2. REVIEW OF LITERATURE

The review of literature pertaining to the studies presented and discussed in this dissertation is broadly covered under the following heads:

2.1 Relative performance of pigeon pea varieties
2.2 Plant population studies
2.3 Phosphate fertilization
2.4 Crop rotation

2.1 Relative Performance of Pigeon pea Varieties

Though arhar occupies an important place in the dietary preparations, its production technology has not received adequate attention because the prevailing varieties were of long duration and had low yield potential. These varieties suffer a great setback during reproductive phase on account of inadequate moisture supply and frost occurrence, resulting in poor seed setting and consequently the productivity is reduced substantially (Singh, 1973).

Continuous efforts of the plant breeders resulted in the simultaneous development and release of short duration high yielding varieties of arhar. Consequently it has upgraded the status of arhar among kharif crops of the country. Variety 'T-21' was the first short duration variety released in 1961 from Kanpur (U.P.) with reasonably good yields and allowing the farmer to take a succeeding rabi crop (Pathak and Singh, 1961). This was followed by 'Pusa Ageti' (AS-5), 'sharda'
(AS-8) and 'Mukta' (R-50) which mature in about 160-170 days. The encouraging performance of these varieties was reported by Jain (1969, 1970, 1971), Singh (1970) and Ramanujan (1972a,b). Subsequently several extra early maturing varieties viz. 'Prabhat', 'UPAS-120', 'BS-a', 'Pant-A-3', 'Pant-A-1' and 'Co-1' have been identified at various centres of All India co-ordinated Pulse Improvement Project. These varieties mature in 110-150 days and their plants are so compact that they provide ample opportunity for increasing the plant-density and thereby the yield per unit area (Swaminathan, 1974; Lal 1976).

Ram and Giri (1973) working at IARI, New Delhi did not notice significant difference in yield of four pigeon pea varieties namely 'Pusa Ayeti', 'Sharada', 'Mukta' 'AS-3'. Saxena (1974) and Saxena and Singh (1976) obtained significantly higher grain yield of 'UPAS-120' than Prabhat under Pantnagar conditions. Further trials conducted at same location by Saxena et al. (1974) revealed that among the eight varieties (T-21, 'Prabhat', 'S-1', 'UPAS-120', 'BS-1', 'Pant-2', 'Pant-1' and 'DL-74-1') tested, 'T-21' outyielded all the varieties followed by DL-74-1' and 'BS-1', 'S-1' the lowest yielder was at par with 'Pant-2', 'Pant-3' and 'Prabhat'. Saxena et al. (1974) also reported from another experiment that among the four varieties ('UPAS-120 'S-1', 'S-2' and 'Prabhat'), 'UPAS-120 produced highest yield; and 'Prabhat' was earliest to mature. However, the differences in yield among the varieties were not significant. Experiments
conducted at other locations also indicated that 'Prabhat' was the lowest yielder (Panwar, 1974; Singh and Bhola, 1975; Raikhekar, 1976; Ahlawat, 1976).

Rao (1977) reported that 'T-21' outyielded 'BS-1' and 'Prabhat' by 89 and 661 kg/ha, respectively; 'Prabhat' had the highest seed protein content. Tiwari et al. (1977) reported that spreading type cultivars like 'Gwalior-3' and local, yielded significantly more (1.33 and 1.22 t seed/ha respectively) than the semi-compact types (675-804 kg/ha) at all row spacing and also had more primary and secondary branches, spread, pod number per plant and seed yield per plant. Singh (1978) obtained the highest yield of variety 'BS-1' (21.43 q/ha) comparing the other two varieties namely, 'Prabhat' (15.9 q/ha) and 'UPAS-120' (18.92 q/ha) under rainfed conditions at IARI, New Delhi. Faroča and Singh (1980) reported that on an average the genotype 'UPAS-120' was most suitable under Haryana conditions. When sown in July, 'UPAS-120' was the best, closely followed by 'Prabhat'. 'Pant A-2' gave the lowest yield. Chauhan and Singh (1981) while comparing three varieties ('Fusa Ageti', 'T-21' and 'Sharda') at R.B.S. College research farm, Bichpuri (Agra) obtained maximum grain yield of 11.24 q/ha with 'Fusa Ageti' being significantly higher than 'Sharda'. Yaseen (1981) reported that 'ST-1' among
the medium duration and 'T-21' and 'UPAS-120' among the short duration varieties proved promising.

One of the reasons often cited the low yields of pigeonpea is the lack of improved genotypes available to the farmers (Singh, 1982). Farmers generally grow land races of medium and late maturing types that are suitable for a single cropping sequence only. These genotypes incur greater risks of being exposed to abiotic stresses such as frosts and droughts. Moreover, they do not fit in to intensive cultivation systems e.g. in rotation with wheat in Northern India. In keeping with the changing requirements of pigeonpea cultivation, a number of short duration genotypes have been developed in India (AICRP, 1986) and elsewhere (e.g., Hunt, Quantum, and Quest from the University of Queensland, Australia).

Tripathi and Chauhan (1990) observed at R.B.S. College, Bichpuri, Agra that the per plant yield and the yield attributes were significantly higher with variety UPAS-120 followed by ICPL-87 and C-11, which also differed significantly from each other. Similar observations were recorded by Singh and Prasad (1987).

Dubey and Upadhyaya (1991) reported from Dindori (M.P.) that 'Prabhat' and 'UPAS-120' were significantly superior to 'Local' for branches/plant and pods/plant whereas 'UPAS-120' and 'Local' were superior to 'Prabhat' for plant height. 'Prabhat' and UPAS-120 produced significantly higher grain and stalk yields than 'Local' variety and also had signi-
ficantly higher harvest index than 'Local' during 1986.

2.2 Plant Population Studies

A variety would perform better only when it is provided with optimum environmental conditions. Amongst the controllable environmental components the establishment of adequate plant population is most important so that the full yield potential of a genotype could be realized. This is also important to realize that plant population should be defined not only in terms of the plants per unit area i.e. Plant density but also in terms of arrangement of these plants in the field viz. row and plant spacing.

2.2.1 plant-density and rectangularity - the concept

Increased plant-density results in enhanced competition among the plants for nutrients, water, light oxygen and CO₂. One would like to define the relationship between plant population and crop yields to evaluate such characteristics as optimum planting density and maximum yield. This relationship is of two types: an asymptotic one, where, with increase in density, the yield rises to maximum and is then relatively constant at high densities; and a parabolic one where, yield rises to a maximum but
then declines at high densities. The total crop dry matter or vegetative part of the crop confirmed to an asymptotic relationship (Donald, 1951 and 1954; Warne, 1951; Holliday, 1960a and Saunt, 1960) and reproductive forms of yield (i.e. grain and seeds) to a parabolic relationship (Engledow, 1925; Hudson, 1941; Krantz, 1949; Lang et al., 1966; Holliday, 1960b and Willey, 1965).

The plant population should be defined not only in terms of the number of plants per unit area (i.e., plant density) but also in terms of rectangularity (arrangement of the plants on the ground). Because the yield per unit area is dependent not only on the plant density, but also on plant rectangularity.

Harvey et al. (1958) observed that yield per unit area declined gradually when rectangularity increased by way of either increasing the seed rate or row distance. Similar findings were also reported by Weber et al (1966) in Soybean and Manjhi (1971) and Singh (1973) in pigeon pea. Reynolds (1950) working on peas also noticed that as the rectangularity increases, the optimum density may decrease.

In most of the plant population experiments, combined effect of both have been studied and this is certainly the case where varying populations have been studied at
a constant row spacing. In row crops, plant rectangularity may be defined as the ratio of distance between plants within the row (intra-row spacing) and distance between rows (inter-row spacing) (Willey and Heath, 1969).

It would thus be desirable that equation describing the relationship between plant population and crop yield should be able to describe the effect of rectangularity as well as those of density. Monga and Gautam (1970) noted that grain yield and yield components reduced if the planting arrangement approached towards extreme rectangularity. The plant growth is adversely affected on account of increased inter-plant competition when the plant density increases and area per plant decreases. Similar observations were also noted by the other workers (Salisbury, 1942; Donald, 1963 and Holliday, 1963).

2.2.2 Effect of plant population/row spacing on growth and yield components

Wilsie (1935) working under Hawaii conditions, observed that densely planted plants of pigeon pea became slender and grew straight with poor branching, whereas properly spaced plants were bushy with profuse branching. Hammerton (1971) tried 14 plant densities in the range of 47,900-40,000 plants per ha (0.21-2.32 m²/plant) under West Indies conditions and found that planting densities had no effect on yield components except pod yield per
plant which increased with increase in area per plant. Plants were taller under higher plant populations. Abrams and Julia (1973) also obtained similar results with 'kaki' variety under Puerto Rice conditions.

Saxena (1969) observed that pods per plant and grains per pod reduced with the increasing plant population from 30,000 to 50,000 plants per ha under Pantnagar conditions. The growth attributes i.e., plant height and branches per plant, however, remained unaffected by various plant population.

Higher plant population densities resulting from closer row spacing decreased the number of pods per plant and tended to decrease the straw-grain ratio of arhar (Anonymous) 1969). Singh (1969) observed that increase in plant population decreased dry matter per plant, stem thickness, number of branches, number of pods per plant and seed size, increased plant height, internodal length and height of the first production node but did not affect the number of seeds per pod. Gupta (1970) also reported that the individual plant productivity gradually decreased with the increasing plant population from 40,000 to 60,000 plants per ha. Singh et al. (1971) found that plant height was not affected by row spacing.

At I.A.R.I. New Delhi, Manjhi (1971) observed that plant height increased with the increase in plant population from 50,000 to 75,000 plants per ha. On the other hand
lower plant population of 50,000 plants per ha produced more branches and dry matter per plant. The total dry matter production on area basis was, however, significantly higher with higher plant population. Pods and grain weight per plant decreased with increased plant population. Singh (1973) observed an inverse relationship between plant population and branches per plant as well as dry matter production and per plant and this relationship was more evident at later stages of crop growth. The yield components viz., pods per plant, grains per pod and test weight had together values with medium plant population of 75,000 plant per ha. He concluded that decrease in these yield components was the result of increased inter-plant competition due to high plant-populations. The productivity per plant was higher with lowest plant population of 50,000 plants per ha. Ahlawat et al. (1975a) while studying the effect of plant population of three pigeon pea varieties, observed that plant population of 100,000 plants per ha produced significantly less number of pods per plant as compared to 66,666 plants per ha. Plant height, branches per plant and test weight, however, remained unaffected due to two plant population.

At Akola, plant height of pigeon pea varieties BS-1 UPAS-120 and prabhat continued to decrease when the row spacing was increased from 25 to 75 cm (AICPIR, 1977-78). In another study at the same location, more pods per plant were recorded with wider row spacing of 90 cm as compared to 75 and 60 cm row spacing (AICIP, 1977-78).

Chauhan and Singh (1981) reported lower number of branches per plant at a closer row spacing of 40 cm. Wider
row spacings of 60 and 80 cm recorded higher test weight.

Sandhu et al. (1981) recorded a significant increase in number of grains per plant with the reduction in plant population.

Masood Ali (1981) working at IGARI, Jhansi observed that plant types and row spacing was significant for number of pods/plant. At 60 cm row spacing cv Hy. 1 produced significantly more pods (104.7) than that at 45 cm where as cv Pusa ageti did not respond to it. Singh et al (1983) reported from LARI, New Delhi that row spacing of 50 cm produced significantly more dry matter/plant than 37.5 cm which in turn produced more than 25 cm. They further reported that inter plant competition was less in wider row spacing and resulted in more LAI and foliage giving higher dry matter accumulation. Ahlawat and Saraf (1983) observed that the dry matter/plant was adversely affected with increasing densities (50 x 10^3, 100 x 10^3, 150 x 10^3).

Ahuja (1984) working at R.B.S. College, Bichpuri, Agra (U.P.) reported that the number of branches/plant decreased with the increase in plant density. The number and weight of pods/plant and 1000 grain weight were also adversely affected with increasing plant densities. Similar results were obtained by Ahlawat and Saraf (1981).

Gondalia et al. (1988) reported from G.A.U. Jungadh (Gujrat) that an inter row spacing of 45 cm increased growth
and yield attributes viz.: plant height, plant spread, number of branches/plant, number of pods/plant and grain weight/plant.

Shankeraling appa and Hegde (1989) reported that days to 50% flowering and days to maturity were not significantly influenced by plant population tested (55, 555 and 74,000 plants/ha) under Nagamangala conditions. Further, they observed that plant height increased significantly with higher plant population (74,000 plants/ha).

Singh et al. (1989) reported from B.C.K. Visva Vidyalaya, Kalyani (West Bengal) that row spacing tested (30, 50 and 70 cm) had significant effect on pods/plant and 100 seed weight.

Tripathi and Chauhan (1990) reported from R.B.S. College, Bichpuri, Agra that plant population exerted a significant influence on various growth and yield attributes except the plant height and secondary branches/plant.

Dubey and Upadhyaya (1991) observed at Lindori (M.P.) that row spacing influenced significantly yield attributing characters like plant height, branches/plant and pods/plant where as grains/pod, grain weight/plant and test weight were not affected by row spacing.

2.2.3 **Effect of plant population/row spacing on grain yield**

Wilsie (1935) did not find any difference in yields
of pigeon pea with two row spacings of 150 cm and 170 cm but spacing wider than 170 cm reduced the yield.

Riollano et al. (1962) working at Isabela Agricultural Sub-station, Puerto Rico found no difference in grain yield with three row spacings of 60, 90 and 120 cm. Under similar conditions, Abrams and Julia (1973) reported that the row spacings of 91.4 cm gave more yield of fresh pods of pigeon pea cv. Kaki than 121.9 and 182.8 cm spacing.

Derieux (1968) working under West Indies conditions tried three spacing pattern (1m x 1m, 1m x 0.5m and 0.5m x 0.5m) with two varieties, namely, GI 54/4 from Trinidad and 208066 from Pakistan and concluded that closer row spacing tended to increase the grain yield. Hammerton (1971) also from Trinidad (West Indies) reported that yield per plant increased linearly with an increase in area per plant in the range of 0.21 to 2.32 m. Under similar conditions, Spence and Williams (1972) reported that dwarf cultivars planted in December with higher plant densities (165,000 plants/ha) gave satisfactory yields (2.5 tonnes/ha) reduced plant height at harvest to about 1m. Grain yield was comparable with those obtained with larger duration cultivars planted at 6,600 plants/ha.

Under Indian conditions, optimum plant population shows tremendous variability on account of varied agro-
climatic conditions. In earlier trials, a spacing of 60 x 60 cm was found significantly superior to the spacing of 120 cm x 60 cm and 120 cm x 120 cm in West Bengal (Anonymous, 1948-1953 and Anonymous, 1954-1959). In trials conducted during 1959-65 at Beharmpore and in 1960-63 at Kalyani on spacing pattern of arhar, it was found that the highest average yields were obtained by 30 cm x 30 cm at Beharmpore and 30 x 90 cm at Kalyani (Sen et al. 1970).

At Hyderabad, an intra-row spacing of 20 cm proved significantly superior to 40 and 60 cm. The differences between 40 and 60 cm were, however, not significant (Anonymous, 1968c).

At Pantnagar, in an experiment involving three inter-row (50, 75 and 100 cm) and three intra-row (20, 33 and 66 cm) spacings on 'T-21' variety, it was found that closer intra-row spacing of 20 and 33 cm gave significantly higher yield over wider spacing of 66 cm (Anonymous, 1968b). In another experiment at the same location, 50,000 plants/ha recorded markedly higher yield as compared to 30,000 and 40,000 plants/ha (Saxena, 1968).

Sharma et al. (1969) reported that closer intra-row spacing tended to give higher yields.

Singh et al. (1971) obtained the highest yield of 1214 kg/ha with a plant population of 60,000/ha. The
second largest population of 50,000/ha gave a yield of 1133 kg/ha. There was no significant difference in yield with row spacing of 75 and 100 cm.

A number of experiments on plant population aspect have been conducted at IARI, New Delhi. A spacing pattern of 50 x 20 cm produced the highest yield of 28.7 q/ha as against 23.7 and 20.1 q/ha with 50 x 30 cm and 50 x 40 cm, respectively (IARI, 1971). Manjhi (1971) working under dryland conditions of Delhi reported that increasing the plant population from 50,000 to 75,000 plants/ha, increased the grain yield. Ramanujam (1972) also reported that a spacing pattern of 50 x 20 cm gave 40% more yield than 50 x 40 cm at IARI, New Delhi. While reviewing the work of AICRP, he reported that 60,000 plants/ha gave better yield as compared to 40 and 50,000 plants/ha.

Singh (1973) found that increasing the plant population from 75,000 to 100,000 plants/ha caused significant reduction in grain yield. He further observed that plant rectangularity had considerable effect on yield with increase or decrease in area per plant beyond a certain limit, plant growth gets a setback resulting in lower grain yield per unit area.

Saxena et al. (1974) observed that grain yield was significantly affected by row spacing and found that row spacing of 50 cm was superior to 75 cm. Saxena et al. (1974) from the same location also obtained the highest yield of
three varieties of arhar ('T-21', 'UPA-120' and 'PS-5') with 75 cm row spacing closely followed by 50 cm. However, the differences were not significant.

Saxena et al. (1974) obtained highest yield of pigeon pea varieties ('T-21', 'Prabhat', 'UPA-120', 'Pant-2', 'Pant-3' and 'Selection-1') at a closer row spacing of 37.5 cm being at par with row spacings up to 62.5 cm, but further widening the rows reduced the yield significantly. Saxena et al. (1974) also found that differences because of row spacing were non significant. Row spacing from 25-30 cm did not affect the yield significantly. However, further widening of rows reduced the yield significantly over closer row spacing.

Several workers (Saraf et al. 1968; Chowdhary et al. 1969; Gupta, 1970 and Singh et al. 1971), found the plant population of 50 to 60,000/ha as optimum for pigeon pea under varied agro-climate conditions. Further research results have, however, shown that a plant population of 100,000 plants/ha appeared to be optimum and gave higher yields (Anonymous, 1975b; AICRIP, 1976 and Khéékar, 1976).

In Kamataka, a plant population of 75,000 plants/ha appeared optimum for medium and long duration varieties of arhar (Yadahalli, 1976 and Yadahalli and Jayaram, 1976).
Tiwari et al. (1977) obtained the highest yield of pigeon pea varieties with a spacing pattern of 45 x 15 cm.

Rathi and Tripathi (1978) obtained the maximum yield of pigeon pea (Variety 'T-21') with a row spacing of 50 cm under central U.P. conditions. Singh et al. (1978) obtained an average seed yield of 2.84 and 2.37 t/ha with row distances of 50 and 75 cm respectively.

The grain yield of pigeon pea remained unaffected by various row spacings (30, 60 and 120 cm) and intra-row spacings (2, 5, 10 and 25 cm) at ICRISAT (Anonymous, 1979-80).

Paroda and Singh (1980) found a row spacing of 37.5 cm as optimum under Haryana conditions.

Rao et al. (1980) reported that increasing the populations beyond 40,000 plants/ha (commonly recommended for medium duration cultivars) had little effect on grain yield but increased the weight of stalks and fallen leaves.

Reddy and Reddy (1980) recorded maximum grain yield of pigeonpea (1.13 t/ha) by sole crop of pigeonpea under rainfed conditions, sown at 90 x 30 cm spacing. Singh and Singh (1980) observed that arhar (cv A 88) which was grown as pure crop at 60 cm row spacing produced significantly higher grain yield over any combination of inter crop under Varanasi conditions.
Sanjida et al. (1981) reported the grain yield of 
erhar was significantly affected by variation in plant 
population in one season only, out of the two seasons. 
The yield increased with the reduction in plant density 
from 75,000 to 50,000/ha.

Chauhan and Singh (1981) found that the row spacing 
of 60 cm produced significantly more grain yield, being 
11.2 and 26.0% higher than 40 and 60 cm row spacings 
respectively. Ali (1981) reported that higher production 
of erhar could be obtained by cultivating 'Hy-1' at 60 cm x 
15 cm. Yaseen (1981) found the optimum population of 
50,000 and 75,000 plants/ha for medium and short duration 
varieties.

Chauhan and Singh (1981) also recorded higher stalk 
yield with 60 cm spacing than 80 cm spacing.

Singh et al. (1983) found that the effect of row 
spacing on grain yield was not significant. The harvest 
index increased significantly with increasing row spacings 
(37.5 and 50 cm), however, there was significant reduction 
in stalk yield. Singh et al. (1983) reported that the 
widest row spacing of 50 cm recorded significantly more 
grain yield than closer spacing of 37.5 and 25 cm.

Patel et al. (1984) observed from college of Agri-
culture, G.A.V. Navsari that the plants in 90 cm row 
 spacing gave significantly higher grain yield (12.0 q/ha).
than 60 and 120 cm row spacings. Further, they reported that 120 cm row spacing proved significantly superior to 60 cm row spacing. Thus 90 cm row spacing gave 40.5 and 19.1% higher grain yield over 60 and 120 cm row spacings respectively. The stalk yield recorded due to 60 cm and 90 cm row spacings was at par but these spacings produced significantly higher yield than wider (120 cm) row spacing.

Srivastava (1984) reported from Birsa Agricultural University, Ranchi, that Bener and T-21 varieties produced higher yields at a row spacing of 25 cm with (20 cm spacing with in the rows) where as for cv Laxmi 37.5 cm row spacing with (13.3 cm spacing with in the rows) proved to be more beneficial. Ahuja (1984) observed that medium (111,111) and high (166, 666 plants/ha) densities out yielded the low density in grain yield under Bichpuri conditions. Further he reported that higher stalk yield with higher plant densities in proportion to grain yield resulted in a lower harvest index.

Gondalia et al. (1988) reported from G.A.U. Junagadh that an inter row spacing of 45 cm out yielded the 30 cm and 60 cm row spacings by recording the highest grain (10.8 q/ha) and stalk yield (26.4 q/ha).

Shankaralingappa and Hegde (1989) did not observe any significant difference in grain yield due to different plant populations. Sinha et al. (1989) reported that
than 60 and 120 cm row spacings. Further, they reported that 120 cm row spacing proved significantly superior to 60 cm row spacing. Thus 90 cm row spacing gave 40.5 and 19.1% higher grain yield over 60 and 120 cm row spacings respectively. The stalk yield recorded due to 60 cm and 90 cm row spacings was at par but these spacings produced significantly higher yield than wider (120 cm) row spacing. Srivastava (1984) reported from Birsa Agricultural University, Ranchi, that Behar and T-21 varieties produced higher yields at a row spacing of 25 cm with (20 cm spacing with in the rows) where as for cv Laxmi 37.5 cm row spacing with (13.3 cm spacing with in the rows) proved to be more beneficial. Ahuja (1984) observed that medium (111, 111) and high (166, 666 plants/ha) densities out yielded the low density in grain yield under Bichpuri conditions. Further he reported that higher stalk yield with higher plant densities in proportion to grain yield resulted in a lower harvest index.

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by Abrams and Julia (1973). Ahlawat (1976) recorded the highest percentage (22.19) of crude protein at lowest population of 50,000 plants/ha. However, difference between the lowest and the highest population (100,000 plants/ha) were not significant. Oracee-Tetco R. (1976) reported from Ghana that the seeds with 20-25% protein content comes under moderate protein quality. Singh (1978) also obtained the highest protein content in seed at a wider row spacing.

Singh et al. (1983) reported that three plant populations (200 c 10^3, 133 x 10^3 and 100 x 10^3) removed 171.3, 108.3 and 97.4 kg N/ha and 9.2, 8.0 and 7.4 kg P/ha respectively. Decreasing plant population reduced phosphorus uptake significantly.

2.2.5 Effect of plant population/row spacing on nutrient uptake

A crop of arhar producing about 1630 kg dry matter per hectare will remove 29 kg N, 9 kg P_2O_5, 10 kg K_2O, 12 kg Ca and 5 kg Mg (Mehta and Khatri, 1962). They have further observed that increase in dry matter and absorption of mineral nutrients occur continuously in the plant reaching peak assimilation/accumulation rates between flowering and seed set. Manjhi (1971) found that N, P and K content in stem and leaves remained unaffected by plant population at 120 days after sowing. Uptake of N, P and K upto 120 days after sowing and N and K uptake upto harvest was significantly more with higher plant population. Uptake of P at harvest was, however, not affected owing to plant populations. Increase in N content of plant component with increasing density was reported by Akinola and Whiteman (1974) from Australia. Ahlawat (1976) observed the increase
in N and P uptake (kg/ha) with the increase in plant population. Similar results were obtained by Singh (1978) at IARI.

2.3 **Phosphate fertilization**

It is generally observed that pigeonpea responds less to fertilizers than other comparable crops of the semiarid tropics. This apparent lack of nutritional problems has perhaps resulted in fewer in depth studies of the mineral nutrition characteristics of this crop than is warranted. Most nutritional, longer duration varieties that are normally grown in inter crops or mixed cropping situations. However, the recent development of short duration genotypes, normally used as sole crops and given higher levels of management, has necessitated a comprehensive examination of the mineral nutritional characteristics of this essentially new plant type.

2.3.1 **Effect of phosphorus on growth and yield components**

Nichols (1965) working at Trinidad (West Indies) reported that Ca, P and Mg had the greatest effect in reducing plant growth and intensity of nodulation. Deshpande and Bathkal (1965) found that number of nodules per plant were significantly increased by application of 40 and 60 Kg P₂O₅/ha over control in moong.

Peitri et al. (1971) observed that fertilizer treatment (N, P and K) had no effect on date of flowering, plant height and seed weight under Puerto Rico conditions.
Manjhi (1971) obtained significant improvement in branches per plant, dry matter weight per plant, pods per plant, grain weight per plant, grains per pod, and test weight with the application of 50 Kg P₂O₅/ha in pigeonpea. However, an increase in P₂O₅ application i.e. 100 Kg/ha did not increase the growth and yield components over 50 Kg P₂O₅/ha. Significant improvement in branches per plant and yield components such as pods per plant, grain weight per plant and test weight owing to increase phosphorus was also noticed by Ram and Girir (1973) at the same location. Similar results were also obtained by Amar Chand (1975) and Ahlawat (1975b). Rao (1975) working at IARI, New Delhi recorded significant improvement in plant growth and development (plant height, primary branches per plant and dry matter production) and yield attributes (pods per plant, seeds per plant and test weight) by phosphorus application. Singh et al. (1976) reported that phosphate had beneficial effect on growth and yield contributing characters. However, the effect was significant only for branches per plant in both the seasons and for grains per pod in one season only.

Panwar and Yadav (1980) reported that phosphate application resulted significant increase in plant height, primary branches, pods per plant, 1000 grain weight, grain yield per plant and harvest index. Chauhan and Singh (1981) found the beneficial effect of phosphorus on number of branches, pods per plant and the size of the grain.
Singh et al. (1983) reported from IARI, New Delhi that phosphorus at 30 Kg P₂O₅/ha increased dry matter production and grain yield/plant significantly over control, however, no additional gain in grain yield/plant was observed when the dose of phosphorus was raised to 60 Kg P₂O₅/ha. Phosphate fertilization also improved LAI, RGR and CGR which resulted in higher dry matter production and hence yield/plant. Ahlawat and Saraf (1983) observed that dry matter yield increased significantly by phosphate application from 2.8 g/plant (under 0 Kg P/ha) to 3.2 g/plant (under 34 Kg P/ha).

Ahuja (1984) reported that application of 90 Kg/ha increased growth and yield attributes (number of branches/plant and number and weight of pods/plant) significantly under Bichpuri conditions.

Rajapurohit and Gaur (1986) reported that the application of 40 Kg P₂O₅/ha markedly improved the growth and yield attributes (plant height, primary and secondary branches, pods/plant and seeds/pod). The difference between 40 and 80 Kg P₂O₅/ha were not significant for any these characters.

Gondalia et al. (1988) working at G.A.U. Junagadh (Gujrat) reported that 50 Kg P₂O₅/ha recorded favourable effect on growth and yield attributes. Pusté and Jana (1988) reported from Kalyani, Nadia that phosphorus resulted in significant increase in yield attributes of pigeonpea.
(Number of pods/plant, number of seeds/pod and 1000 seed weight) at 70 Kg P₂O₅/ha which was, however, at par with 35 and 105 Kg P₂O₅/ha.

Giri (1990) observed in his study made at IARI, New Delhi that 40 Kg P₂O₅/ha recorded significant increase in biomass under rainfed conditions. He did not observe the significant increase in number of pods, seed weight/plant and 1000 seed weight due to 40 Kg P₂O₅/ha.

2.3.2 **Effect of phosphorus on yield**

Significance of adequate supply of P for high yield of pigeonpea has been recognised since along. Higher response to the extent of 51% with 80 Kg P₂O₅/ha was reported by Allen (1933).

Khan and Mathur (1962) and Bhatawadekar et al. (1966) indicated that phosphorus is the first limiting element under tropical conditions and recommended application of 20-80 Kg P₂O₅/ha. Chowdhary (1968) reviewed the work done in India on manuring and fertilization of pulse crops and concluded that the practice of applying 20-30 Kg N and 40-50 Kg P₂O₅/ha is generally beneficial. Almost similar results were obtained at Varanasi (USDA, 1969) and in Tamil Nadu (Krishnam, 1968).

Prasad et al. (1968) on the basis of 1852 trials, conducted on cultivator's field with seven grain legumes, reported 25% increase in yield by application of 33.6 Kg
$P_2O_5$/ha. Similarly in a six years trial (1932-38) of new manual series on calcareous sandy loam soils of Pusa, application of superphosphate at 80 Kg $P_2O_5$/ha increased the yield of pigeon pea by 10.2%, phosphate application alone gave high yields compared to green manuring + 80 Kg $P_2O_5$/ha (Anonymous, 1970).

Bains (1970) working at IARI, New Delhi obtained high response to phosphorus fertilization. Grain yields by 50, 100 and 150% with 33, 66 and 100 Kg/ha, respectively over no phosphorus treatment (12.0 q/ha).

Manjhi (1971) and Singh et al. (1976) also recorded linear increase in yield upto 100 Kg $P_2O_5$/ha. Chowdhury and Bhatia (1971) obtained increased yields from 12.9 q/ha in no phosphorus plot to 20.3, 23.4 and 27.6 q/ha with 33, 67 and 100 Kg $P_2O_5$/ha, respectively. Rao (1975) also noted marked increase in grain yield by phosphorus application.

Ramanikjam (1972b) reviewed the work done under All India Coordinated Pulse Improvement Project and reported that application of 33.3 Kg/ha of $P_2O_5$ led to a 75 per cent increase in yield while 100 Kg $P_2O_5$/ha gave an increase of 125 per cent over control (13.0 q/ha) at IARI, New Delhi. There was, however, no response to P at Pantnagar because of high native fertility status of the soil.
Ram and Giri (1973) obtained the response of phosphorus upto 50 Kg P$_2$O$_5$/ha only.

Mahapatra et al. (1974) on the basis of 11 trials on 'T-21' in Jalaun district of Uttar Pradesh reported a response of 1.0 q/ha with 60 Kg P$_2$O$_5$/ha. While Rathi et al. (1974) obtained linear increase in yield upto 80 Kg P$_2$O$_5$/ha on a light textured loam soil on Meerut in Uttar Pradesh.

Several workers (Krishnan, 1968; Singh, 1973; Anonymous, 1975b; Kaul and Shekhon, 1975 and Yadav and Saxena, 1975) also stressed the need of phosphorus application to arhar crop. Ahlawat et al. (1975b) reported that application of 30 Kg P$_2$O$_5$/ha along with a starter dose of N (10 kg/ha) enhanced the grain yield significantly over control under rainfed conditions at Delhi.

Khedekar (1976) reported that application of 25 Kg N + 75 Kg P$_2$O$_5$/ha gave significantly higher yield than control and 25 Kg N + 50 Kg P$_2$O$_5$/ha at Kutki (Maharashtra). There was, however, no response to applied fertilizer at Akola and Nagpur. Significant response to applied phosphorus at 50 Kg/ha at Baclapur was also reported by Raikhelkar et al. (1976).

Hegde (1977) recommended a dose of 60 Kg P$_2$O$_5$/ha for pigeon pea under rainfed conditions at Delhi.
Rathi and Tripathi (1978) obtained the maximum yield of pigeon pea (var. 'T-21') fertilized with 40 Kg P₂O₅/ha and 20 Kg N/ha.

Ramanathan et al. (1977) observed a significant increase in pod and grain yield by application of 76.4 Kg P₂O₅/ha.

Roysharma et al. (1979) found significant increase in yield of pigeon pea over control by the application of 50 Kg P₂O₅/ha at Dholi (North Bihar) whereas 100 Kg P₂O₅/ha increased the yield significantly over 50 Kg/ha at Piprakothi in Raish Champaran. Singh et al. (1979) also noted a significant increase in yield of pigeon pea by phosphorus application. Singh et al. (1980) noticed that crop of arhar responded favourably upto 80 Kg P₂O₅/ha.

Panwar and Yadav (1980) found 65 Kg P₂O₅/ha as the economic dose for pigeon pea.

Ali (1981) reported 40 Kg P₂O₅/ha as the optimum dose under dryland conditions, while Yaseen (1981) found the optimum at 50 Kg P₂O₅/ha under dryland conditions in AP. Chauhan and Singh (1981) recorded the maximum grain yield of 12.09 q/ha by the application of 80 Kg P₂O₅/ha.

Singh et al. (1981) observed 31% increase in yield by application of 40 Kg P₂O₅/ha.
Singh et al. (1983) reported that 30 Kg $P_2O_5$/ha increased the grain and stalk yields and harvest index significantly. Patel et al. (1984) observed from college of Agriculture, G.A.U. Navsari that the increase in grain yield brought about by 20 Kg N+ 40 Kg $P_2O_5$ and 30 Kg N + 60 Kg $P_2O_5$/ha was significant over 10 Kg N + 20 Kg $P_2O_5$/ha. Fertilizer application also favourably the stalk yield. Ahuja (1984) reported that application of 90 Kg $P_2O_5$/ha increased grain yield significantly. He found 78 to 88 Kg $P_2O_5$/ha as the economic optimum dose for arhar.

Srivastava and Verma (1986) working at B.A.U., Ranchi reported that grain yield of pigeonpea increased with increasing levels of phosphorus up to 60 Kg $P_2O_5$/ha. Singh et al. (1986) reported that increasing levels of phosphorus increased the grain yield of pigeonpea significantly under Hisar conditions. On an average 80 Kg $P_2O_5$/ha increased the grain yield by 29.2% over control and 8.8% over 40 Kg $P_2O_5$/ha.

Gonahla et al. (1988) recorded significantly the highest grain and stalk yields (10.9 and 23.8 g/ha, respectively at 50 Kg $P_2O_5$/ha). Puste and Jana (1988) recorded increased seed yield by 17.3, 32.8 and 35.8% in 1980-81 and 17.1, 27.5 and 30.5% in 1982-83 at 35, 70 and 105 Kg $P_2O_5$/ha respectively over control. Further, they obtained relationship between levels of $P$ and seed yield.
was quadratic in nature. The optimum economic doses were 94.7, 86.1 and 90.3 Kg P₂O₅/ha in 1981-82, 1982-83 and in pooled data respectively. Response to applied phosphorus was maximum at 35 Kg P₂O₅/ha and decreased with increase in levels of P₂O₅. On an average basis it was 6.14, 5.37 and 3.93 Kg seed/kg P₂O₅ at 35, 70 and 105 Kg P₂O₅/ha respectively.

Raghuvanshi et al. (1989) obtained highest grain yield (19.6 q/ha) with recommended fertilizer dose i.e. 20 Kg N + 60 Kg P₂O₅/ha.

Solaippa and Ramiah (1990) pointed out that basal application of 6.25 Kg N and 12.5 Kg P₂O₅/ha followed by foliar spray of three percent diammonium phosphate 70 DAS gave higher grain yield of pigeonpea under rainfed conditions. Giri (1990) reported that 40 Kg P₂O₅/ha recorded significant increase in seed yield of pigeonpea under rainfed conditions of Delhi.

Rao and Mittra (1991) observed that application of 75 Kg P₂O₅/ha recorded significant increase in seed yield at I.I.T. Kharagpur (West Bengal). Dubey and Upadhyaya (1991) reported that phosphorus fertilization increased both grain and stalk yields significantly. The response in grain yield was significant up to 30 Kg P₂O₅/ha.

Singh and Singh (1992) reported from IARI, New Delhi that phosphorus application improved the yield
attributes and grain yield significantly up to 80 kg P\textsubscript{2}O\textsubscript{5}/ha in pigeonpea.

Mohite et al. (1993) observed that application of 100 Kg DAP/ha is desirable for optimum yield.

It has also been demonstrated that P deficiency delays flowering and maturity of short durat on pigeonpea (Y.S. Chauhan, ICRISAT, unpublished). This has implications for fitting pigeonpea into crop rotations where there are time constraints for the cropping period allocated to pigeonpea, an example being the pigeonpea-wheat rotation practiced in northern India.

2.3.3 Effect of phosphorus on quality

Phosphorus application increased the protein content of the seed (Manjhi, 1971 and Singh, 1973). The increase in protein was linear up to 100 Kg P\textsubscript{2}O\textsubscript{5}/ha (Manjhi, 1971). Anarchand (1975) reported that application of 50 Kg P\textsubscript{2}O\textsubscript{5}/ha increased the crude protein content significantly over control. The higher dose of 100 Kg P\textsubscript{2}O\textsubscript{5}/ha also increased the crude protein significantly over 50 Kg P\textsubscript{2}O\textsubscript{5}/ha. Singh and Prasad (1976) while working with 4 varieties of Cajanus cajan recorded increased protein content with increasing levels of P\textsubscript{2}O\textsubscript{5} up to 100 Kg/ha. Ahlawat (1976) observed increased crude protein content in grain significantly up to 80 Kg P\textsubscript{2}O\textsubscript{5}/ha.
2.3.4 **Effect of phosphorus on nutrient uptake**

The quantity of nutrient uptake by most grain legumes is quite large and on an average may amount to as much as 150 to 470 Kg N, 13 to 30 Kg P₂O₅ and 60 to 150 Kg K₂O/ha (Romanie, 1957).

Manjhi (1971) observed that the application of 50 Kg P₂O₅/ha increased the uptake of N, P and K significantly over control. The higher dose of 100 Kg P₂O₅/ha increased only the total phosphorus uptake significantly over 50 Kg P₂O₅/ha. Singh (1973) while investigating the effect of phosphorus fertilization on N and P content in seeds and their uptake by a crop of pigeon pea, reported that N content in grain increased significantly by phosphorus application at higher doses only, whereas P content remained unaffected. Uptake studies showed that 100 Kg P₂O₅/ha increased the N at harvest in both the seasons but the P uptake was more in one season only. Rao (1974) reported that application of P increased the total nitrogen phosphorus and potassium uptake up to the highest level of 60 Kg P₂O₅/ha. Rao (1975) also observed that application of 40 Kg P₂O₅/ha increased the N and P uptake at harvest significantly over control. The higher dose of 80 Kg P₂O₅/ha also significantly increased the N and P uptake over the lower levels. Amarchand (1975) reported that an application of 50 Kg P₂O₅/ha increased total P uptake over control. The higher dose of 100 Kg P₂O₅/ha increased
the total P significantly over 50 Kg/ha. Ahlawat (1976) observed that N and P uptake increased significantly with increasing levels of $P_2O_5$ up to 80 Kg/ha. Hegde (1977) reported that application of 40 Kg $P_2O_5$/ha increased the total nitrogen, phosphorus, and potassium uptake significantly over control. However, the higher dose of 80 Kg $P_2O_5$/ha increased only the total nitrogen and phosphorus uptake over 40 Kg $P_2O_5$/ha. Singh and Prasad (1976) observed the increase in phosphorus accumulation in seeds and stems with increase in $P_2O_5$ rates from 0 to 100 Kg/ha.

Ahlawat (1976) observed that the higher rate of phosphate application (34 Kg P/ha) removed more of nitrogen and phosphorus than 17 Kg P/ha at some stages of plant but there was no difference at harvest.

Dalal and Quilt (1977) noticed an increase in nitrogen and magnesium uptake at the higher level of $P_2O_5$ (250 kg/ha) only, whereas increase in phosphorus uptake was marked at 100 kg/ha.

Singh et al. (1983) observed that application of 30 Kg $P_2O_5$/ha increased the phosphorus uptake significantly over control at all the stages of crop growth, in grain and stalk at harvest.
2.4 **Crop rotation**

2.4.1 **Concept of rotation**

Crop rotation is a practice that has been in use since time immemorial. This has been practiced not only to produce enough food grains which constitute a balanced diet for mankind but is known to restore nitrogen content of soil. The scientific basis of this unique agronomical practice was, however, discovered only about a century ago when it was found that legumes cannot be grown in sterile soils. In India agricultural economy, legumes have played an important role in sustaining the productivity of soil through centuries. The beneficial effect of legumes vary greatly depending upon the type of crop and its duration. *Parker* (1915) defined crop rotation as a system of growing cultivated crops on a given area of land in such an order and succession as to keep the soil productive, in good tilth and provides a productive employment to farm capital and labour.

2.4.2 **Choice of crops for rotation**

Suitable choice of crops in any cropping depends largely on soil type, agroclimatic conditions, socio-economic status of farmer, yield potential, crop duration and ability of the crop to maintain soil fertility. The nutritional imbalance caused and lot of residues left
by certain crops restrict not only their place but also the choice of suitable successive crops to follow them in rotation.

Williams (1924) observed that crops grown in sequence probably utilised the soil nutrients more economically than those in continuous culture and that the rotated crops without a doubt were greatly benefitted by the clover. He also pointed out that this legume not only fix N from the atmosphere but its residues activated the soil as well.

Weir (1926) examined the yield data of rotational experiments conducted at various experimental stations in the USA and concluded that rotation of crops when practised with and without fertilizers averaged 75% as effective as the fertilizers in increasing crop yields and 90% as effective when the comparisons were limited to corn, oats, and wheat. He further observed that maintaining the productive power of soils in respective of these three crops, the rotation was, in general, at least 90% as effective as the fertilizers.

Stewart (1947) stated that the farmers are fully conversant with the advantages of crop rotation but to decide which rotation is better under a particular set of soil and climate, experimental work on crop rotation is essential. However, in India, the need for systematic experimental work on crop rotation was stressed in 1948.
at the seventh meeting of the crops and soil wing of the Board of Agriculture and Animal Husbandry in India (Chandnani et al. 1960).

Inclusion of legumes in rotation increases the availability of nutrients to the succeeding wheat crop and wheat in rotation not only gave higher yields but remove more nutrients than wheat receiving direct application of nitrogen and phosphorus (Sen and Sundara Rao, 1951).

Raleja and Misra (1952) observed that in a cereal cereal rotation there was a progressive decline in grain output of various crops, while it was maintained at much higher level in pulse-cereal rotation.

Higher yields of crops in legume-cereal rotation was recorded due to higher available N contributed by legumes (Wild, 1972; Jones, 1974 and Giri and De, 1979). Singh (1972) in a rotational experiment observed that inclusion of legumes in crop sequences increased the yield yield and nitrogen uptake of following non-legume.

Merey (1976) in a long term rotational experiment observed that grain yield of cereal in rotation having a legume component was higher than cereal following cereal in a rotation.
2.4.3 **Effect of pigeon pea on wheat in pigeon pea - wheat rotation**

As early as 1921, Kreuss from Hawaii reported beneficial effects of pigeon pea in crop rotations. Arhar-wheat rotation was found to be profitable in economic terms, availability of nutrients and mutual crop benefit than maize-wheat or bajra-wheat rotations (Anonymous, 1971b). This rotation was also found to be profitable by Brar et al. (1976). But Saxena and Yadav (1975) reported higher total production of maize-wheat rotation as compared to pigeon pea - wheat rotation. Verma et al. (1978) from Bihar and Banwar (1978) from U.P. also did not observe any advantage of this rotation with a short duration pigeon pea variety because it delayed wheat sowing considerably.

Jeswani (1979) strongly recommended growing of extra early varieties of pigeon pea like 'T-21', 'Prabhat', 'Sharad', 'Pusa Ageti', 'UPAS-129' etc. which mature rather earlier and vacate the land by mid November for wheat. Dhingra (1979) also explored possibilities of growing wheat after pigeon pea in Punjab and reported that even a loss of some amount of wheat when sown late after pigeon pea may be able to mitigate the advantage obtained from pigeon pea as compared to other crops. Patal (1980) reported beneficial effect of pigeon pea grown as pure crop or intercropped with other short duration legumes on the following wheat crop.
Panwar and Yadav (1980) revealed that residual effect of phosphorus applied to previous pulse crop was more in wheat sown after April-planted pigeon pea. The timely sown crop made more efficient use of this residual content.

The development of short duration varieties such as 'Pusa Agati', 'Prabhat', 'UPAS-120', 'Pant A-3' and 'A-1' maturing in 120-130 days, has made the arhar-wheat rotation an economically viable proposition (Jeswani and Saini, 1981).

Sandhu et al. (1981) reported that the yield of wheat was not affected by variation in rows spacing and plant population of preceding arhar.

Pigeon pea wheat sequential cropping has spread widely in irrigated areas of northern and central India (Paroda and Singh 1983, Chandra and Ali, 1986). In eastern and peninsular India, post rainy season pigeon-pea has shown great promise in double-cropping systems (Narayanan and Schweikardke, 1979; Roy Sharma et al., 1981b).

The first shorter-duration cultivar of pigeonpea, T-21 was released for cultivation in 1961. It matures in 150-170 days and yields about 2 t/ha. This variety quickly spread in northern India as it could be double-cropped with wheat and also escaped from the frost, which causes substantial damage to long duration cultivars.
It was however, observed that T-21 delayed wheat sowing since it has a tendency to spill over into the wheat growing season whenever late monsoon showers occur. Later on, short duration varieties (140-150 days), such as UPAS-120, Pusa Ajeti, Pusa 74, Pusa 84, Manak, AL 15, ICPL 151 and TT6 were developed. These allow timely sowing of wheat (IDR, 1980). Results of multi locational AICRIP trials showed that pigeonpea-wheat sequential cropping was highly profitable in northern India.

Sowing time and the choice of an appropriate genotype play key role in deciding the success of a pigeonpea-wheat system. At Ludhiana (Punjab), sowing pigeonpea in the first fortnight of June was found ideal for pigeonpea-wheat rotation (Kaul et al., 1980; Sandhu et al., 1981).

Shrivastava et al. (1988) evaluating four genotypes ICPL 87, ICPL 151, ICPL 161 and UPAS-120 in pigeonpea-wheat rotations at Gwalior (M.P.) reported that ICPL 87 and ICPL 151 were more suitable than the other genotypes. In U.P., Punjab and Haryana, UPAS-120, AL 15 and Manak are considered ideal for double cropping.

Tomar and Tiwari (1990) concluded that seed yield of wheat was higher when grown after soybean, pigeonpea and clusterbean presumably due to utilization of nitrogen fixed by preceding leguminous crop under Moreno conditions. The beneficial effects of legumes on succeeding crop had earlier been reported by many workers (Ahlawat et al., 1981);

Rathi and Yadav (1992) observed at Kanpur (U.P.) that residual effect of P was positive on yield of wheat. The increase in total, grain and straw yields with residual of 90 Kg P<sub>2</sub>O<sub>5</sub>/ha were 12.19, 12.70 and 11.97% respectively. In case of grain yield, residual effects of 30, 60 and 90 Kg P<sub>2</sub>O<sub>5</sub>/ha increased the yield by a 14.42, 30.62 and 47.21% from the control.

Thakur and Khan (1994) observed that a crop sequence of pigeonpea-wheat or gram may be adopted for sandy-loam soil of Tawa command in Madhya Pradesh.

Madak et al. (1994) conducted experiments at IARI, New Delhi in sandy-loam soil, reported that phosphorus uptake by pigeonpea and wheat grown in sequence showed significant response to residual P. They also reported that a total P application of at least 60 Kg P<sub>2</sub>O<sub>5</sub>/ha/annum is essential in pigeonpea-wheat sequence to maintain the soil P fertility against depletion.