by seed and stover decreased with increase in the level of P beyond 30 kg P_2O_5 ha^{-1} (Vir and Verma, 1979).

2.2. Sole chickpea

Phosphorus to legumes is as important as nitrogen is to cereals. Its importance is well emphasised by Russel (1970) according to whom the most limiting soil nutrient to legume crop is phosphorus. Phosphate deficiency is the key factor for poor yields of pulse crops on all soil types and phosphate application to pulse is the basis of manuring of pulses (Saraf, 1983). Chickpea is no exception to this. Legumes require large amount of this nutrient, not only for their growth and development but also for fixation of atmospheric nitrogen in their root nodules (Graham and Rosac, 1979).

Reviewing the work done in India, Mahapatra *et al.* (1973), Prasad and De (1981) and Saraf (1983) opined that phosphorus fertilization was the first step towards increasing pulse production. The influence of phosphorus application on chickpea have been briefly reviewed under the following heads:

2.2.1. Plant growth

Singh (1971) studied the response of chickpea to phosphorus application on sandy loam soil having 0.054 per cent total phosphorus at Varanasi (U.P.). Phosphorus application was found to increase markedly the root dry weight, plant height, fruiting branches per plant, leaf dry weight. Rathi and Singh (1976) conducted trials at Meerut (U.P.) on loamy soils of low fertility and observed that there was significant increase in number of branches per plant. In a field trial under dry conditions of Stavropol province (USSR), Sysoev (1978) observed that as the chickpea plants do not form nodules under very dry conditions, pre-sowing application of ammophos is necessary. It increased the plant height, leafiness and leaf area by 200-300 ha^{-1}. Singh et al. (1983) reported from Varanasi (U.P.) that the economic optimum rate of phosphorus was 45.4 kg P_2O_5 ha^{-1} for better growth of chickpea. Das (1985) obtained good response of tall chickpea to phosphorus application, on sandy loam, alluvial soils of IARI, New Delhi. Phosphorus application had significant influence on growth characters of chickpea. Raju and Verma (1984) conducted experiments at Varanasi (U.P.) under rainfed condition on sandy clay loam soil having available phosphorus 11.5 kg ha^{-1}. There was a significant increase in growth characters with the increasing rate of phosphorus application. Dravid et al. (1985) conducted pot culture experiments at IARI, New Delhi and opined that application of phosphorus, either alone or in combination with zinc, enhanced the dry matter production over control. The field experiment was conducted at Hissar (Haryana) on sandy loam soil having available P 15.25 kg ha^{-1} by Borgohain and Agarwal (1986).

The fruiting branches per plant were increased to 14.05 and 28.59% due to 40 and 80 kg P_2O_5 ha^{-1} over control.

2.2.2. Yield and yield attributes

A large number of experimental findings showed positive response of chickpea to phosphate application upto 50-75 kg P_2O_5 ha^{-1} (Chowdhury *et al.*, 1975; Sharma *et al.*, 1975; Rathi and Singh, 1976; Aulakh and Pasricha, 1979; Suryawanshi and Choudhuri, 1979; Chandra *et al.*, 1983; Singh *et al.*, 1984). However, few workers have reported no response to phosphorus application to chickpea (Srivastava and Singh, 1975; Raikhelkar *et al.*, 1977; Dhingra and Kolar, 1979; Prasad and Sanoria, 1981).

Singh (1971) studied the response of chickpea to phosphorus on a sandy loam soil having 0.054 per cent total phosphorus at Varanasi (U.P.). The increase in level of phosphorus upto 67.5 kg P_2O_5 ha^{-1} enhanced chickpea yields significantly. Rathi and Singh (1976) from their trials conducted at Meerut (U.P.), on loamy soils of low fertility obtained good response upto 75 kg P_2O_5 ha^{-1}. There was significant increase in number of pods per plant, 1000-grain weight and grain yield per plant. Working on sandy loam soil of Sirsa (Haryana), Mudholkar and Ahlawat (1979) reported that the response to applied phosphorus was of a lesser magnitude, being 4.3 and 5.0 kg grain per kg of phosphorus at 40 kg P_2O_5 ha^{-1} and 4.4 and 2.1 kg kg^{-1} of phosphorus at 80 kg P_2O_5 ha^{-1}, respectively during 1970-71 and 1971-72. The available phosphorus status of the soil in the respective seasons was 11.7 kg P_2O_5 ha^{-1} and 14.6 kg P_2O_5 ha^{-1}. Suryawanshi and Chaudhuri (1979) reported increased chickpea yield, pod number and 1000-grain weight by phosphorus application at Parbhani (Maharashtra) under rainfed conditions.

On a sandy loam soil having 13.4 kg ha^{-1} available phosphorus at Delhi, Singn et al. (1980) reported positive yield response to phosphorus upto 30 kg P ha^{-1}. The yield components that were significantly influenced by P application were the number of pods per plant and weight of pods per unit area. Kalsi et al. (1982) obtained 8.0 q ha^{-1} of more chickpea yield by applying 40 kg P_2O_5 ha^{-1} over control under rainfed conditions at Ludhiana (Punjab). Working on red black soil of Rewa (M.P.), Dixit et al. (1983) observed that P application upto 80 kg ha^{-1} resulted in consideraole improvement in yield attributes. Das (1985) obtained good response of tall chickpea to phosphorus application, on sandy loam, alluvial soils of IARI, New Delhi. Phosphorus application had significant influence on yield components and yield.

A field experiment was conducted at Durgapura, Jaipur (Rajasthan) by Shaktawat and Sharma (1985) to study the response of chickpea varieties to seed rate and phosphorus on loamy sand soil. Different levels of phosphorus exerted significant effect on the grain yield of chickpea as compared to control. Increasing levels of phosphorus did not influence the grains per pod, however, test weight was increased significantly. Singh et al. (1984) conducted a field experiment on calcareous sandy loam soil with available phosphorus 8.9 kg ha^{-1}. Application of 17 kg P ha^{-1} significantly increased the number of pods per plant and 1000-grain weight over control. The relationship between grain yield and phosphorus levels was quadratic in nature. The economic optimum dose was worked out at 26 kg P ha^{-1}. Yadav et al. (1985) conducted field experiment during winter seasons of 1977-78 and 1979-80 on sandy loam soil having available phosphorus 13.6 kg ha^{-1}. Increase in phosphorus from 0-30 kg P_2O_5 ha^{-1}, increased the yield significantly in both the seasons. Working on sandy loam soil having available phosphorus 21.25 kg ha^{-1} at Faizabad (U.P.), Singh and Yadav (1985) observed that application of phosphorus upto 80 kg P_2O_5 ha^{-1} resulted in significant increase in the number of pods per plant, number of grains per pod, grain yield and straw yield while test weight increased upto 40 kg P_2O_5 ha^{-1}. Similar results were reported by Dobariya et al. (1985) Arvadia and Patel (1985) conducted field experiment on clay soil having 24.78 kg available phosphorus ha^{-1} at Navsari (Gujarat) and reported that application of phosphorus significantly increased the number of pods per plant and grain yield per plant. However, number of grains per plant, test weight and fodder yield were not significantly influenced by the phosphorus application. Working on clay soil having available P_2O_5 22 kg ha^{-1}, Kushwaha *et al.* (1985) observed that increasing levels of phosphorus from 20-80 kg P_2O_5 ha^{-1} caused a progressive increase in chickpea grain yield. Borgohain and Agarwal (1986) conducted field experiment on sandy loam soil having available phosphorus 15.25 kg ha^{-1} at Hissar (Haryana). They reported that application of 40 and 80 kg P_2O_5 ha^{-1} caused 13.7, 21.6 and 20.1 and 40.0 per cent increase in grain yield.

2.2.3. Nutrient content and uptake

The role of phosphorus in proper development of plant roots and nitrogen fixing nodules is well known which affect nutrient uptake.

The nitrogen content as well as the amount of nitrogen fixed in nodules of legume plants was found to be higher with phosphorus nutrition (Khare and Rai, 1968). Sharma and Yadav (1976) observed at Karnal (Haryana) that the effect of phosphorus fertilization was more pronounced on phosphorus uptake. The successive doses of phosphorus increased its accumulation at all the stages of growth. The uptake of N and P by chickpea has been estimated to vary from 61-143 and 5-10 kg ha^{-1}, respectively, depending upon the crop growth conditions (Saxena and Sheldrake, 1977). Jain (1978) observed that phosphorus applied at 75 kg P_2O_5 ha^{-1} significantly increased the uptake of nitrogen, phosphorus and potassium, the magnitude of increase being 24, 36 and 45 per cent, respectively, over control which removed 123 kg N, 15.3 kg P_2O_5 and 58.9 kg K_2O ha^{-1}. Singh et al. (1978) working on sandy loam soil of Agra (U.P.), having medium available phosphorus status, reported that the phosphorus uptake of chickpea increased with increase in levels of phosphorus application from 0 to 120 kg P_2O_5 ha^{-1}. In pot trials with chickpea, Raut and Ghonsikar (1979) reported from Parbhani (Maharashtra) that the amount of P derived from the fertilizer increased with increasing levels of applied P. The utilization percentage of applied P decreased with its increasing levels. Srivastava and Varma (1983) reported an overall improvement in the uptake of nitrogen and phosphorus and in the quality of legume with the application of phosphorus.

Singh et al. (1984) conducted a field experiment on a calcareous sandy loam soil having available phosphorus 8.9 kg ha^{-1}. Application of 17 kg P ha^{-1} significantly increased the P-uptake over control. Prasad and Sanoria (1984) opined that application of 100 and 150 kg P_2O_5 ha^{-1} increased the N and P in straw. Dwivid et al. (1985) conducted two sets of pot culture experiments at IARI, New Delhi and found application of phosphate carrier either alone or with zinc gave higher values of P-uptake in all the soil situations over control. Utilization of phosphorus was more when phosphorus and zinc were applied together. Mahajan et al. (1985)

conducted a field experiment at Jabalpur (M.P.) on clay soil having available phosphorus 8.9 kg ha^{-1}. There was significant effect in the P-uptake in grain, straw and total dry matter with the increasing fertility status of soil and phosphorus levels. Phosphorus derived from fertilizer in grain, straw and plant decreased significantly with the increasing fertility status of soil. Similar findings were reported in soybean (Mahajan et al., 1982). However, per cent phosphorus derived from fertilizer in grain, straw and plant increased significantly with every successive increase in phosphorus level. This finding also confirms the results reported earlier by Singhania and Goswami (1974) and Rastogi et al. (1981). Utilization of phosphorus in grain, straw and plant decreased significantly with increasing fertility status of soil. While soil phosphorus uptake in grain, straw and plant increased significantly with increasing fertility status of soil and phosphorus levels. This result supports the view reported earlier by Singhania and Goswami (1974), Mahajan and Bisen (1980) and Mahajan et al. (1982).

Roy and Tripathi (1985) conducted experiment at cultivators' fields in the alluvium belt of the south western region of West Bengal during 1980-81 and 1981-82 on sandy loam soil having 0.06% phosphorus. In general, 75 kg P_2O_5 ha^{-1} increased the nutrient concentration both in grain and straw in both years. However, it was at par with 50 kg P_2O_5 ha^{-1} in P and K concentration in straw during the second year and in K concentration only in the first year. Das (1985) also reported that the phosphorus application showed the higher uptake of N, P and K by chickpea crop at different stages of growth in grain, stalk as well as in whole plant. Mahajan _et al._ (1985) in a field experiment on vertisol at Jabalpur (M.P.) using ^{32}P labelled superphosphate to study the uptake and utilization of soil and fertilizer P by gram under different phosphorus levels, observed that the total P uptake by grain, straw and total dry matter increased significantly with increasing P levels.

2.3. Mustard and chickpea intercropping systems

Saxena and Yadav (1975) reported chickpea with _toria_, _sarson_ or mustard to be the common mixture in rainfed agriculture in north India. The studies on phosphorus fertilization in intercropping systems was meagre, but a sincere attempt has been made to review the influence of intercropping systems on the growth, light interception, yield and yield attributes, quality, nutrient content and uptake and yield advantages. Wherever information on proper intercropping systems were not sufficient, other related intercropping systems are also taken into consideration.

2.3.1. Plant height

Gangasaran and Giri (1985) conducted the field experiments to assess the seed yield and competitive ability of associated crop species in binary compositions with mustard in different proportions (1 row of mustard alternated with 4, 6 or 8 rows of chickpea, lentil, barley) under dryland conditions of semi-arid tropics of north India. The dry matter of mustard was adversely affected more with barley than with chickpea or lentil association. Mandal <u>et al.</u> (1986) conducted the experiment at Kalyani (West Bengal) on sandy loam soil having 16 kg available phosphorus ha^{-1}. Wheat and chickpea flowered 2 and 9 days earlier in mixed stand than when grown as sole crops. Chickpea matured 12 days earlier when grown as an intercropping with wheat. There was no significant difference in leaf area index (LAI) at 60 and 70 days after sowing (DAS) between wheat + chickpea and wheat + mustard. But at the subsequent growth stages wheat + chickpea had significantly higher LAI. Higher LAI had been reported under intercropping systems (Lin <u>et al.</u>, 1981; Kundu and Chatterjee, 1982).

Reddy and Willey (1981) concluded that the dry matter yield advantage of the intercrop was due to improved efficiency of conversion of sunlight. Kumar and Singh (1987) conducted field experiment at Pantnagar and observed that intercropping of mustard with gram resulted in reduction of number of branches per plant. However, dry matter of intercrop was significantly affected by intercropping treatments.

2.3.2. Light interception

Light plays an important role and is instantaneously available for interception by crop plants to be simultaneously utilized for photosynthesis (Donald, 1961). Willey and Roberts (1976) remarked that light is the most important growth resource and emphasized needs for its uniform and efficient utilization by intercrops.

The studies made by Willey and Roberts (1976) showed that at optimum plant densities, sole crops attained a peak value of light interception and left little scope for greater spacial interception by intercrops. Similar observations were made in one of the experiments conducted at ICRISAT, Hyderabad on sorghum-pigeonpea intercropping system (Willey, 1979). Although the total dry matter yield was more and leaf area index was slightly better, the peak light interception of 90% was almost identical to the sole sorghum crop. Sheldrake and Saxena (1979) studied effects of shading on chickpea canopies during the reproductive phase at ICRISAT, Patancheru and noted 50% reduction in photosynthetically active radiation (PAR), 15% increase in yield and delay in senescence. This they ascribed to shading which reduced stresses that were accelerating the senescence process. The light intensity was assumed still to be near saturation. Further reduction in light intensity delayed senescence even more but also reduced yield. The same workers observed at Hissar (Haryana) later (Saxena and Sheldrake, 1980) a significant reduction in yield in all chickpea cultivars even when only 25% of sunlight was intercepted. A drastic reduction in total dry matter, harvest index, pods per m^2 and seed per pod, however, occurred at 84% light interception.

At Trinidad (West Indies), Hughes et al. (1980), (1981) studied the effect of change in the light interception during growth period on productivity of pigeonpea. They found that light interception was low during early stage which increased continuously till the crop attained maximum leaf area index (LAI). In early types, the interception was 50% at LAI 1, and it became 95% at LAI 4.4. It was also found that pigeonpea yield was directly related to the length of time for which light was continuous on the leaf canopy and the leaf area index (LAI) attained by it that time. It was also stated that when plant densities increased from 2,00,000 to 6,00,000 plants ha^{-1}, there was an increase of 15% in radiation interception, but in no case the efficiency of conversion of intercepted light to photosynthetic assimilate exceeded 2%. Similar results were obtained by Keating et al. (1980) and Sinha and Savitri (1978). These authors pointed out that efficiency of light utilization by crops and the ultimate increase in grain yield, depended largely on the moisture available in soil, especially during the reproductive phase of the crop.

In chickpea the level of production of assimilates seemed to determine its seed yield, high photosynthetic rate at the stage of flower bud initiation increased the number of pods/plant (Mehrotra et al., 1981). They further remarked that net photosynthesis during grain development and the leaf area index at full bloom stage determined the difference in biological yield which was positively correlated with test weight as well as the seed number per pod.

The total light intercepted in the intercropping system (pigeonpea + groundnut) was higher than pure crops (Pareek, 1987). The advantages in dry matter yield of intercrop was due to the improved efficiency of conversion of light into higher amounts of assimilates and not due to higher interception of sun light (Reddy and Willey, 1981).

Keating et al. (1980) found a non linear relationship between dry matter yield and amount of solar radiation intercepted. They made a more interesting observation in that, the harvest index of early maturing pigeonpea types, remained constant at 43 per cent interception of sunlight.

2.3.3. Yield and yield attributes

Experiments at IARI, New Delhi (Anonymous, 1970) reported that mustard gave higher yield over its sole stand when it was raised with chickpea in a row ratio of 1:1. Saxena and Yadav (1975) reported that chickpea seldom gave as large yield as a pure crop when it was intercropped with Brassica campestris var. toria in alternate rows. It was also found that the magnitude of competition between chickpea and Brassica spp. was lower than between Brassica spp. and lentil. At Bawal, Singh (1981) obtained a total yield advantage of over 70% when chickpea was intercropped in paired rows or in alternate rows with toria. He also observed that a change in the row ratios of either crop gave over 41% increase than the sole chickpea. Experiments conducted in drylands under the All India Coordinated Research Project for Oilseeds (AICRPO, 1983-84) at Pantnagar, Kanpur and Durgapura showed chickpea + mustard in 2:1 and 1:1 as the best system. It gave the high chickpea equivalent yields than other systems viz., 3:1, 4:1, 5:1 and 6:1 row ratios.

Gangasaran and Giri (1985) conducted the field experiments to assess the seed yield and competitive ability of associated crop species in binary compositions with mustard in different proportions (1 row of mustard alternated with 4, 6 or 8 rows of chickpea, lentil, barley) under dryland conditions of semi-arid tropics of north India. Higher yield advantage was in 1:6 row ratio of mustard + chickpea or barley in dry season and in 1:8 row ratio of mustard + barley in wet season.

Competitive ability of mustard was higher in all crop combinations and proportion. The grain yield of chickpea and barley were not affected much by intercropping vis-a-vis the yields recorded from sole crop stands in 1979-80. But in 1980-81, the differences were significant, more being from sole crops. The yield of mustard decreased more in association with barley and less with chickpea and lentil in 1980-81. The grain weight and number of grains per plant that the yield components of mustard were adversely affected more with barley than with chickpea or lentil association in 1980-81 with normal rainfall. In dry year (1979-80) the yield of chickpea and barley were not affected much in intercropping system. Ahlawat et al. (1985) conducted experiment at IARI, New Delhi and reported that pure stand of both semi-spreading (BG-209) and tall (HG-218) chickpea cultivars gave markedly higher grain yield than their mixed stands with different planting patterns i.e. BG 209 and HG 218 in alternate rows, BG 209 + HG 218 in alternate paired rows and BG 209 + HG 218 seed mixture in 1:1 ratio. The reduction in yield was more conspicuous when both the cultivars were grown together in alternate rows.

The results of experiments on crops like, pigeonpea + greengram/blackgram (Giri and De, 1977), cotton + safflower/sesame/greengram/cowpea (Nagre, 1979) and safflower + cowpea (Willey and Rao, 1981) indicated no decrease in the yields of dominant base crops, raised with the population rates, the yields of the less competitive intercrop was improved at its higher plant densities. Studies made by Chowdhary and Misangu (1981) on sorghum (rabi) + cowpea showed large reductions in chickpea yields without affecting the sorghum yields. Pothiraj (1985) conducted the field experiment to study the suitability of wheat, safflower and coriander as intercrops with chickpea. The normal planting with 1 row of intercrop gave the highest yield of chickpea equivalent of 688 kg ha^{-1}. Among 7 intercropping systems, chickpea + safflower as intercrop gave 944 kg ha^{-1} of chickpea equivalent and was found superior to other intercropping systems. Kumar and Singh (1987) reported that gram yield was highest in pure stand and decreased in all intercropping combinations with mustard. Mustard yield was also maximum in pure cropping and decreased in other treatments.

2.3.4. Quality of seed

The information available on quality (oil and protein) of mustard and chickpea, as influenced by intercropping systems is relatively less. So information published in other crops is also reviewed.

The oil was slightly higher when mustard was intercropped with potato and it ranged between 39.7 and 45.7% (AICRPO, 1983-84). In another experiment conducted by AICRPO (1983-84) no change in oil was noted when wheat and mustard were intercropped in 9:1 row ratio. As against this, Jana (1965) noted improvement in protein when planting geometry was modified. A higher protein content between 19 to 21% was reported in different mustard cultivars by Gangasaran and De (1979) under rainfed conditions of IARI, New Delhi.

2.3.5. Nutrient content and uptake

Nutrient uptake by crops raised alone or in an intercropping system is controlled by availability of water in root zone. It is assumed that component crops when raised alone exploit different soil layers and when grew in association exploit a greater total volume of soil. This was considered by some workers (Trenbath, 1974), the possible cause of yield advantage in growing some crop mixtures. The differences in rooting pattern could occur, because of tendency of roots to avoid overlapping in rooting growth mutually. The crop thus, avoids areas that have already depleted resources (nutrient and water) by an associated crop. There is, however, evidence to show that component crops having deep roots may force its roots even deeper by the presence of shallow rooting components (Whitlengton and Obrien, 1968; Fisher, 1976 and Lakhani, 1976).

Uptake of nutrients was less than half (38 kg ha^{-1}) to that of pure pigeonpea when it was intercropped with sorghum (Kumar Rao et al., 1983). Wahua (1983) also made similar observations in maize-cowpea cropping system. Reduction in uptake by intercrop is due to its poor competitive ability than the base crop (Natarajan and Willey, 1980 and Kumar Rao et al., 1983).

Amarchand (1975) did not note any adverse effect on biological yield and nitrogen uptake in a pigeonpea based system. The N content in different parts of field bean at all the stages of growth and at harvest was drastically reduced when water was in short supply (Faraha, 1981).

2.3.6. Yield advantages

To judge whether crops should be grown as intercrop components rather than sole crops, land equivalent ratio (LER) as a measure is often used. In intercrops of legumes with non-legumes, the legume usually obtains much of its nitrogen by fixation of molecular nitrogen whereas the other component exploits the NO_3^- and NH_4^+ of the soil solution. On soils deficient in available N, legume-non-legume intercrop systems may achieve higher LER showing legume components as more useful (Trenbath, 1976).

Saxena and Yadav (1975) reported that chickpea seldom gave as large yield as a pure crop, but when it was intercropped with Brassica campestris var. toria in alternate rows resulted in higher chickpea equivalents. Singh and Bajpai (1982) obtained highest net profit when mustard and chickpea were intercropped. Gangasaran and Giri (1985) reported that the total LER at all the spatial ratios in mustard + chickpea system and in 1:4 and 1:6 spatial ratios in mustard + barley system was recorded to be more than unity.

An intercrop of chickpea and safflower is more remunerative than a pure crop of either chickpea or safflower (Willey and Rao, 1980). There was superior productivity and profitability of chickpea + safflower intercropping over the conventional practice of growing chickpea alone (Itnal *et al.*, 1980 and Nikam *et al.*, 1987). Similarly, Pothiraj (1985) reported that chickpea + safflower intercropping system gave higher net returns.

Mohta and De (1980) evaluated several systems of intercropping maize and sorghum with soybeans. It was reported that LER increased to a maximum of about 48% by intercropping maize and sorghum with soybeans compared with cereal sole crops. Maize rows planted 120 cm apart and intercropped with two rows of soybeans or sorghum planted 90 cm apart and intercropped with one row of soybean proved to be the best intercropping pattern. They attributed this advantage to a better utilization of solar radiation by the component crops. Singh (1981) reported that the LER was influenced considerably by different intercrop and spatial arrangements. He obtained maximum LER by planting sorghum in paired rows having two rows of grain cowpea with 90 cm spacing, although the net returns were maximum with fodder cowpea in the same spatial arrangement. Martin and Snaydon (1982) reported that in barley and field beans grown in pure stands, alternate row mixtures and within row mixtures, the LER based on seed yield was consistently greater than 1 only when the crops were grown in alternate rows. The LER was greatest (1.8) when the mixtures included more barley than beans.

....

3. MATERIALS AND METHODS

The details of the materials used and techniques adopted for getting desired information from the present experiment are presented in this chapter.

3.1. Experimental site

The field experiment was carried out in the Agronomy farm (rainfed Todapur Block) of the Indian Agricultural Research Institute, New Delhi during *rabi* seasons of 1985-86 and 1986-87. The field had fairly levelled topography and sandy loam in texture.

3.2. Climate and weather

The geographic location of New Delhi is 28°40'N latitude and 77°11'E longitude with an altitude of 228.7 metres above the mean sea level. The climate is semi-arid and sub-tropical with extremes of hot in May-June and cold in December-January. Summers are hot and dry with day temperature raising upto 46°C. Winters are very cold with minimum temperature as low as 5°C during January. The daily maximum and minimum temperatures and evaporation rates show an increase from February to June and decrease from July onwards. New Delhi receives an average annual rainfall of about 652 mm of which 547 mm (84%) is contributed by south-west monsoon between June and September and the remaining 105 mm (16%) between October and May. Winter showers are usually received during January-

February. The mean annual evaporation is about 850 mm. The meteorological observations during the experimental period were recorded from the Water Technology Centre, Indian Agricultural Research Institute, New Delhi which is depicted in Fig. 1 and the meteorological weekly averages are detailed in Appendix I.

In 1985-86 season, the total precipitation was normal (102.6 mm), its distribution was also quite well. But in 1986-87 season, the total precipitation was substantially lower (55.2 mm) than the normal, its distribution was also uneven. The crops were under stress in the first half of their growing season because during the first 12 weeks, the amount of precipitation received was only 5.4 mm. The amount and distribution of rainfall in the two crop seasons influenced considerably the temperature (max. and min.) and relative humidity. The mean weekly maximum and minimum relative humidity ranged from 64% to 95% and 25% to 70%, respectively, for 1985-86 crop season, while it was 59% to 98% and from 20% to 69%, respectively, for 1986-87 crop season. The mean weekly maximum temperature ranged from 18.1°C to 38.0°C and from 16.7°C to 32.3°C, respectively, for 1985-86 and 1986-87 crop seasons. The corresponding values for mean weekly minimum temperature were 3.1°C to 19.6°C and from 2.0°C to 19.3°C.

3.3. Soil characteristics

A composite soil sample was collected from the field to study the availability of the major nutrient

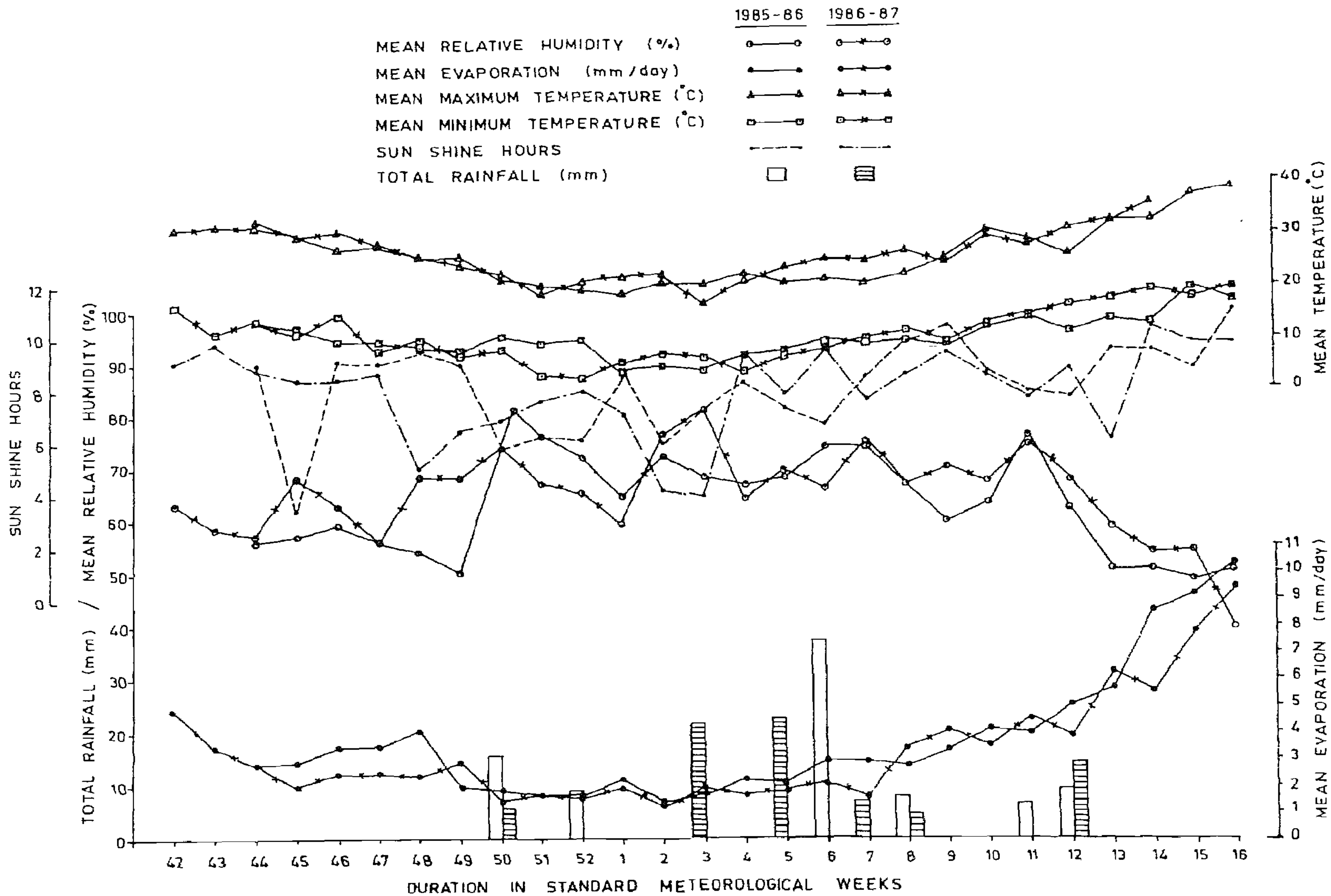

FIG.1. METEOROLOGICAL DATA DURING THE CROP SEASON.

elements and some related properties of the soil of the experimental field prior to experimentation. The mechanical and chemical analysis of the soil is detailed in Table 1, which reveals that the experimental field was sandy loam in texture, low in organic matter and available nitrogen but medium in available phosphorus and potassium. The soil was alkaline in reaction and had low cation exchange capacity. The electrical conductivity was very low and thus low soluble salts.

3.4. Cropping history

Fodder *bajra* without fertilization was taken in *kharif* season from 1980-81 to 1984-85.

3.5. Experimental details

The details of the experiment are as follows:

3.5.1. Treatments

A. Planting patterns:

M = Sole mustard

Cp = Sole chickpea

M + Cp (4:4) = Mustard + chickpea in 4:4 pattern

M + Cp (1:3) = Mustard + chickpea in 1:3 pattern

B. Phosphorus levels:

P_0 = 0 kg P ha^{-1}

P_{10} = 10 kg P ha^{-1}

P_{20} = 20 kg P ha^{-1}

P_{30} = 30 kg P ha^{-1}

Thus, there were 16 treatment combinations.

Table 1. Physical and chemical characteristics of soil

Properties	Method employed	Value 1985-86	Value 1986-87
A. Mechanical composition			
Sand (%)	Hydrometer method (Bouyoucos, 1962)	71.7	71.8
Silt (%)	Hydrometer method (Bouyoucos, 1962)	12.4	12.3
Clay (%)	Hydrometer method (Bouyoucos, 1962)	15.9	15.9
Textural class	Triangular diagram (Brady, 1983)	Sandy loam	
B. Chemical composition			
Organic carbon (%)	Walkley and Black method (1934)	0.27	0.30
Total nitrogen (%)	Modified Kjeldahl's method (Jackson, 1967)	0.03	0.03
Available nitrogen (kg ha^{-1})	Alkaline permanganate method (Subbiah and Asija, 1956)	152.08	184.96
Available phosphorus (kg ha^{-1})	Olsen's method (Olsen *et al.*, 1954)	16.10	13.40
Available potassium (kg ha^{-1})	1 N ammonium acetate extract method (USDA Hand Book No.60)	136.60	196.00
Electrical conductivity (mmhos cm^{-1}) at 25°C	USDA Hand Book No. 60	0.24	0.25
pH (1:2.5 soil to water ratio)	Beckman's pH meter (Piper, 1950)	8.3	8.2
Cation exchange capacity (me/100 g soil)	Schollen Berger's method (Metson, 1956)	9.80	9.80

3.5.2. Design

Randomized Block Design

3.5.3. Replications : 3

3.5.4. Plot size

A. Gross plot : 5.0 m x 4.5 m = 22.0 sq.m.

B. Net plot : 5.0 m x 2.7 m = 13.5 sq.m.

The layout plan of the experiment is given in Fig. 2.

3.5.5. Experimental crop variety

A. Mustard: Pusa Barani (PR-45)

It has been developed by cross breeding and selection at the Indian Agricultural Research Institute, New Delhi. It grows 4 to 5 feet tall, and take 140-145 days to mature. It exhibited high seed yield potentials (25-30 q ha^{-1}) both under irrigated as well as rainfed conditions. It has bold seeds (test weight, 5.5 - 6.0 g) and seed contained 40-43% oil. It is non-shattering in habit and withstand delayed harvesting and adverse weather conditions at maturity.

B. Chickpea : Pusa-261 (BG-261)

This variety has been developed from the cross between P.827, a desi cultivar of Indian origin and a tall Kabuli type P. 9847 from USSR by pedigree method of selection. It was released by Central Sub-Committee on

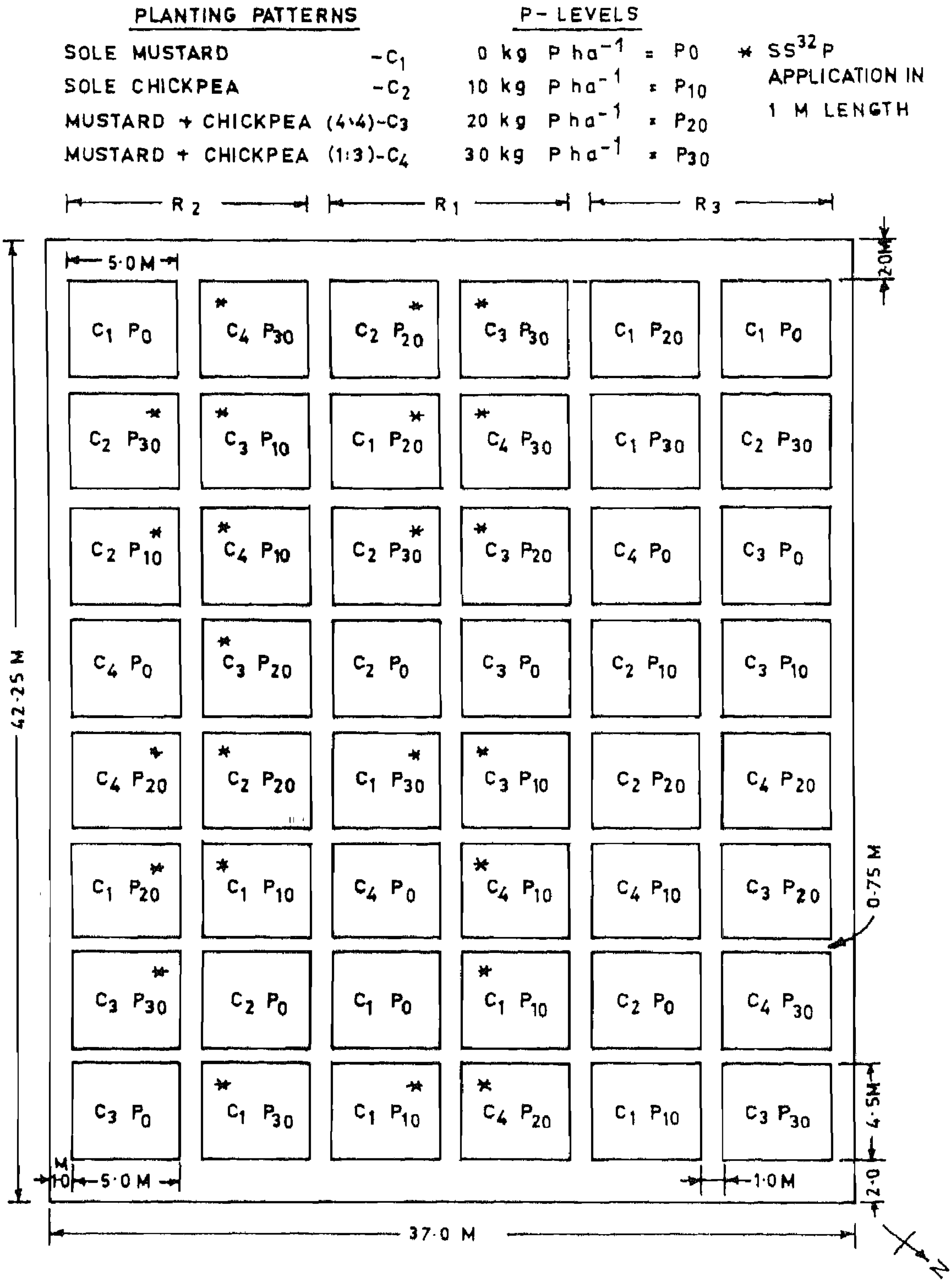

FIG.2. LAYOUT PLAN OF EXPERIMENT

Crop Standards, Notification and Release of Varieties in 1985 for North West Plains Zone consisting, Punjab, Haryana, Rajasthan and Uttar Pradesh. It is a distinctly tall variety with plant height ranging from 65-85 cm, upright and compact growth habit and possessing less number of tertiary and late order branches. The leaflets are medium, long ovate and light green in colour. The seeds are very attractive of golden yellow colour, medium bold in size with seed index 14-18g. It matures in 130-140 days. It possesses excellent resistance to *Ascochyta* blight both under natural and artificial epiphytotic conditions and moderately resistant to pod borers.

3.6. Field operations

Details of the field operations carried out during the experimentation period are given in Table 2.

Table 2. Schedule of field operations during the crop seasons

S.No.	Name of operation	Dates 1985-86	Dates 1986-87
1.	Field preparation	1.11.85	15.10.86
2.	Layout of the experiment	3.11.85	18.10.86
3.	Fertilizer placement	5.11.85	20.10.86
4.	Sowing	6.11.85	21.10.86
5.	Thinning and adjustment and plant population	26.11.85	10.11.86
6.	Intercultural operations		
	(a) First weeding and hoeing	26.11.85	10.11.86
	(b) Second weeding and hoeing	26.12.85	10.12.86
7.	Plant protection measures - Metasystox @ 0.03%	2. 2.86	24. 1.87
8.	Harvesting:		
	(a) Mustard	4. 4.86	28. 3.87
	(b) Chickpea	19. 4.86	2. 4.87

3.6.1. Land preparation

The experimental plot was ploughed thoroughly by a tractor drawn mould board followed by cross discing. The field was levelled and pressed with the help of a tractor drawn leveller.

3.6.2. Fertilizer application

A basal dose of 15 kg N and 30 kg K_2O ha^{-1} was applied in the form of urea and muriate of potash, respectively. Urea, muriate of potash and single superphosphate (as per treatment) were placed 3-5 cm below the seed with the help of a metallic tube attached to the hand plough. The fertilizers were applied on area basis i.e. row basis to both the crops.

3.6.3. Labelled phosphorus fertilizer application

To study fertilizer phosphorus uptake and its utilization by mustard and chickpea under different planting patterns, single superphosphate labelled with ^{32}P was used in this investigation. The labelled fertilizer with specific activity of 0.3 mCi g^{-1} of P_2O_5 was procured from the Isotopes Division of Bhabha Atomic Research Centre, Trombay, Bombay. The labelled fertilizer was applied to one row of one metre length of each plot and banded 3-5 cm below the seed as per the treatment.

3.6.4. Seeds and sowing

The sowing was done manually with the help of a metallic tube attached to a plough in order to place seeds about 3-4 cm below the soil surface. The seed rates used were 4 and 80 kg ha^{-1} for mustard and chickpea, respectively. The inter-row spacing for mustard and chickpea under sole and 4:4 planting patterns was 45 cm apart and inter-plant spacing for mustard was 20 cm. The inter-row spacing for mustard under 1:3 planting pattern was doubled to 90 cm while inter-plant spacing was reduced to 10 cm in order to maintain the same plant population as under sole pattern. For maintaining 15 rows of chickpea under 1:3 planting pattern two inter-row spacing was kept 30 cm apart.

3.7. Cultural operations

3.7.1. Thinning

Due to thick population, the thinning operation became necessary. Thinning was done 20 days after sowing to maintain the required plant to plant spacing.

3.7.2. Weeding

Manual weeding was done twice, 20 and 50 days after sowing (DAS) to provide an ideal environment to crop canopy *in situ*.

3.7.3. Plant protection measures

The mustard crop had infestation of aphids in both the years. Metasystox was sprayed at the rate of 0.03 per cent.

3.7.4. Harvesting and threshing

The crops from the net plot area were harvested at their physiological stages of maturity and allowed for drying in the same plots. The weight of the biological yield (seed + straw) from the net plot was recorded.

Threshing was done using 'Pullman' thresher. The seeds were collected, cleaned and the net plot seed yield was recorded and expressed in terms of q ha^{-1}.

3.8. <u>Biometric observations</u>

3.8.1. <u>Pre-harvest studies</u>

Five plants of mustard and chickpea from each plot were drawn at random at 75 DAS and at harvest and used for recording various biometric observations.

3.8.1.1. <u>Plant height</u>

The height of five plants chosen was measured in cm from ground surface to the tip of the main stem. The average was calculated and expressed as height per plant.

3.8.1.2. <u>Primary branches</u>

The number of primary branches raising from the nodes of the main stem were counted for five plants. The average was calculated and expressed as primary branches per plant.

3.8.1.3. <u>Secondary branches</u>

The number of secondary branches raising from primary branches were counted for five plants. The average was calculated and expressed as secondary branches per plant.

3.8.1.4. Leaf number

The number of leaves for five plants was counted for mustard only and this observation was omitted for chickpea. The average was calculated and expressed as number of leaves per plant.

3.8.1.5. Leaf area

The leaf area of separated leaves of mustard crop was measured with the help of a Leaf Area Meter, LI-3100 (LI.COR. Ltd., Lincoln, Nebraska, U.S.A.). The values of leaf area were obtained directly as in cm^2 per plant and used for computing the leaf area index.

3.8.1.6. Leaf Area Index (LAI)

From the leaf area per plant, the Leaf Area Index (LAI) was worked out for mustard crop by multiplying the leaf area per plant with the number of plants in the net plot area and dividing it by net plot area of respective crop as given by the expression below:

$$LAI = \frac{\text{Leaf area per plant } (cm^2) \times \text{No. of plants in net plot}}{\text{Net plot area } (m^2) \times 10^4}$$

3.8.1.7. Dry matter accumulation

The plants from labelled area of 0.18 m^2 area were sampled at 75 DAS and at harvest. These plants were sun dried first followed by oven drying at 65°C for 24 hrs. and weighed on electric operated top pan balance (Metller, Type K7T, Swiss made). The dry weight of samples was recorded and expressed in terms of kg ha^{-1}.

3.8.1.8. Light interception

Interception of solar light at crop canopy was measured with the help of 'Lux Meter'. The observations were recorded at 75 and 105 DAS. Observations were made at three heights: top, middle of crop canopies and at ground surface for main as well as the intercrop. The values were recorded for each treatment and averaged. The percentage of light incidence and light intercepted was calculated by following formulae.

(i) $$\text{Percentage of light incidence} = \frac{\text{Light incidence of different crop canopy heights}}{\text{Light incidence on the crop canopy}} \times 100$$

(ii) $$\text{Percentage of light intercepted} = 100 - \%\ \text{light incidence}$$

(iii) $$\text{Percentage of light available to intercrop (chickpea)} = \frac{\text{Light incidence at top of intercrop (chickpea)}}{\text{Light incidence on top of main crop (mustard)}} \times 100$$

3.8.2. Post-harvest studies

3.8.2.1. Siliqua/pod number

The total number of siliqua of mustard and pods of chickpea were counted for five plants. The average was worked out and expressed as siliqua/pod number per plant.

3.8.2.2. Seed number

Twenty five siliquae/pods were selected randomly and total number of seeds for mustard and chickpea were counted. The average was worked out and expressed as number of seeds per siliqua/pod.

3.8.2.3. Test weight

Mustard and chickpea seeds were drawn randomly from total produce of each treatment and 1000 seeds were counted and weighed. The weight was expressed as g per 1000 seeds.

3.9. Radiometric analysis

For radiometric analysis, the plant samples were taken at 75 DAS and at harvest from 40 cm length of the row in which labelled fertilizer was applied.

The isotopic investigations were carried out following the method as described by MacKenzie and Dean (1950). The plant samples were first sun-dried and then oven dried at 65°C for 24 hours. These samples were ground with the help of 'Macro-Wiley mill' and passed through 40 mesh sieve. Powdered plant samples weighing 3 g were used for preparing briquettes with the help of a hydraulic press 'Carver Laboratory Press Model C' of Fred S. Carver Inc. USA. The briquette was placed on the platform number 3 below the Geiger-Muller Tube inside a lead-castle manufactured by Trombay Electronic Instruments, Bombay, Type C 1700 A. The Geiger-Muller tube was connected to the counter, model No. GCS 16, made by Electronic Corporation of India Ltd. (E.C.I., Ltd.), Hyderabad. The specific activity of briquette was counted for 200 seconds per sample at 1155 volts which lies in the plateau region of the characteristic curve for Geiger-Muller tube.

3.9.1. Preparation of fertilizer standard

The fertilizer standard was prepared for determining phosphorus derived from the fertilizer source. One gram of labelled single superphosphate was dissolved in distilled water and the volume was made to 1000 ml. The required fertilizer standard solution of 47 ml was mixed with 9 g of plant biomass powder (unlabelled) which was previously oven dried at 65°C for 24 hours and ground. Thus, 3 g of inactive plant material was having 1 mg phosphorus. The 3 g plant material of standard and samples (as per treatment) were pressed into a briquette by hydraulic press for ^{32}P assay to determine the specific activity of the labelled fertilizer phosphorus applied to the plants.

3.9.2. Specific activity

Specific activity is defined as the total radio-activity present per gram of radioactive isotope and is expressed in terms of µCi/g or mCi/g or counts per second/millimole.

Net counts per second (CPS) was obtained with the help of the following formula:

$$CPS = \frac{\text{Sample counts in 200 sec} - \text{Background counts in 200 sec}}{\text{200 sec}}$$

Thereafter, the specific activity of the sample or the standard briquette was calculated with the help of the following formula:

$$\text{Specific activity} = \text{CPS/mg P in 3 g plant material}$$

Decay factor for ^{32}P (from decay chart) was also considered while calculating the specific activity of the fertilizer standard or sample.

3.9.3. Phosphorus derived from fertilizer

The advantage of isotopic fertilizer studies is the quantification of fertilizer contribution in crop production. The proportion of fertilizer phosphorus uptake by a crop was estimated from phosphorus derived from fertilizer (PdfF) and expressed in terms of percentage.

$$\text{PdfF (\%)} = \frac{\text{Specific activity of plant sample}}{\text{Specific activity of fertilizer standard}} \times 100$$

3.9.4. Per cent utilization of applied phosphorus

The use of ^{32}P as a tracer is the only direct and accurate method of quantitative measurement of the efficiency of fertilizer use by plants.

$$\text{Utilization of applied phosphorus (\%)} = \frac{\text{Fertilizer P uptake in plant}}{\text{Fertilizer P added per unit area}} \times 100$$

3.9.5. 'A'-value

'A'-value concept is based on the assumption that when two sources of a given nutrient are present in the soil, a plant will absorb the nutrients from each source in direct proportion to the respective quantities available (Fried and Dean, 1952).

'A'-value was calculated with the help of following formula:

$$\text{'A'-value} = \frac{\%\ \text{PdfS}}{\%\ \text{PdfF}} \times \text{rate of P applied through fertilizer (kg ha}^{-1}\text{)}$$

where,

% PdfS = Percentage of phosphorus derived from soil (100 - % PdfF)

% PdfF = Percentage of phosphorus derived from fertilizer

3.10. Qualitative analysis

3.10.1. Oil content

Five g seeds of mustard were oven dried at 65°C for 24 hrs. These seeds were used to find out the oil content (%) with the help of Nuclear Magnetic Resonance (N.M.R.), Minispee PC-20, Bruker Make, 20 MHZ R.F. (Radio Frequency), West Germany in the Nuclear Research Laboratory, I.A.R.I., New Delhi.

3.10.2. Protein content

A sample of 0.5 g of ground seeds of chickpea from each plot was taken and analysed for nitrogen content using colorimetric method (Snell and Snell, 1939). The protein content of samples was worked out by multiplying N content with 6.25 as detailed by A.O.A.C. (1960).

3.11. Chemical analysis

3.11.1. Nutrient content studies

The plant samples collected at different growth stages for radiochemical assay were oven dried at 65°C for 24 hrs. The dried samples of plants were ground to pass through 40 mesh sieve in a 'Macro-Wiley Mill'. From each sample 0.5 g was weighed separately for chemical analysis to determine the content of nitrogen and phosphorus at different stages of growth.

3.11.1.1. Total nitrogen

The total nitrogen content of plant was determined by colorimetric method (Snell and Snell, 1955).

3.11.1.2. Phosphorus

The estimation of phosphorus content was done by analysing 0.5 g of ground sample, using Vanado-molybdo-phosphoric yellow colour method (Jackson, 1973).

3.12. Mustard grain equivalent

Since the sale prices of the grains of the component crops, mustard and chickpea are different, for proper evaluation of the treatments it is necessary that the produce of the component crop is expressed in terms of the main crop. For this purpose the grain yield of intercrop chickpea was converted into mustard grain equivalent, based on the prevailing selling prices of the commodity by the following formula:

$$\text{Mustard grain equivalent (q ha}^{-1}) = \frac{\text{Grain yield of intercrop (q ha}^{-1}) \times \text{price of intercrop (Rs q}^{-1})}{\text{Price of mustard (Rs q}^{-1})}$$

3.12. Land Equivalent Ratio (LER)

LER is the relative size of land under a sole crop system which will be necessary for obtaining the same yield as in an intercropping system. LER is computed by using the following formula:

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

where,

Yab = Yield of 'a' grown in mixture (a and b)

Yba = Yield of 'b' grown in mixture (a and b)

Yaa = Yield of 'a' in pure stand

Ybb = Yield of 'b' in pure stand

3.14. Soil moisture studies

Soil samples for estimation of moisture were drawn from 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths. The first set of samples was taken at sowing and subsequent sampling was done at 30 days interval.

The soil samples were weighed immediately and dried in an oven at 105°C for 24-48 hours. After drying, samples were again weighed and the loss of moisture was estimated and expressed as percentage of moisture on oven dry weight of soil. These values were utilized in computing moisture depletion pattern.

3.15. Soil moisture depletion

Soil moisture depletion in each layer was worked out by the following formula:

$$Q = \frac{n(Pw\% \times dbi \times Di)}{i=1} \times Re + PET + Dp + Cw$$

where,

Q = Quantity of moisture depleted (mm)

Pw% = Change in soil moisture percentage between the two sampling dates for (ith) layer

dbi = Bulk density of the ith soil layer (g/cm^3)

Re = Effective rainfall (mm) between the two soil sampling intervals

Di = Soil depth of the ith layer (mm)

PET = Potential evapotranspiration (mm) for the continuously raising period when soil moisture depletion by gravimetric method cannot be worked out.

Dp = Deep percolation losses (mm)

Cw = Capillary water contribution (mm)

Depth of soil moisture depleted between two sampling dates was worked out by adding the values obtained for all the 5 layers sampled and was expressed in mm. Soil moisture depletion in each layer was expressed (%) of the total quantity of moisture depleted from the field. PET, deep percolation losses and capillary water contribution were not considered in the present study.

3.16. Statistical analysis

The data collected in the experiment were subjected to statistical test by following Analysis of Variance Technique (Cochran and Cox, 1967). Whenever the variance ratio (F-value) was found significant, the critical difference was computed for making comparison among the treatment means. A second degree polynomial response equation was fitted between phosphorus levels and grain yield by the method of least square. From this regression line economic level of phosphorus was calculated with the help of the following equation:

$$\text{Economic optimum dose} = \frac{Q/P - b}{2c}$$

where,

Q = Price of fertilizer

P = Price of product

b and c are the parameters

...

4. EXPERIMENTAL FINDINGS

The observations recorded during the experiment pertaining to growth, yield, quality, radio-chemical assay and chemical properties of soil as influenced by planting patterns and phosphorus levels were statistically analysed and after evaluating the data for their test of significance, observed results are discussed in this chapter and presented in suitable tables as and where required.

4.1. Pre-harvest studies

4.1.1. Plant height

The planting patterns and phosphorus levels did not affect mustard height significantly while planting patterns significantly influenced the chickpea height (Table 3). Invariably plant height of both the crops was higher during 1985-86 than 1986-87 and increased with the increasing levels of phosphorus. The plant height of chickpea was significantly higher in mustard + chickpea (1:3) than sole chickpea at both the stages during both the years. It was also significantly superior over mustard + chickpea (4:4) at both the stages during 1985-86 and only at one stage i.e. 75 days of sowing during 1986-87.

4.1.2. Number of main branches

The planting pattern and phosphorus levels did not significantly influence the number of mustard main branches while planting patterns significantly influenced

Table 3. Effect of treatments on plant height (cm)

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	133.0	151.5	121.5	143.3	-	-	-	-
Sole chickpea	-	-	-	-	32.8	81.1	21.4	47.9
Mustard + chickpea (4:4)	131.1	152.8	119.0	142.5	35.0	85.7	20.8	48.3
Mustard + chickpea (1:3)	134.4	156.6	125.3	151.0	50.0	103.9	25.8	55.7
S.Em ±	2.07	2.22	7.99	6.06	0.71	2.16	1.13	1.42
CD 5%	NS	NS	NS	NS	2.08	6.34	3.32	8.34
B. Phosphorus levels ($kg\ P\ ha^{-1}$)								
0	131.4	150.0	110.5	142.1	37.2	86.5	20.7	49.6
10	132.8	153.2	124.0	146.2	39.6	92.3	21.7	50.7
20	133.9	155.5	124.9	146.7	40.3	91.8	23.4	50.4
30	133.2	155.8	128.4	146.3	40.0	93.0	24.2	51.9
S.Em ±	2.39	2.57	9.23	6.99	0.82	2.49	1.30	1.64
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS

the number of chickpea main branches (Table 4). Invariably number of main branches of both the crops were more during 1985-86 than 1986-87 and increased with increasing levels of phosphorus. The number of main branches in chickpea were significantly more in sole mustard and mustard + chickpea (4:4) than mustard + chickpea (1:3).

4.1.3. Number of sub-branches

Planting patterns and phosphorus levels did not affect number of mustard sub-branches significantly whereas planting patterns significantly influenced the number of chickpea sub-branches (Table 5). The number of sub-branches were more during 1985-86 than 1986-87. Except at harvest during 1986-87, the number of chickpea sub-branches were significantly more in mustard + chickpea (4:4) than in mustard + chickpea (1:3) while the difference between mustard + chickpea (4:4) and sole mustard was at par.

4.1.4. Number of leaves

There was no significant effect of planting patterns and phosphorus levels on number of leaves of mustard during both the years except at 75 days after sowing where planting pattern significantly affect the number of leaves during the crop season of 1985-86 (Table 6). The number of leaves were significantly more in mustard + chickpea (1:3) pattern than sole mustard.

Table 4. Effect of treatments on main branches per plant

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	3.6	3.6	2.9	3.4	-	-	-	-
Sole chickpea	-	-	-	-	4.0	4.9	2.8	4.0
Mustard + chickpea (4:4)	3.6	3.6	3.0	3.5	3.8	5.0	2.7	4.2
Mustard + chickpea (1:3)	3.7	3.7	2.9	3.6	3.3	4.0	2.2	3.2
S.Em ±	0.08	0.10	0.12	0.16	0.15	0.11	0.12	0.14
CD 5%	NS	NS	NS	NS	0.44	0.33	0.35	0.43
B. Phosphorus levels ($kg\ P\ ha^{-1}$)								
0	3.4	3.4	2.9	3.2	3.6	4.5	2.5	3.7
10	3.6	3.6	2.9	3.5	3.7	4.6	2.6	3.7
20	3.8	3.8	2.9	3.5	3.7	4.7	2.6	3.8
30	3.7	3.8	3.0	3.5	3.8	4.7	2.7	4.0
S.Em ±	0.10	0.12	0.14	0.19	0.17	0.13	0.14	0.11
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Effect of treatments on sub-branches per plant

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	14.6	18.1	12.4	16.8	-	-	-	-
Sole chickpea	-	-	-	-	8.7	10.9	7.1	8.7
Mustard + chickpea (4:4)	15.1	18.7	12.6	16.9	9.4	11.2	7.5	8.9
Mustard + chickpea (1:3)	15.4	21.2	11.9	17.4	6.9	8.2	6.0	7.5
S.Em ±	0.77	1.26	1.36	0.89	0.29	0.36	0.39	0.58
CD 5%	NS	NS	NS	NS	0.86	1.06	1.14	NS
B. Phosphorus levels (kg P ha^{-1})								
0	14.1	18.9	11.5	16.2	7.7	9.6	6.0	7.8
10	14.6	19.2	12.5	17.4	8.5	10.0	6.9	8.1
20	15.6	19.7	12.5	17.4	8.7	10.2	7.2	8.8
30	15.5	19.5	12.7	17.1	8.6	10.5	7.5	8.7
S.Em ±	0.90	1.45	1.57	1.03	0.33	0.41	0.45	0.67
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS

Table 6. Effect of treatments on number of leaves per plant

Treatments	Mustard			
	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. <u>Planting patterns</u>				
Sole mustard	43.9	26.9	41.3	20.5
Sole chickpea	-	-	-	-
Mustard + chickpea (4:4)	46.3	27.2	43.0	21.5
Mustard + chickpea (1:3)	49.2	28.9	46.4	23.3
S.Em ±	1.28	0.73	2.09	0.89
CD 5%	3.75	NS	NS	NS
B. <u>Phosphorus levels (kg P ha^{-1})</u>				
0	43.8	25.8	40.0	19.8
10	45.5	27.7	43.3	21.3
20	47.3	28.2	44.3	22.5
30	49.3	29.0	46.5	23.6
S.Em ±	1.47	0.84	2.42	1.03
CD 5%	NS	NS	NS	NS

The application of phosphorus towards higher side did not reflect significant effect, however, the number of leaves per plant increased with the increasing levels of phosphorus.

4.1.5. Leaf Area Index (LAI)

The planting patterns significantly influenced the LAI of mustard in both the years while the effect of phosphorus levels was found significant only at 75 days after sowing in 1985-86 (Table 7).

The LAI of mustard differed in the two crop seasons and the differences were marked, it was higher in 1985-86 than in 1986-87. The LAI of mustard was higher in sole mustard and mustard + chickpea (1:3) than mustard + chickpea (4:4) to the tune of 81 and 101% at 75 days after sowing in 1985-86, respectively, while at 105 days after sowing it was 90 and 95%. In 1986-87, similar results were obtained and the increase was recorded to the tune of 93 and 103% at 75 days after sowing while 85 and 104% at 105 days after sowing. The application of phosphorus increased the LAI of mustard but results were significant only at 75 days after sowing in 1985-86 and application of 10, 20 and 30 kg P ha^{-1} enhanced the LAI to the order of 8, 15 and 22% over the control.

4.1.6. Dry matter production

The planting patterns significantly influenced the dry matter production of both the crops in both the

Table 7. Effect of treatments on leaf area index (LAI)

Treatments	Mustard			
	1985-86		1986-87	
	75 DAS	105 DAS	75 DAS	105 DAS
A. Planting patterns				
Sole mustard	1.052	1.848	0.994	1.688
Sole chickpea	-	-	-	-
Mustard + chickpea (4:4)	0.580	0.973	0.515	0.842
Mustard + chickpea (1:3)	1.164	1.899	1.044	1.722
S.Em ±	0.010	0.044	0.048	0.062
CD 5%	0.030	0.129	0.163	0.182
B. Phosphorus levels (kg P ha^{-1})				
0	0.837	1.496	0.762	1.316
10	0.908	1.523	0.827	1.373
20	0.964	1.591	0.876	1.438
30	1.019	1.683	0.939	1.542
S.Em ±	0.042	0.050	0.055	0.071
CD 5%	0.123	NS	NS	NS

years while phosphorus levels could only influence significantly, the dry matter of mustard at 75 days after sowing in 1985-86 (Table 8). The dry matter of both the crops in two crop seasons differed markedly, it was higher in 1985-86 than in 1986-87.

The dry matter of mustard was higher in sole mustard and mustard + chickpea (1:3) than mustard + chickpea (4:4) to the tune of 75 and 86% at 75 days and 121 and 131% at harvest, respectively, in 1985-86. In 1986-87, similar trend was observed and increase was noted to the tune of 107 and 116% at 75 days and 109 and 122% at harvest, respectively. Phosphorus levels significantly influenced dry matter production of mustard at 75 days after sowing in 1985-86 and the application of 10, 20 and 30 kg P ha^{-1} increased the production of dry matter to the tune of 5, 9 and 16% over control, respectively. At harvest, the effect of phosphorus on dry matter production lack the level of significance in both the years.

The dry matter of chickpea was higher in sole chickpea and mustard + chickpea (1:3) than mustard + chickpea (4:4) of the order of 114 and 60% at 75 days and 149 and 57% at harvest, respectively, in 1985-86. In 1986-87, similar type of results were observed and increase was recorded to the tune of 121 and 78% at 75 days and 156 and 85% at harvest, respectively. Though, there was an increase in dry matter production at each

Table 8. Effect of treatments on dry matter production (q ha^{-1})

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	49.13	82.72	41.58	70.87	-	-	-	-
Sole chickpea	-	-	-	-	15.69	38.56	12.99	28.21
Mustard + chickpea (4:4)	28.02	37.35	20.10	33.91	7.33	15.46	5.87	11.00
Mustard + chickpea (1:3)	52.07	86.28	43.48	75.28	11.75	24.35	10.48	20.38
S.Em ±	1.253	1.598	2.242	1.659	0.614	1.657	0.653	0.806
CD 5%	3.676	4.688	6.576	4.866	1.801	4.861	1.916	2.364
B. Phosphorus levels (kg P ha^{-1})								
0	39.83	67.33	31.37	56.39	11.12	23.50	9.38	19.07
10	41.70	68.20	35.17	59.43	11.25	26.40	9.78	19.98
20	43.53	69.80	36.52	62.07	11.81	26.95	9.93	20.05
30	47.23	69.80	37.16	62.21	12.19	27.63	10.04	20.30
S.Em ±	1.447	1.846	2.589	1.916	0.709	1.913	0.754	0.931
CD 5%	4.245	NS	NS	NS	NS	NS	NS	NS

successive level of phosphorus application but the difference in the increment did not affect significantly.

4.2. Post-harvest studies

4.2.1. Yield contributing characters

4.2.1.1. Number of siliquae or pods per plant

The planting patterns and phosphorus levels did not affect significantly to the number of siliquae per plant in mustard in either of the years, while it had significantly influenced the number of pods per plant in chickpea during both the crop seasons (Table 9).

The maximum number of siliquae per plant were recorded in the planting pattern of mustard + chickpea (1:3) followed by mustard + chickpea (4:4) and sole mustard in both the years. In the case of phosphorus, 30 kg P ha^{-1} increased the number of siliquae maximum and minimum at control.

The number of pods per plant were higher in sole chickpea and mustard + chickpea (4:4) than mustard + chickpea (1:3) to the tune of 43 and 62% in 1985-86 and 63 and 59% in 1986-87, respectively. However, application of phosphorus did not affect number of pods per plant but increasing levels of phosphorus increased the number of pods in both the years.

4.2.1.2. Number of seeds per siliqua or pod

Though, the varied level of P application

Table 9. Effect of treatments on siliqua and pods per plant

Treatments	Mustard Siliqua 1985-86	Mustard Siliqua 1986-87	Chickpea Pod 1985-86	Chickpea Pod 1986-87
A. Planting patterns				
Sole mustard	365.1	322.5	-	-
Sole chickpea	-	-	23.1	21.0
Mustard + chickpea (4:4)	386.5	331.3	25.8	20.2
Mustard + chickpea (1:3)	402.4	357.0	15.9	12.6
S.Em ±	20.10	27.50	1.35	0.91
CD 5%	NS	NS	3.96	2.69
B. Phosphorus levels ($kg\ P\ ha^{-1}$)				
0	353.4	309.2	21.8	17.0
10	390.9	343.5	22.1	17.6
20	396.8	345.6	23.3	18.1
30	397.7	349.2	22.8	19.1
S.Em ±	23.21	31.76	1.55	1.05
CD 5%	NS	NS	NS	NS

significantly influenced the number of seeds per siliqua in both the years but the magnitude of response was more pronounced at higher level of phosphorus application in the crop season of 1986-87. Regarding planting pattern, maximum seeds per siliqua were observed in mustard + chickpea (1:3) in both the years. In chickpea, neither the level of phosphorus nor planting pattern gave any significant impact on the number of seeds per pod.

4.2.1.3. 1000-seed weight

The planting pattern and levels of phosphorus application significantly influenced the 1000-seed weight of mustard, while test weight of chickpea was not affected to the level of significance (Table 11).

In the crop season of 1986-87, 1000-seed weight was significantly higher in mustard + chickpea (1:3) over sole mustard and mustard + chickpea (4:4). The application of 10, 20 and 30 kg P ha^{-1} significantly produced higher 1000-seed weight over control in both the years.

There was no significant effect of planting patterns and phosphorus levels on 1000-seed weight of chickpea in both the years. The minimum 1000-seed weight was recorded in mustard + chickpea (1:3) and increasing levels of phosphorus increased the 1000-seed weight of chickpea in both the years.

Table 10. Effect of treatments on number of seeds per siliqua and pod

Treatments	Mustard Siliqua 1985-86	Mustard Siliqua 1986-87	Chickpea Pod 1985-86	Chickpea Pod 1986-87
A. Planting patterns				
Sole mustard	13.2	11.7	-	-
Sole chickpea	-	-	2.0	1.6
Mustard + chickpea (4:4)	13.1	11.7	2.0	1.6
Mustard + chickpea (1:3)	13.5	12.4	2.0	1.6
S.Em ±	0.34	0.35	0.01	0.02
CD 5%	NS	NS	NS	NS
B. Phosphorus levels (kg P ha^{-1})				
0	12.5	10.8	2.0	1.6
10	13.5	12.2	2.0	1.6
20	13.5	12.4	2.0	1.6
30	13.7	12.4	2.0	1.6
S.Em ±	0.39	0.40	0.01	0.03
CD 5%	NS	1.200	NS	NS

Table 11. Effect of treatments on 1000-seed weight (g)

Treatments	Mustard		Chickpea	
	1985-86	1986-87	1985-86	1986-87
A. <u>Planting patterns</u>				
Sole mustard	5.93	5.90	-	-
Sole chickpea	-	-	134.29	123.39
Mustard + chickpea (4:4)	5.97	5.95	134.87	123.32
Mustard + chickpea (1:3)	5.99	6.21	132.57	122.47
S.Em ±	0.093	0.073	1.739	1.736
CD 5%	NS	0.215	NS	NS
B. <u>Phosphorus levels ($kg\ P\ ha^{-1}$)</u>				
0	5.61	5.61	129.50	118.94
10	5.98	6.06	134.70	123.85
20	6.06	6.21	135.61	125.01
30	6.09	6.20	135.83	124.44
S.Em ±	0.108	0.084	2.009	2.005
CD 5%	0.316	0.248	NS	NS

4.2.2. Yield

The yield of mustard and chickpea was greatly influenced by planting patterns and phosphorus levels in both the years (Table 12a) and interaction effect was also found significant for mustard in 1985-86 (Table 12b). The seed yield of both crops differed markedly in both the years, it was higher in 1985-86 than 1986-87.

The mustard yield was significantly higher in the planting pattern of mustard + chickpea (1:3) and sole mustard over mustard + chickpea (4:4) in both the years and the increase was to the tune of 30 and 17% in 1985-86 and 26 and 20% in 1986-87, respectively. The supremacy of the planting pattern, mustard + chickpea (1:3) was not only maintained over 4:4 mustard and chickpea but also commendable over sole mustard in the crop year of 1985-86. The application of phosphorus proved beneficial in boosting the seed yield of mustard in both the years but the increase in the seed yield with increasing level of phosphorus application was more pronounced in 1985-86.

The chickpea yield was significantly higher in sole chickpea over mustard + chickpea (1:3) and mustard + chickpea (4:4) in both the years. The increase was recorded in the order of 148 and 258% in 1985-86 and 126 and 188% in 1986-87, respectively. However, mustard +

Table 12(a). Effect of treatments on seed yield (q ha^{-1})

Treatments	Mustard		Chickpea	
	1985-86	1986-87	1985-86	1986-87
A. Planting patterns				
Sole mustard	22.85	19.73	-	-
Sole chickpea	-	-	18.31	12.27
Mustard + chickpea (4:4)	19.54	16.48	5.11	4.26
Mustard + chickpea (1:3)	25.35	20.75	7.37	5.42
S.Em ±	0.300	0.737	0.216	0.430
CD 5%	0.881	2.161	0.634	1.261
B. Phosphorus levels (kg P ha^{-1})				
0	20.69	16.64	8.83	5.95
10	23.11	18.82	10.50	7.75
20	23.11	19.92	10.76	7.83
30	23.41	20.56	10.96	7.75
S.Em ±	0.347	0.851	0.250	0.496
CD 5%	1.018	2.495	0.733	1.378

chickpea (1:3) was significantly superior over mustard + chickpea (4:4) in 1985-86. As was the case in mustard, in chickpea also, the seed yield increased markedly over control with the increasing level of phosphorus application. It was further, observed that the magnitude of response was more pronounced at higher level of phosphorus application. However, the difference in the seed yield due to varied level of phosphorus application was at par in the two consecutive years.

Table 12(b). Interaction effect of treatments on mustard seed yield (q ha^{-1}) in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	19.64	21.85	24.07	25.84
Sole chickpea	-	-	-	-
Mustard + chickpee (4:4)	18.80	20.66	19.57	19.13
Mustard + chickpea (1:3)	23.63	26.82	25.69	25.25
S.Em ±		0.601		
CD 5%		1.763		

The interaction effect between planting pattern of 1:3 mustard + chickpea and levels of phosphorus application on the mustard yield was significantly superior in 1985-86 over mustard + chickpea (4:4) planting pattern at each level of phosphorus (Table 12b). However, mustard + chickpea (1:3) was significantly better over sole mustard at lower dose of phosphorus i.e. 10 kg P ha^{-1} while sole mustard significantly produced more yield than 4:4 system at higher doses of phosphorus i.e.

20 and 30 kg P ha^{-1}. The data further revealed that the sole mustard yield was benefitted significantly by phosphorus application and the increase was recorded to the tune of 11, 22 and 31% with the application of 10, 20 and 30 kg P ha^{-1}, respectively, over control. It was further observed that either of the planting pattern (1:3 or 4:4) was only responded significantly to 10 kg P ha^{-1} and thereafter yield declined with increasing level of phosphorus application.

4.2.3. <u>Quality</u>

The significant effect of planting patterns was only observed on the oil content of mustard (Table 13). The oil content differed markedly in both the years and was higher in 1986-87. In 1986-87, sole mustard was significantly superior over mustard + chickpea (1:3) and at par with mustard + chickpea (4:4). The various levels of phosphorus application could not give marked effect on the oil content in either of the years.

Though, the protein content of chickpea seed was not significantly effected by planting patterns and phosphorus levels in both the years (Table 14) but there was an increase in protein content with each successive level of phosphorus application.

4.3. <u>Nutrient uptake</u>

4.3.1. <u>Total phosphorus uptake</u>

The influence of planting patterns and phosphorus

Table 13. Effect of treatments on per cent oil content

Treatments	Mustard	
	1985-86	1986-87
A. Planting patterns		
Sole mustard	36.12	41.58
Sole chickpea	-	-
Mustard + chickpea (4:4)	35.65	41.22
Mustard + chickpea (1:3)	35.60	40.71
S.Em ±	0.320	0.227
CD 5%	NS	0.667
B. Phosphorus levels (kg P ha^{-1})		
0	35.97	41.50
10	35.78	41.13
20	35.83	41.35
30	35.56	40.71
S.Em ±	0.370	0.262
CD 5%	NS	NS

Table 14. Effect of treatments on per cent protein content

Treatments	Chickpea	
	1985-86	1986-87
A. Planting patterns		
Sole mustard	-	-
Sole chickpea	22.96	21.10
Mustard + chickpea (4:4)	23.21	22.10
Mustard + chickpea (1:3)	22.34	21.30
S.Em ±	0.665	0.415
CD 5%	NS	NS
B. Phosphorus levels ($kg\ P\ ha^{-1}$)		
0	21.55	20.70
10	22.86	21.25
20	23.40	21.72
30	23.54	22.38
S.Em ±	0.768	0.479
CD 5%	NS	NS

levels on total phosphorus uptake was significant in both the crops in the two consecutive years (Table 15a) and interaction effect was also significant in mustard in 1985-86 at harvest (Table 15b). There was marked difference in both the years, it was higher in 1985-86 than 1986-87.

The total phosphorus uptake in mustard was significantly higher in sole mustard and mustard + chickpea (1:3) over mustard + chickpea (4:4). It was recorded in the order of 86 and 84% at 75 days and 77 and 91% at harvest, respectively, in 1985-86. In 1986-87, similar trend was observed and increase was to the tune of 94 and 93% at 75 days and 73 and 106% at harvest, respectively. The application of 20 and 30 kg P ha^{-1}, significantly increased the total phosphorus uptake over control at both the stages in 1985-86 and at 75 days in 1986-87 while at harvest application of 10 kg P ha^{-1} too had significant edge over control. The increase in the total phosphorus uptake with the application of 10, 20 and 30 kg P ha^{-1} over control was to the tune of 28, 44 and 49% at 75 days and 13, 32 and 37% at harvest, respectively, in 1985-86. In 1986-87, increase was to the order of 46, 68 and 73% at 75 days and 40, 56 and 69% at harvest, at 10, 20 and 30 kg P ha^{-1}, respectively.

The total phosphorus uptake in chickpea was significantly higher in sole chickpea and mustard +

Table 15(a). Effect of treatments on total phosphorus uptake (kg ha^{-1})

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	18.85	22.16	15.71	19.01	-	-	-	-
Sole chickpea	-	-	-	-	6.14	11.85	4.88	9.38
Mustard + chickpea (4:4)	10.13	12.52	8.11	10.99	2.79	4.89	2.22	3.81
Mustard + chickpea (1:3)	18.67	23.87	15.69	22.67	4.35	7.38	3.96	6.50
S.Em ±	1.035	1.309	1.234	1.098	0.300	0.695	0.306	0.407
CD 5%	3.036	3.839	3.620	3.222	0.881	2.039	0.898	1.195
B. Phosphorus levels (kg P ha^{-1})								
0	12.18	16.19	8.98	12.42	3.46	6.22	3.09	5.18
10	15.65	18.33	13.10	17.37	4.54	7.92	3.43	6.27
20	17.51	21.42	15.07	19.39	4.68	8.39	3.64	6.49
30	18.20	22.13	15.53	21.04	5.03	9.62	4.58	8.32
S.Em ±	1.195	1.511	1.425	1.268	0.347	0.803	0.353	0.470
CD 5%	3.505	4.433	4.180	3.720	1.017	2.355	1.037	1.380

chickpea (1:3) over mustard + chickpea (4:4) and recorded to the order of 120 and 56% at 75 days and 142 and 51% at harvest, respectively, in 1985-86. In 1986-87, similar trend was observed and increase was to the tune of 120 and 78% at 75 days and 146 and 71% at harvest, respectively. The application of 10, 20 and 30 kg P ha^{-1}, significantly increased the total phosphorus uptake over control at 75 days in 1985-86 while application of 30 kg P ha^{-1} had significant edge over control at harvest in 1985-86 and at both the stages in 1986-87. The application of 10, 20 and 30 kg P ha^{-1} increased the total phosphorus uptake over control to the tune of 31, 35 and 45% at 75 days and 27, 35 and 55% at harvest, respectively, in 1985-86. In 1986-87, the increase was to the order of 11, 18 and 48% at 75 days and 21, 25 and 61% at harvest, respectively.

Table 13(b). Interaction effect of treatments on total phosphorus uptake (kg ha^{-1}) at harvest in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	16.80	14.27	32.26	25.31
Sole chickpea	-	-	-	-
Mustard + chickpea (4:4)	8.67	19.53	10.27	11.60
Mustard + chickpea (1:3)	23.08	21.19	21.74	29.47
S.Em ±	2.618			
CD 5%	7.679			

The total phosphorus uptake in mustard at harvest was significantly higher in mustard + chickpea (1:3) than mustard + chickpea (4:4) at 0, 20 and 30 kg P ha^{-1} in 1985-86 (Table 15b). However, total phosphorus uptake in sole mustard and mustard + chickpea (1:3) was on par at different levels of phosphorus except at 20 kg P ha^{-1} where sole mustard had significant edge over mustard + chickpea (1:3).

4.3.2. Fertilizer phosphorus uptake

The influence of planting patterns and phosphorus levels on fertilizer phosphorus uptake was significant in both the crops in both the years (Table 16a) and interaction effect was also significant in mustard crop at both the stages in 1985-86 and at 75 days in 1986-87, the data is presented in Table 16(b), 16(c) and 16(d).

The fertilizer phosphorus uptake in mustard was to the order of 83 and 76% at 75 days and 95 and 95% at harvest in sole mustard and mustard + chickpea (1:3) over mustard + chickpea (4:4), respectively, in 1985-86 (Table 16a). In 1986-87, similar trend was observed and increase was to the tune of 89 and 120% at 75 days and 75 and 121% at harvest, respectively. The application of 20 and 30 kg P ha^{-1}, significantly increased the fertilizer phosphorus uptake over 10 kg P ha^{-1} at both the stages in both the years. However, application of 30 kg P ha^{-1} was also significantly superior over 20 kg P ha^{-1} at both

Table 16(a). Effect of treatments on fertilizer phosphorus uptake (kg ha^{-1})

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	3.01	4.05	2.27	3.03	-	-	-	-
Sole chickpea	-	-	-	-	0.50	0.40	0.53	0.40
Mustard + chickpea (4:4)	1.64	2.08	1.20	1.73	0.23	0.16	0.23	0.16
Mustard + chickpea (1:3)	2.89	4.06	2.64	3.83	0.31	0.26	0.32	0.26
S.Em ±	0.176	0.269	0.197	0.325	0.047	0.023	0.047	0.023
CD 5%	0.529	0.806	0.592	0.977	0.142	0.070	0.142	0.074
B. Phosphorus levels (kg P ha^{-1})								
10	1.63	2.20	1.26	1.80	0.21	0.21	0.22	0.21
20	2.41	3.55	2.02	2.84	0.32	0.25	0.32	0.25
30	3.51	4.44	2.83	3.95	0.51	0.36	0.52	0.36
S.Em ±	0.176	0.269	0.197	0.325	0.047	0.023	0.047	0.023
CD 5%	0.529	0.806	0.592	0.977	NS	0.070	0.142	0.074

the stages in both the years. The increase in the fertilizer phosphorus uptake with the application of 20 and 30 kg P ha^{-1} over 10 kg P ha^{-1} was to the tune of 48 and 115% at 75 days and 61 and 102% at harvest, respectively, in 1985-86. In 1986-87, similar trend was observed and increase was to the order of 60 and 125% at 75 days and 58 and 119% at harvest, respectively.

The fertilizer phosphorus uptake in chickpea was significantly higher in sole chickpea over mustard + chickpea (4:4) and mustard + chickpea (1:3) and was recorded to the order of 117 and 61% at 75 days and 150 and 87% at harvest, respectively, in 1985-86 (Table 16a). In 1986-87, similar trend was observed and increase was to the tune of 130 and 66% at 75 days and 150 and 54% at harvest, respectively. However, fertilizer phosphorus uptake was significantly higher in mustard + chickpea (1:3) over mustard + chickpea (4:4) at harvest in both the years. The application of 30 kg P ha^{-1}, significantly increased the fertilizer phosphorus uptake over 10 kg P ha^{-1} at harvest in 1985-86 and at both the stages in 1986-87. The application of 20 and 30 kg P ha^{-1} increased the fertilizer phosphorus uptake over 10 kg P ha^{-1} to the tune of 52 and 143% at 75 days and 19 and 71% at harvest, respectively, in 1985-86. In 1986-87, the similar trend was observed and increase was to the tune of 45 and 136% at 75 days and 19 and 71% at harvest, respectively.

The fertilizer phosphorus uptake in mustard at 75 days in 1985-86 was significantly higher in mustard + chickpea (1:3) over mustard + chickpea (4:4) at 10 kg P ha^{-1}

while application of 20 kg P ha^{-1}, sole mustard was significantly superior over mustard + chickpea (4:4) and mustard + chickpea (1:3) (Table 16b). However, sole mustard and mustard + chickpea (1:3) were significantly superior over mustard + chickpea (4:4). The fertilizer phosphorus uptake increased with the increasing levels of phosphorus in all planting patterns. The application of 20 and 30 kg P ha^{-1} was significantly superior over 10 kg P ha^{-1} in sole mustard, while application of 30 kg P ha^{-1} had significant edge over 10 kg P ha^{-1} in mustard + chickpea (4:4) and mustard + chickpea (1:3).

The fertilizer phosphorus uptake in mustard at harvest in 1985-86 was significantly higher in sole mustard and mustard + chickpea (1:3) over mustard + chickpea (4:4) at 20 and 30 kg P ha^{-1} (Table 16c). However, planting patterns were at par with the application of 10 kg P ha^{-1}. The application of 20 and 30 kg P ha^{-1} was significantly superior over 10 kg P ha^{-1} in sole mustard. However, there was no significant effect of phosphorus levels in mustard + chickpea (4:4). The increasing levels of phosphorus, increased the fertilizer phosphorus uptake in mustard + chickpea (1:3) and application of 30 kg P ha^{-1} had significant edge over 10 and 20 kg P ha^{-1} with the same planting pattern.

The fertilizer phosphorus uptake in mustard at 75 days in 1986-87 was significantly higher in sole mustard and mustard + chickpea (1:3) over mustard + chickpea (4:4) at 20 and 30 kg P ha^{-1} (Table 16d). However,

Table 16(b). Interaction effect of treatments on fertilizer phosphorus uptake (kg ha^{-1}) at 75 days in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})		
	10	20	30
Sole mustard	1.41	3.48	4.14
Sole chickpea	-	-	-
Mustard + chickpea (4:4)	1.25	1.41	2.26
Mustard + chickpea (1:3)	2.22	2.32	4.12
S.Em ±		0.306	
CD 5%		0.917	

Table 16(c). Interaction effect of treatments on fertilizer phosphorus uptake (kg ha^{-1}) at harvest in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})		
	10	20	30
Sole mustard	1.66	5.28	5.19
Sole chickpea	-	-	-
Mustard + chickpea (4:4)	2.33	1.65	2.26
Mustard + chickpea (1:3)	2.60	3.70	5.87
S.Em ±		0.466	
CD 5%		1.397	

Table 16(d). Interaction effect of treatments on fertilizer phosphorus uptake (kg ha^{-1}) in 1986-87 at 75 days

Planting patterns	Phosphorus levels (kg P ha^{-1})		
	10	20	30
Sole mustard	1.23	2.37	3.24
Sole chickpea	-	-	-
Mustard + chickpea (4:4)	1.30	0.98	1.33
Mustard + chickpea (1:3)	1.26	2.72	3.94
S.Em ±		0.342	
CD 5%		1.026	

planting patterns were at par at lower dose of phosphorus i.e. 10 kg P ha^{-1}. The application of phosphorus significantly increased the fertilizer phosphorus uptake in sole mustard and mustard + chickpea (1:3). The application of 20 kg P ha^{-1} was significantly superior over 10 kg P ha^{-1} while 30 kg P ha^{-1} was superior over 20 kg P ha^{-1}.

4.3.3. Per cent utilization of applied phosphorus

The influence of planting patterns and phosphorus levels on per cent phosphorus utilization of applied phosphorus was significant in both the crops in both the years (Table 17a). The interaction effect was also significant in mustard at harvest in 1985-86 (Table 17b). There was marked difference in both the years, it was higher in 1985-86 than 1986-87.

The utilization of applied phosphorus by mustard was significantly higher in sole mustard and mustard + chickpea (1:3) over mustard + chickpea (4:4) to the tune of 55 and 81% at 75 days and 53 and 61% at harvest, respectively, in 1985-86 (Table 17a). In 1986-87, similar trend was observed and increase was to the order of 56 and 78% at 75 days and 55 and 86% at harvest, respectively. However, sole mustard and mustard + chickpea (1:3) were at par but higher values were always obtained in mustard + chickpea (1:3). The increasing levels of phosphorus decreased the utilization of applied phosphorus, however, significant effect was observed at harvest in both the years. The application of 20 and 30 kg P ha^{-1}, decreased

Table 17(a). Effect of treatments on per cent utilization of applied phosphorus

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	15.11	20.04	11.67	15.95	-	-	-	-
Sole chickpea	-	-	-	-	3.96	3.54	2.61	2.29
Mustard + chickpea (4:4)	9.77	13.06	7.47	10.27	1.68	1.50	1.21	0.90
Mustard + chickpea (1:3)	17.71	21.04	13.30	19.16	2.26	1.79	1.66	1.41
S.Em ±	1.389	1.378	1.299	1.314	0.413	0.513	0.221	0.182
CD 5%	4.163	4.132	3.896	3.939	1.239	1.539	0.663	0.546
B. Phosphorus levels (kg P ha^{-1})								
10	15.99	21.93	12.68	18.01	3.42	3.50	2.17	2.12
20	14.18	17.74	10.13	14.21	2.32	1.86	1.60	1.27
30	12.42	14.80	9.45	13.16	2.17	1.46	1.72	1.20
S.Em ±	1.389	1.378	1.299	1.314	0.413	0.513	0.221	0.182
CD 5%	NS	4.132	NS	3.939	NS	1.539	NS	0.546

the utilization of applied phosphorus at harvest over 10 kg P ha^{-1} to the tune of 24 and 48% in 1985-86, 26 and 37% in 1986-87, respectively.

The utilization of applied phosphorus by chickpea was significantly higher in sole chickpea over mustard + chickpea (4:4) and mustard + chickpea (1:3) to the order of 136 and 75% at 75 days and 136 and 98% at harvest, respectively, in 1985-86. In 1986-87, similar trend was observed and increase was to the tune of 116 and 57% at 75 days and 154 and 62% at harvest, respectively. However, mustard + chickpea (4:4) and mustard + chickpea (1:3) were at par but higher values were obtained in mustard + chickpea (1:3). The utilization of applied phosphorus was decreased with the increasing level of phosphorus application and the effect was to the level of significance in both the years at harvest stage. The application of 20 and 30 kg P ha^{-1}, decreased the utilization of applied phosphorus over 10 kg P ha^{-1} to the tune of 88 and 140% in 1985-86, 67 and 77% in 1986-87, respectively.

The utilization of applied phosphorus by mustard at harvest in 1985-86 was significantly higher in mustard + chickpea (1:3) over sole mustard at 10 kg P ha^{-1}, while sole mustard and mustard + chickpea (1:3) were significantly superior to mustard + chickpea (4:4) at 20 and 30 kg P ha^{-1} (Table 17b). The utilization of applied phosphorus in sole mustard significantly increased at

20 kg ha^{-1} over 10 kg P ha^{-1} and declined significantly from 20 kg to 30 kg P ha^{-1}. With the application of 20 and 30 kg P ha^{-1}, the utilization of applied phosphorus was significantly lower than 10 kg P ha^{-1} in mustard + chickpea (4:4) and mustard + chickpea (1:3).

Table 17(b). Interaction effect of treatments on per cent utilization of applied phosphorus at harvest in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})		
	10	20	30
Sole mustard	16.40	26.41	17.30
Sole chickpea	-	-	-
Mustard + chickpea (4:4)	23.36	8.28	7.54
Mustard + chickpea (1:3)	26.03	18.54	18.56
S.Em ±		2.387	
CD 5%		7.157	

4.4. Available nutrient in soil

4.4.1. 'A'-value

The influence of planting patterns on 'A'-value was not significant, however, phosphorus levels significantly influenced the 'A'-value at both the stages in both the crops in both the years (Table 18). There was marked difference in both the years, it was higher in 1986-87 than 1985-86.

The 'A'-value in mustard was minimum in mustard + chickpea (1:3) at all the stages in both the years while

Table 18. Effect of treatments on 'A'-value

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns								
Sole mustard	117.3	102.0	124.3	116.6	-	-	-	-
Sole chickpea	-	-	-	-	160.4	433.9	184.8	477.9
Mustard + chickpea (4:4)	113.8	105.1	125.7	116.7	168.5	403.9	190.9	473.9
Mustard + chickpea (1:3)	103.3	101.9	114.6	114.1	221.9	448.2	245.7	514.6
S.Em ±	10.402	12.245	8.189	9.037	24.826	61.786	20.009	37.789
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS
B. Phosphorus levels (kg P ha^{-1})								
10	85.9	74.3	93.9	86.9	128.3	262.7	149.0	299.0
20	116.1	108.5	129.9	122.0	193.7	450.9	238.1	355.5
30	131.9	126.3	140.7	138.5	224.5	572.4	251.5	657.7
S.Em ±	10.402	12.245	8.189	9.037	24.826	61.786	20.009	37.789
CD 5%	31.848	36.706	24.549	27.090	74.422	185.217	59.980	113.281

maximum values were obtained in sole mustard (117.3) at 75 days in 1985-86 and in mustard + chickpea (4:4) at harvest in 1985-86 and at both the stages in 1986-87. The application of 30 kg P ha^{-1} was significantly superior over 10 kg P ha^{-1} at both the stages in 1985-86 while application of 20 and 30 kg P ha^{-1} was significantly superior over 10 kg P ha^{-1} at both the stages in 1986-87. The higher levels of phosphorus i.e. 20 and 30 kg P ha^{-1} increased the 'A'-value over 10 kg P ha^{-1} to the order of 35 and 53% at 75 days and 46 and 70% at harvest, respectively, in 1985-86. While in 1986-87 the increase was to the order of 38 and 50% at 75 days and 40 and 59% at harvest, respectively.

The sole chickpea gave the minimum 'A'-value at 75 days in both the years, while at harvest it was in mustard + chickpea (4:4) in both the years. However, maximum 'A'-value was obtained in mustard + chickpea (1:3) at both the stages in both the years (221.9, 448.2, 245.7 and 514.6, respectively). The higher dose of phosphorus i.e. 30 kg P ha^{-1} was significantly superior over lower dose i.e. 10 kg P ha^{-1} at both the stages in both the years. However, application of 20 kg P ha^{-1} had significantly higher 'A'-value over 10 kg P ha^{-1} at harvest in 1985-86 and at 75 days in 1986-87. The application of 20 and 30 kg P ha^{-1} increased the 'A'-value over 10 kg P ha^{-1} to the tune of 51 and 75% at 75 days and 72 and 118% at harvest, respectively and increase was to the order of 60 and 69% at 75 days and 19 and 120% at harvest in 1986-87, respectively.

4.4.2. Available nitrogen in soil

There was significant effect of planting patterns and phosphorus levels on available nitrogen, except at 75 days after sowing in 1986-87 (Table 19a). The interaction effect of treatments was also significant in 1985-86 at both the stages (Table 19b, 19c). There was marked difference in available nitrogen in both the years, it was higher in 1986-87 than 1985-86.

The available nitrogen was significantly higher in sole chickpea and mustard + chickpea (1:3) than sole mustard and mustard + chickpea (4:4) at both the stages in 1985-86 while, sole chickpea had significant edge over other treatments at harvest in 1986-87. However, sole mustard and mustard + chickpea (4:4) were at par at both the stages in both the years. In general, there was decline in available nitrogen with the increase in the levels of phosphorus. Application of 10, 20 and 30 kg P ha^{-1} significantly reduced the amount of available nitrogen over control at 75 days after sowing in 1985-86. While at harvest in both the years, application of 20 and 30 kg P ha^{-1} significantly decreased the amount of available nitrogen over control.

The available nitrogen was significantly higher in sole chickpea over sole mustard, mustard + chickpea (4:4) and mustard + chickpea (1:3) at control at 75 days after sowing in 1985-86 (Table 19b). The sole

Table 19(a). Effect of treatments on available nitrogen in soil (kg ha^{-1})

Treatments	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns				
Sole mustard	125.10	87.61	160.37	125.33
Sole chickpea	136.38	99.38	181.97	132.92
Mustard + chickpea (4:4)	125.73	88.73	170.48	126.83
Mustard + chickpea (1:3)	130.67	95.17	175.56	128.31
S.Em ±	0.699	1.357	6.743	0.659
CD 5%	2.020	3.980	NS	1.903
B. Phosphorus levels (kg P ha^{-1})				
0	133.10	95.54	175.25	129.50
10	130.87	95.23	176.35	129.08
20	127.83	89.89	174.91	127.13
30	126.08	90.23	161.87	127.42
S.Em ±	0.699	1.357	6.743	0.659
CD 5%	2.020	3.980	NS	1.903

Table 19(b). Interaction effect of treatments on available nitrogen in soil (kg ha^{-1}) at 75 days in 1985-86

Planting patterns	Phosphorus levels (kg P ha-1)			
	0	10	20	30
Sole mustard	123.73	126.40	124.83	125.46
Sole chickpea	159.16	131.32	128.59	126.40
Mustard + chickpea (4:4)	124.20	127.02	126.24	125.46
Mustard + chickpea (1:3)	125.30	138.71	131.66	127.02
S.Em ±	1.399			
CD 5%	4.041			

Table 19(c). Interaction effect of treatments on available nitrogen in soil (kg ha^{-1}) at harvest in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	92.07	87.34	85.03	86.02
Sole chickpea	107.03	102.40	100.07	88.08
Mustard + chickpea (4:4)	88.73	83.40	87.06	95.73
Mustard + chickpea (1:3)	94.35	107.83	87.40	91.09
S.Em ±	2.713			
CD 5%	7.960			

chickpea and mustard + chickpea (1:3) had significantly higher amount of available nitrogen over sole mustard and mustard + chickpea (4:4) at 10 kg P ha^{-1} while with the application of 20 kg P ha^{-1}, mustard + chickpea (1:3) proved significantly superior over sole mustard and mustard + chickpea (4:4). The higher dose of 30 kg P ha^{-1} could not bring significant difference between planting patterns. There was no significant effect of increasing levels of phosphorus on available nitrogen in sole mustard and mustard + chickpea (4:4). The increasing levels of phosphorus significantly reduced the amount of available nitrogen in sole chickpea while in mustard + chickpea (1:3), it increased significantly upto 10 kg P ha^{-1} than declined significantly upto 30 kg P ha^{-1}.

The available nitrogen was significantly higher in sole chickpea over sole mustard, mustard + chickpea (4:4) and mustard + chickpea (1:3) at control and 20 kg P ha^{-1} at harvest in 1985-86 (Table 19c). The sole chickpea and mustard + chickpea (1:3) had significantly higher amount of available nitrogen over sole mustard and mustard + chickpea (4:4) at 10 kg P ha^{-1}. The higher dose of 30 kg P ha^{-1} could not produce significant difference between planting patterns. Though increasing levels of phosphorus decreased the available nitrogen in sole mustard but effect was not significant. The increasing levels of phosphorus decreased the available nitrogen in sole chickpea; 0, 10, 20 kg P ha^{-1} had significantly higher amount of soil available nitrogen over 30 kg P ha^{-1}. The available nitrogen in mustard + chickpea (4:4) decreased upto 10 kg P ha^{-1}, thereafter, increased upto 30 kg P ha^{-1}. There was significant difference between 30 and 10 kg P ha^{-1}. The available nitrogen significantly increased upto 10 kg P ha^{-1} thereafter, decreased significantly in mustard + chickpea (1:3).

4.4.3. Available phosphorus in soil

There was significant effect of planting patterns on available phosphorus at harvest in 1986-87 while of phosphorus levels at 75 days after sowing in 1985-86 and at harvest in 1986-87 (Table 20a). The interaction effect of treatments was also significant at harvest in 1986-87 (Table 20b).

Though, there was no significant effect of planting patterns on available phosphorus at both the stages in 1985-86 and at 75 days after sowing in 1986-87 but maximum amount of available phosphorus was found in case of sole chickpea followed by mustard + chickpea (1:3), mustard + chickpea (4:4) and sole mustard. At harvest in 1986-87, sole chickpea had significantly higher amount of available phosphorus than rest of the planting patterns. The increasing levels of phosphorus increased the available phosphorus at both the stages in both the years but application of 30 kg P ha^{-1} had significantly higher amount of available phosphorus than control at 75 days after sowing in 1985-86. At harvest in 1986-87, application of 10, 20 and 30 kg P ha^{-1} had significantly higher available phosphorus than control. However, application of 30 kg P ha^{-1} had significant

Table 20(a). Effect of treatments on available phosphorus in soil (kg ha^{-1})

Treatments	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns				
Sole mustard	13.49	13.64	11.46	11.62
Sole chickpea	17.66	17.72	12.57	13.06
Mustard + chickpea (4:4)	14.74	13.93	11.68	11.75
Mustard + chickpea (1:3)	14.90	16.15	11.69	12.00
S.Em ±	1.431	1.372	1.358	0.313
CD 5%	NS	NS	NS	0.919
B. Phosphorus levels (kg P ha^{-1})				
0	11.66	13.75	10.83	9.74
10	15.25	13.62	11.34	11.47
20	15.63	16.91	12.17	12.07
30	18.24	17.17	13.04	15.16
S.Em ±	1.431	1.372	1.358	0.313
CD 5%	4.199	NS	NS	0.919

edge over 10 and 20 kg P ha^{-1}.

There was no significant difference in the amount of available phosphorus among planting patterns at control at harvest in 1986-87 (Table 20b), while sole mustard had significant edge over mustard + chickpea (1:3) with the application of 10 kg P ha^{-1}. With the application of 20 kg P ha^{-1}, sole mustard and sole chickpea had significantly higher amount of available phosphorus than mustard + chickpea (1:3) while sole chickpea and mustard + chickpea (1:3) were significantly superior over sole mustard and mustard + chickpea (4:4) with the application of 30 kg P ha^{-1}. There was significant increase in available phosphorus upto 10 kg P ha^{-1} in sole mustard while, application of 20 and 30 kg P ha^{-1} were significantly superior over control and 10 kg P ha^{-1} in sole chickpea. The application of 30 kg P ha^{-1} was significantly superior over 0, 10 and 20 kg P ha^{-1} in mustard + chickpea (4:4) and mustard + chickpea (1:3). However, there was no significant difference in 0, 10 and 20 kg P ha^{-1} in both mustard + chickpea (4:4) and mustard + chickpea (1:3).

Table 20(b). Interaction effect of treatments on available phosphorus in soil (kg ha^{-1}) at harvest in 1986-87

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	9.11	12.77	12.78	11.84
Sole chickpea	9.22	11.10	13.00	18.91
Mustard + chickpea(4:4)	10.63	11.29	11.66	13.44
Mustard + chickpea(1:3)	10.00	10.73	10.85	16.44
S.Em ±	0.627			
CD 5%	1.810			

4.4.4. Available potassium in soil

The available potassium was not significantly influenced by planting patterns and phosphorus levels at both the stages in both the years (Table 21).

The maximum amount of available potassium was found in sole chickpea at both the stages in both the years and the minimum amount in case of mustard + chickpea (1:3) at both the stages in 1985-86 and sole mustard at both the stages in 1986-87. There was decrease in the available potassium with the increase in the levels of phosphorus. The maximum amount was observed at control and minimum with 30 kg P ha^{-1}.

4.5. Response and economics

The response of mustard and chickpea crops to phosphorus fertilization was quadratic. The response in kg kg^{-1} P was higher in 1986-87 than 1985-86 in both the crops (Appendix II). With the application of 1 kg P ha^{-1}, there was increase in mustard seed yield to the order of 14.28 and 14.93 kg in 1985-86 and 1986-87, respectively. Similarly the use of 1 kg P ha^{-1} gave additional chickpea seed yield of 11.77 and 12.98 kg in 1985-86 and 1986-87, respectively. The returns per rupee investment in phosphorus was higher in 1985-86 (Rs 4.52) than 1986-87 (Rs 4.39) in case of mustard. In contrast, the returns were higher in 1986-87 (Rs 2.48) than 1985-86 (Rs 2.32) in case of chickpea.

Table 21. Effect of treatments on available potassium in soil (kg ha^{-1})

Treatments	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns				
Sole mustard	90.30	94.50	119.90	106.52
Sole chickpea	103.43	116.15	127.87	130.02
Mustard + chickpea (4:4)	91.65	109.03	127.40	111.77
Mustard + chickpea (1:3)	85.87	86.40	120.87	108.10
S.Em ±	6.969	9.767	9.372	8.167
CD 5%	NS	NS	NS	NS
B. Phosphorus levels (kg P ha^{-1})				
0	98.23	105.83	137.67	117.87
10	92.00	105.67	121.80	115.95
20	91.19	102.10	120.37	112.36
30	89.83	92.48	116.20	110.24
S.Em ±	6.969	9.767	9.372	8.167
CD 5%	NS	NS	NS	NS

4.6. Studies on planting patterns

4.6.1. Light interception

There was marked difference in light interception in two years, it was higher in 1985-86 than 1986-87 (Table 22). The maximum light interception by mustard was observed in mustard + chickpea (1:3) at 75 days and 105 days stage in both the years and values were 45.33, 53.33, 40.21 and 48.57%, respectively, while light interception was more or less same in sole mustard and mustard + chickpea (4:4). There was clear effect of phosphorus application on light interception and maximum values were observed with the application of 30 kg P ha^{-1} and minimum with control.

The light intercepted by chickpea was maximum in mustard + chickpea (1:3) at early stage i.e. 75 days in both the years, while at later stage i.e. 105 days sole chickpea had precedence over others in both the years. With the increasing levels of phosphorus there was increase in the light interception.

4.5.2. Light available to chickpea in mustard + chickpea (1:3)

The light available at the top of chickpea plants was 100% in case of sole mustard and mustard + chickpea (4:4) while it was less in mustard + chickpea (1:3) due to shading of mustard. The data is presented in Table 23. The available light for chickpea varied from

Table 22. Effect of treatments on per cent light interception by crop canopy

Treatments	Mustard				Chickpea			
	1985-86		1986-87		1985-86		1986-87	
	75 DAS	105 DAS	75 DAS	105 DAS	75 DAS	105 DAS	75 DAS	105 DAS
A. Planting patterns								
Sole mustard	42.10	49.25	38.31	45.57	-	-	-	-
Sole chickpea	-	-	-	-	24.93	43.60	22.25	42.54
Mustard + chickpea (4:4)	41.95	48.30	38.10	45.75	24.53	44.32	21.22	41.45
Mustard + chickpea (1:3)	45.33	53.30	40.21	48.57	26.60	44.03	22.60	41.40
B. Phosphorus levels ($kg\ P\ ha^{-1}$)								
0	38.56	43.95	35.05	41.91	21.05	44.36	18.05	41.72
10	42.08	51.01	37.75	47.30	26.25	44.23	23.28	40.88
20	45.45	52.43	40.10	47.56	27.08	44.80	23.75	41.47
30	46.41	53.75	42.60	49.75	27.05	45.21	23.01	43.00

94.75% to 77.30%. It reduced with the advancement of crop growth and with the increasing levels of phosphorus in both the years.

Table 23. Effect of phosphorus on per cent light available to chickpea in mustard + chickpea (1:3) planting pattern

Phosphorus levels (kg P ha^{-1})	1985-86		1986-87	
	75 DAS	105 DAS	75 DAS	105 DAS
0	94.75	88.20	94.35	89.20
10	90.05	86.00	89.65	85.90
20	90.15	81.90	90.55	81.40
30	89.00	79.30	89.80	77.30

4.6.3. Total dry matter production

There was significant effect of planting patterns on total dry matter production in both the stages in both the years, but phosphorus levels could influence significantly only at 75 days in 1985-86 and at harvest in 1986-87 (Table 24). Total dry matter production differed markedly in both the years, it was higher in 1985-86 than 1986-87.

The total dry matter production was significantly higher in mustard + chickpea (1:3) than sole mustard, sole chickpea and mustard + chickpea (4:4), the increase was to the tune of 30, 306 and 81% at 75 days and 34,

Table 24. Effect of treatments on total dry matter production (q ha^{-1})

Treatments	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns				
Sole mustard	49.13	81.47	41.58	70.87
Sole chickpea	15.69	38.56	12.99	28.21
Mustard + chickpea (4:4)	35.35	51.56	25.98	44.92
Mustard + chickpea (1:3)	63.82	109.39	53.97	95.67
S.Em ±	1.186	1.881	1.987	1.429
CD 5%	3.426	5.431	5.738	4.126
B. Phosphorus levels (kg P ha^{-1})				
0	38.21	68.13	30.57	56.60
10	39.71	67.20	33.72	59.56
20	41.51	72.57	34.84	61.59
30	44.56	73.08	35.40	61.92
S.Em ±	1.186	1.881	1.987	1.429
CD 5%	3.426	NS	NS	4.126

184 and 121% at harvest, respectively, in 1985-86. The sole mustard was significantly superior over mustard + chickpea (4:4) and sole chickpea at both the stages in 1985-86. However, mustard + chickpea (4:4) also had significant edge over sole chickpea at both the stages. Similarly, in 1986-87, total dry matter production was significantly higher in mustard + chickpea (1:3) than sole mustard, sole chickpea and mustard + chickpea (4:4) to the order of 30, 315 and 108% at 75 days and 35, 239 and 113% at harvest, respectively. The sole mustard was significantly superior over mustard + chickpea (4:4) and sole chickpea at both the stages, while mustard + chickpea (4:4) had significant edge over sole chickpea at both the stages.

The application of 30 kg P ha^{-1}, produced significantly higher total dry matter production at 75 days in 1985-86 over control and 10 kg P ha^{-1}. The increase recorded was to the tune of 17 and 12%, respectively. Though, there was no significant effect of application of phosphorus on total dry matter production at harvest in 1985-86 and at 75 days in 1986-87 but increasing levels of phosphorus increased the values. In 1986-87, application of 20 and 30 kg P ha^{-1}, produced significantly higher total dry matter production over control at harvest.

4.6.4. <u>Mustard equivalent yield</u>

There was significant influence of planting patterns and phosphorus levels on mustard equivalent yield in both the years (Table 25a). Though, there was marked difference in both the years and it was higher in 1985-86 than 1986-87.

The mustard equivalent yield was significantly higher in mustard + chickpea (1:3) over sole mustard, sole chickpea and mustard + chickpea (4:4) to the tune of 32, 153 and 32% in 1985-86 and 23, 204 and 26% in 1986-87, respectively. However, sole mustard and mustard + chickpea (4:4) were at par but significantly superior over sole chickpea.

The mustard equivalent yield significantly increased upto 10 kg P ha^{-1} thereafter, there was no significant difference. The application of 10, 20 and 30 kg P ha^{-1} increased the mustard equivalent yield over control to the tune of 13, 14 and 15% in 1985-86 and 16, 22 and 25% in 1986-87, respectively.

The interaction effect of treatments on mustard equivalent yield was also significant in 1985-86 (Table 25b). The mustard equivalent yield of mustard + chickpea (1:3) was significantly higher than sole mustard, sole chickpea and mustard + chickpea (4:4) at the each level of phosphorus application. However, sole mustard and mustard + chickpea (4:4) were also significantly superior over sole chickpea at all the levels of phosphorus. The mustard + chickpea (4:4) was significantly superior over

Table 25(a). Effect of treatments on mustard equivalent yield (q ha^{-1})

Treatments	1985-86	1986-87
A. <u>Planting patterns</u>		
Sole mustard	22.85	19.73
Sole chickpea	11.90	7.98
Mustard + chickpea (4:4)	22.86	19.25
Mustard + chickpea (1:3)	30.14	24.27
S.Em ±	0.281	0.659
CD 5%	0.812	1.903
B. <u>Phosphorus levels (kg P ha^{-1})</u>		
0	19.82	15.38
10	22.45	17.90
20	22.58	18.76
30	22.90	19.20
S.Em ±	0.281	0.659
CD 5%	0.812	1.903

sole mustard at control and 10 kg P ha^{-1} and a reverse trend was observed at 30 kg P ha^{-1}. The mustard equivalent yield significantly increased upto 30 kg P ha^{-1} in sole mustard, while there was significant increase upto 10 kg P ha^{-1} in sole chickpea and mustard + chickpea (1:3). There was also significant increase upto 10 kg P ha^{-1} in mustard + chickpea (4:4) thereafter, it decreased.

Table 25(b). Interaction effect of treatments on mustard equivalent yield (q ha^{-1}) in 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	19.64	21.85	24.07	25.84
Sole chickpea	10.24	12.41	12.66	12.29
Mustard + chickpea (4:4)	21.75	23.93	22.87	22.89
Mustard + chickpea (1:3)	27.65	31.61	30.71	30.57
S.Em ±	0.562			
CD 5%	1.625			

4.6.5. Land equivalent ratio (LER)

The land equivalent ratio was estimated for intercropping systems and the data is presented in Table 26.

In both the years, LER values were higher in mustard + chickpea (1:3) than mustard + chickpea (4:4) and was recorded to the tune of 33% in 1985-86 and 25% in 1986-87. With the increasing levels of phosphorus LER decreased. The maximum values were obtained at control i.e. 1.42 in 1985-86 and 1.44 in 1986-87 and minimum values at 30 kg P ha^{-1} i.e. 1.23 in 1985-86 and 1.28 in 1986-87.

Table 26. Effect of intercropping systems and phosphorus levels on land equivalent ratio (LER)

Treatments	1985-86	1986-87
A. Intercropping systems		
Mustard + chickpea (4:4)	1.14	1.21
Mustard + chickpea (1:3)	1.52	1.51
B. Phosphorus levels (kg P ha^{-1})		
0	1.42	1.44
10	1.41	1.40
20	1.27	1.33
30	1.23	1.28

4.6.6. Combined total phosphorus uptake

The combined total phosphorus uptake was significantly influenced by planting patterns and phosphorus levels at both the stages in both the years (Table 27a). There was marked difference between both the years, it was higher in 1985-86 than 1986-87. The interaction effect of treatments on combined total

Table 27(a). Effect of treatments on combined total phosphorus uptake (kg ha^{-1})

Treatments	1985-86		1986-87	
	75 DAS	Harvest	75 DAS	Harvest
A. Planting patterns				
Sole mustard	18.86	22.16	15.71	19.01
Sole chickpea	6.14	11.85	4.88	9.39
Mustard + chickpea (4:4)	13.37	17.41	10.34	14.80
Mustard + chickpea (1:3)	23.26	31.25	18.83	29.18
S.Em ±	0.910	1.171	1.142	1.008
CD 5%	2.629	3.380	3.297	2.911
B. Phosphorus levels (kg P ha^{-1})				
0	11.75	16.81	9.05	13.21
10	15.65	19.69	12.40	17.73
20	16.81	22.36	13.20	19.41
30	17.42	23.82	15.08	22.02
S.Em ±	0.910	1.171	1.142	1.008
CD 5%	2.629	3.380	3.297	2.911

phosphorus uptake was also significant at harvest in both the years (Table 27b, 27c).

The combined total phosphorus uptake was significantly higher in mustard + chickpea (1:3) than sole mustard, sole chickpea and mustard + chickpea (4:4) to the tune of 23, 279 and 74% at 75 days and 41, 164 and 79% at harvest in 1985-86, respectively. The sole mustard and mustard + chickpea (4:4) were significantly superior over sole chickpea at both the stages in 1985-86. Similarly, in 1986-87, combined total phosphorus uptake was significantly higher in mustard + chickpea (1:3) than sole mustard, sole chickpea and mustard + chickpea (4:4) to the order of 20, 286 and 82% at 75 days and 53, 211 and 97% at harvest, respectively. The sole mustard and mustard + chickpea (4:4) had significant edge over sole chickpea at both the stages.

The application of 10, 20 and 30 kg P ha^{-1} significantly increased the combined total phosphorus uptake over control at 75 days in 1985-86 and at both the stages in 1986-87 (Table 27a). However, the application of 20 and 30 kg P ha^{-1} significantly increased the uptake over control at harvest in 1985-86. The maximum uptake values were obtained at 30 kg P ha^{-1} at both the stages in both the years.

The combined total phosphorus uptake was

Table 27b. Interaction effect of treatments on combined total phosphorus uptake (kg ha^{-1}) at harvest 1985-86

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	16.81	14.28	32.26	25.31
Sole chickpea	10.58	12.19	11.61	13.01
Mustard + chickpea (4:4)	12.04	24.31	16.25	17.07
Mustard + chickpea (1:3)	27.81	27.99	29.34	39.88
S.Em ±	2.341			
CD 5%	6.761			

Table 27c. Interaction effect of treatments on combined total phosphorus uptake (kg ha^{-1}) at harvest in 1986-87

Planting patterns	Phosphorus levels (kg P ha^{-1})			
	0	10	20	30
Sole mustard	13.02	18.30	21.57	23.15
Sole chickpea	7.56	9.64	9.07	11.29
Mustard + chickpea (4:4)	9.99	18.85	14.36	16.00
Mustard + chickpea (1:3)	22.27	24.13	32.67	37.66
S.Em ±	2.016			
CD 5%	5.822			

significantly higher in mustard + chickpea (1:3) over rest of the planting patterns at control and 30 kg P ha^{-1} application, while it had significant edge over sole mustard and sole chickpea at 10 kg P ha^{-1} and sole chickpea , mustard + chickpea (4:4) at 20 kg P ha^{-1} at harvest in 1985-86 (Table 27b). The sole mustard had significantly higher uptake with the application of 20 and 30 kg P ha^{-1} over control and 10 kg P ha^{-1}. There was no significant effect of increasing levels of phosphorus in sole chickpea. The phosphorus uptake increased significantly upto 10 kg P ha^{-1} thereafter, declined significantly in mustard + chickpea (4:4). The application of 30 kg P ha^{-1} significantly increased the uptake over 0, 10 and 20 kg P ha^{-1} in mustard + chickpea (1:3).

The combined total phosphorus uptake was significantly higher in mustard + chickpea (1:3) over rest of the planting patterns at control, 20 and 30 kg P ha^{-1}, while over sole mustard and sole chickpea at 10 kg P ha^{-1} at harvest in 1986-87 (Table 27c). Sole chickpea had significantly minimum phosphorus uptake at all the levels of phosphorus. The sole mustard and mustard + chickpea (1:3) had significantly higher uptake at 20 and 30 kg P ha^{-1} over control while sole chickpea could not have significant effect

Table 28. Monthly soil moisture depletion pattern (mm)

	Month					Total	Mean depletion/day
	I	II	III	IV	V		
			1985-86				
Soil moisture depletion	24.2	4.7	10.4	24.3	42.2	105.8	
Effective rainfall (mm)	0	24.8	22.4	39.6	15.2	102.0	
Consumptive use (mm)	24.2	29.5	32.8	63.9	57.4	207.8	1.38
Depletion/day	0.81	0.95	1.06	2.20	1.85		
			1986-87				
Soil moisture depletion	28.3	23.5	24.4	16.3	15.8	108.3	
Effective rainfall (mm)	0	5.4	24.0	7.0	18.8	55.2	
Consumptive use (mm)	28.3	28.9	48.4	23.3	34.6	163.5	1.09
Depletion/day	0.91	0.96	1.61	0.75	1.23		

of phosphorus levels. The uptake increased significantly upto 10 kg P ha^{-1} in mustard + chickpea (4:4) thereafter, it declined.

4.6.7. Soil moisture depletion

The data of monthly soil moisture depletion pattern is presented in Table 28. The soil moisture depletion was more or less same in both the years through, it was higher in 1986-87. The contribution of rainfall was almost double in 1985-86 as compared to 1986-87. The consumptive use of water was markedly higher in 1985-86 than 1986-87. The mean value for a day was 1.38 mm in 1985-86 and 1.09 mm in 1986-87.

Except first month of 1985-86 season, there was sufficient rains in all the months which was well distributed too. In 1986-87, the first two months were dry, only 5.4 mm rain was received but there was sufficient rains in the third and fifth month which concided to flowering and siliqua/pod development stages.

....

5. DISCUSSION

In this experiment, mustard (Brassica juncea L. Czern and Coss) variety, Pusa Barani and chickpea (Cicer arietinum L.) variety, Pusa 261 were grown in different planting patterns viz., sole crops of mustard and chickpea, mustard + chickpea in 4:4 and mustard + chickpea in 1:3 row ratios. The row spacing for mustard and chickpea under sole cropping as well as under 4:4 row ratio was kept as 45 cm whereas 20 cm spacing was maintained between the plants. When mustard + chickpea were planted in 1:3 row ratio the inter-row spacing for mustard was doubled to 90 cm and inter-plant spacing was reduced to 10 cm to maintain the uniform plant population level of base crop mustard in the planting systems. The inter-row spacing was kept 30 cm when chickpea was raised as intercrop between the mustard rows in 1:3 system. The fertilizer phosphorus doses given were 0, 10, 20 and 30 kg P ha^{-1} to both the crop components on area basis and labelled fertilizer was applied to both the crops in the specified rows. Total 16 treatment combinations were tested in a Randomised Block Design with three replications.

Mustard and chickpea are the most important crops of rainfed agriculture in North and North-west India. These are cultivated in sole as well as in mixed/intercrop stands. The Pusa Barani mustard and Pusa-261 chickpea differed in their growth patterns. The peak vegetative and reproductive phases of both the crops did not occur simultaneously, making the intercropping more compatible than normally expected with the conventional varieties of mustard and chickpea, cultivated earlier. The planting patterns and phosphorus levels were expected to influence the utilization pattern of growth resources (moisture, nutrients, light and space) and exhibit the changes in the growth, development and yield of the crops. It was, therefore, necessary to identify the reasons for advantages/reductions in crop yields, the different planting patterns under varying levels of phosphorus where moisture was limiting and seasonal variations in rainfall were very wide both in terms of amount and its distribution.

5.1. <u>Crop season</u>

The crops in 1985-86 season were sown on November 6 but in 1986-87 the sowing was done on October 21 which is seventeen days earlier to first year. The weekly weather data collected in the two crop seasons are given in Appendix I and depicted by Fig. 1. The data showed large variations in the amount and distribution of rainfall in the two crop seasons but the differences recorded in other weather parameters were small.

In 1985-86, the rains 3 weeks before sowing were sufficient (77.4 mm) and seven more showers were received in the crop season. The total amount of rainfall received during the crop season was 102.6 mm having better distribution and it concided with vegetative, flowering and siliqua/pod development stages. Therefore, the crop growth, development and yield were as good as obtained from a normal irrigated crop (Tables 3 to 9). Contrary, in 1986-87, 45.4 mm rains 3 weeks before sowing were received and moisture was just sufficient for germination and seedling establishment. But later on only 5.4 mm rainfall was received in 12 weeks period and crops suffered moisture stress in the initial period of growth. The prolonged drought period of 77 days adversely affected the vegetative growth of crop plants (Tables 3 to 7) but later rains (49.8 mm)received between January to March coincided with the flowering and siliqua/pod formation stages of both the crops. The moisture supply at these stages favoured the crop growth and losses caused, due to drought in initial crop growth was compensated to some extent (Tables 3,4,5,8).

The moisture deficit in soil during the dry periods, adversely affected growth, development and yield of mustard and chickpea (Table 12). It is a well recognised fact that water deficit in rooting zone reduced nutrient uptake by crop plants and adversely affect the growth and development (Gupta, 1982), thereby reducing the crop yield (Shaw and Laing, 1965).

5.2. Effect of planting patterns

5.2.1. Biomass production

The growth and development of crop plants are specially influenced by its constitution, though the environmental and rhizospheric factors along with the

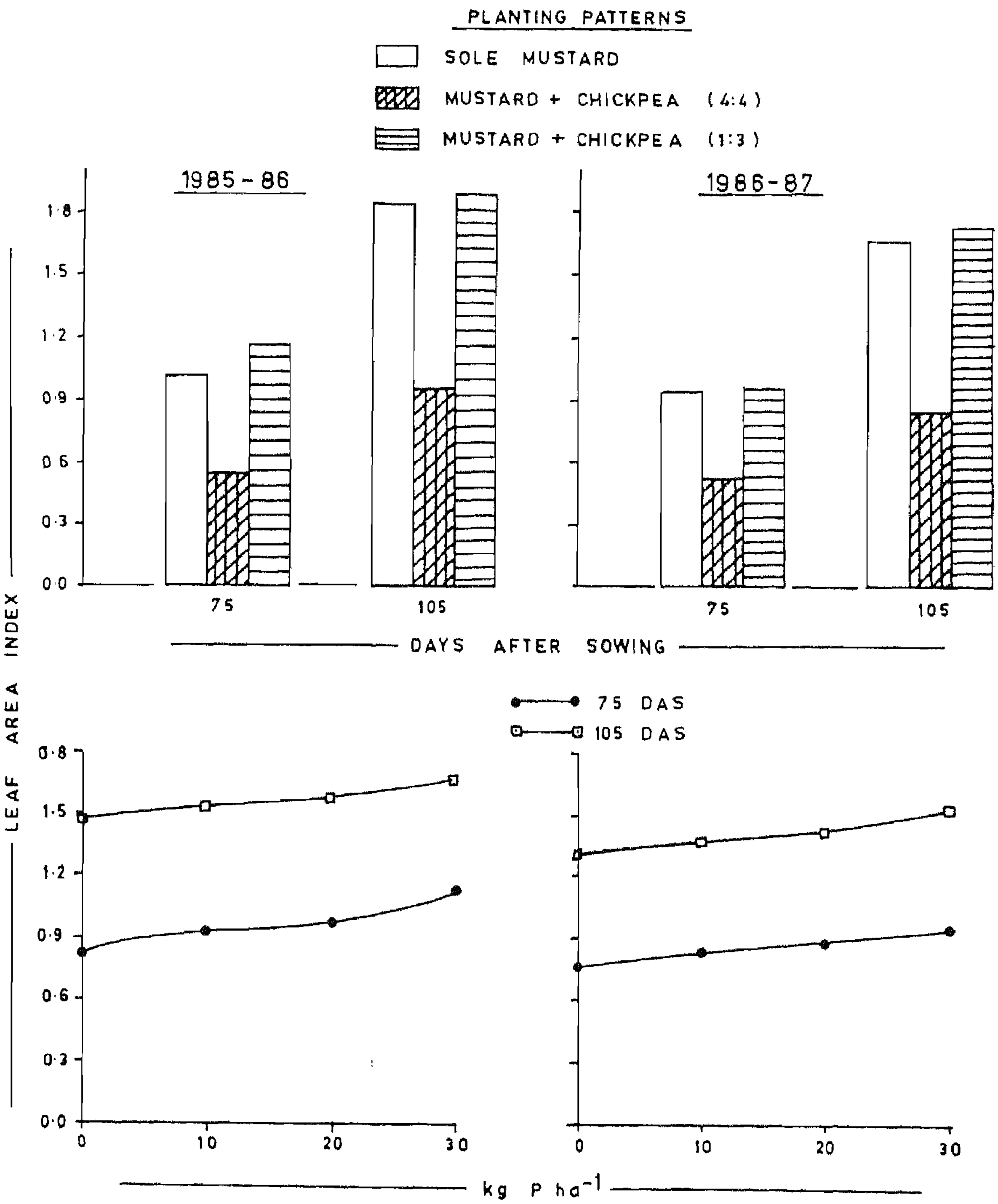

FIG.3. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON LEAF AREA INDEX OF MUSTARD.

cultural practices adopted are equally important. These factors play an important role in carrying out total plant processes which ultimately determine the effective crop production.

It has been observed during the critical evaluation of the experimental data that the biomass production in mustard was maximum when mustard was raised in 1:3 system (Fig. 4). This may be attributed to the superiority in all growth parameters contributing towards increased biomass production i.e. plant height (Table 3), number of main branches (Table 4), sub-branches (Table 5), leaves (Table 6) and LAI (Fig. 3). Higher LAI had been reported under intercropping systems by Lin et al. (1981). In mustard + chickpea (1:3) system due to increase in the inter-row space (90cm), the number of plants within the row increased. Though, this resulted in greater inter-plant competition in a row but the adverse effect of plant to plant competition within the row was offset by the wider inter-row space available in this pattern, making utilization of growth resources more efficient (Tables 15a, 22).

Better resource utilization in mustard + chickpea intercropping system was also reported by Kushwaha (1983) under dryland conditions. Wider inter-row spacing provided more lateral space for branching and leaf formation and growth. The mustard plants faced competition for light due to less intra-row spacing which forced the plants to go for light thus, plants grew taller in 1:3

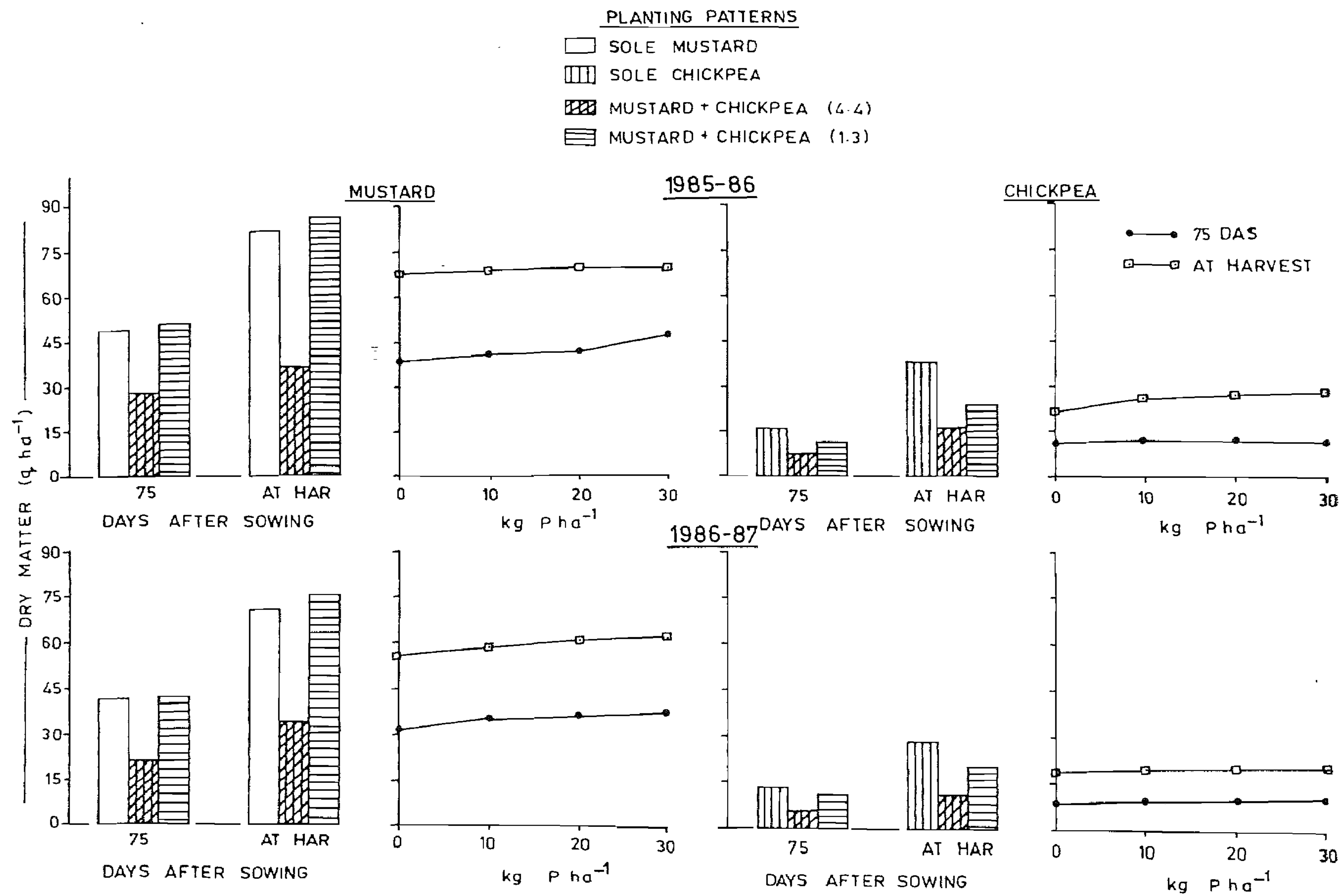

FIG.4. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON DRY MATTER PRODUCTION

planting pattern. The association of legume (chickpea) with mustard provided more availability of nitrogen fixed by chickpea. Such association effect of legume with more lateral space was absent when mustard was raised in sole cropping. The biomass production was minimum in mustard + chickpea (4:4) planting pattern mainly due to reduction in plant population of the component crop (mustard) planted in replacement series.

Contrary to mustard, chickpea biomass was adversely affected in mustard + chickpea (1:3) system as compared to chickpea sole cropping. This is in conformity with the findings of Meena (1985). It may be attributed to reduced branching (Tables 4 and 5) and % light available (Table 23) in 1:3 system. Saxena and Sheldrake (1980) also reported that significant reduction in dry matter was recorded even when only 25% of sunlight was intercepted. This was otherwise evident from the higher dry matter production and short compact plants of chickpea raised in sole stand. Higher dry matter production in sole chickpea was due to better utilization of growth resources (light, moisture and space) as also observed by Meena (1985). Further, chickpea biomass production was more in mustard + chickpea (1:3) planting pattern than mustard + chickpea (4:4) row ratio mainly due to the fact that the plant population in latter was reduced to half as the system was based on replacement series.

5.2.2. Yield

The mustard seed yield was maximum in mustard +

chickpea (1:3) in both the years (Fig. 5) which may be attributed to superiority in all yield attributing characters i.e. number of siliquae per plant (Table 9), number of seeds per siliqua (Table 10), 1000-seed weight (Table 11) and higher leaf area (Table 7). Higher leaf area intercepted more light and produced higher yield in several crops have been reported by Donald (1963), Willey (1979) and Hughes et al. (1981). The lateral growth i.e. branches was better (Tables 4 and 5) which borne more number of siliquae and due to better utilization of growth resources i.e. light (Table 22), moisture and nutrients (Table 15a), the number of seeds per siliqua and 1000-seed weight were higher resulting in higher yield in 1:3 system. The yield advantages obtained through intercropping were due to efficient utilization of available growth resources like nutrients (Dalal, 1974 and Lakhani, 1976) and light (Nelliet et al., 1974; Backer and Yusuf, 1976).

Sole mustard crop was sown with narrow inter-row spacing (45 cm) as compared to 1:3 system (90 cm) which led to more inter-row competition than intra-row competition for growth resources. Sole mustard was devoid of association effect of chickpea. The seed yield in mustard + chickpea (4:4) was minimum due to its half population. Though, the population was half but the yield was more than half of the sole stand which may be attributed to association of legume crop i.e. chickpea and availability of more space to one row nearer to the chickpea row.

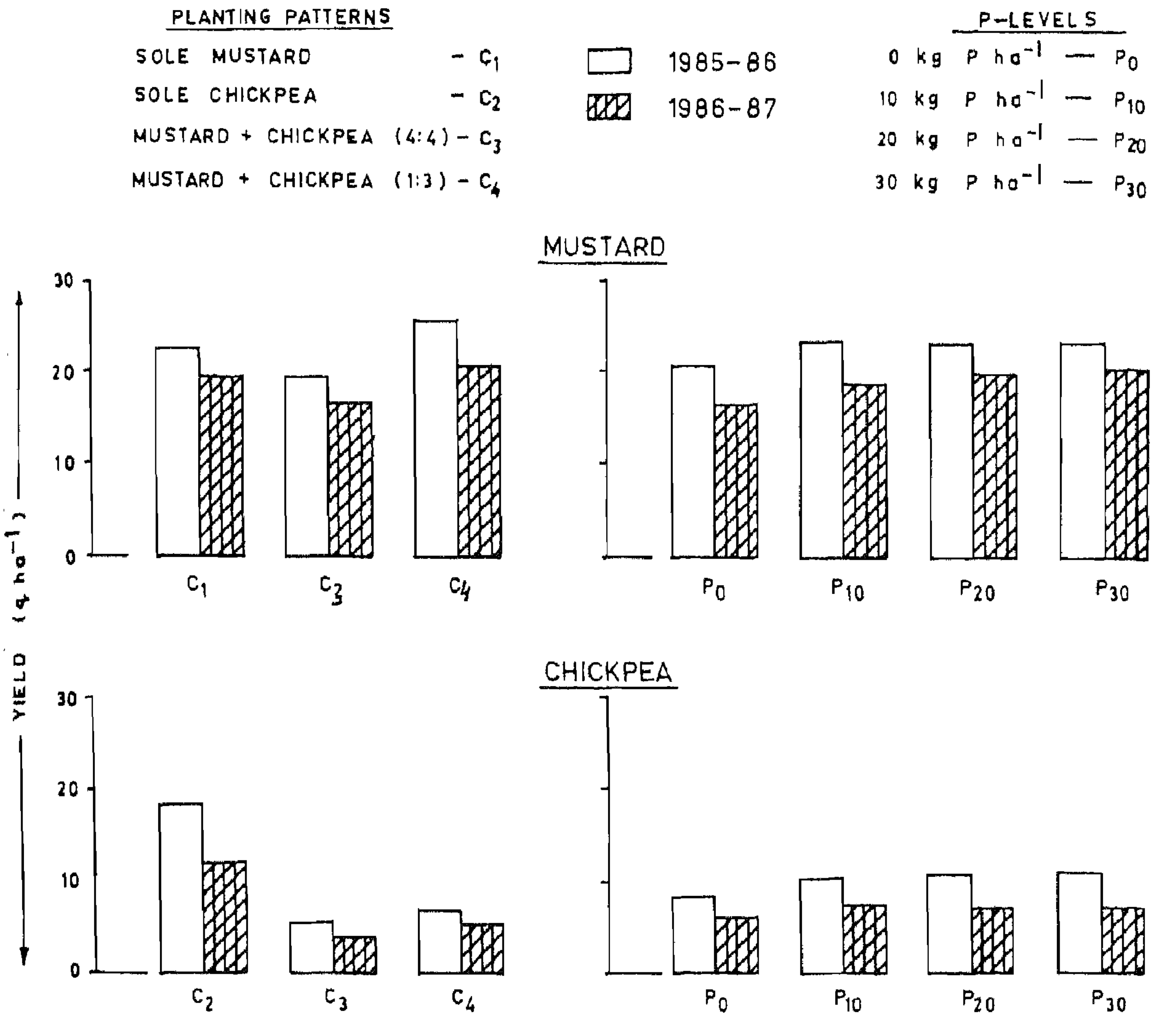

FIG.5. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON SEED YIELD.

On the contrary, the chickpea seed yield was maximum in sole stand (Fig. 5) due to more number of pods per plant (Table 9) and more light interception at later stage of growth (Table 22). The higher chickpea yield was also realised when it was grown as sole crop by Saxena and Yadav (1975) and Ahlawat et al. (1985). Saxena and Sheldrake (1980) reported significant reduction in yield in all cultivars even when only 25% of light was intercepted. The chickpea yield was reduced in mustard + chickpea (1:3) due to less number of pods per plant (Table 9) and increased vegetative growth due to shading of mustard plants. The yield realised in 1:3 system was better than in 4:4 system due to population of chickpea crop was reduced to half in replacement series resulted in lower yields.

5.2.3. Quality

The oil content in mustard (Table 13) and protein content in chickpea (Table 14) is mainly governed by the genetic make up of these crop varieties. However, the different planting patterns and use of phosphorus fertilizers did not bring remarkable change in these quality parameters. Similar results have been noted in past by several workers (Gangasaran and De, 1979; Meena, 1983).

5.2.4. Radio-chemical assay

The total phosphorus uptake increased from 75 days to harvest which was due to increase in dry matter

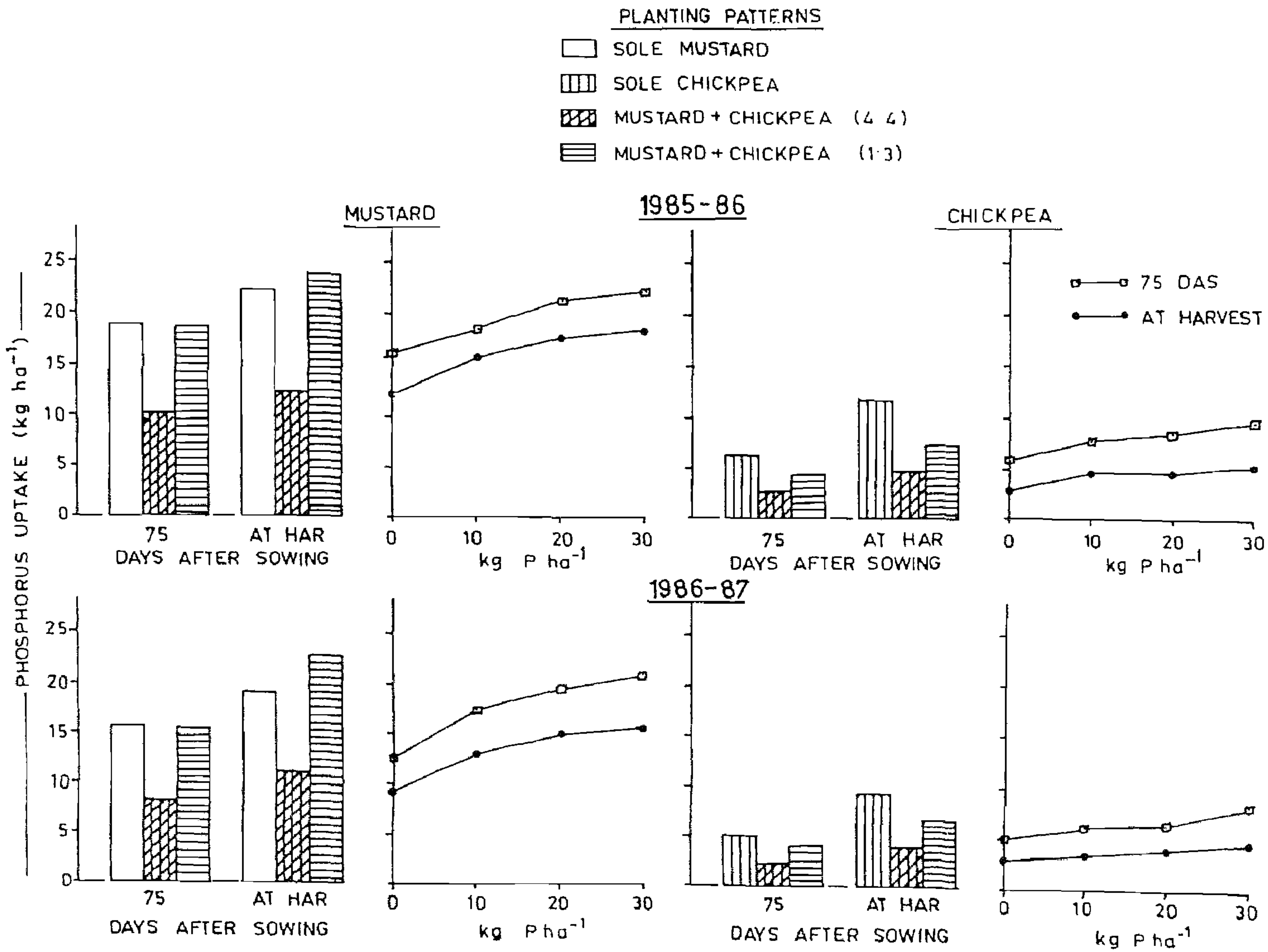

FIG.6. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON TOTAL PHOSPHORUS UPTAKE.

production (Fig. 4). The total phosphorus uptake by mustard was maximum in 1:3 system. This was also due to the higher total biomass production in these treatments rather than the per cent content of the element. Another evidence put forth is the difference in rooting pattern, because the roots have tendency to avoid the overlapping in rooting zone. Thus, crop avoids the area that has already depleted by an associate crop (Trenbath, 1974). On the other hand, total phosphorus uptake by chickpea was maximum in sole cropping (Table 15a). This is due to the fact that dry matter production was maximum in sole chickpea stand (Fig. 4). The trend of total phosphorus uptake was same as of biomass production i.e. sole chickpea followed by mustard + chickpea (1:3) and mustard + chickpea (4:4).

Further, fertilizer phosphorus uptake continued to increase upto harvest but the proportionate uptake value was much lower between 75 days to harvest than sowing to 75 days (Table 16a). This may be attributed to higher phosphorus uptake by plants at early growth stages and later it became sluggish during the reproductive phase. The fertilizer phosphorus pool might have also depleted at later stage. The fertilizer phosphorus uptake by mustard was maximum in mustard + chickpea (1:3) system due to higher biomass production (Table 8) and % phosphorus derived from fertilizer source (Fig. 8). The mustard + chickpea (4:4) had minimum fertilizer phosphorus uptake

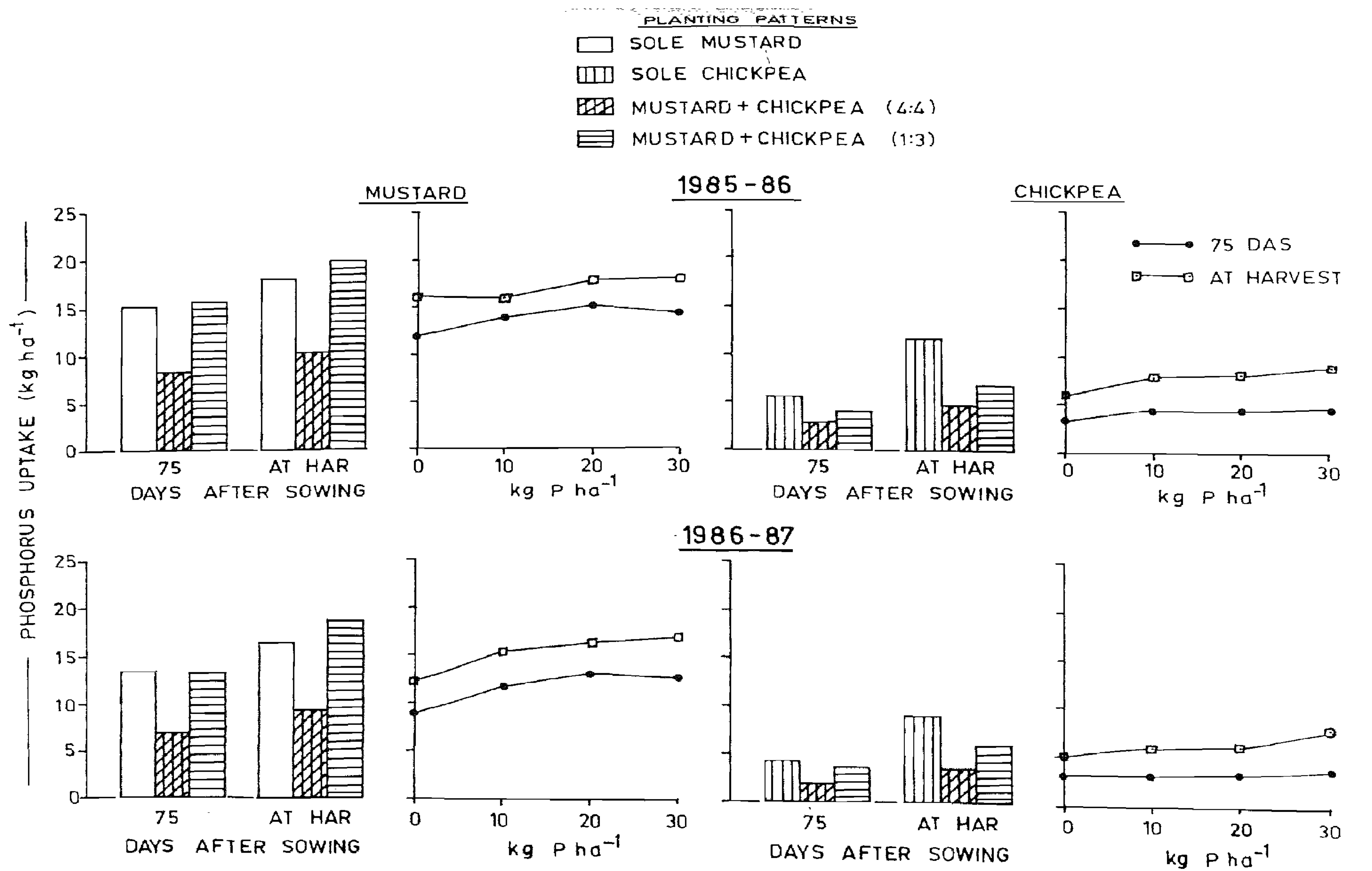

FIG.7. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON SOIL PHOSPHORUS UPTAKE.

due to reduction in plant population to half in replacement series. On the contrary, fertilizer phosphorus uptake by chickpea was maximum in sole stand. Because it was primarily depended on biomass production and lower inter-row competition due to wider inter-row spacing (45 cm) than in mustard + chickpea (1:3) system in 30 cm. The fertilizer phosphorus uptake by chickpea was higher at 75 days than at harvest in both the years of experimentation (Table 16a). The increased mineralization of native phosphorus due to root exudates with the advancement of crop growth resulted in higher uptake. Thus, there was increase in soil phosphorus uptake at later stage (Fig. 7). The mustard + chickpea (4:4) had only 50% of plant population than sole crop though chickpea derived maximum percentage of phosphorus from fertilizer.

Likewise, fertilizer phosphorus uptake, the utilization of applied phosphorus also increased from 75 days to harvest (Table 17a) and falls in similar line that obtained with total phosphorus uptake. The per cent utilization of applied phosphorus by mustard was maximum in mustard + chickpea (1:3) pattern mainly due to higher biomass production and % phosphorus derived from fertilizer. The sole mustard ranked second in utilization of applied phosphorus due to relatively low biomass production (Fig. 4) and % phosphorus derived from fertilizer (Fig. 8). The utilization of applied phosphorus

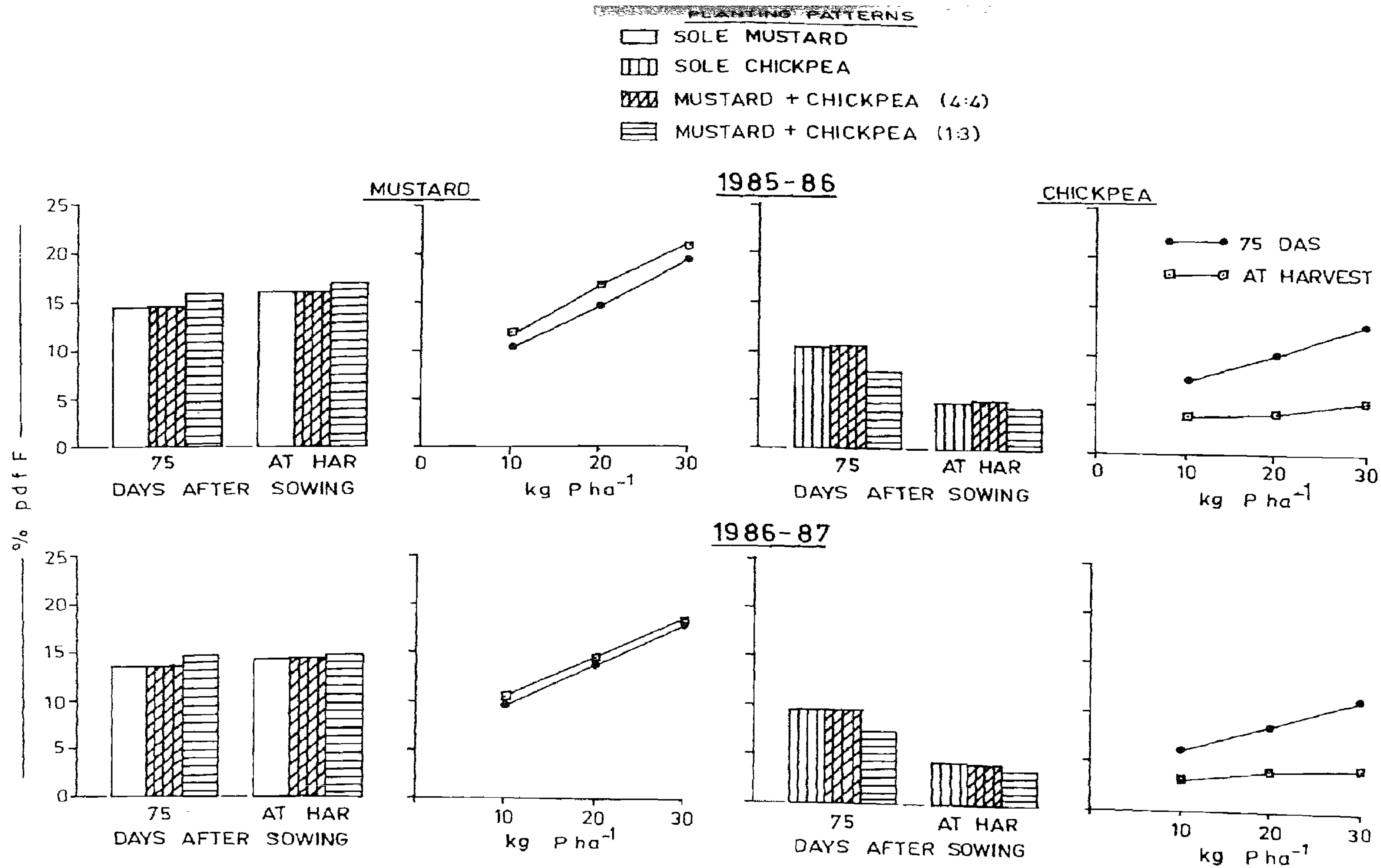

FIG. 8. EFFECT OF PLANTING PATTERNS ON PHOSPHORUS DERIVED FROM FERTILIZER

by mustard was least in mustard + chickpea (4:4) due to reduced biomass and fertilizer phosphorus uptake. The per cent utilization of applied phosphorus by chickpea was maximum in sole stand followed by mustard + chickpea (1:3) and mustard + chickpea (4:4) (Table 17a). This may be attributed to higher biomass production. The per cent utilization of applied phosphorus by chickpea was higher at 75 days than at harvest. The possible reason for this observation may be due to very active vegetative growth of plants which took more phosphorus from fertilizer and resulted in the increased utilization of applied phosphorus. This fact supports the concept of crop competition for nutrient at active growth period.

It is very interesting to note that mustard proved its superiority in mustard + chickpea (1:3) system over sole mustard and mustard + chickpea (4:4) system in all the observations recorded but in 'A'-value the trend was reverse. As it could be seen from Fig. 9 that mustard had maximum 'A'-value in mustard + chickpea (4:4) except at 75 days in 1985-86 followed by sole mustard and mustard + chickpea (1:3). It is quite natural because mustard had utilized less applied phosphorus in 4:4 system than sole mustard and 1:3 system. In case of chickpea, the trend was reverse as observed in mustard and maximum 'A'-value was observed in mustard + chickpea (1:3) due to the fact that per cent phosphorus derived from fertilizer was low.

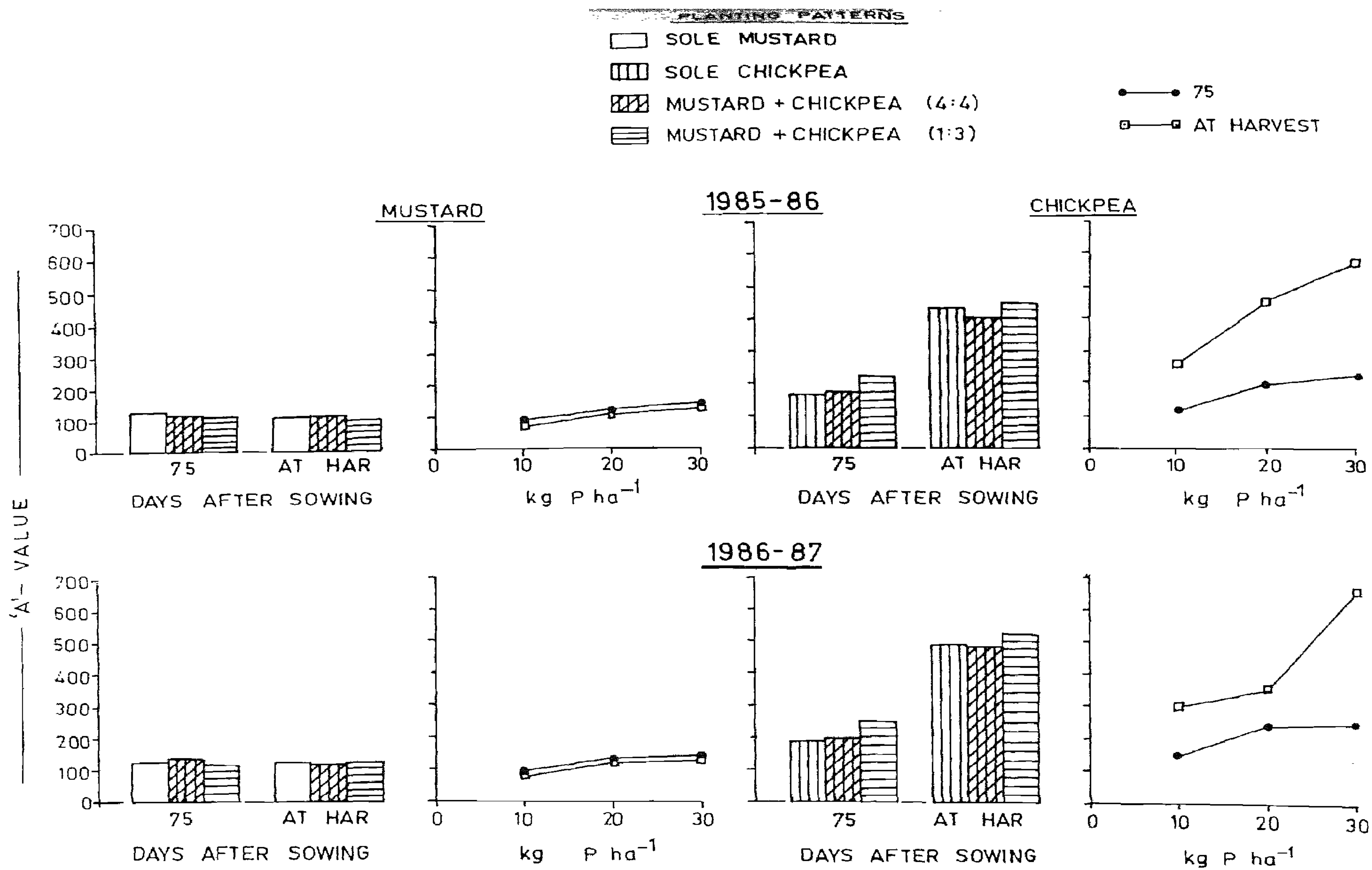

FIG.9 EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVLS ON 'A'- VALUE

5.2.5. Available nutrient in soil

Analysis of soil samples showed that available nitrogen content in soil was maximum in sole chickpea followed by mustard + chickpea (1:3), mustard + chickpea (4:4) and sole mustard (Table 19a). This was due to the simple fact that chickpea being legume added atmospheric N into the soil and utilized relatively lower amount of nitrogen, while mustard being exhaustive crop did not add N into the soil.

The available phosphorus content in soil followed the same trend as available nitrogen content in soil (Table 20a). Maximum available phosphorus was recorded in sole chickpea due to lower uptake of phosphorus and greater mineralization of native phosphorus. Minimum values were obtained in sole mustard which may be attributed to higher P uptake and poor capacity of mineralization of native phosphorus. Though, combined total phosphorus uptake was maximum in mustard + chickpea (1:3) system but supplementary effect of chickpea association brought higher values of available phosphorus content.

The available potassium content in soil was also maximum in sole chickpea (Table 21) because of minimum dry matter production (Fig. 11). Mustard + chickpea (4:4) pattern followed the sole chickpea due to third rank in total dry matter production (Fig. 11). The sole mustard and mustard + chickpea (1:3) did not give any clear picture.

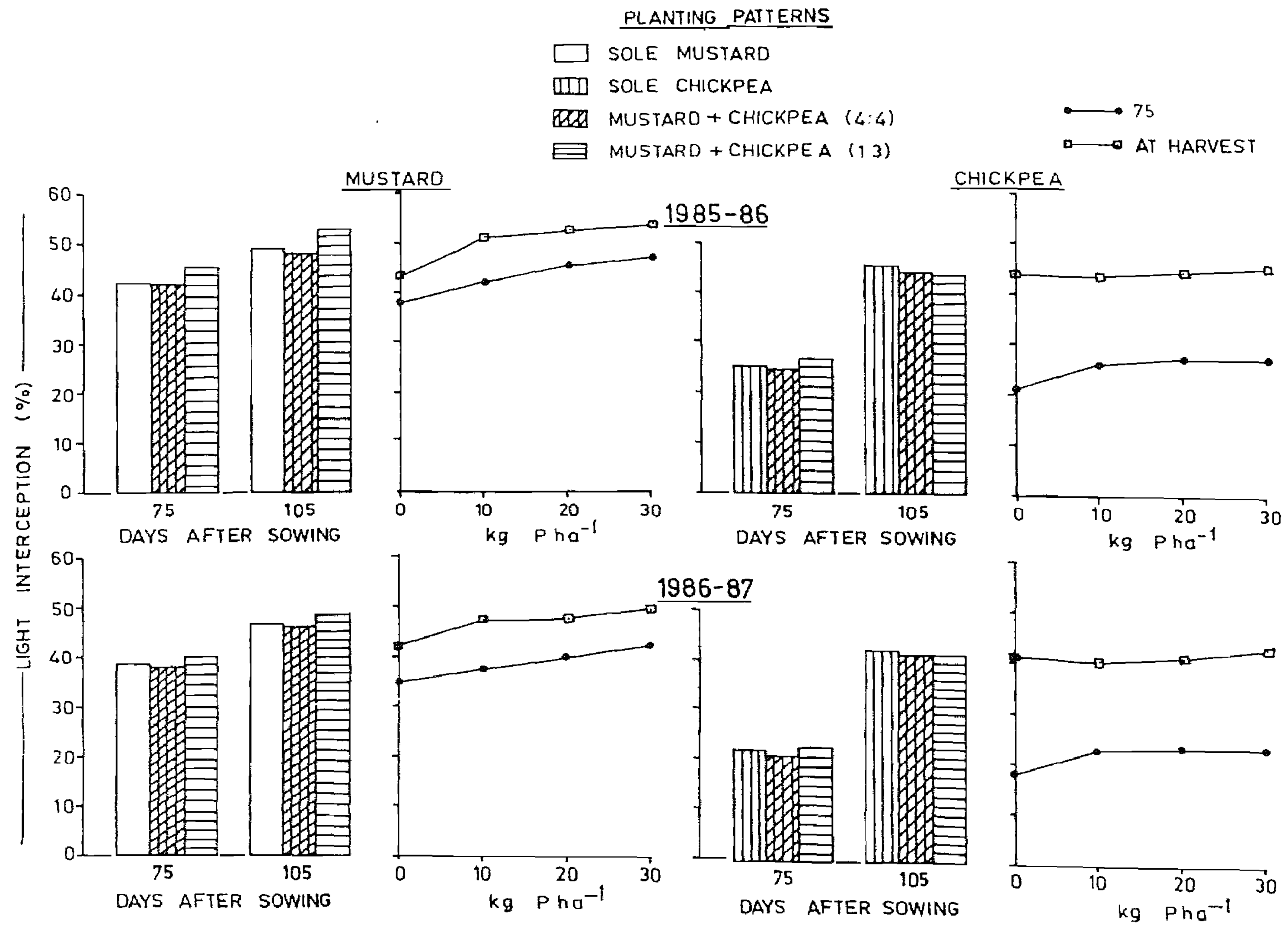

FIG.10. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON LIGHT INTERCEPTION BY CROP CANOPY

5.2.6. Leaf area index (LAI) and light interception

The LAI increased from 75 days to 105 days (Table 7 and Fig. 3) with the continuation of vegetative growth of plants. The maximum LAI of mustard was observed in mustard + chickpea (1:3) pattern may be attributed to wider inter-row spacing which provided more lateral space for branching and leaf formation and growth. There was also better utilization of growth resources viz., nutrients (Fig. 6), light (Fig. 10) and space. Higher LAI had been reported under intercropping systems by Lin *et al.* (1981), Meena (1985) and Pareek (1987).

The association effect of legume and more lateral space was absent in sole stand. The LAI was minimum in mustard + chickpea (4:4) system mainly due to reduction in plant population of mustard crop in replacement series.

The mustard + chickpea (1:3) proved its superiority in light interception by mustard crop canopy (Fig. 10). This is mainly attributed to higher LAI. The light interception increased with the advancement of crop. This finding is in confirmity of Hughes *et al.* (1980) and Meena (1985). Because of minimum LAI, the light interception was also least in mustard + chickpea (4:4) pattern. On the other hand, maximum light interception was observed in sole chickpea (Table 22) followed by mustard + chickpea (4:4) and mustard + chickpea (1:3)

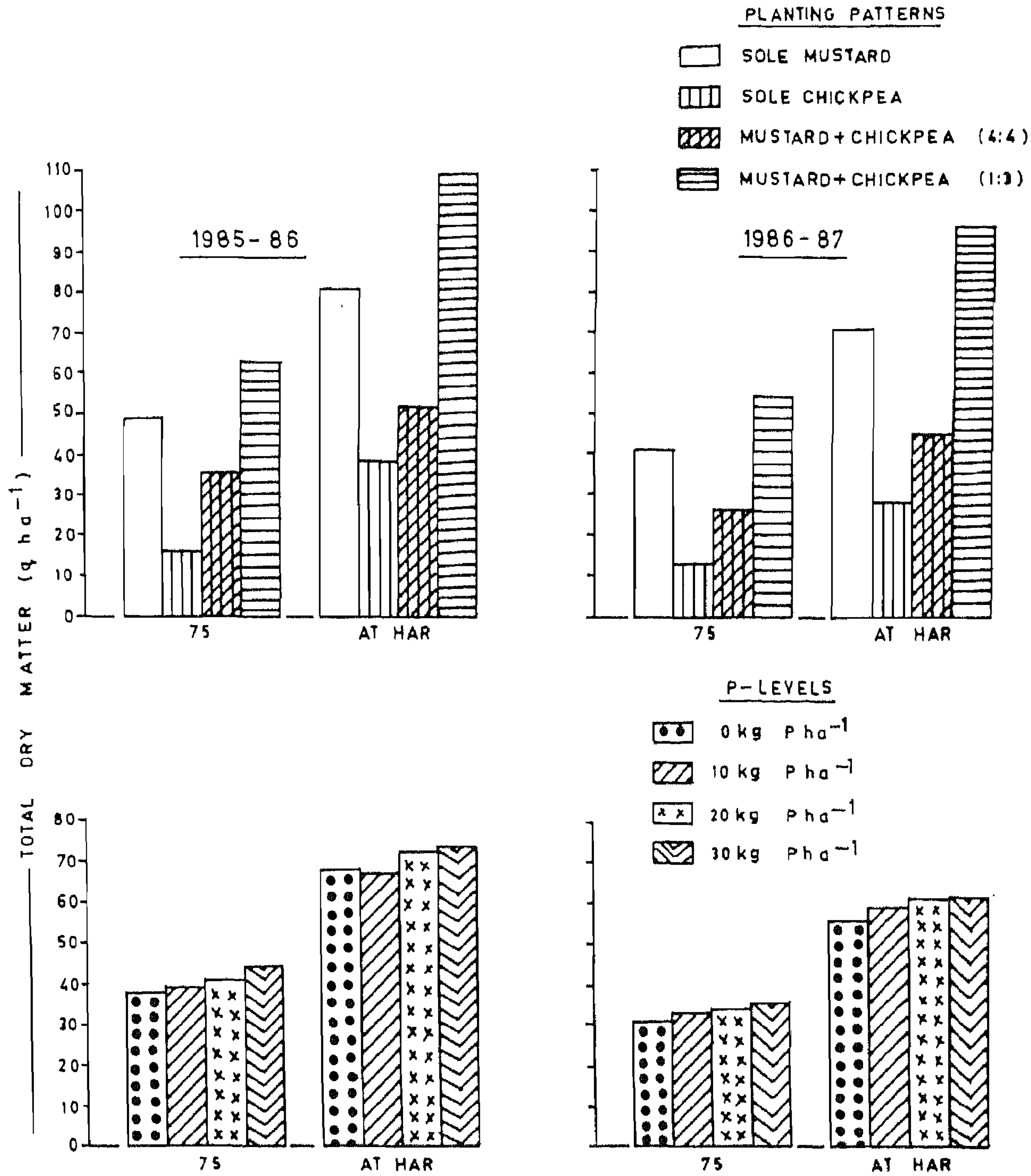

FIG.11. EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON THE TOTAL DRY MATTER PRODUCTION.

system. This may be due to better branching and no shading. While the light available to chickpea in 1:3 pattern was never 100% rather, it varied from 77.3% to 94.75% (Table 23). Similar results were also reported by Meena (1985).

5.2.7. Total dry matter production

The total dry matter production was maximum in mustard + chickpea (1:3) system followed by sole mustard, mustard + chickpea (4:4) and sole chickpea (Fig. 11). Total dry matter production was mainly influenced by the contribution of mustard component which had superiority in all growth parameters (Tables 3 to 7) in 1:3 system. The values were minimum in sole chickpea which was quite natural due to its genetic constitution. Sole mustard proved to be superior to mustard + chickpea (4:4) because of higher plant population over 4:4 system which was based on replacement series.

5.2.7. Combined total phosphorus uptake

The combined total phosphorus uptake followed the pattern of dry matter and it was maximum in mustard + chickpea (1:3) followed by sole mustard, mustard + chickpea (4:4) and sole chickpea (Fig. 12). Likewise, it was the main contribution of mustard component due to higher biomass production and exhaustiveness. The contribution of chickpea in intercropping was quite lower

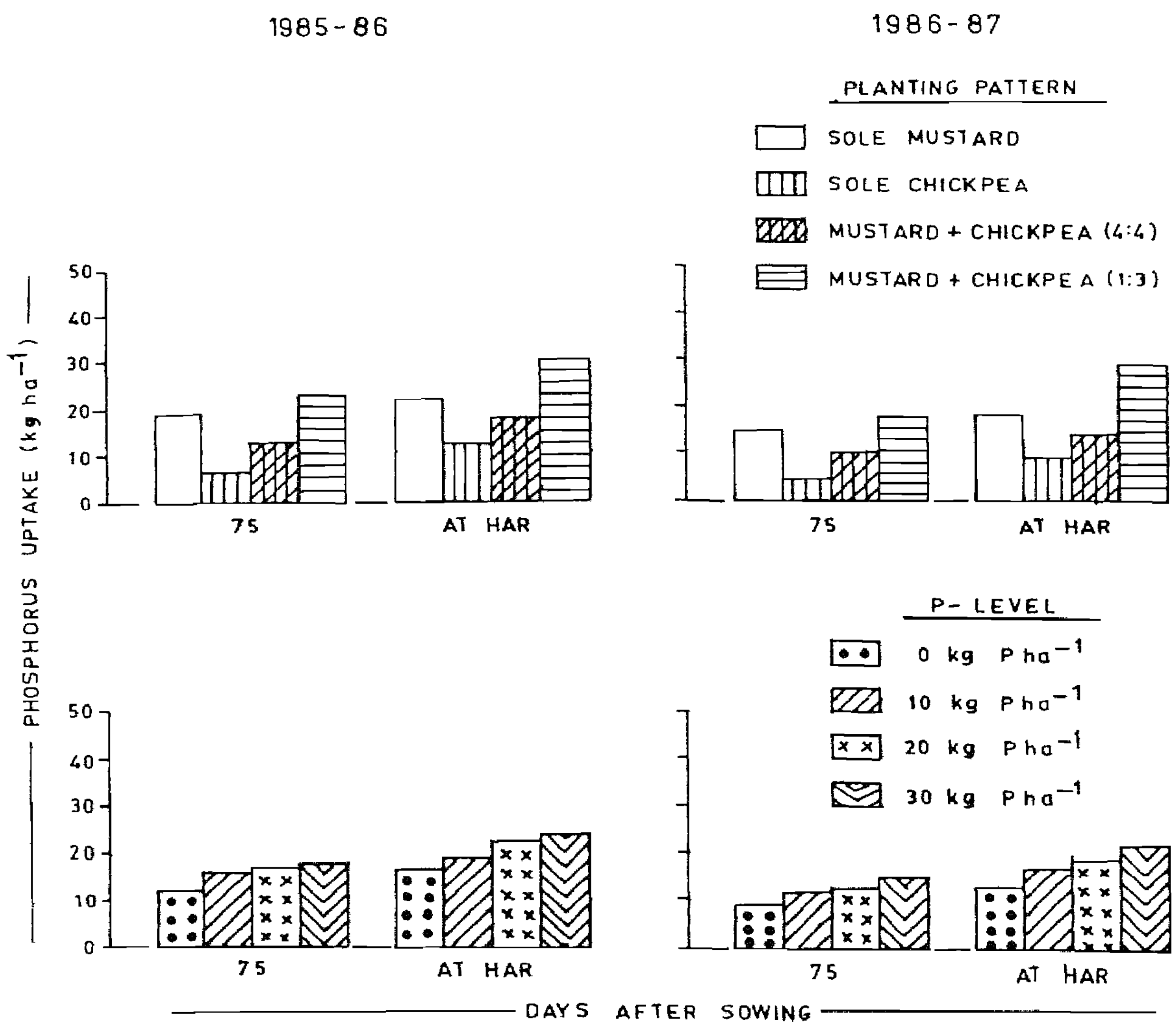

FIG.12. EFFECT OF PLANTING PATTERN AND PHOSPHORUS LEVELS ON THE COMBINED TOTAL PHOSPHOR'JS UPTAKE.

than sole chickpea and varied between 41% to 79% (Table 15a). This finding is in confirmity of Natarajan and Willey (1980) and Kumar Rao et al. (1983) and Meena (1985). The values were minimum in sole chickpea due to lower biomass production as compared to mustard.

5.2.8. Mustard equivalent yield and land equivalent ratio (LER)

The mustard equivalent yield was maximum in mustard + chickpea (1:3) pattern followed by sole mustard, mustard + chickpea (4:4) and sole chickpea (Fig. 13). This may be attributed to superiority of mustard in all yield contributing characters (Tables 9 to 11), LAI (Table 7), higher light interception (Table 22) and higher selling price of mustard. These findings are in confirmity of Meena (1985). There was marked difference in both the years, it was higher in 1985-86 due to good amount (102.6 mm) and better distribution of rainfall than 1986-87, where only 55.4 mm rainfall was received and crops suffered moisture stress at vegetative phase.

The LER values registered a progressive increase from sole crop and attained highest value (1.52 - 1985-86; 1.51 - 1986-87) in mustard + chickpea (1:3) system (Fig. 13). This may be due to the fact that mustard yield was comparable to sole crop in the 1:3 system and additional chickpea yield was also obtained. The lower yield values in 4:4 system were mainly due

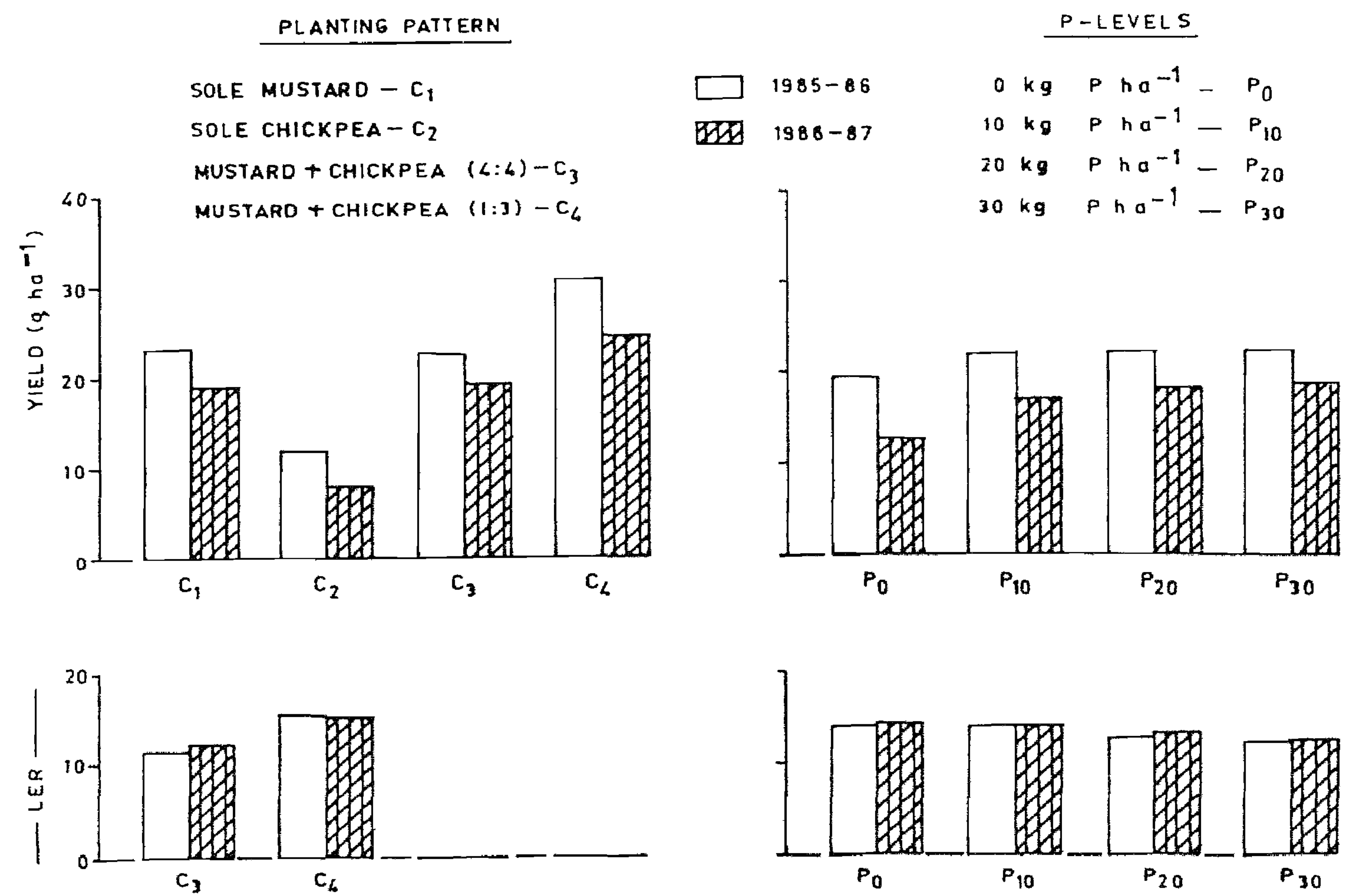

FIG.13 EFFECT OF PLANTING PATTERNS AND PHOSPHORUS LEVELS ON MUSTARD EQUIVALENT YIELD AND LAND EQUIVALENT RATIO (LER).

to reduction in the plant population to half in replacement series.

5.3. Effect of phosphorus

5.3.1. Biomass production

Successive application of phosphorus levels from 0 to 30 kg P ha^{-1} increased the biomass production in both the crops at both the stages (Table 8). It could be seen from the preceding chapter, that all the components responsible for higher biomass production were favourably influenced by the application of phosphorus. For instance, plant height (Table 3), number of main branches (Table 4), sub-branches (Table 5), leaves (Table 6) and LAI (Table 7). Further, the favourable effect of phosphorus on biomass production was due to effective utilization of soil nutrients through the extensive root system developed by crop plants under phosphorus application (Chatterjee, 1969). The experimental results were in confirmity with the findings of Osborne and Batten (1978) and Mudholkar and Ahlawat (1981).

5.3.2. Yield

The application of phosphorus significantly increased the seed yield of mustard and chickpea but the differences were clear only with lower doses of P (Table 12a). This may be attributed to favourable effect of phosphorus application on yield contributing characters i.e. siliquae or pods/plant (Table 9), number of seeds/siliqua (Table 10), 1000-seed weight

(Table 11) and higher leaf area (Table 7). Higher leaf area intercepted more light and produced higher yield in several crops have been reported by Donald (1963), Willey (1979) and Hughes et al. (1981).

Many workers have also reported improvement in yield attributing characters of chickpea i.e. pod number and 1000-seed weight with the increasing levels of phosphorus (Suryawanshi and Chaudhuri, 1979; Singh et al., 1980). With the application of phosphorus higher mustard seed yield was obtained by Joshi et al. (1973), Bhan and Singh (1976), Monoz (1979), Vir and Verma (1981) and Christensen et al. (1985). Similarly, favourable response of chickpea to phosphorus application was observed by Chowdhury et al. (1975), Suryawanshi and Dhaudhuri,(1979), Singh et al. (1984) and Borgohain and Agarwal (1986).

5.3.3. Quality

Seasonal variation in oil content in mustard were marked, it was lower in 1985-86 than 1986-87 when the yield was comparatively lower. The oil content in mustard marginally decreased with the increasing levels of phosphorus though, the differences were non-significant (Table 13). The reports on the effect of phosphorus on oil content are contradictory. But there was favourable effect of phosphorus application on protein content in chickpea (Table 14). This may be attributed to the extensive root system developed due to phosphorus application which resulted in higher uptake of nitrogen from soil and leaving lower values of available nitrogen in soil (Table 19a).

5.3.4. Radio-chemical assay

Marked favourable effect of phosphorus application on the total phosphorus uptake by mustard and chickpea was observed (Fig. 6). Maximum phosphorus uptake was recorded at 30 kg P ha^{-1} and minimum at control at both the stages and in both the crops. The possible explanation would be that higher the availability of phosphorus in soil solution with higher doses which increased the phosphorus content in plant (Racz et al., 1965; Mehrotra et al., 1972 and Strong and Berry, 1980) and dry matter production (Osborne and Batten, 1978 and Mudholkar and Ahlawat, 1981). The results were in confirmity with the findings of Virmani and Gulati, 1971; Strong and Berry (1980).

The fertilizer phosphorus uptake increased significantly with the application of phosphorus in both the crops (Table 16a). The favourable response to phosphorus application could be explained in the light of absorption of fertilizer phosphorus due to mass effect and as a consequence of which higher amounts of fertilizer phosphorus found its way in the soil solution around the root hairs of the plant as evidenced by other workers (Nye, 1968; Phillips et al., 1968; Venkatachalam et al., 1969; Hampaiah et al., 1982 and Mallikharjuna et al., 1984). The fertilizer phosphorus uptake values increased from 75 days to harvest in case of mustard but decreased or remained unchanged in case of chickpea. This may be due to the fact that, increase in the mineralization of native phosphorus due to root exudates of chickpea with the advancement of crop growth. Thus, there was increase in soil phosphorus uptake at later stage (Fig. 7).

On the contrary, the decreasing trend in the utilization of applied phosphorus with the increasing rates of phosphorus application was observed in both the crops (Table 17a). Since, the uptake of phosphorus by crop is limited, the higher doses of fertilizer applied were not accumulated in the plant in the same proportion as the lower doses. The other explanation would be that, at higher rate of phosphorus application, greater retention of applied phosphorus is possible which limits the availability of applied phosphorus to plants. Therefore, at higher level of phosphorus application, there will be less competition among the plants for the nutrient as compared to lower doses. Similar views were also expressed by Wild (1980), Sinha and Rai (1976) and Rai et al. (1984). The utilization of applied phosphorus increased from 75 days to harvest in mustard but invariably decreased in chickpea. The reason being increase in the mineralization of native phosphorus at later stage and increase in soil phosphorus uptake.

'A'-value increased as the level of phosphorus application increased from 10 to 30 kg P ha^{-1} (Table 9) because it depends on the rate of phosphorus application. On the contrary, 'A'-value was higher in 1986-87 than 1985-86 this may be due to lower biomass production (Fig.4), yield (Fig. 5) and phosphorus uptake (Fig. 6) resulting in more availability of phosphorus in soil. 'A'-value decreased from 75 days to harvest in mustard due to increase in biomass, yield and P uptake values while in chickpea reverse trend was observed, which may be attributed to increase in mineralization of native phosphorus resulting in more availability of soil phosphorus.

5.3.5. Available nutrient in soil

The available nitrogen content in soil decreased with the increasing levels of phosphorus. The maximum content was found at control and minimum at 30 kg P ha^{-1} (Table 19a). This may be attributed to development of extensive root system with the application of phosphorus which extracted more nitrogen from the soil. Chatterjee (1969) also found well developed plant root system which extracted higher nutrients as a result of phosphorus application. Dhillon and Vig (1985) also observed that application of phosphorus improved the efficiency of applied nitrogen. Available nitrogen content decreased with the advancement of stage due to continuation of uptake of nitrogen till grain formation. The values were higher in 1986-87 than 1985-86 due to poor biomass production (Fig. 4) and yield (Fig. 5).

The values of available phosphorus content in soil increased continuously with the increasing levels of phosphorus (Table 20a). This is due to the fact that the uptake of phosphorus by crops is limited, the higher doses of fertilizer applied are not accumulated in the plant in the same proportion as the lower doses thus, higher doses increased the available phosphorus content of soil. Similar findings were reported by Joshi et al. (1973). The values of available phosphorus content were lower in 1986-87 may be due to more retention of phosphorus in dry season.

The increasing levels of phosphorus declined the available potassium content in soil (Table 21). The maximum values were obtained at control and minimum at 30 kg P ha^{-1}. This may be attributed to development of extensive root system. With the application of phosphorus which extracted more potassium from soil and left lower amount of available potassium. This finding confirmed the results reported by Das (1985). The values were higher in 1986-87 than 1985-86 due to lower total biomass production (Fig. 11) and yield (Fig. 5).

5.3.6. Leaf area index (LAI) and light interception

The leaf area index of mustard crop increased with the increasing levels of phosphorus (Fig. 3). This may be attributed to the complex phenomenon of phosphorus utilization in plant metabolism. This element enters into the oxidative disintegration process of carbohydrates to yield hexose phosphate which is further transformed due to the development of meristematic tissues, cell division and leaf area development. The LAI increased from 75 days to 105 days because upto that stage vegetative growth continued. Interception of light by both the crops increased with the increasing levels of phosphorus (Table 22). This is simply due to increase in LAI and vegetative growth. The per cent light intercepted by crops was more in 1985-86 than 1986-87 due to higher plant height (Table 3) and LAI (Fig. 3).

5.3.7. Total dry matter production

The maximum total dry matter production was observed with the application of 30 kg P ha^{-1} and minimum with no application (Fig. 11). The increasing levels of phosphorus increased the values. This may be attributed to favourable effect of phosphorus application on growth parameters i.e. plant height (Table 3), number of main branches (Table 4), number of sub-branches (Table 5), number of leaves (Table 6) and LAI (Table 7). The main contribution in total dry matter production was of mustard which had favourable effect of phosphorus application on growth parameters. The values of total dry matter production were higher in 1985-86 than

1986-87 may be due to better soil moisture availability (Table 28).

5.3.8. Combined total phosphorus uptake

There was significant effect of application of phosphorus on combined total phosphorus uptake (Table 27a) and maximum values were obtained at 30 kg P ha^{-1}. This may be attributed to increase in biomass production and % phosphorus content. This view was shared by Mahajan *et al.* (1985). The major contribution in combined total phosphorus uptake was of mustard which responded favourably to phosphorus levels.

5.3.9. Mustard equivalent yield and land equivalent ratio (LER)

There was significant effect of application of phosphorus on mustard equivalent yield in both the years (Table 25a). Maximum equivalent yield was obtained at 30 kg P ha^{-1} (Fig. 13). The trend observed in mustard equivalent yield was same as mustard yield because of its pre-dominance in yield and selling price. On the contrary, LER values decreased with the increasing levels of phosphorus this may be attributed to the fact that the proportionate increase in sole crop yields was much higher which brought the ratio (LER) to lower side at higher levels of phosphorus.

5.4. Effect of planting patterns and phosphorus

5.4.1. Yield and mustard equivalent yield

The interaction effects of planting patterns and phosphorus levels on mustard seed yield and mustard equivalent yield was significant in 1985-86 (Tables 12b and 25b). The maximum response to applied phosphorus at the rate of 10 kg P ha^{-1} was noticed with 1:3 system. This response of applied phosphorus lies in the capacity to provide balanced nutritional environment within the rhizosphere and it was more prominent with the association of legume. Thus, the system proved to be an efficient and higher yielder. Similar results were obtained with nitrogen by Meena (1985).

5.4.2. Radio-chemical assay

The examination of data in Tables 15(b), 16(b), 16(c) and 16(d) revealed that by and large the phosphorus uptake (total as well as fertilizer) by mustard crop either grown as sole or in intercropping (1:3) system *per se* did not differ markedly with the use of higher levels of phosphorus beyond 20 kg P ha^{-1}. It clearly brought out the fact that phosphorus utilization pattern remained more or less unchanged for mustard crop at varying levels of phosphorus. Therefore, the mustard crop seems to be a suitable component crop for inter-cropping system with chickpea. The association of chickpea with mustard in 1:3 system not only utilized the native phosphorus but also applied phosphorus suggesting the use of phosphorus is a must for realization of higher yield in intercropping. The use of fertilizer for obtaining higher yields in intercropping system has been recently reported by Meena (1985) and Pareek (1987).

5.4.3. Available nutrient in soil

The available nitrogen in soil was influenced by different planting patterns as well as phosphorus doses applied (Tables 19b and 19c). The effect was more pronounced when chickpea raised as a sole crop. The higher available nitrogen in control plots was mainly due to the poor utilization of nutrient by chickpea because the lack of phosphorus restricted the root growth. Contrary to this, the nitrogen in phosphorus applied plots reduced due to better root proliferation thereby, making higher utilization of nitrogen. Here, the phosphorus application helped the plant not only for efficient nitrogen fixation but at the same time better utilization of the fixed nitrogen and this was finally reflected in the yield. Whereas in other systems the differences were less visible, this can be attributed to an equilibrium maintained in fixation and utilization of nitrogen.

The available phosphorus in soil was influenced by planting patterns as well as by phosphorus doses applied (Table 20b). When phosphorus was not applied then irrespective of systems the values remained unchanged but an application of phosphorus upto 20 kg P ha^{-1} increased the phosphorus content in soil. The increase was more prominent with sole cropping as compared to 1:3 pattern or with this system only marginal increase in available phosphorus in soil was noticed. This finding clearly showed that when these crops are grown in intercropping particularly in 1:3 system removed more phosphorus from soil. Thereby suggesting the use of phosphorus fertilizer for both the component crops. At 30 kg P ha^{-1}, the rate of accumulation was higher than its utilization hence, an accumulative effect was noted.

The data generated on mustard and chickpea and discussion thereon is the suggestive of one remarkable finding for rainfed agriculture. The sole cropping of mustard has to go and a new concept developed on inter-cropping particularly 1:3 system where the mustard yield by no way is found to reduce over sole cropping but the additional chickpea yield is obtained. Thereby making the system more viable. The yield advantage further geared up by use of phosphorus on area basis meeting the requirement of both the component crops.

...

6. SUMMARY AND CONCLUSION

SUMMARY

A field experiment entitled "Tracer studies on phosphorus use efficiency in mustard - chickpea planting patterns under rainfed conditions" was conducted on the farm of the Division of Agronomy, Indian Agricultural Research Institute, New Delhi, during *rabi* seasons of 1985-86 and 1986-87. The treatments consisted of four planting patterns (sole mustard, sole chickpea, mustard + chickpea (4:4) and mustard + chickpea (1:3) and four phosphorus levels (0, 10, 20 and 30 kg P ha^{-1}). The 16 treatment combinations were tested in a Randomised Block Design with 3 replications. The salient findings obtained during the course of this investigation are summarised below:

6.1. Crop season

The weather parameters particularly rainfall influenced the treatments effect significantly on the productivity of crops as there was large variation in the amount and distribution in the two crop seasons. In the crop season of 1985-86, the rains before sowing (77.4 mm) were sufficient for proper germination and seedling establishment, whereas the amount of rainfall was 102.6 mm in the crop season which coincided with vegetative, flowering and siliqua/pod development stages. In 1986-87, the rainfall amount was just sufficient (45.4 mm) for sowing and crop suffered moisture stress at initial growth period resulting in poor seedling establishment and vegetative growth but later showers (53.2 mm) at flowering and siliqua/pod development stages compensated the loss occured at initial growth period.

6.2. Biomass production

The planting patterns significantly influenced the dry matter production of both the crops in both the years. The biomass production of mustard was maximum when it was sown in 1:3 system followed by sole mustard and least in 4:4 system. Mustard showed its superiority in all growth parameters i.e. plant height, number of main branches, sub-branches, leaves and LAI in the 1:3 system. Contrary to mustard, chickpea biomass was adversely affected in 1:3 system as compared to sole chickpea.

The application of phosphorus proved highly beneficial in increasing the biomass production of both the crops at all stages. Further, all the components responsible for higher biomass production were favourably influenced by the application of phosphorus.

6.3. Yield and quality

The yield of both the crops in both the years was significantly influenced by planting patterns and phosphorus levels. The mustard yield was significantly higher in 1:3 system and sole mustard over 4:4 system in both the years. Mustard grown in 1:3 system showed its superiority in all yield attributing characters i.e. number of siliquae/plant, seeds/siliqua and 1000-seed weight. The chickpea yield was significantly higher in sole chickpea over 1:3 and 4:4 systems in both the years.

In the crop season of 1985-86, the varied levels of phosphorus application significantly increased the mustard yield over control while in 1986-87 only higher levels of phosphorus application were found superior over control. Similar, beneficial effects were also noticed with chickpea. There was favourable effect of phosphorus doses on yield contributing characters of both the crops.

The oil content in mustard was higher in 1986-87 than 1985-86. The different planting patterns and use of phosphorus fertilizer did not bring remarkable change in oil content in mustard. Though, planting patterns did not effect the protein content in chickpea but phosphorus application increased the protein content.

6.4. <u>Radio-chemical assay</u>

The total phosphorus uptake in mustard was significantly higher in sole mustard and 1:3 system over 4:4 system. However, maximum phosphorus uptake was found in 1:3 system. The total phosphorus uptake in chickpea was significantly higher in sole chickpea and 1:3 system over 4:4 system. However, sole chickpea had edge over 1:3 system. The application of 20 and 30 kg

P ha^{-1}, significantly increased the total phosphorus uptake in mustard over control at both the stages in 1985-86 and only at harvest in 1986-87. In case of chickpea, the maximum phosphorus uptake was recorded at 30 kg P ha^{-1} and minimum at control.

There was significant effect of planting patterns on fertilizer phosphorus uptake. The maximum fertilizer phosphorus uptake in mustard was observed in 1:3 system and least in 4:4 system. The fertilizer phosphorus uptake in chickpea was significantly higher in sole chickpea over 4:4 and 1:3 systems. There was increase in the fertilizer phosphorus uptake in both the crops with the application of 20 and 30 kg P ha^{-1} over 10 kg P ha^{-1}.

The per cent utilization of applied phosphorus by mustard was maximum in 1:3 pattern followed by sole mustard and 4:4 pattern. The utilization of applied phosphorus by chickpea was significantly higher in sole chickpea over 4:4 and 1:3 systems in both the years. The increasing levels of phosphorus application decreased the utilization of applied phosphorus in both the crops.

The 'A'-value in mustard was maximum in 4:4 system at all the stages in both the years followed by sole mustard and 1:3 system. Contrary to mustard, 'A'-value was maximum in 1:3 system in chickpea. The higher levels of phosphorus i.e. 20 and 30 kg P ha^{-1} increased the 'A'-value over 10 kg P ha^{-1}, in both the crops.

6.5. Available nutrient in soil

The available nitrogen was significantly higher in sole chickpea and 1:3 system than sole mustard and 4:4 system. In general, there was decline in available nitrogen with the increase in the levels of phosphorus. Though, there was no significant effect of planting patterns on available phosphorus but maximum amount was observed in case of sole chickpea followed by 1:3 system, 4:4 system and sole mustard. The increasing levels of phosphorus increased the available phosphorus at both the stages. The maximum amount of available potassium was found in sole chickpea and minimum in 1:3 system. There was decrease in the available potassium with the increase in the levels of phosphorus.

6.6. Leaf area index (LAI) and light interception

The maximum LAI of mustard was recorded in 1:3 system followed by sole mustard and 4:4 system. The application of phosphorus increased the LAI of mustard. Likewise, maximum light interception by mustard was observed in 1:3 system at 75 days and 105 days in both the years, while sole chickpea had precedence over other patterns in both the years. There was a marked effect of phosphorus application on light interception. The maximum values were observed with the application of 30 kg P ha^{-1} and minimum with control.

6.7. Total dry matter and combined total phosphorus uptake

The total dry matter production was significantly higher in 1:3 system than sole mustard, 4:4 system and sole chickpea. However, sole mustard was also significantly superior over 4:4 system and sole chickpea. The maximum total dry matter production was observed with the application of 30 kg P ha^{-1} and minimum with no application. The combined total phosphorus uptake was significantly higher in 1:3 system than sole mustard, sole chickpea and 4:4 system. The maximum uptake values were obtained at 30 kg P ha^{-1} at 75 days after sowing and at harvest in both the years.

6.8. Mustard equivalent yield and land equivalent ratio (LER)

The mustard equivalent yield was maximum in 1:3 pattern followed by sole mustard, 4:4 pattern and sole chickpea. The maximum equivalent yield was obtained with the application of 30 kg P ha^{-1}. The LER values were maximum in 1:3 system and decreased with the increasing levels of phosphorus.

6.9. Response and economics

The response of mustard and chickpea crops to phosphorus fertilization was quadratic. With the application of 1 kg P ha^{-1}, there was increase in mustard seed yield in the order of 14.28 and 14.93 kg in 1985-86 and 1986-87, respectively. Similarly, the use of 1 kg P ha^{-1} gave additional chickpea seed yield of 11.77 and 12.98 kg in 1985-86 and 1986-87, respectively.

CONCLUSION

On the basis of experimental findings, it can be concluded that mustard and chickpea were compatible components of intercropping system. The mustard + chickpea (1:3) system i.e. additive series was markedly superior to sole mustard and mustard + chickpea (4:4) system i.e. replacement series in terms of utilization of growth resources and yield advantages. The mustard showed its superiority in total phosphorus uptake, fertilizer phosphorus uptake, per cent utilization of applied phosphorus in 1:3 system over sole mustard and 4:4 system. Contrary to mustard, chickpea performed better in sole cropping than any intercropping patterns.

Phosphorus application proved beneficial in maximising yields. The positive relationship was observed between the phosphorus levels and various growth parameters and yield attributing characters. Application of phosphorus increased the total phosphorus uptake, fertilizer phosphorus uptake and 'A'-value while a reverse trend was observed for the utilization of applied phosphorus.

Thus, on the basis of two year experimentation, it can be said that growing mustard and chickpea in 1:3 system with the application of phosphorus is a remunerative approach in maximising the crop productivity and utilization of native as well as applied phosphorus.

...

BIBLIOGRAPHY

Ahlawat, I.P.S., Saraf, C.S. and Singh, A. (1985). Effect of cultivars bunding, seed rate and phosphate fertilization on chickpea. Indian J. Agron. 30(3):373-376.

Ahlgren, H.L. and Aamodt, O.S. (1939). Harmful root interactions as a possible explanation for effects noted between various species of grasses and legumes. J. Am. Soc. Agron. 31:982-985.

AICRP (1983-84). All India Co-ordinated Research Project for oilseeds - Annual Progress Report. Directorate of Oilseeds Research. pp. 273-279.

Amarchand (1975). Intercropping studies in pigeonpea as influenced by levels of phosphorus. M.Sc. Thesis, IARI, New Delhi.

Andrews, D.J. and Kassam, A.H. (1975). Importance of multiple cropping in increased world food supplies. Proc. Am. Soc. Agron. 24:29.

A.O.A.C. (1960). Official methods of analysis of the Association of Official Agricultural Chemists, Washington D.C. 9th Ed. pp. 15-16.

Anonymous (1970). The annual report. Indian Agricultural Research Institute, New Delhi.

Archar, J.K. and Vaidyanathan, L.V. (1982). Fertilizer for winter oilseed rape. Journal of Sciences of Food and Agric. 33(12):1262-1263.

Arvadia, M.K. and Patel, Z.G. (1985). Response of grain to dates of sowing under different fertility levels. GAU Res. J. 11(1):57-58.

Aulakh, M.S. and Pasricha, N.S. (1979). Response of gram (Cicer arietinum L.) and lentil (Lens culinaris L.) to phosphorus as influenced by applied sulphur and its residual effect on moong (Phaseolus aureus L.). Bull. Indian Soc. Soil Sci. 12:433-438.

*Baker, F.F.I. and Norman, D.W. (1975). Cropping system in Southern Nigeria. Proc. Cropping System Workshop. IRRI, Los Banos (Philippines).

*Baker, F.F.I. and Yusuf, Y. (1976). Research in mixed cropping at Samaru, Nigeria. Symp. Intercropping Semi-Arid Areas, Morogoro, Tanzania.

Bhan, S. and Singh, A.(1974). Studies on the optimum dose of fertilizer for rai in Agra tract of Uttar Pradesh. Indian J. Agric. Res. 8(1):69-70.

Bhan, S. and Singh, A. (1976). Note on the response of mustard (Brassica juncea L. Czern & Coss) to NPK fertilizers in central tract of Uttar Pradesh. Indian J. Agric. Res. 10(3):207-208.

Bhan, S. (1977). Agronomical requirements for rapeseed-mustard - A review of research in India. Oilseeds J. 6(1 & 2):29-35.

Bhat, K.K.S. and Nye, P.J. (1973). Diffusion of phosphate in plant roots in soil. Quantitative autoradiography of the defection zone. Plant and Soil. 38:161-175.

Bole, J.B. (1973). Influence of root hairs in supplying soil phosphorus in supply soil phosphorus to rape and wheat. Can. J. Soil Sci. 53:169-175.

Borgohain, M. and Agrawal, S.K. (1986). Influence of rates and sources of phosphorus and irrigation levels on yield and yield attributes of Kabuli gram (Cicer arietinum L.). Indian J. Agron. 31(3):229-234.

Bouyoucos, G.J. (1962). Hydrometer method for making particle size analysis of soil. Agron. J. 55:464-465.

Brady, N.C. (1983). The nature and properties of soils. Macmillan Publishing Company, New York and Collier Macmillan Publishers, London. pp. 750.

Chandra, J., Tomar, N.K., Chahal, R.S. and Kala, R. (1983). Response of gram to N, P, K application. J. Res. (HAU). 13:385-388.

Chaniara, N.J. and Damor, U.M. (1982). Effect of irrigation intervals and various levels of nitrogen and phosphorus on the yield of mustard variety, Varuna. Indian J. Agron. 27(4):472-474.

Chatterjee, S.C. (1969). The availability and uptake of phosphorus by rice and barley from phosphatic fertilizers in the soil of Sindri. Technology 6(1): 24-30.

Chowdhury, M.S. and Misangu, R.N. (1981). Sorghum/chickpea intercropping; trials at Morogoro, Tanzania (in) Proc. International Workshop on Intercropping, ICRISAT, Hyderabad. pp. 217-221.

Chowdhury, S.L., Sewa Ram and Giri, G. (1975). Effect of P, N and inoculum on root, nodulation and yield of gram. Indian J. Agron. 20(3):290-291.

Christensen, J.V., Legge, W.G., De Pauw, R.M., Henning, A.M.F., McKenzie, J.S., Siemens, B. and Thomas (1985). Effect of seeding date, nitrogen and phosphate fertilizer on growth, yield and quality of mustard in northwest Alberta. Can. J. Plant Sci. 65:275-284.

Cochran, W.G. and Cox, G.M. (1967). Experimental Designs. IInd Ed. John Willey and Sons, Inc., New York.

Dalal, R.C. (1974). Effects of intercropping of maize with pigeonpea on grain yield and nutrient uptake. Expl. Agric. 10:219-224.

Das, D. (1985). Water and weed management studies in tall chickpea in relation to different levels of phosphorus. Ph.D. Thesis, Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Dhillon, N.S. and Vig, A.C. (1985). Response of raya to applied N with and without P fertilization. J. Res. P.A.U. 22(3):589-591.

Dhingra, K.K. and Kolar, J.S. (1979). Cultivation of gram and lentil in Punjab. Prog. Fmg. 16(2):13-14.

Dixit, J.P., Pandey, R.P. and Namdeo, K.N. (1983). Influence of phosphate fertilizers on Bengal gram (Cicer arietinum L.). Madras Agril. J. 70:478-479.

Dobariya, D.K., Patel, J.C. and Malavia, D.D. (1985). Response of gram to irrigation scheduling based on IW/CPE ratio under varying levels of nitrogen and phosphorus. Indian J. Agron. 30(4):518-519.

Donald, C.M. (1946). Competition between pasture species with reference to the hypothesis of harmful root interactions. J. Coun. Scient. Indust. Res. 19:32-37.

Donald, C.M. (1961). Competition for light in crops and pastures; mechanism for biological competition. Proc. Symp. Soc. Expt. Bio. 282-13.

Donald, C.M. (1963). Competition among crop and pasture plants. Adv. Agron. 15:11-18.

Dravid, M.S., Goswami, N.N. and Kamath, M.B. (1985). Zinc and phosphate nutrition to some grain legumes in relation to their tolerance under varied soil conditions. J. Nuclear Agric. Biol. 14(2):52-56.

Faraha, S.M. (1981). An experimentation of the effect of water stress on leaf growth of crops of field beans (Vicia faba L.). 2. Mineral content. J. agric. Sci., Camb. 96:337-346.

*Fisher, N.M. (1976). A limited objective approach to the design of agronomic experiments with mixed crops. Symp. Intercropping in Semi-Arid areas, Morogoro, Tanzania.

Freyman, S. and Venkateswarlu (1977). Intercropping on rainfed red soils of the Daccan. Platue of India. Can. J. Pl. Sci. 57:697-705.

Fried, M. and Dean, L.A. (1952). A concept concerning the measurement of available soil nutrient. Soil Sci. 73:263-271.

Gangasaran and De, R. (1979). Influence of seeding dates, varieties and rates and method of nitrogen application on the seed yield and quality of rapeseed grown on rainfed land. Indian J. agric. Sci. 49:197-201.

Gangasaran and Giri, G. (1985). Intercropping of mustard with chickpea, lentil and barley in drylands. Indian J. Agron. 30(2):244-250.

Giri, G. and De, R. (1977). Canopy management under rainfed conditions. Indian Fmg. 27:21-22.

Graham, P.H. and Rosac, J.C. (1979). Phosphorus fertilization and symbiotic nitrogen fixation in common bean. Agron. J. 71(6):925-926.

Gupta, B.K., Pathak, B.K., Bhan, S. and Singh, A. (1972). Effect of NPK on yield, nutrient uptake and quality of toria (Brassica campestris var. toria T-9). Indian J. Agron. 17(2):88-91.

Gupta, U.S. (1982). Physiological aspects of dryland farming. Oxford & IBH Publishing Co., New Delhi. pp. 156-157.

Hampaiah, R., Sinha, M.N. and Rai, R.K. (1982). Tracer studies on utilization of phosphorus by crop plant in cereal-cereal and legume-cereal rotations. J. Nuclear Agric. Biol. 11(3):76-79.

Harper, J.L. (1961). Approaches to the study of plant competition; mechanism in biological competition. Proc. Symp. Soc. Int. Bio. 37:39.

Hughes, G., Keating, J.D.H. and Scott, S.P. (1980). Pigeonpea as a dry season crop in Trinidad (West Indies). II. Interception and utilization of solar radiation. Tropical Agric. 57:151-152.

Hughes, G., Keating, J.D.H. and Scott, S.P. (1981). Pigeonpea as a dry season crop in Trinidas (West Indies). II. Interception and utilization of solar radiation. Tropical Agric. 58:191-199.

Ibrahim, N.E. and Kahesh, M.O. (1971). Effect of associated growth on the yield and nutrition of legume and grass plants, wheat and horse beans mixed for grain production. UAR J. Soil Sci. 11:271-283.

Itnal, C.J., Archar, M.S., Desai, G.S. and Saljan, G.C. (1980). Intercropping of Bengal-gram and safflower pays rich dividents. Currents Research, Bangalore 9(8):132-133.

Jackson, M.L. (1967). Soil Chemical Analysis. Prentice Hall of India Pub. Pvt. Ltd., New Delhi.

Jackson, M.L. (1973). Soil chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Jain, B.P. (1978). Effect of irrigation and P with and without pest control on growth and yield of gram (Cicer arietinum L.). M.Sc. Thesis, Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Jana, P.K. (1963). The effects of spacing and fertilization on the growth, yield and quality of raya (B. juncea). M.Sc. Thesis, IARI, New Delhi.

Joshi, D.C., Seth, S.P. and Pareek, B.L. (1973). Studies on sulphur and phosphorus uptake by mustard. J. Indian Soc. Soil Sci. 21(2):167-172.

Kassam, A.H. and Stockinger, K.R. (1971). Growth and nitrogen uptake of sorghum and millet in mixed cropping. Samaru Agricultural Newsletter 15:28-32.

Kassam, A.H. (1973). In search for greater yields with mixed cropping in Northern Nigeria. Annual report, Institute for Agriculture Research, Samaru, Nigeria.

Kalsi, H.S., Kapur, M.L., Sodhi, J.S. and Rana, D.S. (1982). Response of gram and mash to nitrogen and phosphorus application under rainfed conditions. Indian J. Agron. 27(2):173-174.

Keating, J.D.H., Hughes, G. and Scott, S.P. (1980). Productivity of short duration pigeonpea varieties under semi-arid conditions in West Indies. Tropical Grain Legumes Bull. 20:20-22.

Khare, N.K. and Rai, M.M. (1968). Effect of phosphorus on symbiotic fixation of nitrogen by leguminous crops. J. Indian Soc. Soil Sci. 16:111-114.

Kushwaha, B. (1983). Studies on population variations in a mustard (Brassica juncea L. Czern & Coss) and chickpea (Cicer arietinum L.) intercropping system grown under rainfed conditions. Ph.D. Thesis, Division of Agronomy, IARI, New Delhi.

Khushwaha, S.S., Sharma, R.A. and Patidar, M.D. (1985). Influence of time of irrigation and phosphorus levels on yield of chickpeas grown on a vertisol. International chickpea Newsletter No. 13:8-9.

Kumar, A. and Singh, R.P. (1987). Production potential and economic systems of gram and mustard intercropping systems under rainfed conditions. Symposium on Alternate Farming Systems". Feb. 21-23, IARI, New Delhi.

Kumar Rao, J.V.D.K., Dart, P.J. and Sastry, V.S.S. (1983). Residual effect of pigeonpea (Cajanus cajan) on yield and nitrogen response of maize. Expl. Agric. 19:131-141.

Kundu, A.L. and Chatterjee, B.N. (1982). Growth analysis of turmeric as a sole crop and in mixture with other crops. Indian J. agric. Sci. 52(9):584-589.

*Lakhani, D.A. (1976). A crop physiological study of mixtures of sunflower and fodder raddish. Ph.D. Thesis, Reading University, England:171.

*Lin, S.H., Han, X.L., Zhao, M.Z. and Kong, Y.Z. (1981). Studies on solar energy utilization, crop competition and yield analysis in double-cropped wheat-fields on the North China plain. Acta Agronomic Sinica 7(1):63-72.

*Litsinger, J.A. and Moody, K. (1975). Integrated plant management in multiple cropping systems. Proc. Am. Soc. Agron.

MacKenzie, A.J. and Dean, L.A. (1950). Measurement of ^{32}P in plant material by the use of briquets. Analyt. Chem. 22:489-490.

Mahajan, J.P. and Bisen, D.C. (1980). Uptake and utilization of soil and fertilizer phosphorus by wheat in medium black soils. J. Nuclear Agric. Biol. Vol. 9:144-146.

Mahajan, J.P., Bisen, D.C. and Rathore, G.S. (1985). Studies on uptake and utilization of soil and fertilizer phosphorus by gram (Cicer arietinum) as influenced by P levels and fertility status of soil in a vertisol. J. Nuclear Agric. Biol. 14(2):57-58.

Mahajan, J.P., Bisen, D.C. and Sinha, S.B. (1982). Studies on uptake and utilization and fertilizer phosphorus by soybean as influenced by P levels and fertility status of soil in vertisol. J. Nuclear Agric. Biol. 11:113-114.

Mahapatra, I.C., Bapat, S.R., Sardana, M.G. and Bhendia, M.L. (1973). Fertilizer response of wheat, gram and horsegram under rainfed conditions. Fertil. News 18(4):57-63.

Mallikharjuna Rao, P., Sreenivasa Raju, A. and Vithal Rao, T.M. (1984). Relative efficiency of utilization of soil and fertilizer phosphorus by crops in red (chalka) soil. J. Nuclear Agric. Biol. 13(1):18-21.

Mandal, B.K., Ray, P.K. and Dasgupta, S. (1986). Water use by wheat, chickpea and mustard grown as sole crops and intercrops. Indian J. agric. Sci. 56(3): 187-193.

Martin, M.P.L.D. and Snaydon, R.W. (1982). Intercropping barley and beans. 1. Effect of planting pattern. Expl. Agric. 18:139-148.

Meena, S.L. (1983). Studies on production potential of pigeonpea, groundnut, dew gram and green gram intercropping systems under rainfed conditions. M.Sc. Thesis, Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Meena, S.L. (1985). Studies on nitrogen management in mustard-chickpea intercropping systems under rainfed conditions. Ph.D. Thesis, IARI, New Delhi.

Mehrotra, D.N., Sinha, N.S., Srivastava, R.D.L. and Rajendrakumar (1972). Effect of fertilizers on uptake of nutrients, yield and oil content of Indian mustard (Brassica juncea). Indian Agriculturist. 16(1):49-53.

Mehrotra, O.N., Saxena, H.K., Lal, K.B., Singh, Rajendra and Yadav, S.S. (1981). Varietal differences in photosynthesis and productivity of chickpeas. Indian J. agric. Sci. 51:306-312.

Metson, A.J. (1956). Methods of chemical analysis for soil survey samples. Bull. N.Z. Dep. Scient. Md. Res. Soil Bur. 12.

Mohta, N.K. and De, R. (1980). Intercropping maize and sorghum with soybean. J. agric. Sci., Camb. 95: 117-122.

Mondal, M.R.I. and Gaffer, M.A. (1983). Effect of different levels of nitrogen and phosphorus on the yield and yield contributing characters of mustard. Bangladesh J. Agric. Res. 8(1):37-43.

*Monoz, F.I. (1979). Response of two species of rape to different levels of nitrogenous and phosphorus fertilizer in different planting dates. Proc. of 5th International Rapeseed Conference Malmo Sweden (1979):257-259.

Mudholkar, N.J. and Ahlawat, I.P.S. (1979). Response of Indian rape genotypes to date of seeding, plant density and nitrogen application. Indian J. Agron. 24:361-364.

Mudholkar, N.J. and Ahlawat, I.P.S. (1981). Response of rapeseed to plant density and fertilization. Indian J. Agron. 26(2):184-188.

Nagre, K.T. (1979). Studies on the effect of inter-cropping on growth, yield and economics of rainfed American cotton. Indian J. Agron. 24:390-394.

Natarajan, M. and Willey, R.W. (1980). Sorghum-pigeonpea intercropping and the effects of plant population density. 2. Resource use. J. agric. Sci., Camb. 95:59-65.

Nelliet, V., Bavappa, K.V. and Nair, P.K.R. (1974). Multiple cropping. A new dis. in multiple cropping for coconut plantation. World Crops. 262-266.

Nikam, S.M., Tendulkar, A.V., Deokar, A.B. (1987). Production potential of safflower-chickpea inter-cropping under rainfed conditions. Indian J. agric. Sci. 57(3):151-156.

Nye, P.H. (1968). Processes in the root environment. J. Soil Sci. 19(2):205-215.

Olsen, S.R., Cole, C.V., Watanabe, C.S. and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939.

Osborne, G.J. and Batten, G.D. (1978). Yield, oil and protein content of oilseed rape as affected by soil and fertilizer nitrogen and phosphorus. Aust. J. Exp. Agric. Anim. Husb. 18(90):107-111.

Pareek, S.K. (1987). Studies on population and fertilizer management in pigeonpea-groundnut intercropping systems under rainfed conditions. Ph.D. Thesis, IARI, New Delhi.

Patel, K.A., Parmar, M.T. and Patel, J.C. (1980). Response of mustard to different spacings and levels of nitrogen and phosphorus. Indian J. Agron. 25(3): 524-525.

Pathak, G.N., Verma, G. and Singh, D.N. (1963). Response of yellow sarson and rai to different doses of nitrogen and phosphatic fertilizers. Indian Oilseed J. 7(1):10-19.

Phillips, R.E., Place, G.A. and Brown, D.A. (1968). Self-diffusion of phosphorus in clay soil. 1. The effect of phosphorus rate. Soil Sci. Soc. Am. Proc. 32(1):41-48.

Pillai, G.K., Nanjappa, M.V., Suseladevi, L. and Jayaramu, C.V. (1984). Increasing the production of rapeseed-mustard. Indian Fmg. 34(9):3-5.

Piper, G.S. (1950). Soil and Plant Analysis. Academic Press, New York.

Pothiraj, P. (1985). Introduction of cereals and oilseeds with chickpea. Madras Agric. J. 72(12):715-716.

Prasad, J. and Sanoria, C.L. (1981). Response of Bengal gram to seed bacterisation and phosphorus. Seeds and Farms. 7(4):31-32.

Prasad, J. and Sanoria, C.L. (1984). Associative effect of Rhizobium and Azotobacter at different levels of phosphorus on yields and nutrients content of Bengal gram (Cicer arietinum L.). Legume Research 7(1): 13-16.

Prasad, R. and De, R. (1981). Agronomic research in the service of India's changing agriculture. Indian Fmg. 30(7):85-94.

Racz, C.J., Webber, M.D., Soper, R.J. and Heddin, R.A. (1965). Phosphorus and nitrogen utilization by rape, flox and wheat. Agron. J. 57:335-337.

Rai, R.K., Mahatim Singh and Sinha, M.N. (1984). Phosphorus use efficiency and maize-wheat sequence. Indian J. Agron. 29(3):267-273.

Raikhelkar, S.V., Chaudhri, S.J. and Bagade, D.N. (1977). Irrigation and fertilizer requirement of gram (Cicer arietinum). J. Maharashtra Agril. Univ. 2(2):144-147.

Raju, M.S., Varma, S.C. (1984). Response of Bengal gram (Cicer arietinum L.) varieties to phosphate fertilization in relation to F.Y.M. application and Rhizobial inoculation. Legume Research. 7(1): 23-26.

Rana, D.S., Kalsi, H.S., Kapur, M.L. and Bhandari, A.L. (1984). Response of groundnut (Arachis hypogaea L.) and raya (Brassica juncea L.) to fertilizer application. Indian J. Agron. 29(1):122-124.

Rao, M.R. and Shetty, S.V.R. (1977). Some biological aspects of intercropping system on crop weed balance. Weed Sci. Workshop, A.P.A.U., Hyderabad (India).

Rastogi, A.K., Mahajan, J.P. and Sinha, S.B. (1981). Phosphorus utilization by three rice varieties at different stages of growth in a vertisol. J. Nuclear Agric. Biol. 10:48-50.

Rathi, S.S. and Singh, D. (1976). Effect of nitrogen and phosphate fertilization on the growth and yield of gram. Indian J. Agron. 21(3):305-306.

Raut, R.S. and Ghonsikar, C.P. (1979). Phosphorus utilization by Bengal gram in presence of ^{32}P as tracer. Res. Bull. Marathwada Agric. Univ. 3(8):103-104.

Reddy, M.S. and Willey, R.W. (1981). A study of pearl-millet groundnut intercropping with particular emphasis on the efficiencies of leaf canopy and rooting pattern. In. International Workshop on Intercropping. ICRISAT, Hyderabad. pp. 202-209.

*Rice, E.L. (1974). Allelopathy. Academic Press, New York, USA.

Risser, P.G. (1969). Competitive relationship among herbaceous grassland plants. Biol. Rev. 35:351.

Roy, R.K. and Tripathi, R.S. (1985). Effect of irrigation and phosphorus on yield, nodulation, water use efficiency and nutrient concentration in chickpea. Indian J. Agron. 30(4):401-406.

Russel, J.S. (1970). Soil factor affecting the growth of legumes on low fertility soils in tropics and sub-tropics. In. Mineral Nutrition of Legumes in Tropical and Sub-tropical soils. CSIRO, Melbourne, Australia, pp. 75-92.

Russel, J.S. (1978). Soil factor affecting the growth of legumes on low fertility soils in tropics and sub-tropics. In. Mineral nutrition of legumes in tropical and sub-tropical soils. CSIRO, Melbourne, Australia, pp. 75-92.

Saraf, C.S. (1983). Advances in fertilizer management for rainfed pulses. Fertil. News 28(9):91-98.

Saxena, M.C. and Yadav, D.S. (1975). Some agronomic considerations of pigeonpea and chickpea. In. International Workshop on grain legumes held at ICRISAT, Hyderabad, Jan. 13-16, 1975. pp. 31-61.

Saxena, N.P. and Sheldrake, A.R. (1977). Pulses physiology. Annual Rep. 1976-77. Part II. Chickpea Physiology, ICRISAT, Hyderabad, pp. 179.

Saxena, N.P. and Sheldrake, A.R. (1980). Physiology of growth, development and yield of chickpea in India. In Proc. International Workshop on chickpea Improvement. ICRISAT, Hyderabad, India. pp. 106-120.

Shaktawat, M.S. and Sharma, R.K. (1985). Response of chickpea varieties to seed rate and phosphorus. Indian J. Agron. 30(3):389-390.

Sharma, B.M. and Yadav, J.S.P. (1976). Availability of phosphorus to gram as influenced by phosphate fertilization and irrigation regime. Indian J. agric. Sci. 46(5):205-210.

Sharma, P.P., Singh, P. and Singh, P.P. (1975). Response of nitrogen and phosphorus in relation to method of application on the yield of gram (Cicer arietinum). J.N.K.V.V. Res. J. 9(1/2):21-23.

Shaw, R.W. and Laing, D.R. (1965). Moisture stress and plant response. In. American Society of Agronomy. Plant Environment & Efficient Water Use. American Soc. Agronomy, Madison, Wisconsin, U.S.A.

Sheldrake, A.R. and Saxena, N.P. (1979). The growth and development of chickpea under progressive moisture stress. In. Stress Physiology in important crop plants by H. Mussel and Staples, R.C. J. Wiley, New York, 1979. pp. 463-483.

Sheppard, S.C. and Bates, T.E. (1980). Yield and chemical composition of rape in response to nitrogen, phosphorus and potassium. Can. J. Soil Sci. 60: 150-162.

Singh, A., Ahlawat, I.P.S. and Saraf, C.S. (1984). Response of chickpea (Cicer arietinum L.) cultivars to seeding rates and phosphate levels. Indian J. Agron. 29:331-334.

Singh, B.P. (1981). Compatible intercropping of toria-sarson in gram and its effect on seed yield, total productivity and returns. Pulse Crops Newsl. 1:3-35.

Singh, D.V., Chauhan, R.P.S., Singh, K. and Pal, B. (1978). Nitrogen and phosphorus needs of gram (Cicer arietinum L.) along with bacterial fertilization. Madras agric. J. 65:22-24.

Singh, G. and Bajpai, M.R. (1982). Response of Bengal gram to direction of planting and companion cropping. Transaction of Indian Society of Desert Technology and University, Centre of Desert Studies 7:1-3.

Singh, K., Rao, K.L., Jamwal, J.S. and Bohra, J.S. (1983). Effect of phosphorus and bio-fertilizers on growth, yield and quality of chickpea. Trans. of Indian Soc. of Desert Technology and Univ. Centre of Desert Studies 8(1):33-83.

Singh, R.G. (1971). Response of gram (Cicer arietinum L.) to the application of nitrogen and phosphate. Indian J. agric. Sci. 41(2):101-106.

Singh, S., Singh, N.P. and Singh, M. (1980). Influence of irrigation and phosphorus on growth and yield of chickpea (Cicer arietinum L.). Agric. Res. Rural Dev. 3(1 & 2):19-25.

Singh, S.C. and Yadav, D.S. (1985). Response of chickpea (Cicer arietinum) varieties to phosphorus levels and seeding rates. Indian J. Agron. 30(4):414-416.

Singh, S.P. (1981). Studies on spatial arrangement in sorghum-legume intercropping systems. J. agric. Sci., Camb. 97:655-661.

Singh, U.B., Singh, A.K. and Sharma, M.L. (1967). Note on manuring of mustard. Indian Agric. 11:74-75.

Singh, U.B. and Tomer, S.P. (1971). Response of mustard to varying irrigation levels, spacing and fertilizer application. Indian J. Agron. 16(4):465-467.

Singh, V. (1978). Crop improvement project on rapeseed mustard. Note prepared for the Indo-Swedish Joint Commission meeting, New Delhi. 24-25 Oct., 1978.

Sinha, M.N. and Rai, R.K. (1976). Efficiency of fertilizer utilization by wheat using ^{32}P as a tracer. Indian J. Agron. 21(3):180-183.

Sinha, S.K. and Savitri, A.R. (1978). Biology of yield in food legume. Ecology & control, New York, Academic Press.

Singhania, R.A. and Goswami, N.N. (1974). Use of radiations and radioisotopes in studies of plant productivity. Proc. Symp. Pantnagar. pp.437.

Snell, F.D. and Snell, C.T. (1955). Colorimetric Methods of Analysis.2:813-816.

Soper, R.J. (1971). Soil tests as a means of predicting response of rape to added NPK. Agron. J. 63:564-566.

Srivastava, S.N.L. and Varma, S.C. (1983). Phosphate fertilization of legume with special reference to pulses - A review. Agric. Rev. 4(1):34-46.

Srivastava, S.P. and Singh, A.P. (1975). Phosphorus fertilization in gram under dryland conditions. Soil Culture.41(11):527-528.

Strong, W.M. and Barry, G. (1980). The availability of soil and fertilizer phosphorus to wheat and rape at different water regimes. Aust. J. Soil Res. 18:353-362.

Subbiah, B.V. and Asija, C.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25:328.

Suryawanshi, B.M. and Choudhuri, C.J. (1979). Response of gram to soil and foliar application of phosphorus. Indian J. Agric. Res. 13(1):18-22.

*Sysoev, Y.A. (1978). Effect of fertilizers on yield of chickpea. Referotivnyi Zhurnal 8.55:268. (c.f. Field Crop Abst. 32(7):4690, 1979).

Trenbath, B.R. (1974). Biomass productivity of mixtures. Adv. Agron. 26:177-210.

Trenbath, B.R. (1976). Plant interactions in mixed crop communities. In. Multiple Cropping. M. Stelly (ed.). Am. Soc. of Agronomy, Madison, Wis. pp.129-169.

USDA (1968). Diagnosis and improvement of saline and alkali soils. Agriculture Handbook No. 60. Oxford and IBH Publishing Co. New Delhi.

Vanden Bergh, J.P. (1968). An analysis of yield of grasses in mixed and pure stand. Versl. Landbouwkd. Onderz. 714:1-71.

Venkatachalam, S., Premanathan, S., Arunachalam, G. and Vivekanandan, S.N. (1969). Soil fertility studies in Madras State using radio tracer technique. I. Placement of phosphate to hybrid sorghum. Madras agric. J. 56(3):104-109.

Vidyapatiroy, Maiti, S. and Chatterjee, B.N. (1981). Growth analysis and fertilizer response of 'Varuna' Indian mustard. Indian J. agric. Sci. 51:173-180.

Vir, P. and Verma, B.S. (1979). Effect of nitrogen and phosphorus fertilization and row spacing on drymatter, nitrogen and phosphorus contents and their uptake in rainfed mustard. Indian J. agric. Sci. 49(12):950-952.

Vir, P. and Verma, B.S. (1981). Effect of nitrogen, phosphorus and row spacing and yield, yield attributes and oil content of rainfed mustard. Indian J. Agron. 26(1):37-41.

Virmani, S.M. and Gulati, H.C. (1971). Effect of S on the response of Indian mustard to P fertilization. Indian J. agric. Sci. 41(2):143-146.

Wahua, T.A.T. (1983). Nutrient uptake by intercropped maize and cowpea as a concept nutrient supplementation index (NSI). Expl. Agric. 19:263-275.

Walkley, A.J. and Black, I.A. (1934). An experimentation of the Degtjareff Method for determination of soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Wild, A. (1950). The retention of phosphate by soil. A review. J. Soil Sci. 1(2):221-238.

Willey, R.W. (1975). The use of shade in coffee cocoa and tea. Horti. abstr. 45:791-798.

Willey, R.W. (1979). Intercropping - Its importance and research needs. Part. I. Competition and yield advantages. Field Crop Abstr. 32:1-10.

Willey, R.W. and Rao, M.R. (1980). A competitive ratio for quantifying competition between intercrops. Expl. Agric. 16:117-125.

Willey, R.W. and Rao, M.R. (1981). A systematic design to examine effects of plant population and spatial arrangement. In. Intercropping, illustrated by an experiment on chickpea/safflower. Expl. Agric. 17:63-73.

Willey, R.W. and Roberts, R.H. (1976). Mixed cropping. Proc. Univ. Reading, England, U.K.

Whitelengton, W.J. and Obrien, T.A. (1968). Comparison of yield from plot sown with a single species or mixtures of grass species. J. Applied Ecology 5:203-213.

Yadav, M.P., Singh, M.M. and Dixit, R.S. (1985). Response of chickpea (Cicer arietinum L.) varieties to phosphorus. Indian J. Agron. 30(1):122-123.

* Original not seen

APPENDIX I. Weekly average meteorological data during the crop seasons (1985-86 and 1986-87)

Std. week	Date	Temp. °C Max.	Temp. °C Min.	Mean wind speed km/hr.	Sunshine hr.	R.H. (%) Max.	R.H. (%) Min.	RH (%) Av.	Rainfall (mm)	P.E. (mm)
1985-86										
44	30-05 Nov.	31.9	13.3	1.7	8.9	83.0	29.0	56	0.0	2.8
45	06-12	29.4	12.0	1.2	3.4	83.0	31.0	57	0.0	1.9
46	13-19	27.0	9.4	1.7	9.1	86.0	32.0	59	0.0	2.4
47	20-26	27.5	9.2	2.1	8.9	84.0	28.0	56	0.0	2.4
48	27-03 Dec.	25.9	8.2	3.0	9.6	83.0	25.0	54	0.0	2.3
49	04-10	25.3	7.6	2.8	9.0	74.0	26.0	50	0.0	2.3
50	11-17	21.1	10.2	3.3	5.7	92.0	70.0	81	15.8	1.3
51	18-24	21.0	9.0	4.8	6.2	92.0	60.0	76	0.0	1.6
52	25-31	19.4	9.6	6.3	6.0	86.0	58.0	72	9.0	1.5
1	01-07 Jan.	18.1	3.1	4.8	8.6	92.0	37.0	64	0.0	1.9
2	08-14	20.4	4.6	1.3	5.9	95.0	49.0	72	0.0	1.2
3	15-21	20.1	3.9	2.7	7.2	94.0	42.0	68	0.0	1.7
4	22-28	22.0	6.7	3.7	8.3	91.0	42.0	66	0.0	1.6
5	29-04 Feb.	20.8	7.6	3.9	7.3	90.0	46.0	68	22.4	1.8
6	05-11	21.4	8.7	4.4	6.7	93.0	55.0	74	37.0	2.8
7	12-18	20.5	8.6	3.9	8.5	92.0	56.0	74	0.0	1.6
8	19-25	22.6	9.4	5.9	9.9	84.0	49.0	66	2.6	3.4
9	26-04 Mar.	25.2	8.1	4.0	10.4	83.0	36.0	59	0.0	4.0
10	05-11	30.2	12.0	2.4	8.6	89.0	37.0	63	0.0	3.5
11	12-18	28.8	13.6	6.6	7.9	86.0	66.0	76	6.6	4.5
12	19-25	25.7	11.1	5.6	7.7	87.0	37.0	62	9.2	3.8
13	26-01 Apr.	31.6	13.7	5.8	9.5	74.0	27.0	50	0.0	6.2
14	02-08	32.3	12.7	3.2	9.5	71.0	30.0	50	0.0	5.5
15	09-15	37.1	19.6	5.5	8.7	64.0	33.0	48	0.0	7.7
16	16-22	38.0	17.8	2.6	11.0	66.0	35.0	50	0.0	9.4

Contd.....

App ndix I(contd.....)

Std. week	Date	Temp. °C Max.	Temp. °C Min.	Mean wind speed km/hr	Sun-shine hr.	R.H. (%) Max.	R.H. (%) Min.	RH (%) Av.	Total rainfall (mm)	Pan evapo-ration (mm)
1986-87										
42	16-22 Oct.	31.5	15.9	7.2	9.0	84	43	63	0.0	4.9
43	23-29	31.0	10.7	3.4	9.8	87	30	58	0.0	3.6
44	30-05 Nov.	32.2	13.2	2.5	8.8	84	30	57	0.0	2.8
45	06-12	29.2	10.5	1.9	8.3	93	43	68	0.0	2.9
46	13-19	30.6	14.4	3.0	8.4	85	41	63	0.0	3.4
47	20-26	27.3	7.8	3.4	8.6	78	34	56	0.0	3.4
48	27-03 Dec.	25.4	9.9	3.7	5.0	90	47	68	0.0	4.0
49	04-10	24.1	6.5	2.0	6.4	91	45	68	0.0	1.9
50	11-17	21.8	7.8	6.1	6.8	94	54	74	5.4	1.7
51	18-24	18.2	2.8	3.4	7.6	93	41	67	0.0	1.6
52	25-31	20.4	2.0	2.7	7.9	91	40	65	0.0	1.6
1	01-07	21.8	5.2	3.2	7.0	84	35	59	0.0	2.2
2	8- 14	22.1	7.0	1.1	4.2	96	57	76	0.0	1.4
3	15-21	16.7	6.6	4.7	3.9	94	69	81	24.0	1.4
4	22-28	21.3	3.7	3.1	9.4	91	37	64	0.0	2.2
5	29-04 Feb.	23.6	6.3	2.0	7.8	98	41	69	0.0	2.0
6	05-11	25.2	7.7	3.0	9.5	88	44	66	0.0	2.9
7	12-18	24.5	9.6	6.0	7.6	93	57	75	7.0	2.9
8	19-25	26.7	11.6	4.8	8.6	85	49	67	4.4	2.7
9	26-04 Mar.	24.8	9.0	3.2	9.4	93	47	70	0.0	3.3
10	05-11	29.6	12.7	4.0	8.5	86	48	67	0.0	4.0
11	12-18	28.0	14.7	6.7	7.7	93	56	74	0.0	3.9
12	19-25	30.7	16.4	6.5	8.8	86	49	67	14.4	5.1
13	26-01 Apr.	32.5	17.3	6.3	6.1	84	33	58	0.0	5.6

APPENDIX II

Mustard (1985-86)

X kg P ha^{-1}	Y q ha^{-1}	ξ'_1	$Y\xi'_1$	ξ'_2	$Y\xi'_2$	ξ'^2_1	ξ'^2_2
1	2	3	4	5	6	7	8
0	20.69	-3	-62.07	+1	+20.69	9	1
10	23.11	-1	-23.11	-1	-23.11	1	1
20	23.11	+1	+23.11	-1	-23.11	1	1
30	23.41	+3	+70.23	+1	+23.41	9	1
	90.32		+ 8.16		- 2.12	20	4

$$A' = \bar{Y} = \frac{\sum Y}{n} = \frac{90.32}{4} = 22.58$$

$$B' = \sum \xi'_1 Y / \sum \xi'^2_1 = \frac{8.16}{20} = 0.41$$

$$C' = \sum \xi'_2 Y / \sum \xi'^2_2 = \frac{-2.12}{4} = -0.53$$

$$Y = (\bar{Y} - 3B' + C') + (2B' - 3C')\,x + C'X^2$$

$$Y = (22.58 - 3 \times 0.41 - 0.53) + (2 \times 0.41 - 3 \times (-0.53))X - 0.53X^2$$

$$Y = 20.82 + \frac{2.41}{10} X - \frac{0.53\,X^2}{100}$$

$$Y = 20.82 + 0.2410\,X - 0.0053\,X^2$$

Calculation of optimum economic dose

Price of fertilizer = Rs. 12.16 per kg P as SSP

Price of produce = Rs 385 per q.

Appendix II (contd....)

$$X \text{ opt} = \frac{12.16/38) - 0.2410}{(-0.0053)\ X^2} = \frac{-0.2094}{-0.0106} = 19.75 \text{ kg P}$$

$$Y \text{ opt} = 20.82 + 0.2410 \times 19.75 - 0.0053\ (19.75)^2 = 23.51 \text{ q ha}^{-1}$$

<u>Chickpea</u> (1985-86)

X kg P ha^{-1}	Y q ha^{-1}	ξ_1'	$Y\xi_1'$	ξ_2'	$Y\xi_2'$	$\xi_1'^2$	$\xi_2'^2$
0	8.83	-3	-26.49	+1	+ 8.83	9	1
10	10.50	-1	-10.50	-1	-10.50	1	1
20	10.76	+1	+10.76	-1	-10.76	1	1
30	10.96	+3	+32.88	+1	+10.96	9	1
	41.05		+ 6.65		- 1.47	20	4

$$A' = \bar{Y} = \frac{\sum Y}{n} = \frac{41.05}{4} = 10.26$$

$$B' = \sum Y \xi_1' / \sum \xi_1'^2 = \frac{6.65}{20} = 0.33$$

$$C' = \sum Y \xi_2' / \sum \xi_2'^2 = \frac{-1.47}{4} = 0.37$$

$$Y = (\bar{Y} - 3B' + C') + (2B' - 3C')\ x + C^1 X^2$$

$$= (10.26 - 3 \times 0.33 - 0.37) + (2 \times 0.33 - 3(-0.37)X - 0.37\ x^2$$

$$= 8.90 + \frac{1.77}{10}\ X - \frac{0.37\ X^2}{100}$$

Appendix II (contd....)

$= 8.90 + 0.1770\,X - 0.0037\,X^2$

Calculation of optimum economic dose:

Price of fertilizer : Rs 12.16 per kg P as SSP

Price of produce : Rs 240 per q

$$X\ opt = \frac{12.16/240 - 0.1770}{(-0.0037)\ X^2} = \frac{-0.1263}{-0.0074} = 17.07\ kg$$

$$Yopt = 8.90 + 0.1770 \times 17.07 - 0.0037\ (17.07) = 10.84\ q\ ha^{-1}$$

Mustard (1986-87)

X kg P ha^{-1}	Y q ha^{-1}	ξ'_1	$Y\xi'_1$	ξ'_2	$Y\xi'_2$	ξ'^2_1	ξ'^2_2
0	16.64	-3	-49.92	+1	+16.64	9	1
10	18.82	-1	-18.82	-1	-18.82	1	1
20	19.92	+1	+19.92	-1	-19.92	1	1
30	20.56	+3	+61.68	+1	+20.56	9	1
	75.94		+12.86		- 1.54	20	4

$$A' = \bar{Y} = \frac{\Sigma Y}{n} = \frac{75.94}{4} = 18.98$$

$$B' = \Sigma Y \xi'_1 / \Sigma \xi'^2_1 = \frac{12.86}{20} = 0.64$$

$$C' = \Sigma Y \xi'_2 / \Sigma \xi'^2_2 = \frac{-1.54}{4} = -0.38$$

$$Y = (\bar{Y} - 3B' + C') + (2B' - 3C')\,X + C'X^2$$

$$= (18.98 - 3x\ 0.64 - 0.38) + (2x\ 0.64 - 3(-0.38)\ X - 0.38\ x^2$$

$$= 16.68 + \frac{2.62X}{10} - \frac{0.38\ X^2}{100}$$

Appendix II (contd...)

$= 16.68 + 0.2620\, X - 0.0038\, X^2$

Calculation of optimum economic dose

Price of fertiliser : Rs 13.60 per kg P as SSP

Price of produce : Rs 400 per q

$$X\ opt = \frac{13.60/400 - 0.2620}{(-0.0038)\ X^2} = \frac{-0.2280}{-0.0076} = 30.0\ kg$$

$$Y\ opt = 16.68 + 0.2620 \times 30.0 - 0.0038\ (30.0)^2 = 21.12\ q\ ha^{-1}$$

Chickpea (1986-87)

X kg P ha^{-1}	Y q ha^{-1}	ξ'_1	$Y\xi'_1$	ξ'_2	$Y\xi'_2$	ξ'^2_1	ξ'^2_2
0	5.95	-3	-17.85	+1	+5.95	9	1
10	7.75	-1	- 7.75	-1	-7.75	1	1
20	7.83	+1	+ 7.83	-1	-7.83	1	1
30	7.75	+3	+23.25	+1	+7.75	9	1
	29.28		+ 5.48		-1.88	20	4

$$A' = \bar{Y} = \frac{\sum Y}{n} = \frac{29.28}{4} = 7.32$$

$$B' = \sum Y \xi'_1 / \sum \xi'^2_1 = \frac{5.48}{20} = 0.27$$

$$C' = \sum Y \xi'_2 / \sum \xi'^2_2 = \frac{-1.88}{4} = -0.47$$

$$Y = (\bar{Y} - 3B' + C') + (2B' - 3C')X + C'X^2$$

$= (7.32 - 3 \times 0.27 - 0.47) + (2\times 0.27 - 3(-0.47)X - 0.47\ X^2$

$= 6.04 + \frac{1.95\ X}{10} - \frac{0.47}{100}\ X^2$

$= 6.04 + 0.1950\ X - 0.0047\ X^2$

Calculation of optimum economic dose

Price of fertilizer : Rs 13.60 per kg P as SSP

Price of produce : Rs 260 per q

$X\ opt = \frac{13.60/260 - 0.1950}{(-0.0047)\ X^2} = \frac{-0.1427}{-0.0094} = 15.18\ kg$

$Y\ opt = 6.04 + 0.1950 \times 15.18 - 0.0047\ (15.18)^2 = 7.92\ q\ ha^{-1}$

Response kg/kg P

Mustard (1985-86)

Seed yield with 0 kg P ha^{-1} = 20.69 q ha^{-1}

Seed yield with 19.75 kg P ha^{-1} = 23.51 q ha^{-1}

Additional seed yield with 19.75 kg P ha^{-1} = 2.82 q ha^{-1}

= 282 kg ha^{-1}

So, additional seed yield with 1 kg P ha^{-1} = $\frac{282}{19.75}$ = 14.28 kg

Mustard (1986-87)

Seed yield with 0 kg P ha^{-1} = 16.64 q ha^{-1}

Seed yield with 30 kg P ha^{-1} = 21.12 q ha^{-1}

Additional seed yield with 30 kg P ha^{-1} = 4.48 q ha^{-1} = 448 kg ha^{-1}

So, additional seed yield with 1 kg P ha^{-1} =

$\frac{448}{30}$ = 14.93 kg

Appendix II (contd....)

<u>Chickpea (1985-86)</u>

Seed yield with 0 kg P ha^{-1} = 8.83 q ha^{-1}

Seed yield with 17.07 kg P ha^{-1} = 10.84 q ha^{-1}

Additional seed yield with 17.07 kg P ha^{-1} = 2.01 q ha^{-1} = = 201 kg ha^{-1}

So, additional seed yield with 1 kg P ha^{-1} = $\frac{201}{17.07}$ = 11.77kg

<u>Chickpea (1986-87)</u>

Seed yield with 0 kg P ha^{-1} = 5.95 q ha^{-1}

Seed yield with 15.18 kg P ha^{-1} = 7.92 q ha^{-1}

Additional seed yield with 15.18 kg P ha^{-1} = 1.97 q ha^{-1} = 197 kg ha^{-1}

So, additional seed yield with 1 kg P ha^{-1} = $\frac{197}{15.18}$ = 12.98 kg

<u>Return/Re on P</u>

<u>Mustard (1985-86)</u>

Price of 14.28 kg mustard = Rs 54.98

Fertilizer of Rs 12.16 gives = Rs 54.98

Fertilizer of Re 1.00 will give = $\frac{54.98}{12.16}$ = Rs 4.52

<u>Mustard (1986-87)</u>

Price of 14.93 kg mustard = Rs 59.72

Fertilizer of Rs 13.60 gives = Rs 59.72

Fertilizer of Re 1.00 will give = $\frac{59.72}{13.60}$ = Rs 4.39

Appendix II (contd.....)

Chickpea (1985-86)

Price of 11.77 kg chickpea = Rs 28.25

Fertilizer of Rs 12.16 gives = Rs 28.25

Fertilizer of Re 1.00 will give = Rs 2.32

Chickpea (1986-87)

Price of 12.98 kg chickpea = Rs 33.75

Fertilizer of Rs 13.60 gives = Rs 33.75

Fertilizer of Re 1.00 will give = $\frac{33.75}{13.60}$ = Rs 2.48

...