I. INTRODUCTION

India is a large country with a population of more than 1028 million, ranking second behind China in the world. It has to feed this large population with a net cropped area of 140.88 m ha having a net irrigated area of 55.1 m ha only. In the years to come, the area under agriculture and also the water availability to irrigation are likely to shrink further with a burgeoning population, urbanisation and industrialisation.

A large population of India being vegetarian in food habit depends on agricultural production to meet its nutritional requirement. The need for protein is mostly met with a variety of pulses cultivated across the length and breadth of the country. However the demand for pulses has remained much above the production over the last many decades with per capita availability of less than FAO recommended 80g per person per day. Although India has the largest area under pulses cultivation with 22.76 m ha with a production of 13.13 million tonnes at an average productivity of meagre 577 kg/ha (FAI, 2006), has been a net importer of pulses over the last many years. The situation looks quite grim with an expected demand for pulses put at 22.3-23.8 million tonnes by 2020 at productivity of 1029-1095 kg/ha (Paroda and Kumar, 2000). Among the pulses, chickpea (*Cicer arietinum* L.) is a leading crop in India. It is cultivated in 6.72 m ha with a total production of 5.47 million tonnes at an average productivity of 815 kg/ha (FAI, 2006). It is known by different names such as gram, Bengal gram, chana etc. Together with pigeon pea it accounts for more than 70% of the total pulses grown in the country. It is rich in nutrients with 21g protein, 5.6 g fat and 59.8g carbohydrate per every 100 g of seeds.

Likewise the oil demand for human consumption is also met through various oilseeds cultivated in the country. Among the 9 major oilseeds, the rapeseed and mustard (*Brassica juncea*) group of crops stand second with an area of 7.32 m ha and production of 7.59 million tonnes at an average productivity of 1038 kg/ha (FAI 2006). It is a rich source of edible oil containing around 40% good quality oil. It accounts for more than 25% of the total area and production under oilseeds in India.

Chickpea is cultivated during *rahi* i.e. winter in many parts of the country. Madhya Pradesh, Uttar Pradesh, Haryana, Punjab, Maharashtra, Karnataka are leading
growers of this crop. Mustard is also a *rabi* crop and competitor for the acreage with chickpea and is confined mostly to Rajasthan, Haryana, Uttar Pradesh and Punjab. However the productivity of both chickpea and mustard is quite low as compared to their potential. A large number of reasons have been identified for the low productivity of these crops. Among these the common agronomic practices like irrigation and nutrition have been observed to affect their performance in many areas of the country. Although India has sizeable area under irrigation, it is mostly used for growing cereals like rice, wheat and commercial crops like sugarcane and cotton. The chickpea and mustard are mostly cultivated under rainfed condition and in dryland areas making use of the residual moisture after the monsoonal rains. There are large number of reports indicating the enhanced productivity of these crops under 1-2 irrigations during critical stages of growth.

Further lack of sufficient quantity of nutrient application tends to weaken the production capacity of these crops leading to lower productivity. These are also high nutrients requiring crops due to their high protein and oil content in the seeds in chickpea and mustard, respectively. A crop of chickpea producing around 1000 kg/ha removes 60.4 kg N, 23.9 kg P and 155.2 K (Singh and Sharma, 1980); while a crop of mustard yielding around 1500 kg/ha removes 32.8 kg N, 16.4 kg P and 41.8 kg K (Hegde and Sudhakara Babu, 2000). Although about 12.7 million tonnes N, 5.2 million tonnes P₂O₅ and 2.41million tonnes K₂O (FAI, 2006) are used in Indian agriculture, these crops are seldom supplied with sufficient quantity of nutrients. Further as these crops are rich in protein and oil, their production is greatly augmented by the availability of sulphur in the soil as sulphur rich amino acids and fatty acid will help in the synthesis of protein and oil. However the intensive cultivation coupled with lack of supplementation of sulphur though fertilizers has resulted in decline in the available sulphur in the soil. This has further aggravated the nutrient availability situation to the crop.

As both chickpea and mustard are *rabi* season crops with diverse rooting pattern, phenology and morphology, there is a possibility of successfully growing these in intercropping systems. Intercropping system insures against the failure of one or other crop owing to natural vagaries like moisture stress, pests and diseases etc. Besides it also boosts the productivity of the system giving higher return and stability to the farming community. Further, intercropping is not only a risk avoiding cropping programming suitable for rain-fed conditions but also seen as a crop intensification
measure in irrigated agriculture in the recent times. With the availability of high yielding crop varieties of varying maturity duration and growth rhythms, plant protection measures, irrigation and chemical fertilizers the concept of intercropping has been virtually changed. It now aims at augmenting the productivity per unit area of land and unit time (Kumar et al., 2006).

Uttar Pradesh is a leading agricultural state in the country contributing greatly for the pulses and oilseeds production. The western Uttar Pradesh endowed with fertile soil, water resources and congenial agro-climate is a front runner in the production of these crops. Although irrigation water is not limited, it is often diverted for the cultivation of crops like rice, wheat, sugarcane etc. Thus the pulses and oilseeds are relegated to marginal land with fewer irrigation facilities and less intensive agricultural areas. In these areas there is a vast potential for increasing the productivity of these crops with judicious management of resources like water, nutrient and making maximum use of improved agro-techniques.

Keeping all the above facts in view an experiment entitled “Effect of irrigation and fertility levels on chickpea + mustard inter-cropping system” was carried out with the following objectives:

- To study the effect of irrigation on chickpea + mustard inter-cropping system.
- To study the influence of different fertility levels on chickpea + mustard inter-cropping system.
- To study the interaction between irrigation and fertility levels, if any, on chickpea + mustard inter-cropping system.
- To work out the economics of crop production of chickpea + mustard inter-cropping system.
II. REVIEW OF LITERATURE

In this chapter an attempt has been made to present a brief review of the research information available on the influence of irrigation and fertility levels on growth, quality and yield of chickpea (*Cicer arietinum* L.) grown alone and such effects on component crops when grown in association with mustard (*Brassica juncea* (L.) Czern and Coss) in different intercropping systems. In addition, information on yield advantages reckoned through land equivalent ratio (LER) and profit potentials of chickpea + mustard and related intercropping systems is also provided.

2.1 Effect of intercropping system on performance of chickpea

Chickpea with *Toria*, *sarson* or mustard was reported to be the common mixture in rain-fed agriculture in North India (Saxena and Yadav, 1975). However, the scientific studies on mustard + chickpea intercropping systems with special reference to spatial arrangement and nitrogen fertilization are meagre; but a sincere attempt has been made to review the influence of intercropping systems on the growth, yield, quality, N, P & S content and uptake, economics of production and yield advantages. Whenever information on proper intercropping systems were not sufficient, other related intercropping systems are also taken into consideration.

Most of the factors for which there is competition, are found as a pool of material from which competitors draw their supply. When the pool is depleted and is not sufficient to meet the demands of the competing plants, the competition begins (Donald, 1963). Kaushik *et al.* (1980) reported that suitable modification of planting pattern and a careful selection of crops can reduce to a considerable extent, the mutual competition. May and Misangu (1980) also reported the same.

In a field experiment carried out during 1998-99 to 2001 at Indian Institute of Pulses Research, Kanpur to study the genotypic compatibility in *kabuli* chickpea and Indian mustard intercropping system showed that among the various intercropping system 'BG 1003' chickpea + 'vardan' Indian mustard recorded significantly highest growth and yield attributes of chickpea and Indian mustard than the other intercropping systems. Significantly higher chickpea equivalent, land equivalent ratio (LER), net returns and benefit: cost ratio were recorded in 'BG 1003' + vardan
intercropping system. Higher seed yield of component crops in intercropping system showed compatibility relationship, which resulted in higher chickpea equivalent yield.

2.1.1 Growth attributes

Kushwaha (1983) reported that increase in chickpea proportion (1:4) in the mustard + chickpea intercropping systems increased the number of primary and secondary branches per plant of mustard as compared with sole mustard. On the other hand reduction in the chickpea proportion due to intercropping reduced both the primary and secondary branches per plant of chickpea.

Meena (1985) reported an increase in the pod bearing branches of mustard in the mustard + chickpea intercropping system (3 rows of chickpea in between the mustard rows spaced 90 cm apart) gave maximum pod bearing branches plant at harvest over the pure stand. But the differences in other systems (1:1 and 1:2) were less marked. Intercropping of chickpea in safflower planted in paired rows (45-75 cm) in 2:1 proportion recorded higher primary branches followed by safflower + chickpea in 1:1 proportion in normal planting as compared to 1:2, 1:3 proportions in normal planting or 2:2 and 2:3 proportions in paired rows planting in 45-75 cm and 30-60 cm, respectively (Hiremath et al., 1991). Kumar and Singh (1987) conducted field experiment at Pantnagar and noted that intercropping of mustard with chickpea resulted in reduction of branches per plant.

Saraf et al. (1990) in the proceedings of the second international workshop on chickpea improvement, ICRISAT, Hyderabad, stressed the need of various cropping systems designed to improve profitability both in time and space and emphasized that in view of the improved plant types and soil ameliorative properties, cropping systems involving chickpea were increasingly being adopted. They also revealed that inclusion of chickpea in cropping systems had resulted in enhanced yields under both rain-fed and irrigated conditions.

In a study conducted by Tripathi et al. (2000) at Kanpur, by introducing mustard (Brassica juncea) as intercrop with two row proportions in bengal gram (Cicer arietinum) supplied with 0, 30, 60 and 90 kg P₂O₅/ha to study the growth and yield behaviour of bengal gram in association with mustard. Inclusion of mustard as intercrop reduced the growth parameters of bengal gram in intercropping systems. The yield attributes such as pods per plant, pod weight per plant, seeds per pod and seed weight per plant of all types of branches were also decreased by intercropping of mustard. Further among the intercropping systems, bengal gram + mustard grown in
8:2 row ratio resulted in significantly higher growth and yield attributes over 6:2 row planting system. Respective means of bengal gram seed yield were 404, 309 and 370 g per row when gram was grown as pure and intercropped with mustard in 6:2 and 8:2 row planting pattern, respectively. Bengal gram responded to P application up to 60 kg/ha.

2.1.2 Yield attributes

Kushwaha (1983) observed comparatively higher dry matter per plant of mustard and chick pea when two rows of mustard 60 cm spacing were replaced with four rows of chickpea (1:4), as compared to their sole crops and 2:2 row arrangement (1 row of mustard replaced by 2 rows of chickpea). In a field experiment conducted to assess the seed yield and competitive ability of associated crop species in binary composition's with mustard in different proportions (1 row mustard alternated with 4, 6 or 8 rows of chickpea, lentil, barley) under dry land conditions.

Gangasaran and Giri (1988) observed that the dry matter of mustard was adversely affected more with barley than with chickpea or lentil association. Higher dry matter per plant was recorded with 1:6 compositions of mustard + chickpea than 1:4 or 1:8 systems. Meena (1985) did not find any significant difference in dry weight plant of mustard when intercropped with chickpea in various proportions viz., 1:1, 1:2, and 1:3. In chickpea however, dry weight of plant at 120 DAS decreased significantly in 1:2 system compared to 1:1 system. Significant reduction in dry matter plant of intercrop was noticed when mustard was intercropped with chickpea. At harvest the reduction was 18.6 and 24.6 percent as compared to sole wheat in 1985-86 and 1986-87, respectively. Similarly such reduction in drymatter (gm) was observed in mustard as compared to its sole stand as a result of lower population.

A field experiment was conducted by Singh et al. (2006) to evaluate the productivity potential of chickpea in relation to raya intercropping in different planting patterns and row orientation under rainfed conditions. All the chickpea based intercropping systems resulted in higher chickpea equivalent yield (CEY) compared to sole cropping. Sowing of chickpea in north-south direction recorded 10.2% higher mean seed yield over its sowing in east-west direction. Intercropping of raya with chickpea 3.0-3.5 m apart resulted in the highest mean crop equivalent yield, net returns and benefit: cost ratio compared to the other treatments. The water use was not influenced appreciably under different planting pattern; however it was higher in
north-south row direction. The results also demonstrate the impact of extent and distribution of rainfall particularly under rainfed conditions.

Kumar et al. (2005) in a field experiment to evaluate different patterns of chickpea-yellow sarson intercropping observed that all intercropping treatments were superior to sole crops in terms of chickpea equivalent yield and net return. Intercropping chickpea and yellow sarson in a 4:1 ratio gave the highest total yield (2379 kg/ha), chickpea equivalent yield (2406 kg/ha), land equivalent ratio (1.25), net return (Rs.26501/ha), benefit: cost ratio (1.41), sustainable yield index (0.86) and sustainable value index (0.80).

2.1.3 Yield

The yield advantage 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; and 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 (Rao and Shetty, 1977).

2.1.4 Nutrient uptake and quality

Parihar et al. (2000) in a field experiment to study the effect of different row proportions of mustard and chickpeas and irrigation on the yield and economics of different intercropping systems revealed that the sole crop of chickpeas gave the highest seed yield, chickpea equivalent yield, and total uptake of N and P, followed by the other intercropping systems, indicating that mustard interfered with chickpea yield, whereas the sole mustard crop recorded the lowest seed yield and nutrient uptake as there was less total biomass than in the other cropping systems. Irrigation had a significant positive effect on the seed yield of both chickpeas and mustard. However, more than one irrigation was detrimental for chickpeas on a clay loam soil, while mustard responded significantly. The highest gross return, net return and benefit:cost ratio were recorded with the sole chickpea crop followed by chickpeas + mustard intercrop at 4:2 row proportions.

2.1.5 Economics

Avanesh et al. (2001) observed the highest land-equivalent ratio (LER), area x time equivalency ratio (ATER), effective yield total (EYT), net return and benefit:cost
ratio were obtained at 6:2 row-ratio. Among the phosphorus levels tried, 60 kg P$_2$O$_5$/ha was found most economic. P uptake was significantly higher at 60 kg P$_2$O$_5$/ha in comparison with 30 kg P$_2$O$_5$/ha. Net return was also highest, i.e. Rs. 22, 042.90 and 20, 182.04/ha at 6:2 row ratio and 60 kg P$_2$O$_5$/ha, respectively.

Against the benefits noted, intercropping sometimes produced injurious (allelopathic) effects in one or both the crop components (Risser, 1962 and Rice, 1974). The intercrops also posed problem of crop management in countries/regions where higher degree of mechanization is practiced (Willey, 1979).

Kumar et al. (2006) in a field experiment to determine the effect of row ratios (4:2, 6:2 and 8:2) on chickpea (Cicer arietinum) + Indian mustard (Brassica juncea) intercropping on growth, yield attributes, yield, yield assessment and monetary returns as well as P uptake under dryland conditions. The highest land-equivalent ratio (LER), area x time equivalency ratio (ATER), effective yield total (EYT), net return and benefit:cost ratio were obtained at 6:2 row-ratio. Net return was also highest, i.e. Rs 22, 042.90 and 20, 182.04/ha at 6:2 row ratio.

2.2 Effect of irrigation practices on chickpea

2.2.1 Growth attributes

Ahlawat et al. (2005) found that irrigation in gram at 0.4 IW:CPE ratio caused 31.6% reduction in seed yield compared with 0.2 IW:CPE ratio. The yield of gram + Indian mustard in intercropping systems was dependent on row proportions of component crops. Gram-equivalent yield (GEY) was highest in sole Indian mustard (3.04 tonnes/ha) and with irrigation at 0.2 IW:CPE ratio (2.42 tonnes/ha). At closer row proportions (2:1 and 3:1) of gram and Indian mustard intercropping system, irrigation at 0.4 IW:CPE ratio recorded higher gram-equivalent yield (2.88 and 2.744 tonnes/ha), while at wider row proportions (4:1 and 6:1) irrigation at 0.2 IW:CPE ratio gave higher gram-equivalent yield (2.41 and 2.33 tonnes/ha). The water-use efficiency (kg/ha-mm) was highest in sole Indian mustard (12.66) and unirrigated crops (11.7).

The performance of 25 chickpea genotypes was evaluated by Durga et al. (2005) under irrigated and unirrigated conditions in Andhra Pradesh. The parameters tested included: days to 50% flowering, days to maturity, plant height, branch number/plant, pod number/plant, seed yield and test weight. Genotypes took more time to flower and mature, but were taller and had higher pod number under irrigated conditions, compared to unirrigated conditions. ICCV 94916-8 showed the maximum
seed yield under irrigated and unirrigated conditions (2799 and 2498 kg/ha, respectively). ICCV 94916-8 had bold seeds of equal sizes under both conditions. ICCV 98936 and ICCV 98908 were superior under both conditions, indicating yield and drought tolerance stability.

2.2.2 Yield attributes

Roy and Tripathi (1985) reported irrigation at IW/CPE ratio of 0.4 proved better for chickpea under humid alluvial belt of south western region of West Bengal. They further noted that increase in grain yield was associated with increase in number of pods and grains per plant.

Kaushik and Chaubey (1999) found that chickpeas cv. Avrodhi was not irrigated or was irrigated at branching (B), pre-flowering (FL) or pod filling (PF), or at B + FL or B + PF. Grain yield was greater with irrigation than without irrigation, and with 2 rather than 1 irrigation, with irrigation at B + PF giving the greatest yield. With 1 irrigation, yield decreased with delay in irrigation. Water use efficiency was greatest with 1 irrigation at B.

Singh et al. (2006) in a field experiment conducted to evaluate the effect of irrigation (one irrigation at pre-flowering; and 2 irrigations, at pre-flowering and pod development), S (20 and 40 kg/ha) and seed inoculation (Rhizobium; phosphate solubilizing bacteria, PSB; and Rhizobium sp. + PSB) on late sown chickpea cv. HC1. Rhizobium sp. + PSB and S at 40 kg/ha resulted in the highest pod number/plant (37.87), seed yield (1744 kg/ha), total S uptake (45.57 kg/ha) and net returns (Rs. 2357/ha). The control treatment (no irrigation and S treatment) showed that the lowest values for these parameters. Seed yield was significantly and positively correlated with dry matter accumulation, yield attributes, nutrient uptake, protein yield and consumptive water use.

2.2.3 Yield

Prasad et al. (2006) in a field experiment to screen the most suitable cultivar of mustard grown in association with chickpea and to evaluate the effect of mustard cultivars on the yield of chickpea and vice-versa, in which seven mustard cultivars were tested with chickpea in 1:4 row ratio showed that intercropped chickpea produced statistically lower grain yield than sole crop during both years on area basis. On an average, intercropping of mustard cultivars with chickpea reduced the grain yield of chickpea to the extent of 10.15, 9.40, 5.01, 5.50, 9.44, 5.05 and 8.31% with Varuna, Vaibhav, Urvashi, Kanti, Vardan, Basanti and Rohini, respectively. Intercropped
mustard gave significantly lower yield than pure cropping during both years on area basis. The positive effects of chickpea on the seed yield of mustard cultivars on mean basis were 14.04, 15.49, 22.41, 9.16, 16.55, 14.04 and 12.44% in Varuna, Vaibhav, Urvashi, Kanti, Vardan, Basanti and Rohini, respectively. Intercropping of mustard cv. Urvashi proved to be the most suitable for association with chickpea (1:4 row ratio) as it gave the highest seed yield of 11.65 q ha\(^{-1}\), chickpea equivalent yield of 36.94 q ha\(^{-1}\), net profit of Rs 33 359 ha\(^{-1}\), land equivalent ratio (1.18) and monetary advantage index of Rs 7321 ha\(^{-1}\), followed by Basanti.

Tigga et al. (2004) in a field experiment conducted to investigate the effect of intercropping and integrated nutrient management on the performance of Indian mustard cv. Pusa Bold and chickpea cv. JG-74. The intercropping treatments included: I\(_1\), sole mustard at 40 cm spacing; I\(_2\), sole chickpea at 30 cm; I\(_3\), mustard:chickpea at 1:2 ratio; I\(_4\), mustard:chickpea at 1:3; and I\(_5\), mustard:chickpea at 2:3 ratio. The nutrient management treatments were: F\(_1\), recommended N:P:K rate (RFD, 80:50:30 and 20:50:30 kg/ha for mustard and chickpea, respectively); F\(_2\), RFD + phosphorus solubilizing bacteria; F\(_3\), RFD at 50% + 50% N through farmyard manure (FYM); and F\(_4\), 50% RFD + 50% N as FYM. F\(_4\) produced the highest values for plant height, dry matter accumulation and number of branches. I\(_3\) also resulted in the maximum dry matter accumulation. Maximum mustard height was obtained under I\(_1\) treatment, while chickpea height was maximum under I\(_5\). Seed yields of each crop were highest with sole cropping.

2.2.4 Nutrient uptake and quality

Singh et al. (2004) reported that two irrigations at preflowering and pod development stages recorded highest seed, straw and protein yields and nutrient uptake over no irrigation and one irrigation at preflowering stage; however, nutrient content reduced slightly with increasing number of irrigations due to dilution effect. Seed, straw and protein yield, protein content and nutrient uptake increased with increasing levels of sulfur. Inoculation with *Rhizobium* + PSB resulted in higher seed and straw yields, protein content, N content in seed and sulfur content in seed and straw and uptake of all nutrients compared to no inoculation and single inoculation with *Rhizobium* or PSB.

2.2.5 Economics

Singh et al. (2005) reported that gross returns, net returns, and benefit:cost ratio increased with increasing levels of irrigation and sulphur. Seed inoculation with
Rhizobium+ PSB resulted in the highest gross returns, net returns, and benefit:cost ratio over no inoculation and inoculation with Rhizobium or PSB. The highest gross return (37575 rupees ha⁻¹), net return (26340 rupees ha⁻¹) and benefit:cost ratio(2.35) were obtained with irrigation at the pre-flowering and pod initiation stages, 40 kg S ha⁻¹, and seed inoculation with Rhizobium + PSB.

2.3 Effect of N, P and S nutrition on chickpea

2.3.1 Growth attributes

Karande et al. (2006) in an experiment conducted on chickpea cv. Local in which the treatments comprised 3 field layouts (flat bed, ridges and furrows at 60 and 90 cm apart) and 4 fertilizer levels (100% recommended dose of fertilizer (RDF), 100% RDF + phosphate solubilizing bacteria (PSB) + Rhizobium, 75% RDF + 25% N through farmyard manure, and 75% RDF + 25% N through farmyard manure + PSB + Rhizobium) revealed that dry matter accumulation increased from 0.91 g at 28 days to 43.65 g per plant at harvest. The dry matter accumulation rate was faster during the vegetative and reproductive stages (28-84 days after sowing) and slower during later stages of crop growth. The mean number of pods per plant, number of seeds and seed weight per plant, number of seeds per pod and 100-seed weight were 43.91, 50.25, 14.99 g, 1.17 and 31.69 g, respectively. The mean seed and straw + bhusa yields were 27.25 and 30.99 q/ha, respectively. The ridges and furrows at 90 cm apart produced significantly more total dry matter per plant, number of pods per plant, number of seeds and seed weight per plant, number of seeds per pod and 100-seed weight. The application of 75% RDF + 25% N through farmyard manure + PSB + Rhizobium produced significantly more total dry matter per plant than 100% RDF, 100% RDF + PSB + Rhizobium at harvest and 75% RDF + 25% N through farmyard manure throughout the crop growth period except at 42 days after sowing where it was on par with 100% RDF + PSB + Rhizobium. This treatment also produced significantly more number of pods per plant, number of seeds and seed weight per plant, number of seeds per pod and 100-seed weight. The uptake of N, P and K was significantly more with 75% RDF + 25% N through farmyard manure + PSB + Rhizobium than the other fertilizer treatments. The interaction between land layouts and fertilizer levels in respect to yield contributing characters, yield and nutrient uptake were not significant.

2.3.2 Yield attributes

Singh et al. (1997) noted that B. juncea equivalent yield was 46.0 and 23.2% higher than the sole B. juncea and chickpea crops, respectively. B. juncea seed yield
was highest with 80 kg N and 60 kg P₂O₅. Chickpea seed yield was not affected by N rate, but was highest with 60 kg P₂O₅. Vyas and Rai (1993) reported that chickpea seed yields were decreased by intercropping, whereas mustard seed yields were highest when intercropped in a 1:3 row ratio with chickpeas. P application increased seed yields and P uptake in both crops. Except with mustard in 1986-87, increasing P rate above 10 kg did not increase seed yields.

Singh et al. (1993) observed that chickpea seed yields were similar with single (2.15 t/ha) or paired rows (2.22 t) in pure stands. Chickpea seed yields were decreased under intercropping, but the chickpea equivalent yields were similar to yields from pure stands. P application decreased seed yields.

**2.3.3 Yield**

Biological and economical feasibility of chickpea (Cicer arietinum) + Indian mustard (Brassica juncea) cropping systems under varying levels of phosphorus was studied by Tripathi et al. (2005) showed that intercropping of chickpea and Indian mustard resulted in the highest land equivalent ratio (1.19), relative crowing coefficient (2.30) net returns (Rs. 17101/ha) and benefit:cost ratio (2.11). The number of pods per plant and seeds per pod, 1000-seed weight, seed yield, land equivalent ratio and relative crowing coefficient increased with increasing rates of P. Returns and benefit:cost ratio increased with increasing rates of P up to 60 kg/ha.

Kumar and Singh (1987) recorded highest land-equivalent ratio (LER), area - time equivalency ratio (ATER), effective yield total (EYT), net return and benefit:cost ratio were obtained at 6:2 row-ratio. Among the phosphorus levels tried, 60 kg P₂O₅/ha was found most economic. P uptake was significantly higher at 60 kg P₂O₅/ha in comparison with 30 kg P₂O₅/ha. Net return was also highest, i.e. Rs. 22,042.90 and 20,182.04/ha at 6:2 row ratio and 60 kg P₂O₅/ha, respectively.

**2.3.4 Nutrient uptake and quality**

Chand et al. (2004) reported that chickpea significantly produced higher yield, nutrient uptake and protein content in pure stand than in the intercropped chickpea. Among the intercropping systems, the highest yield, protein content, N, P and K uptakes were recorded in chickpea + Indian mustard in 8:2 row ratio. The intercropped Indian mustard produced lower yield and nutrient uptake than the pure stand. The yield, quality parameters and nutrient content of the component crops exhibited an increasing trend with increasing P levels. The grain and straw yields of the component crops increased significantly up to 60 kg and 30 kg P/ha, respectively. The N, P and K
uptakes increased significantly up to highest level of 90 kg P/ha in chickpea and up to 60 kg P/ha in Indian mustard. The value of protein content in chickpea and oil content in Indian mustard also increased significantly up to 60 kg P/ha. The energy output and net energy return were highest (109.69 and 96.32 MJ x 103/ha) with sole Indian mustard and lowest with sole chickpea, but the energy output:input ratio was highest (10.67) with chickpea + Indian mustard in 8:2 row ratio. The application of 90 kg P/ha recorded the maximum energy output and net energy return (134.40 and 123.48 MJ x 103/ha), whereas the application of 60 kg P/ha resulted in the highest energy output:input ratio (12.62).

2.3.5 Economics

The highest land-equivalent ratio (LER), area x time equivalency ratio (ATER), effective yield total (EYT), net return and benefit:cost ratio were obtained at 6:2 row-ratio. Among the phosphorus levels tried, 60 kg P2O5/ha was found most economic. P uptake was significantly higher at 60 kg P2O5/ha in comparison with 30 kg P2O5/ha. Net return was also highest, i.e. Rs. 22,042.90 and 20,182.04/ha at 6:2 row ratio and 60 kg P2O5/ha, respectively.

Tripathi et al. (2005) observed that in intercropping of chickpea and Indian mustard resulted in the highest land equivalent ratio (1.19), coefficient (2.30) net returns (Rs. 17,101/ha) and benefit:cost ratio (2.11). The number of pods per plant and seeds per pod, 1000-seed weight, seed yield, land equivalent ratio and relative crowing coefficient increased with increasing rates of P. Returns and benefit:cost ratio increased with increasing rates of P up to 60 kg/ha.

2.4. Effect of cropping system on performance of mustard

2.4.1. Growth attributes

Singh et al. (1997) showed that dry matter accumulation by mustard was increased whereas that of chickpeas was decreased by intercropping. Total uptake of N and P was significantly higher with intercropping than with single cropping. Application of up to 80 kg N/ha and up to 60 kg P2O5/ha increased N and P uptake by component crops as well as by the intercropping system.

2.4.2. Yield attributes

Jana (1963) studied the effect of row spacing on grain yield, yield components and quality of mustard crop (Brassica juncea) at IARI, New Delhi and pointed out that the increase in row spacing up to 60 cm resulted in higher number of branches and pods/plant, it also enhanced pod length and seeds per pod substantially but this did not
reflect in the ultimate grain yield, on other hand it showed a decline in yield. He also noted a significant reduction in oil when row spacing was increased.

Singh and Singh (1987), however reported that number of siliquae and seed yield per plant were markedly reduced with closer row spacing of 30 cm (higher plant density) as compared to 45 to 60 cm spacing, which was attributed to the competition for growth resources. A row spacing of 45 cm produced higher seed yield than 30 and 60 cm. The improvement in yield attributes with wider spacing of 60 cm failed to compensate for the lower number of plants per unit area. Singh and Singh (1991) reported significantly higher seed yield per plant and 1000-seed weight with 60 cm row spacing but recorded significantly higher seed yield per hectare in 45 cm row spacing and oil content in closer row spacing of 30 cm in mustard.

2.4.3. Yield

The results of Asthana (1973) who tested 14 varieties of mustard (Brassica juncea) for their reactions to change in row spacing found that wider row spacing of 45 cm gave 23 percent more yield over narrow rows (35 cm). This was true particularly for varieties which had compact plant height where less bushy in habit. The studies made by Patel et al. (1980), Vir and Verma (1981) and Singh (1983) showed similar advantages of medium spacing (45 cm) over narrow spacing (30 cm) or wider (60 cm) spacing.

Kaushik et al. (2001) observed the mustard seed yield was higher in the sole cropping than the intercropping system. Among the intercropping systems, mustard + chickpea obtained the highest mustard seed yield (15.54 q/ha). The highest intercrop seed yield (215.22 q/ha), mustard seed equivalent (35.25 q/ha), land equivalent ratio (1.16), income equivalent ratio (1.18) and net returns (22,443 Rs/ha) were recorded for mustard + potato. This intercropping system likewise exhibited the lowest percentage of yield reduction (19.38).

2.4.4. Nutrient uptake and quality

Chand et al. (2005) observed that intercropping reduced the number of branches per plant, number of pods per plant, number of seeds per pod, seed weight per plant, and 1000-seed weight in gram, but enhanced these parameters in Indian mustard. Higher values of growth and yield parameters were obtained when gram-Indian mustard intercropping was established at 8:2 than at 6:2 row proportion. Plant height of gram was reduced under intercropping. The growth and yield parameters of gram increased with increasing P rate up to 60 kg/ha; a similar trend except for plant
height was observed in Indian mustard. Intercropping at 6:2 and 8:2 row proportions reduced the mean grain yield by 35.7 and 28.3% over sole gram, and by 54.1 and 47.4% over sole Indian mustard, respectively. The seed yield of sole Indian mustard and gram+Indian mustard intercropping at 8:2 increased with increasing P level up to 60 kg/ha, whereas that of gram+Indian mustard at 6:2 increased only up to 30 kg P/ha. Gram+Indian mustard at 8:2 supplied with 90 kg P/ha recorded the highest gram-equivalent yield (2.720 t/ha). The net returns under all cropping systems increased with increasing P rate up to 60 kg/ha, then decreased at the higher P rate. Gram-Indian mustard at 8:2 recorded the highest net return (Rs.20,143/ha).

2.4.5. Economics

Singh et al. (2003) observed that a spacing of 45 cm resulted in the highest seed yield (20.64 quintal/ha), straw yield (22.59 quintal/ha), stick yield (44.82 quintal/ha), net profit (Rs.13 581/ha), and cost benefit ratio (0.94) in a study on the effects of row spacing (30, 45 or 60 cm) on the yield of Indian mustard cv. Basanti. N was applied at sowing (50%) and after the initial irrigation (50%).

2.5. Effect of irrigation practices on mustard

2.5.1. Growth attributes

Tomar et al. (1992) in a study on effect of irrigation and fertility levels on growth, yield and quality of mustard (Brassica juncea) found significant increase in growth, yield attributes and yield with an increase in level of irrigation and NPK. The number of branches, dry matter accumulation/plant and seed yield were maximum with 120:60:60 kg N: P₂O₅ : K₂O/ha when two irrigations were applied whereas oil content was highest under no irrigation and fertilization.

2.5.2. Yield attributes

Bandopadhyay and Bose (2004) noted that increasing irrigation level gradually increased the oil content. No significant differences in crop growth rates due to increase in irrigation level were observed, except at 45-60 days after sowing. The highest crop growth rate was recorded upon treatment with three irrigations, and with 80 kg P/ha concentration at 45-60 days after sowing. At all irrigation levels, phosphorus significantly increased seed yield over the control, except in twice irrigation+80 kg P/ha treatment combination.

Mandal et al. (2006) revealed that treatment combinations of I₁₈₀ x F₁₀₀M₁₀, I₁₂₀ x F₁₀₀M₁₀ and I₁₈₀ x F₁₀₀ maintained significantly greater leaf area index (LAI), above-ground dry matter (DM), ET, seed and biomass yield of the crop than
other combinations. The duration of a LAI of ≥2.5 was more in F_{100} and F_{100M_{10}} than in F_{0}. Under I_{120}, LAI remained ≥2.5 for 8 and 22 days in F_{100} and F_{100M_{10}}, respectively. This leaf area duration increased to 28 and 39 days in the corresponding nutrient treatments under I_{180}. The root length, mass and volume densities were significantly higher in I_{180} than I_{120} and I_{60}, and in F_{100M_{10}} than F_{100} and F_{0}. For a particular irrigation regime, ET increased significantly in F_{100} and F_{100M_{10}} compared to F_{0}. The maximum seed yield of 1736 kg ha\(^{-1}\) was recorded in I_{180} x F_{100M_{10}}; and the seed yields under I_{120} x F_{100M_{10}} (1440 kg ha\(^{-1}\)) and I_{180} x F_{100} (1431 kg ha\(^{-1}\)) did not vary significantly. The WUE seed and WUE biomass decreased with the increase in amount of irrigation water. On the contrary, these WUE parameters increased in F_{100} and F_{100M_{10}} compared to F_{0}. The regression relationships of root length density on ET, and yield (both seed and biomass yield) on ET could be described by linear. Thus, I_{180} x F_{100M_{10}} is the best combination; and as the crop response to I_{120} x F_{100M_{10}} and I_{180} x F_{100} was similar, this study concludes that application of organic manure along with 100% NPK fertilizers could reduce the need for one post-sowing irrigation without compromising the yield of this crop under deficit irrigation.

2.5.3. Yield

Piri, et al. (2006) observed that seed yield of mustard increased significantly with increasing levels of irrigation. Water use efficiency was highest in 9-16 October-sown crop and beyond this sowing date, the WUE decreased steadily. WUE of crops grown under irrigated conditions were always higher than those grown under rainfed conditions. The relationships between WUE and SDD were negative and significant. The yield of the crops was closely related with the SDD.

Sharma et al. (2005) in their studies revealed that irrigation brought about significant increase in grain and stover yield of both mustard and linseed over control. Two irrigations at 30 and 60 DAS recorded the higher grain yield of both mustard and linseed, mustard grain yield equivalent and net return and benefit:cost (B:C) ratio, while LER decreased markedly with increasing irrigation.

Singh et al. (2003) in studies to find out the optimum irrigation schedule for gram (Cicer arietinum cv. Pusa 256) + Indian mustard (Brassica juncea cv. Pusa Jaikisan) intercropping system observed that irrigation at 0.2 irrigation water:cumulative pan evaporation (IW:CPE) ratio in sole gram and 0.4 IW:CPE ratio in Indian mustard was optimum for seed yield. Irrigation in gram at 0.4 IW:CPE ratio caused 31.6% reduction in seed yield compared with 0.2 IW:CPE ratio. The yield of
gram + Indian mustard in intercropping systems was dependent on row proportions of component crops. Gram-equivalent yield (GEY) was highest in sole Indian mustard (3.04 tonnes/ha) and with irrigation at 0.2 IW:CPE ratio (2.42 tonnes/ha). At closer row proportions (2:1 and 3:1) of gram and Indian mustard intercropping system, irrigation at 0.4 IW:CPE ratio recorded higher gram-equivalent yield (2.88 and 2.744 tonnes/ha), while at wider row proportions (4:1 and 6:1) irrigation at 0.2 IW:CPE ratio gave higher gram-equivalent yield (2.41 and 2.33 tonnes/ha). The water-use efficiency (kg/ha-mm) was highest in sole Indian mustard (12.66) and unirrigated crops (11.7).

2.5.4. Nutrient uptake and quality

Ghadge et al. (2005) recorded the highest S, P and N content in the seed and straw. After harvest, the S, N and P contents in the soil were highest with 3 irrigations applied at pre-sowing and at the flowering and grain filling stages (55 and 70 days after sowing, respectively).

2.5.5. Economics

In a field experiment conducted by Singh et al. (2006) to evaluate the productivity potential of chickpea in relation to raya intercropping in different planting patterns and row orientation under rainfed conditions revealed that all the chickpea based intercropping systems resulted in higher chickpea equivalent yield (CEY) compared to sole cropping. Sowing of chickpea in north-south direction recorded 10.2% higher mean seed yield over its sowing in east-west direction. Intercropping of raya with chickpea 3.0-3.5 m apart resulted in the highest mean crop equivalent yield, net returns and benefit:cost ratio compared to the other treatments. The water use was not influenced appreciably under different planting pattern, however it was higher in north-south row direction. The results also demonstrate the impact of extent and distribution of rainfall particularly under rainfed conditions.

2.6. Effect of N, P and S nutrition on mustard

Mustard, exhibits positive response to the application of nitrogenous fertilizer. The growth of the plant is very often restricted by deficiency of nitrogen. At the same time, high doses are responsible for the excessive vegetative growth and leads to reduction in oil content of the seeds. The studies related to effect of nitrogen on mustard crop have been reviewed in a detailed manner.
2.6.1. Growth attributes

The work by Allan and Morgan (1972) revealed that dry matter production per plant was increased remarkably due to nitrogen fertilization.

The influence of N application was well marked as number of branches per plant increased with the increasing doses of N (Allen and Morgan, 1972). Ali et al. (1976) concluded that dry weight of plants increased significantly with N application upto 78.5 kg per hectare. Ali et al. (1976) concluded that number of branches increased with successive levels of N application of 39.25 and 78.5 kg per hectare.

Increase in number of branches per plant was significant up to 120 kg N per hectare as stated by Bhan and Singh (1978). According to Bishnoi and Singh (1979), the dry matter accumulation per plant increased significantly with the increase in N levels.

However, pronounced effect of N on secondary branches was observed by Vidyapatroy et al. (1981). Investigations carried out by Chaiara and Damor (1982) reflected perceptible increase in number of primary and secondary branches with application of N upto 75 kg per hectare. Mohan and Sharma (1992) corroborated this view.

The remarkable increase in number of branches was reported by Mondal and Gaffer (1983). Maximum dry matter production was obtained with the application of 90 kg N per hectare (Antil et al., 1986). However, Samui et al. (1986) postulated that dry matter production increased with increasing levels of nitrogen upto 100 kg N per hectare in 1979-80 and upto 150 kg N ha in 1980-81. Increment in dry matter accumulation per plant with increasing levels of nitrogen was also observed by Mudholkar and Ahlawat (1981) and Upasani and Sharma (1986). Significant increase in dry matter plant was observed upto 75 kg N per hectare by Mohan and Sharma (1992). Dubey and Khan (1993a) noted significant increase in dry matter plant with successive doses of N upto 90 kg per hectare. Khanpara et al. (1993a) recorded significant increase in dry matter per plant at 60 kg N per hectare.

Increase in number of branches was observed up to 90 kg N per hectare by Kumar et al. (1988) and Bharadwaj (1991), where as it was confined to 40 kg per hectare only (Gangasaran and Giri, 1990). Joshi et al. (1991a) reported a significant increase in primary branches up to 45 kg per hectare but secondary branches were increased significantly upto 60 kg N per hectare, with each successive dose of nitrogen.
Khanpara et al. (1993a) concluded that both primary and secondary branches were significantly increased up to 60 kg N per hectare with their two years of experimentation. He also observed an increase in the plant height, number of primary branches and siliquae/plant, seeds/silqua and test weight with in levels.

Sharma (1994) summarized his findings on response of Indian mustard (Brassica juncea) to different irrigation schedules, nitrogen and sulphur levels that each successive increase in the level of N from 0 to 80 kg/ha significantly increased the growth characters, yield attributes, seed and stover yields and net income/ha. A two year field experiment was carried out by Tomar et al. (1997) on response of Indian mustard (Brassica juncea) to nitrogen, phosphorus and sulphur fertilization. It was observed that growth attributes (plant height, branches/plant, dry matter accumulation/plant) yield attributes (pods/plant, seeds/plant and 1000- seed weight) and seed and straw yield/ha increased significantly with increasing levels of N, P and S up to 180, 80 and 80 kg/ha respectively. The oil content decreased with increasing levels of N and P, whereas increased with increasing levels of S.

In a study on Indian mustard (Brassica juncea) in Harsi command area, Gurjar and Chauhan (1997) found that each successive increase in fertility level up to 100 kg N + 66.4kg P significantly increased the height, leaf nitrogen content, primary and secondary branches per plant.

Liao et al. (1998) found that plant N and K concentrations increased with N rate throughout growth while P concentration increased during early growth stages and decreased in later stages. In the study on mineral nutrition in hybrid rapeseed (Brassica napus) under different N rates, Patil and Shelke (1999) reported that the growth characters of mustard were increased by FYM at 5t/ha. These parameters were also increased significantly by increasing levels of phosphate up to 120 kg P2O5/ha.

Prakash et al. (2000) found that biomass accumulation was significantly higher at 120 kg N/ha at 60 DAS and 80 kg N/ha at harvest. Nanwal et al. (2000), in his investigation on response of Indian mustard (Brassica juncea) cultivars to nitrogen and Azotobacter under conserved moisture conditions observed increase in growth, seed yield and oil content with increasing N rate. Prakash et al. (2000) found that biomass accumulation was significantly higher at 120 kg N/ha at 60 DAS and 80 kg N/ha at harvest. Nanwal et al. (2000), in his investigation on response of Indian mustard (Brassica juncea) cultivars to nitrogen and Azotobacter under conserved moisture
conditions observed increase in growth, seed yield and oil content with increasing N rate.

Sumeriya et al. (2000) observed in a study to evaluate the effect of phosphorus, tricontanole granule and growth promoters on the productivity of mustard (Brassica juncea (L.) czern and coss) that application of phosphorus fertilizes at 60 kg/ha and triacontanol. Granules at 30 kg/ha significantly increased the growth parameters and yield forming characters in mustard. The highest number of siliquae per plant, seeds per siliquae and pod yield (342.5, 15.26 and 14.07 q/ha, respectively) were obtained with 60 kg P.

Bhari et al. (2000) concluded his three years experiment on response of Indian mustard (Brassica juncea) to nitrogen and phosphorus on Torripsamments of north-western Rajasthan that application of nitrogen up to 120 kg/ha and phosphorus up to 45 kg/ha resulted in significant increase in plant height, primary and secondary branches and siliquae per plant. It was also observed that the increased supply of P up to 45 kg P$_2$O$_5$/ha, the N need of the crop was raised up to 120 kg/ha for significantly higher seed yield (17.05 q/ha.) Irrespective of P application, the seed yield increased up to the application of 120 kg N/ha.

A field experiment was conducted at Jobner, Rajasthan by Jat et al. (2000) to assess the effect of different fertility levels on growth and yield of mustard (Brassica juncea, L. Czern and Coss) and it was concluded that application of 10t FYM + 30 kg N +20 kg P$_2$O$_5$/ha significantly increased the plant height, dry matter accumulation, number of primary and secondary branches, number of siliquae/plant, number of seeds/siliqua and seed yield over the control. Harvest index was not affected by FYM, N and P application.

A two year field experiment was conducted under rain fed conditions of Rajouri to study the response of rainfed mustard (Brassica juncea) to sulphur and phosphorus on Inceptisol in mid hill-intermediate zone of Jammu and Kashmir by Sharma and Jalali (2001). Rathod et al. (2001) in a study on physiological response of mustard to different levels of fertilizers under irrigated conditions found that fertility levels of 60:50 kg N and P$_2$O$_5$/ha significantly increased plant height, number of leaves and primary branches/plant, total dry matter production, leaf area and seed yield.

Rana and Pachauri (2002) reported that nitrogen showed favorable effect on growth and yield attributes, seed yield, oil yield and biological yield. They also observed that effect of nitrogen on these parameters was up to the highest in level.
Meena and Gupta (2002) conducted his study on effect of phosphorus and sulphur on growth, yield and quality of Indian mustard (Brassica juncea). They concluded that application of 40 kg P significantly increased plant height and secondary branches at harvest over lower levels (0 and 20kg/ha) whereas leaf area significantly increased up to 60kg P₂O₅/ha. They also found that increased levels of phosphorus up to 60 kg/ha significantly increased dry matter/plant, seed yield and oil yield over lower doses.

The effects of cropping systems (sole Indian mustard, Indian mustard + C. arietinum cv. KPG-59 at 2:6 or 2:8, and sole C. arietinum) and P rates (0, 30, 60 and 90 kg/ha through single superphosphate) on the performance of Indian mustard (cv. RK-8501) were studied in Kanpur, by Tripathi et al. (2005). Intercropping significantly enhanced the growth and yield attributes (number of branches per plant, number of siliques per plant, seed weight per plant) of Indian mustard over sole cropping. In general, the highest values of these parameters were obtained under a planting ratio of 2:8. Intercropping increased the mean seed yield per row but reduced the seed yield per hectare, especially at 2:8. The growth and yield parameters increased with the increase in the rate of P up to 90 kg/ha, although increases beyond 60 kg P/ha were not significant in most of the cropping systems. P at 30 and 60 kg/ha were on a par in terms of number of tertiary branches per plant, number of siliques in main shoots, and number of primary branches in 1999-2000, and number of secondary branches in 1998-99. The number of seeds per silique in main shoots and tertiary branches were similar under 30 and 90 kg P/ha in both years P at 90 kg/ha increased the mean seed yield by 27.9 and 6.5% over the control and 30 kg P/ha, respectively. Indian mustard was most responsive to P under intercropping at 2:6.

Yadav et al. (2005) recorded the highest seed yield of 24.51 and 21.25 q/ha was recorded with basal application of 66 kg P/ha (through DAP) and 30 kg S (through 1/2 gypsum+1/2 elemental S), which was at par with yield of 23.86 and 21.11 q/ha obtained with basal application of 66 kg P/ha and 30 kg S/ha applied both through the new multinutrient, Cargill product during, 2001-02 and 2002-03, respectively. Growth and yield attributes also responded in a similar manner. Hence, both the sources of P and S were equally efficient in respect of yield parameters and yield.

Sharma et al. (2005) observed that S application significantly increased the number of primary branches, number of siliques per plant, length of silique, and 1000-seed weight. Optimum seed yield (14.9 quintal/ha) was obtained with the application
of 65.0 kg S/ha. S application also increased the stover and total dry matter yields. The application of S up to 97.5 kg/ha increased the S uptake by seeds. The oil content of seeds increased up to 32.5 kg S/ha. The mean value of recovery on added S varied from 13.8 to 21.6% S use efficiency was higher with the lower rate of S.

Bhat et al. (2006) reported that application 100 kg N + 50 kg P/ha significantly improved all the parameters measured compared to the other treatments. Higher fertilizer rates also resulted in a significant increase in number of siliqua per plant, length of siliqua and number of seeds per siliqua, which consequently resulted in a marked increase in harvest index and seed yield of both the cultivars. Application of 100 kg N + 50 kg P/ha also resulted in an over all increase in leaf N, P and K contents and seed protein content. Oil content decreased with increasing N and P rates, although the extent of decrease in seed oil content was lower than the increase in seed yield and thus the total edible oil production was still higher with higher fertilizer rates compared to the normal recommended rates of the fertilizer.

Singh and Sinsinwar (2006) noted that the number of branches, 1000-seed weight, and oil content of Indian mustard, and yields of seed and straw increased significantly with the application of farmyard manure at 5 t/ha + Azotobacter chroococcum over the control. The application of nitrogen resulted in a linear increase in the afore mentioned parameters. up to 80 kg/ha.

2.6.2. Yield attributes

Results of Allan and Morgan (1972), Singh and Sharma (1982); Mondal and Gaffar (1983) revealed that nitrogen fertilization significantly improved the yield attributes viz. number of silique and seed weight per plant and test weight. In alluvial soils of Varanasi (U.P.) and Gwalior (M.P) yield attributes were improved up to 60 kg N/ha, as reported by Reddy (1985) and Bharadwaj (1991) respectively. Response of yield attributes to the same magnitude of N was corroborated by Tomar and Misra (1991) and Khanpura et al. (1993) in a clay loam soil. Apart from the above attributes, Prasad and Eshanullah (1988) identified significant increase in length of silique with the same level of N in a sandy loam soil.

When nitrogen application was combined with planting pattern the results changed (AICRPO, 1983-84). Higher grain yield of mustard was obtained at 30 x 15 cm planting and full dose of N at sowing.

Reddy and Sinha (1987) revealed that the yield attributes like number of silique and yield/plants were increased only upto 40 kg/ha. From same location,
Swamy and Bajaj (1988) noted response in yield attributes up to 100 kg N/ha in irrigated condition, but Gangasaran and Giri (1988) did not find any significant difference between 40 and 80 kg N/ha. Same authors in 1990 reported that under rainfed conditions number of pods were increased by 59.9 percent at 40 kg N/ha over control but not beyond this level. But seeds per silique and 1000 seed weight were improved and length remain unaffected or increased moderately only at highest level of N i.e., 80 kg/ha.

Studies conducted by Swamy and Bajaj (1988) in sandy loam soils of IARI, New Delhi revealed that the yield attributes like number of siliqueae and yield/plant increased only upto 40 kg/ha and noted response in yield attributes upto 100 kg N/ha in irrigated condition, but Gangasaran and Giri (1988) did not find any significant difference between 40 and 80 kg N/ha. Same authors in 1990 reported that under rainfed conditions number of pods were increased by 59.9 percent at 40 kg N/ha over control but not beyond this level. But seeds per silique and 1000 seed weight were improved and length remain unaffected or increased moderately only at highest level of N i.e., 80 kg/ha.

Chauhan et al. (1988), however, recorded no significant response in siliqueae length and seeds/siliqueae and test weight by N levels viz. 30, 60 and 90 kg/ha, but significant response was found in siliqueae per plant and seed yield per plant upto 60 kg/ha.

Though Singh and Dixit (1989) observed increase in yield attributes upto 120 kg, Bharadwaj (1990) found response upto 90 kg N/ha only. Choudhary and Bose (1986) obtained increase in siliqueae per plant and seed siliqueae upto 50 kg and seed weight upto 75 kg ha. Incremental doses of 30 kg N/ha was reported to increase siliqueae per plant, seed yield per plant over its lower doses upto 60 kg level and seed siliqueae upto 90 kg/ha. Nitrogen levels did not affect 1000-seed weight (Kumar et al. 1988). Similarly Joshi et al. (1991) that siliqueae per plant, seeds per siliqueae were significantly affected by N application upto 60 kg/ha and 45 kg/ha, respectively and 1000-seed weight was not found significant. Singh and Singh (1991), however reported significant increase in seed yield per pant and 1000-seed weight due to N application up to 120 kg/ha. On the other hand, no noticeable influence on 1000-seed weight and seed number per siliqueae has been obtained by Mudholkar and Ahlawat (1981), Vidyapatroy (1981) and Rathore and Manohar (1989 and 1990).
Though Singh and Dixit (1989) observed increase in yield attributes upto 120 kg, Bharadwaj (1990) found response upto 90 kg N/ha only. Chowdhary and Bose (1986) obtained increase in siliqueae per plant and seed siliqueae upto 50 kg and seed weight upto 75 kg ha. Incremental doses of 30 kg N/ha was reported to increase siliqueae per plant and seed yield per plant over its lower doses upto 60 kg level and seed siliqueae upto 90 kg/ha. Nitrogen levels did not affect 1000-seed weight (Kumar et al. 1988). Similarly Joshi et al. (1991a) observed that siliqueae per plant, seeds per siliqueae were significantly affected by N application upto 60 kg/ha and 45 kg/ha, respectively and 1000-seed weight was not found significant. Singh and Singh (1991), however reported significant increase in seed yield per plant and 1000-seed weight due to N application upto 120 kg/ha.

Nitrogen upto 75 kg/ha did not increase 1000-seed weight but further increase in level of 100 kg/ha decreased it significantly. Siliqueae per plant, length of siliqueae and seed per siliqueae were found to be increased significantly upto 75 kg/ha, an experiment with two irrigation at 30 DAS at Satour, Bihar (Mohan and Sharma, 1992).

From various investigations carried out, a general trend of increase in yield attributes like number of siliqueae per plant, seed weight per plant, and seed weight per plant is discernible with N application. But no clear picture can be visualized by the results seen on 1000-seed weight, number of seeds per siliqueae and siliqueae length due to the nitrogen application.

A two year investigation on effect of sulphur and nitrogen on yield attributes and seed yield of Indian Mustard (Brassica juncea) on vertisol was carried out by Khanpara et al. (1993), which indicated that N @60kg/ha significantly improved the yield parameters viz. siliqueae per plant, seed yield per plant and 1000 seed weight during both the years. Thakur (1999), in his study on response of promising varieties of Indian Mustard (Brassica juncea) to nitrogen and spacing under midhills, rainfed conditions of Himachal Pradesh observed significant increase in all yield attributes and yield up to 60 kg N/ha. While discussing the effects of nitrogen levels and row spacing on growth and yield of rainfed Indian Mustard (Brassica juncea) Sahoo et al. (2000), in an experiment on influence of spacing regimes and nitrogen levels on yield and quality of mustard cultivars, observed that increase in N rate from 25-75 kg/ha decreased the oil content but increased the oil yields. While both protein content and protein yield increased significantly with higher N rates.
Dubey and Khan (1993) reported that nitrogen up to 90 kg/ha significantly increased the seed and oil yield. They also found that N had adverse effect on oil content. Kakati and Kalita (1996) observed in his investigation that all the yield attributes and yield were increased with levels of N over no N. However oil content is seeds decreased. Significant response was observed up to 75 kg N/ha.

Narang et al. (1993) revealed that the highest seed yield of 16.9 and 14.0 q/ha in 1987 and 1988, respectively were obtained at 60 kg P/ha which was significantly more than 20 and 0 kg P/ha. Oil and protein contents of toria increased significantly up to 40 kg P/ha in both the years.

Arthamwar (1996) found that each higher level of N significantly improved all the yield attributes and seed yield in seed due to N level from 0 to 100 kg/ha. Similarly every increase in the level of phosphorus significantly improved all the yield attributes, seed yield oil content and oil yield of Indian mustard. But the highest yield was recorded with 100 kg N at 80 kg P₂O₅. N and P uptake also increased with increasing N and P rates. Sadhu et al. (1997) observed that each successive increase in fertilizer level from control significantly increased growth; yield attributes and yields of Indian mustard up to recommended dose but decreased the oil content in seed. Manuring with FYM also significantly increased yield attributes and yield of mustard.

Sugawe et al. (1996) observed that application of 120 kg N produced the highest oil yield (0.78 t/ha) and seed protein content (21.35%). Dubey and Khan (1993) reported that N up to 90 kg/ha and S up to 30 kg/ha significantly increased the seed and oil yields, but N had adverse effect on oil content. Charjan (2000) in his investigation on response of Indian mustard to irrigation schedules under varying levels of nitrogen and sulphur, observed that 0.92 t/ha seed yield was recorded at 60 kg N/ha.

Increasing levels of N decreased the oil content while application of S increased the oil content. Almost the same result was reported by Sharma et al. (1997) who also reported that seed yield increased with up to 60 kg N/ha. N application decreased seed oil content and increased seed protein. Deekshitulu et al. (1998), in a study on effect of nitrogen and sulphur on seed yield, oil content and oil yield of Indian mustard found that seed and oil yield increased with increasing N and S rates. Deekshitulu and Subbaiah (1997) reported that the number of siliqua/plant, 1000-seed weight and seed N uptake increased significantly up to 100 kg/ha. The highest seed yields were realized at higher dose of N (150 kg/ha) and S (50 kg/ha).
Kumar et al. (1997) summarized his research on leaf area index relationship with solar radiation interception and yield of Indian mustard (Brassica juncea) as influenced by plant population and nitrogen and indicated that maximum LAI, SRI, and dry matter were obtained with 150 kg N/ha.

Jaggi and Sharma (1997) concluded that Indian mustard responded up to 26.2 kg/ha for both seed and straw yields. Maximum seed (21.5 q/ha) and straw (69.0 q/ha) were recorded from treatment combination of P 26.2 + S 90 kg/ha. S and P uptake by seed and straw and seed + straw significantly increased up to 30 kg S/ha and 26.2 kg P/ha.

In a field experiment conducted by Velichka et al. (1998) at Ludhiana during 1991-1995 revealed highest yields of rapeseed (2.85 t/ha, an increase of 1.69 t/ha over control) with 180 kg N. Oil content was decreased by 2.84% but raw protein increased by 1.97% due to 180 kg N/ha. Prakash et al. (1999) tested nitrogen doses on three Brassica species which showed a quadratic response in Brassica juncea and significant response was observed up to 80 kg N/ha.

Singh et al. (1998) found that uptake of N, P$_2$O$_5$ and K$_2$O in seed and stalk significantly increased with increasing N rates from no nitrogen to 80 kg N/ha. Maximum water use efficiency and net returns were also recorded with 80 kg N/ha. Seed yield increased with increasing N rates from no nitrogen to 80 kg N/ha. Maximum water use efficiency and net returns were also recorded with 80 kg N/ha. Seed yield increased with N rates and was not affected by cultivars.

Singh and Singh (1998) concluded an investigation on performance of rain fed Indian mustard (Brassica juncea) at varying levels of nitrogen and reported that increasing levels of N significantly enhanced the seed yield, water use efficiency, oil content and yield as well as nutrient content and uptake. In a field experiment on effect of levels of irrigation, nitrogen and jalaashakti on growth and yield of Indian mustard (Brassica juncea). Padmani et al. (1994) found that seed and stover yields of Indian mustard as well as leaf area index, net assimilation rate and crop growth rate increased with increasing levels of irrigation and nitrogen.

A study was conducted in Western Australia to compare the response of grain legume, wheat and canola to application of sulphur phosphate by Bollard and Siddique (1999) and found that canola and wheat produced very large yield response to increasing application of current P. A field experiment carried out at IARI, New Delhi by Garnayak et al. (2000) revealed that N application significantly increased the
biomass up to 120 kg/ha but yield attributes, seed and oil yield as well as uptake of nutrients were increased only up to 80 kg/ha. Oil in seed decreased due to N application up to 40 kg/ha. Response to applied N was quadratic in *Brassica juncea* but linear in *Brassica carinata*. Padmani *et al.* (1992) concluded the findings on effect of irrigation and nitrogen on yield and yield attributes of mustard (*Brassica juncea*) that response of N was positive up to 60 kg N/ha.

Patel (1999), in his investigation on effect of irrigation and nitrogen on mustard recorded the seed yield of 0.43, 0.73, 0.95 and 1.21 t/ha with 0, 20, 40 and 60 kg/ha, respectively. Phenology and physiology of *Brassica* genotypes with nitrogen levels on aridisols was studied by Kumar *et al.* (1999) during winter season of 1992-93 and 1993-94 at Hisar.

Results revealed that phenological development was delayed by increasing N rate while LAI, while growth rate and seed yield were increased in *Brassica juncea* cultivars. Meena *et al.* (2002) reported that the application of 60 kg N/ha being on par with 90 kg registered significantly higher seed and stover yield of mustard over control and 30 kg N/ha. Almost the same results were noticed by Meena *et al.* (2001), which indicated that seed and stover yields, N uptake by seed and stover and P uptake by stover increased with increasing N rates up to 60 kg/ha. They further reported that progressive increase in P uptake in seed and total N uptake of the crop was observed with increasing N rates up to 90 kg/ha. The highest N content of the seed was obtained at 90 kg/ha. N recovery decreased with increasing N rates.

A study was undertaken by Rana *et al.* (2002) to evaluate the effect of nitrogen alone or in combination with *Azotobacter* on the growth and yield of mustard under dryland conditions. They observed that N level alone or in combination with *Azotobacter* recorded significantly higher seed yield as compared to control. Jena *et al.* (1998) in a study on response of mustard (*Brassica juncea*) varieties to nitrogen, observed highest seed yield (1.18 t/ha) was with 120 kg N/ha. Singh *et al.* (1997) observed higher yield with 125 or 150 kg N/ha than 100 kg N/ha.

Meena and Sumeriya (2002) concluded that application of 60kgN/ha proved economically viable. Brar *et al.* (1998) obtained significant increase in growth and yield attributes along with seed, oil and straw yields up to 200 kg N/ha.

Poonia *et al.* (2002) in a study on effect of levels and sources of phosphorus on yield and nutrient of mustard (*Brassica juncea* L.) found that the application of phosphorus through DAP at 40 kg P₂O₅/ha significantly increased the seed (16.92 q/ha)
and oil yield (6.54 q/ha) over 20 kg P₂O₅ but was at par with 60 kg P₂O₅. A field experiment was conducted during early winter season of 1987 and 1988 to study the effect of P and S on growth and yield of toria (Narang et al., 1993) and it was concluded that the highest seed yields of 16.9 and 14.0 q/ha, respectively were obtained with P @ 60 kg/ha which were significantly more than 20 and 0 kg P/ha. They also found that oil and protein content of toria increased significantly up to 40 kg P/ha in both the years. They concluded that P also enhanced the grain and straw yield. However, the significant effect of P application was up to 40 kg P/ha. It was also observed that application of P decreased the oil content which ranged between 39.80% at 0 level of P and 39.35% at 60 kg P while oil yield increased significantly.

A field investigation by Punia et al. (2002) on varietal response of mustard to phosphorus fertilization on vertisols of Rajasthan revealed that application of 40 kg P₂O₅/ha was significantly superior to 20 kg P₂O₅ with respect to seed yield per plot and number of siliquae/plant, the per cent increase was 7.7 and 9.9%, respectively. They also found that significantly higher seed yield with application of 40 kg P₂O₅/ha (16.9 q/ha) compared to 20 kg P₂O₅/ha (14.4 q/ha) which was at par with 60 kg P₂O₅/ha. The application of 40 kg P₂O₅/ha produced the highest oil yield of 6.5 q/ha, which was 18.2 and 10.2% more over 20 and 60 kg P₂O₅/ha, respectively. Ram and Pareek (1999) reported that application of 15 kg P₂O₅/ha significantly increased plant height, dry matter accumulation, number of siliquae/plant, seeds/siliqua, test weight over control but the number of primary and secondary branches was higher with 30 kg P₂O₅/ha, respectively. They also reported that seed and straw yields were increased by 30 kg P₂O₅/ha, compared with 15 or no P.

Mina and Manohar (2002) concluded the study on effect of phosphorus and zinc on yield and quality of mustard (Brassica juncea) in loamy sand soil and reported that phosphorus application brought about 5-12% enhancement in seed yield and 6-15% increase in oil yield of mustard. The results also indicated that application of all the levels of phosphorus and zinc progressively increased number of siliquae/plant, seed yield, stover yield, oil yield, test weight, oil and protein content in seed of mustard. But increase in number of siliquae/plant, seed yield, stover yield and oil yield were found to be significant up to 60 kg P₂O₅/ha and 5 kg Zn/ha.

Singh and Kumar (2002) reported that nutrients applied at recommended fertility levels produced higher seed yield over all treatments. In an experiment conducted by Choudhary et al. (2002) on effect of varying levels of fertility on growth
and yield of *Brassica* spp. under rainfed conditions of North Western Himalayas revealed that the magnitude of increase in seed yield with application of 150 kg N + 80 kg P₂O₅ + 60 kg K₂O/ha over control, 50 kg N + 40 kg P₂O₅ + 30 kg K₂O/ha and 100 kg N + 60 kg P₂O₅ + 45 kg K₂O/ha was 208.9, 88.9 and 10.6 percent, respectively.

Singh (2002) observed in his field experiment conducted in Azamgarh, UP during *rabi* 1998-99 and 1999-2000 to investigate the effect of different levels of N and P on yield, yield components and oil content of mustard that application of N and P increased the length of silique, number of siliqueae/plant, seeds/silique, seed yield and 1000-seed weight. The medium seed yield was recorded from 45 kg P/ha (11.43 and 13.85 q/ha) and 120 kg N/ha (12.98 and 13.83 q/ha) in 1999 and 2000, respectively.

Nepalia and Daniel (2002) conducted an experiment on effect of agrichemicals and NPK fertilization on growth and yield of Indian mustard (*Brassica juncea*) and found higher dry matter yield with combined application of NPK. Highest seed yield (20.88 q/ha) was obtained by collective application of NPK, which was 49.9% higher than unfertilized control.

Singh and Singh (2005) reported that the seed yield of Indian mustard significantly increased with increasing levels of applied N, S and Zn. Nitrogen application increased the mean seed yield by 36.2%, but decreased the oil content by 0.5% from the control. Sulfur application increased the mean seed yield and oil content by 35.6 and 6.3% and zinc application increased 12.0 and 0.7%, respectively over the control. Nitrogen, S and Zn application increased significantly the protein content in seeds.

Giri *et al.* (2005) recorded significantly more seed yield (13.47 q ha⁻¹) as compared to other levels of phosphorus. Similarly, application of 60 kg S ha⁻¹ produced significantly higher seed yield. However, interaction effects between P₂O₅ and S application were not significant.

### 2.6.3. Yield

Observed that seed yield and seed protein content increased with increase in the rate of N and S. Whereas seed oil content decreased with rate of N application. The highest net income and benefit: cost ratio were observed with 80 kg N/ha and 60 kg S/ha, respectively. The finding was very much similar to the findings of Uttam *et al.* (1997) who also reported that yield, net return and cost: benefit ratio increased up to 60 kg N/ha. Joshi *et al.* (1998), in a study on effect of nitrogen and sulphur application on
yield and fatty acid composition of mustard (*Brassica juncea* L.) oil found that application of N up to 60 kg/ha and S up to 40 kg/ha increased yield.

A field experiment was conducted at Gwalior by Bhadoria and Chauhan (1994) to study the effect of fertilizer and weed control in mustard cv. Varuna. It was concluded that fertility levels markedly affected the number of leaves, secondary branches, Siliquae/plant, and 1000-grain weight. Seed yield was higher with 75 + 45 kg of N + P₂O₅/ha, respectively. To explore the possibilities of raising their yields through increased fertilizer use, location trials were conducted on farmer’s fields for 4 years in Ghaziabad district by Singh *et al.* (1994). Results revealed that 90 kg N + 90 kg P₂O₅/ha + 60 kg K₂O/ha for Indian mustard would be optimum fertilizer level to get higher productivity and net return in inceptions of western UP. Nitrogen up to 75 kg/ha did not increase 1000-seed weight but further increase in level of 100 kg/ha decreased it significantly. Siliquae per plant, length of siliquae and seed per siliquae were found to be increased significantly up to 75 kg/ha, an experiment with one irrigation at 30 DAS at Sabour, Bihar (Mohan and Sharma, 1992). Jaggi (1998) summarized the findings on Indian mustard (*Brassica juncea*) that 30 and 60 kg P₂O₅/ha increased the seed yield by 36 and 82%, respectively. This finding was further supported by Jaggi and Sharma (1999). They found that seed and oil yield increased significantly with application of S and P₂O₅ up to 60 kg/ha.

In the hill zone of Assam, Sarma *et al.* (1999) reported that seed yield increased significantly up to 60 kg N/ha which gave the highest benefit: cost ratio. Almost the similar results were reported by Sugaw and Shelke (1999) who concluded that optimum N level was 115 kg/ha at current price structure.

An experiment was conducted by Patel and Shalke (1999) to study the effect of FYM, phosphorus and sulphur on yield attributes, yield, quality and net return of mustard. They observed that application of phosphorus significantly increased the yield parameters, seed and stover yields, oil and protein content and net return up to 80 kg P₂O₅/ha. Patel and Shelke (1998) reported higher value of yield components, oil and protein contents with higher dose of FYM and increasing level of P. Net return was highest with 80 kg P/ha.

Maurya *et al.* (2002) found in his investigation on effect of integrated nutrient management in Indian mustard (*Brassica juncea*) that NPK fertilizers @ 90 + 45 + 30 kg/ha through inorganic fertilizers along with 6 tonnes FYM was optimum for obtaining higher yield and net returns.
From various investigations carried out, a general trend of increase in yield attributes like number of siliquae per plant, seed weight per plant, and seed weight per plant is discernible with N application. But no clear picture can be visualized by the results seen on 1000-seed weight, number of seeds per siliquae and siliquae length due to the nitrogen application.

Sah et al. (2005) noted that siliquae per plant, siliqua length and seed yield per plant increased significantly up to 120 kg N/ha and seeds per siliqua and 1000-seed weight up to 80 kg N/ha. The seed yield increased significantly up to 120 kg N/ha, whereas the harvest index only up to 80 kg N/ha. The yield attributes and yields increased significantly with the increasing levels of P and S up to 40 kg/ha. A non-significant effect on harvest index was recorded with the application of P and S.

2.6.4. Nutrient uptake and quality

Singh and Kamath (1991) reported that application of 90 kg P₂O₅ slightly reduced yields in all crops compared with 60 kg. Percentage P utilization decreased with increase in P application and was 12.2-23.0% in *B. juncea*, 6.0-13.7% in safflower and 8.3-18.2% in chickpeas. P uptake at maturity was highest in *B. juncea* followed by chickpeas and safflower.

Maliwal et al. (1998) conducted the investigation in response of mustard (*Brassica juncea*) to irrigation and fertilization and reported that mean highest yield with highest fertilizer rates.

Puri et al. (1999) observed significant influence of varying degree of soil fertility status on nutrient concentration (N&P) and oil content in mustard seed in vertisols. They also recorded that removal of major nutrients was significantly affected by fertilization. The N and P content in seed, total removal of nutrients (NPK), seed yield and oil content were significantly affected by levels of fertilizers (NPK). The highest seed yield of 16.8 q/ha and oil content of 39.72% were noticed in the treatment with 100:40: 20 kg NPK/ha.

Qian and Schocau (2000) reported from Sasakatoon, Canada that addition of pig manure and urea enhanced canola P accumulation and led to higher P in seeds. Application of urea significantly increased N supply rates, but led to slight decrease in measured soil supply rate of available P. A study on effect of nitrogen fertilizer on concentration of real protein in canola (*Brassica napus*) seed was carried out in West Australia by Brennan et al. (2000). They revealed increase in rate with increase in N rate. Percentage oil was not correlated with seed yield, although oil yield increased in
(10.6%), uptake of P (8.3%), S (7.30%) and B (14.3%), and net returns (13.9%) and benefit:cost ratio (4.8%).

Mehdi et al. (2006) recorded that nitrogen and sulphur content decreased, whereas nitrogen and sulphur uptake increased with the growth of the crop but increased with increasing rates of sulphur during harvest. Seed oil content and yield, and protein yield increased with increasing rates of sulphur, whereas sulphur and protein contents of the seeds increased with increasing rates of sulphur up to 60 kg/ha and decreased thereafter.

Kumar et al. (2006) found that application of 40 kg S/ha gave the highest seed yield (18.37 g/ha), which was 28.1% more in comparison with that of the control. The uptake of S significantly increased up to 40 kg S/ha and 40 kg/ha. Oil content increased significantly with S addition. The added S was utilized maximum under application of the lowest levels of S.

Sah et al. (2006) recorded that plant height and primary branches per plant increased significantly up to 80 kg N/ha, while secondary branches, dry matter per plant and leaf chlorophyll content increased up to 120 kg N/ha. Application of P up to 60 kg/ha significantly enhanced dry matter per plant. On the other hand, plant height, branches per plant and leaf chlorophyll content increased significantly only up to 40 kg P/ha. All growth attributes increased significantly only up to 40 kg S/ha. The results showed that the uptake of NPK and S by both seed and stover increased significantly with successive increase in nitrogen levels up to 120 kg N/ha, sulfur levels up to 60 kg S/ha, and phosphorus levels up to 60 kg P/ha.

2.6.5. Economics

Kantwa and Meena (2002) in their study on water use efficiency, yield and net return of mustard (Brassica juncea) concluded that 45 kg P₂O₅/ha and seed inoculation with PSB produced significantly higher seed yield of 20.02 and 19.24 q/ha and net return of Rs. 15,328 and Rs. 14,635, respectively as compared to lower levels.

Kumar and Gaur (2002) reported that application of 45 kg along with 30 kg P₂O₅/ha and 60 kg S/ha was found remunerative for taramira (Eruca sativa) under rainfed conditions.

Singh et al. (2005) resulted in the highest values of produce cost (Rs. 24,299 and 24,962/ha), net returns and benefit:cost ratio with 75% fertilizer + FYM @ 6t/ha.
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